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This Chapter:

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Structure of the Yakima Fold Belt, Central Washington

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Structure of theYakima Fold Belt, Central Washington

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INTRODUCTION

The Yakima Fold Belt is a series of anticlinal ridges and synclinal valleys that covers about 14,000 km2 of the western Columbia Plateau (Fig. 1). The fold belt formed as basalt flows of the Columbia River Basalt Group (CRBG), intercalated sediments of the Ellensburg Formation, and correlative units were folded and faulted under north-south-directed compression. Interest in the fold belt has increased over the past several decades because of hydrocarbon exploration and the siting of nuclear power plants. Despite the wealth of information from several decades of research, the Yakima Fold Belt is still incompletely understood. Although field studies have greatly increased our knowledge of the structure of the Columbia Plateau and the fold belt, timing of deformation, and growth rates of the folds, very little is known about the subsurface structure and the origin of the fold belt.

Many structural and tectonic models have been proposed to explain the origin and geologic evolution of the Columbia Plateau (for example, Laval, 1956; Davis, 1977, 1981; Bentley, 1977, 1980; Barrash and others, 1983; Reidel, 1984), but no one model has gained general acceptance because of differing interpretations of the nature of the geologic structures, extrapolation of structures to depth, character of basement involvement, and the timing and rates of deformation.
This field guide is designed to provide an introduction to the geology of the Yakima Fold Belt. It consists of two parts. The route for Day 1 of the trip is along the western margin of the Columbia River basalt west of Yakima. This part of the trip examines evidence for the influence of pre-Miocene structures on the Yakima folds and the nature of the folds along the margin of the Columbia Plateau. The route for the trip on Day 2 covers the central portion of the Yakima Fold Belt in the Pasco Basin area. This part of the trip examines the geology of the Yakima folds and the style of folding and faulting. Together, the two parts of the field guide provide not only an introduction to the geology of the Yakima Fold Belt, but also locations of easily accessible sites that demonstrate the structural characteristics of the fold belt.

REGIONAL SETTING

The Columbia Plateau is a broad plain situated between the Cascade Range to the west and the Rocky Mountains to the east and is constructed of the Miocene CRBG. In the central and western parts, the basalt is underlain predominantly by Tertiary continental sedimen¬tary rocks and overlain by late Tertiary and Quaternary fluvial and glaciofluvial deposits. The CRBG covers four general structural-tectonic regions or subprovinces of the Columbia Plateau, each of which has a distinctly different structural style: the Yakima Fold Belt, the Palouse, the Blue Mountains, and the Clearwater and Weiser embayments (Fig. 1). The Yakima Fold Belt consists of a series of generally west-trending (N50°W to S50°W) anticlinal ridges and synclinal valleys (Fig. 2). The Palouse paleoslope is the least deformed region and has only minor faults and low-amplitude, long-wavelength folds on an otherwise gentle

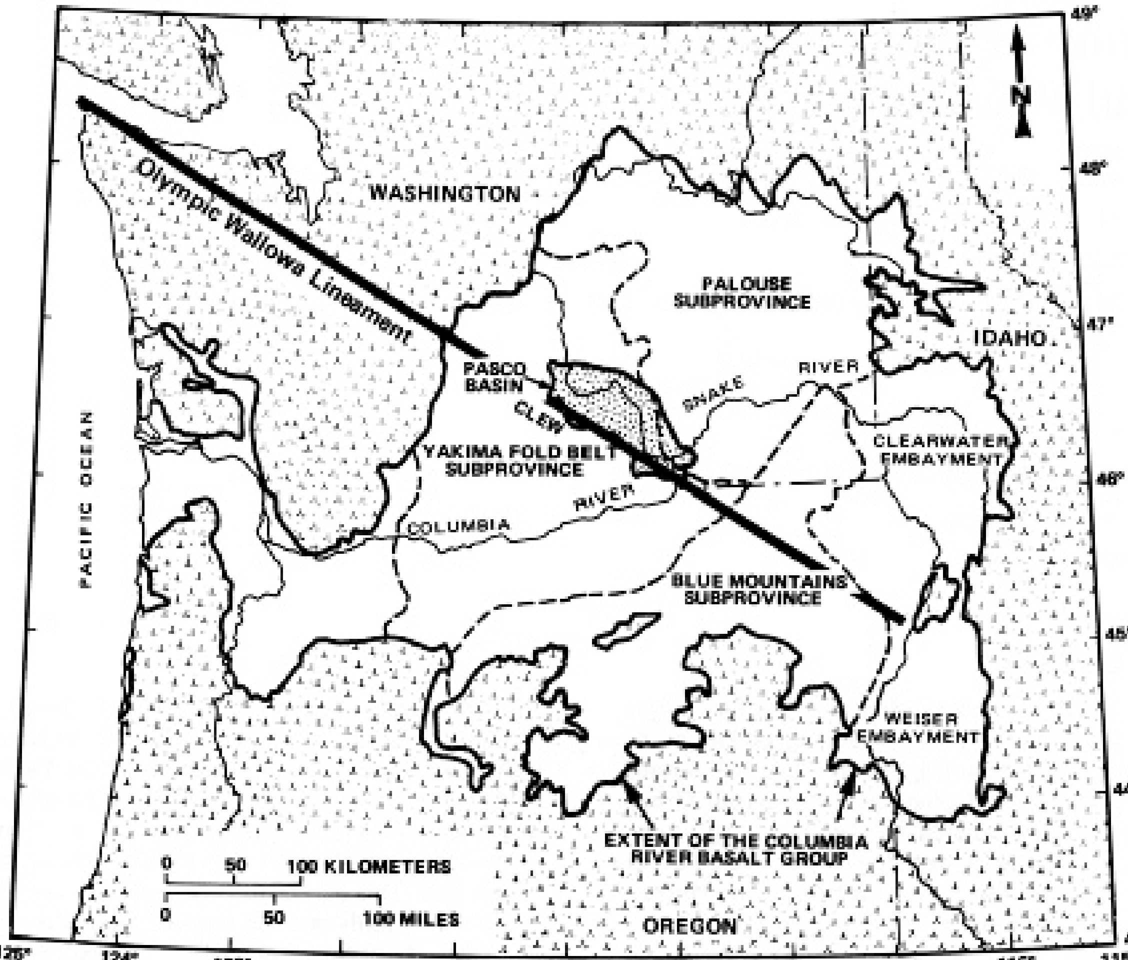

Figure 1. The Columbia Plateau. Shown are the areal extent of the Columbia River Basalt Group, the four major struc¬tural-tectonic subprovinces (the Yakima fold belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament, and the CLEW, which is the central portion of the OWL that passes through the western part of the Columbia Plateau.

west-dipping paleoslope (Swanson and others, 1980). The Palouse paleoslope marks the eastern boundary of the Yakima Fold Belt and has been a relatively stable feature since at least the middle Miocene (Swanson and Wright, 1976). The Blue Mountains is a northeast-trending anti-clinorium that extends 250 km from the Cascades to the eastern pan of the plateau. The Blue Mountains form the southern boundary of the Yakima Fold Belt.

Two regional structures cross-cut the central and western part of the Columbia Plateau: the Olympic-Wal-lowa lineament (OWL) (Figs. 1 and 2), and the Hog Ranch-Naneum Ridge anticline (Fig. 2). The segment of the OWL that crosses the Yakima Fold Belt is referred to as the Cle Elum-Wallula deformed zone (CLEW; Keinle and others, 1977) and is marked by a rather diffuse zone of anticlines that has a N50°W orientation (Fig. 2). The Hog Ranch-Naneum Ridge anticline is a basement-controlled anticline that extends southward from the North Cascades (Tabor and others, 1984) and forms the western boundary of the Pasco Basin (Reidel, 1984), one of the larger basins in the fold belt (Figs. 1 and 2).

STRATIGRAPHY

The dominant rocks of the area of this field guide are the Columbia River basalts and intercalated sedimentary rocks of the Ellensburg Formauon. These are overlain by younger sedimentary rocks of the Ringold Formation and the Pleistocene catastrophic flood deposits of the Hanford formation (informal). Sedimentary and volcanic units of the Naches, Ohanapecosh, and Fifes Peak formations un¬derlie the basalt along the western margin. The stratigraphy in the area covered by the field guide is shown in Figure 3.

Pre-Columbia River Basalt Group Units

In the central Cascade Range west of Yakima, early Tertiary sedimentary and volcanic rocks underlie the middle Miocene

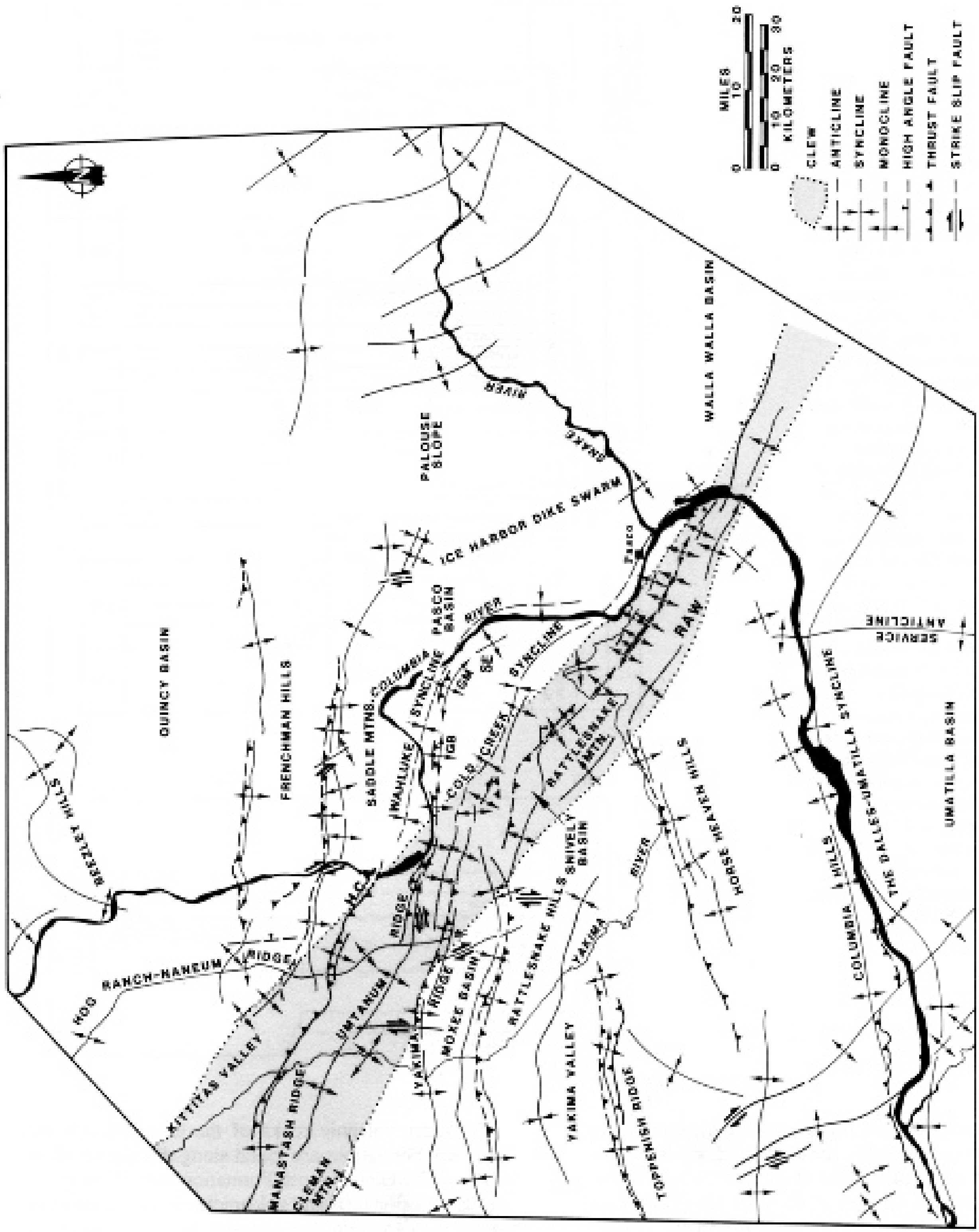

Figure 2. Major faults and folds in the central part of the Yakima Fold Belt and the western part of the Palouse (from Reidel and others, in press [b]). Shown are the Hog Ranch-Naneum Ridge anticline that forms the western boundary of the Pasco Basin, the Cle Elum-Wallula Deformed zone (CLEW, stippled), and the Rattlesnake-Wallula alignment (RAW) that forms that portion of the OWL and CLEW in the Pasco Basin. GB, Gable Butte; GM, Gable Mountain; SE, Southeast anticline along the Umtanum anticline; H.C.A., Hansen Creek anticline.

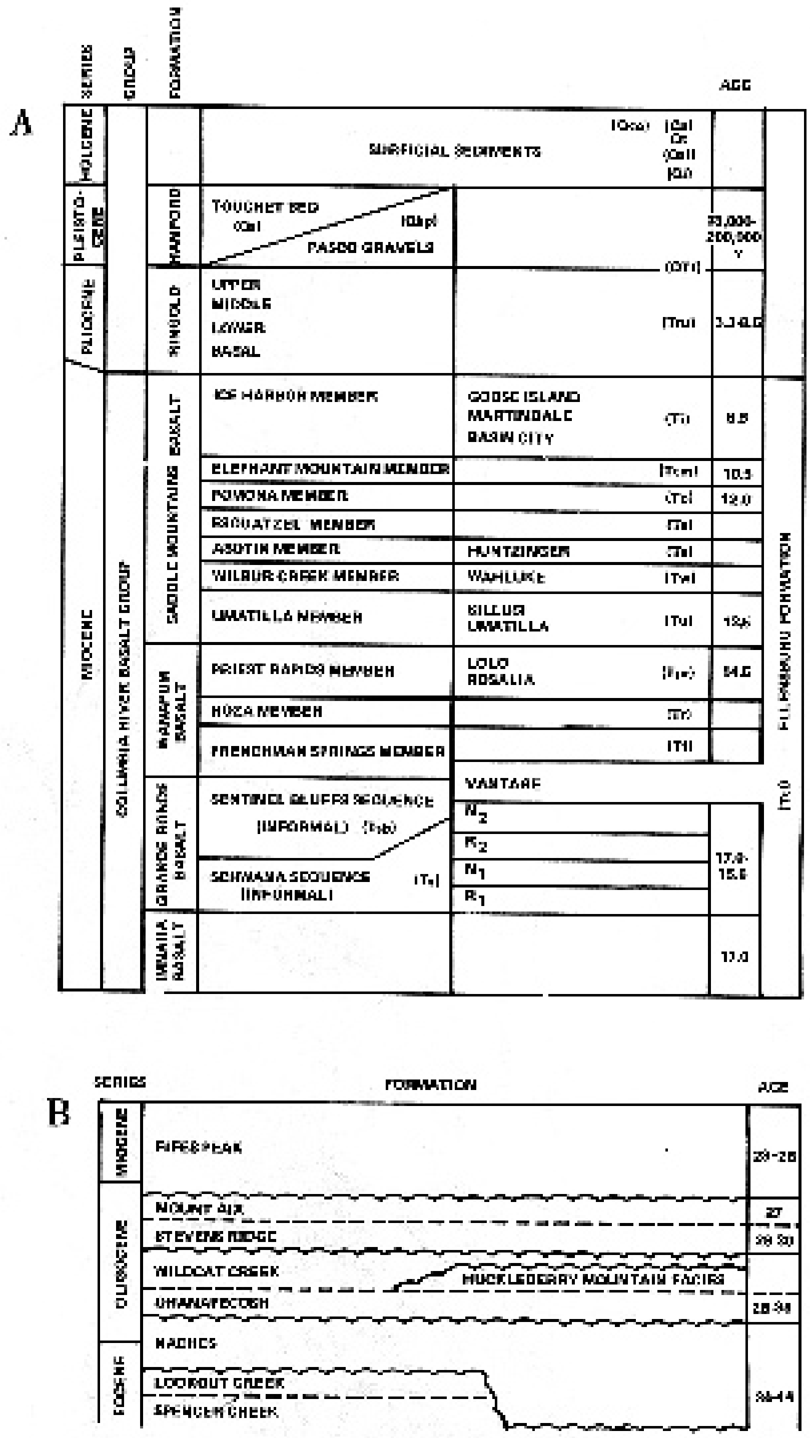

Figure 3. Major Tertiary stratigraphic units in the area covered by the field guide. Ages in million years

A. Units of the Columbia River Basalt Group, intercalated sediments, and overlying sediments. Symbols in parentheses are used on geologic maps of Figs. 12, 13, and 14.

B. Units older than the Columbia River Basalt Group that are exposed along the margin of the Columbia River basalt Holocene surficial sediments are generalized as: alluvium (Qa), talus (Qt), alluvial fans (Qaf), colluvium (Qco), and loess (Ql). Older alluvial fans of uncertain age are shown as (QTf)- Goose Island, Mar-tindale. Basin City, Huntzinger, Wahluke, Umatilla, Lolo, and Rosalia are individual basalt flows. Vantage is the sedimentary interbed between the Wanapum and Grande Ronde Basalts. The Grande Ronde is divided into four magnetostratigraphic units, N1.R2.Ni.Ri.

CRBG (Fig. 3). The late Eocene Naches Formation is composed of fluvial, feldspathic sandstones and rhyolite flows and tuffs; basalt and andesite flows are present in the upper part. K-Ar dates near the base of the Naches Formation give ages of 40 to 44 Ma (Tabor and others, 1984). The Naches Formation is principally confined to the area bounded on the south by the White River-Naches River fault zone and on the north by splays of the Straight Creek fault (Fig. 4).

Younger volcanic rocks of the Ohanapecosh and Fifes Peak Formations are found along the Naches River drainage. The Ohanapecosh Formation consists of multi¬colored andesitic tuffs and volcaniclastic sediments inter-bedded with rhyolite and andcsitc flows. Fission-track ages on zircons range from 28 to 36 Ma (Vance and others, 1987). Ohanapecosh rocks are more voluminous south of the White River-Naches River fault (Fig. 4). The

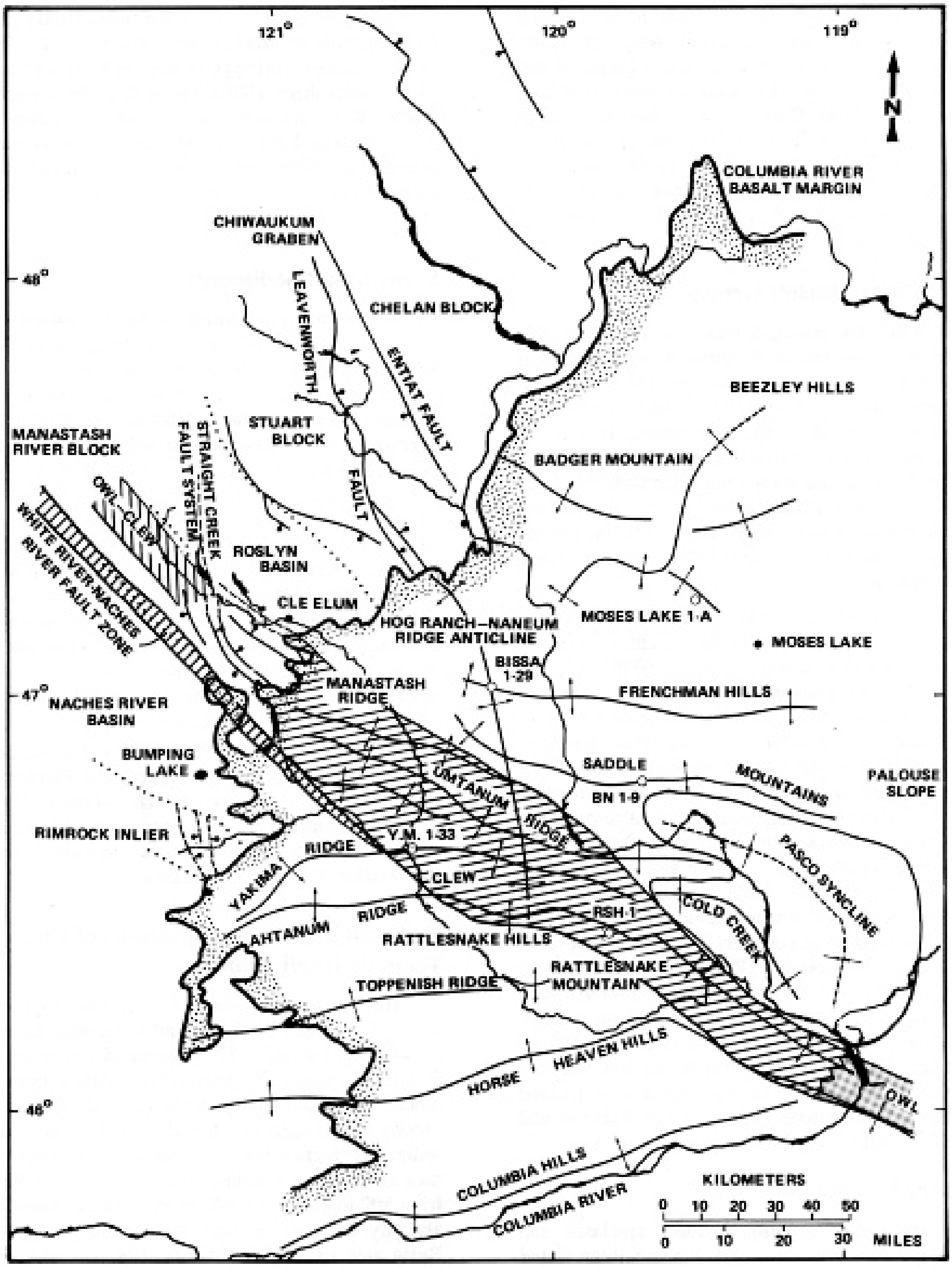

Figure 4. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Hydrocarbon exploration boreholes are shown as open circles.

Fifes Peak Formation consists of three or more eroded volcanic cones along the eastern flank of the Cascade Range. The Edgar Rock volcano is dissected by the Naches River and contains both an apron facies of ash-flow tuffs and a cone facies of andesitic brecciated lavas (Campbell, 1975,1988; Carkin, 1988). These rocks range in age from about 23 to 26 Ma (Vance and others, 1987). The Edgar Rock volcano was built above the surrounding topography during the early Miocene. Lavas of the CRBG were forced to flow around the cone before they could spread up the Little Naches River.
Columbia River Basalt Group

The CRBG, the principal rock unit in the Yakima Fold Belt, is a sequence of tholeiitic flood-basalt flows that were erupted between 17 and 6 Ma. The CRBG now covers approximately 164,000 km and consists of 174,000 km3 of basalt (Tolan and others, 1987). The CRBG has been divided into five formations (Fig. 3; Picture Gorge Basalt is not shown but intercalates with the Grande Ronde Basalt) (Swanson and others, 1979a); only the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt are exposed within the western Columbia Plateau.

The basalt flows of the CRBG can be distinguished by using a combination of lithology, chemistry, and paleomagnetic data (Swanson and others, 1979a). Chemical composition and paleomagnetic data have proven to be the most reliable criteria for flow recognition and correlation; lithology is reliable for many flows primarily within the Wanapum and Saddle Mountains Basalts, but chemical compositions are still used to confirm identifications. Chemical composition and paleomagnetic data are most important in identifying flows of the Grande Ronde Basalt because of the similarity of their lithology. In the field the Grande Ronde Basalt has been divided into four magnetostratigraphic units (msu) (Fig. 3) which, from oldest to youngest are: Reversed 1 (Ri), Normal 1 (Ni), Reversed 2 (Rz), and Normal 2 (N2) (Swanson and others, 1979a). The composition has been broadly subdivided into two groups based on relative concentrations of MgO (Swanson and others, 1979a) (Fig. 3, high MgO is Sentinel Bluffs and low MgO is Schwana), but recent studies have provided more detailed compositional subdivisions (Reidel, 1983; Mangan and others, 1986; Reidel and others, in press [b]).

Ellensburg Formation

The Ellensburg Formation includes epiclastic and volcaniclastic sedimentary rocks that are intercalated with and overlie the CRBG (Waters, 1961; Swanson and others, 1979a). Most volcaniclastic material in the Ellensburg Formation was produced by volcanic events in the Cascade Range. In the Naches drainage, deposition was primarily by volcanic debris flows (lahars) and related stream and sheet floods. Some air-fall and pyroclastic-flow deposits are also present. The age of the formation in the Naches drainage is between 16.5 and 7.4 Ma (Smith and others, 1988). The bulk of the material in the Naches River drainage was derived from a single source near Bumping Lake (Fig. 4). Farther east in the central plateau, the Ellensburg Formation is mixed with sediments deposited by the ancestral Clearwater and Colum¬bia Rivers (Fecht and others, 1982,1987).

Suprabasalt Sediments

Sediments continued to be deposited in most synclinal valleys long after the eruptions of the Columbia River basalt. During the late Neogene, epiclastic and volcaniclastic rocks of the Ringold Formation were deposited in the central Columbia Plateau. The Ringold Formation of Pliocene age represents main- and side-stream facies of the ancestral Columbia River. The Ringold has been divided into four units (Fig. 3) primarily on the basis of texture. The basal unit represents a complete fining-upward fluvial cycle deposited by a braided-river system associated with the ancestral Columbia River system (Fecht and others, 1982, 1987). The lower and upper units are fine-grained sediments that were deposited in a low-energy lacustrine and(or) fluvial overbank deposi-tional environment. The middle unit is composed of stream gravels, which were also deposited by the ancestral Columbia River system.

The most recent deposits are the sediments deposited by cataclysmic flood waters during the Pleistocene and post-flood alluvium and eolian deposits. The flood deposits are informally called the Han ford formation and are divided into the fine-grained, slackwater sediments, the Touchet beds, and the Pasco gravels.

Regional Thickness Variations of Units and Tectonic Implications

The greatest thickness of both Tertiary pre-CRBG rocks (Campbell, in press) and Columbia River basalt (Reidel and others, 1982, in press [a]) is in the central Columbia Plateau. Magnetotelluric data (Berkman and others, 1987) and seismic-reflection data (Catchings and Moody, 1988) suggest that both the CRBG and sub-basalt sediments thicken from the Palouse paleoslope into the area covered by Yakima Fold Belt. The CRBG ranges from 500 to 1,500 m thick on the Palouse paleoslope but abruptly thickens to more than 4,000 m in the Pasco Basin area (Reidel and others, 1982, in press [a]). Although the total thickness of the sub-basalt sediments is not known, these sediments appear to thicken dramatically beneath the Yakima Fold Belt (Campbell, in press; Reidel and others, in press [a]).

The regional thickness pattern of both the CRBG and underlying Tertiary sediments indicates that prior to the eruption of the basalts, the area encompassing the present-day Yakima Fold Belt had subsided relative to the Blue Mountains and Palouse paleoslope and filled with sediments. There is no evidence of encroachment by the sea into the central Columbia Plateau during the Tertiary. The continental nature of the sediments (Campbell, in press) suggests that aggradation kept pace with sub¬sidence, and the subaerial nature of the CRBG (Reidel and others, 1982, in press [b]) indicates that subsidence continued through the eruption of the basalts and that basalt accumulation kept pace with subsidence. Furthermore, the suprabasalt sediments in the Pasco Basin indicate that subsidence continued beyond the Miocene and into the Pliocene. Evidence for the thinning and pinchouts of basalt flows onto the Blue Mountains (for example, Ross, 1978; Hooper and Camp, 1981; Fox and Reidel, 1987) indicates that the Blue Mountains were growing during the eruption of the CRBG and while the central part of the plateau was subsiding. The regional tectonic setting of the central Columbia Plateau throughout much of the Cenozoic, therefore, appears to be one of a subsiding intermontane basin that is bounded on the west by the rising Cascade Range, on the south by the slowly growing Blue Mountains, and on the east by a relatively stable westward-dipping paleoslope.

GEOLOGY OF THE NACHES RIVER AREA

The Naches River area along the northwest margin of the Columbia Plateau is an important place to develop an understanding of the effects of pre-basalt structures on the Yakima Fold Belt. The principal structural elements that border the basalt include the Straight Creek fault, faults thought to be associated with the Olympic-WalIowa lineament (OWL), and the White River-Naches River fault zone (Fig. 4).

Straight Creek Fault

The Straight Creek fault of the Cascade Range is a major fault zone extending from north of the Canadian border to at least as far south as Snoqualmie Pass in central Washington. There is little or no evidence to extend this fault south of the drainages of the White River-Naches River fault zone (Fig. 4). Instead, the Straight Creek fault turns southeastward and splays into a series of subparallel faults (Tabor and others, 1984; Frizzell and others, 1984). These fault splays pass under the CRBG and align with northwest-trending folds in the Yakima Fold Belt (Manastash Ridge). However, at the plateau margin, only small faults of low displacement and broad, flat folds are present in sub-basalt rocks. Farther to the southeast, within the Yakima Fold Belt, the deformation becomes more intense.

Olympic- Wallowa Lineament

The OWL has been recognized as a major through-going topographic feature in Washington (Raisz, 1945; Fig. 1). This feature aligns with pre-basalt structural trends northwest of the Columbia Plateau. Within the Yakima Fold Belt, deformation along Manastash Ridge and abrupt bending of the eastern ends of Umtanum Ridge, Yakima Ridge, and Rattlesnake Ridge (Fig. 2) are considered to be evidence for Miocene or younger deformation along the OWL. This portion of the OWL is called the Cle Elum-Wallula deformed zone (CLEW).

Just northwest of the Columbia River basalt margin, on Manastash Ridge, numerous northwest-trending faults and shear zones of the Straight Creek fault system are subparallel to the OWL (Tabor and others, 1984). It is not known whether the OWL affects Tertiary rocks here or if deformation is solely related to the Straight Creek fault system. White River-Naches River Fault Zone

White River - Naches River Fault Zone

The Naches River and Little Naches River flow in a rather straight, southeasterly direction from near the crest of the Cascade Range toward Yakima (Fig. 5). The White River-Naches River fault zone is a major fault zone and is aligned with this 50-km-long Naches-Little Naches val¬ley system that separates two terranes of dissimilar structure, stratigraphy, and topography (Campbell, 1988). Northeast of the White River-Naches River fault zone, faults and folds in pre-Tertiary through Pliocene rocks parallel (N60°W) splays of the Straight Creek fault zone. Southwest of the White River-Naches River fault zone, faults in pre-Tertiary rocks trend N5°E to N20°W. Middle and late Tertiary rocks in this area reflect Miocene folding and are commonly aligned east-west.

Within the basalts the White River-Naches River fault zone appears to influence fold development in the Yakima Fold Belt as far southeast as Yakima. The fault zone separates a domain of ENE-trending folds on the southwest from dominantly northwest-trending folds on the northeast, and it defines structural low points along the Yakima Ridge and Rattlesnake Hills anticlines. The fault zone can be shown to offset flows of the CRBG for several kilometers southeast of the margin (Campbell, 1988).

The White River-Naches River fault zone derives its name from an alignment northwest of this area between this fault zone in the Naches River and the White River fault (Hammond, 1963; Frizzell and others, 1984), a major fault that continues at least 50 km WNW of the area. The length of the entire fault zone, from Enumclaw to Naches, exceeds 90 km.

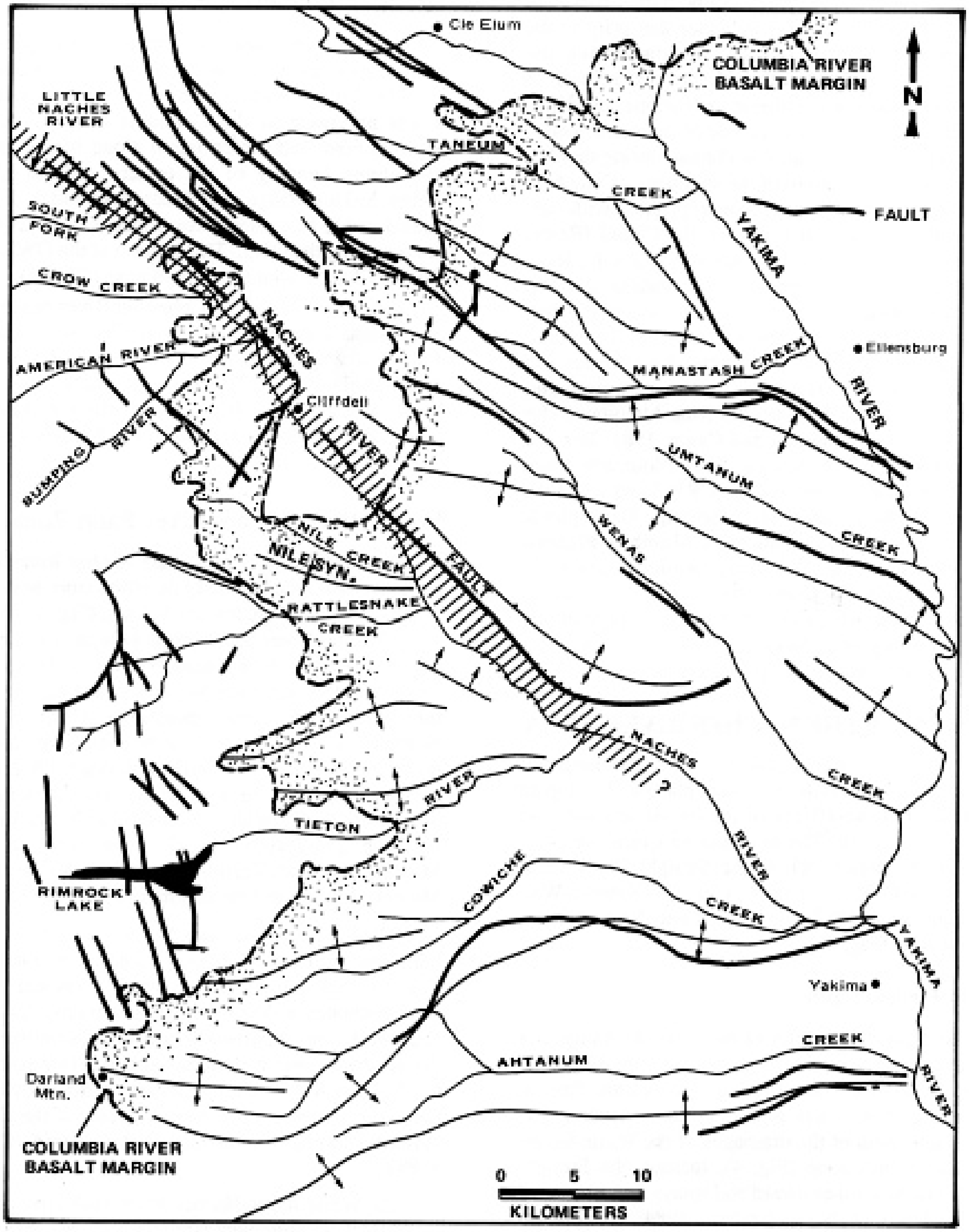

Figure 5. Comparison of drainage orientation and geologic structural patterns on both sides of the Naches-Little Naches rivers. The Naches River-White River fault zone is the striped pattern superimposed on the map. Thin lines are drainage systems, and heavy lines are major faults.

Deformation of the CRBG in the Naches River Drainage

Along the Naches River drainage at the margin of the CRBG, the Cleman Mountain anticline is the dominant structure in the Columbia River basalt (Fig 2). Cleman Mountain has the greatest amplitude and west structural closure of any anticline in the Yakima Fold Belt. A large folded thrust fault along the southwest limb of the fold places the R2 msu of the Grande Ronde Basalt over the N2 msu. Some of the complex faulting on this limb is attributed to movement on the White River-Naches River fault zone.

THE YAKIMA FOLDS

Introduction

The anticlines of the Yakima Fold Belt consist of non-cylindrical, asymmetrical anticlinal ridges and synclinal valleys. The anticlines are typically segmented and have a general north vergence, although some folds such as the Columbia Hills have a south vergence. Synclines typically have a gently dipping north limb and a steeply dipping south limb. Fold length is varied, ranging from several kilometers to more than 100 km; fold wavelengths range from several kilometers to as much as 20 km. Structural relief is typically about 600 m but varies along the length of the fold. The greatest structural relief along the Frenchman Hills, the Saddle Mountains, Umtanum Ridge, and Yakima Ridge occurs where they intersect the south-trending Hog Ranch-Naneum Ridge anticline (Fig. 2).

In general, the axial trends produce a “fanning” pattern across the fold belt (Figs. 2 and 4). Anticlines on the western side of the fold belt generally have a N50°E trend (Swanson and others, 1979b). Anticlines in the central part of the fold belt have west trends except along the CLEW where a N50°W trend predominates. The Rattlesnake Hills, Saddle Mountains, and Frenchman Hills have overall west trends across the fold belt, but Yakima Ridge and Umtanum Ridge change eastward from due west to N50°W in the zone of the CLEW. In the central part of the fold belt, the Horse Heaven Hills, the Rattlesnake Hills, and the Columbia Hills have eastward terminations against the CLEW. There is no evidence for continuation of any anticline to the northeast across the CLEW.

Fold and Fault Geometry

Within the east-central fold belt, the fold geometry typically consists of steeply dipping to overturned north flanks and gently dipping (5 degrees) south flanks. Exceptions, however, include the doubly plunging anticlines within the Rattlesnake-Wallula alignment (RAW) of the CLEW (Fig. 2) and the conjugate box-fold geometry of parts of the anticlines such as the Smyrna segment of the Saddle Mountains (Reidel, 1984). The main variable in fold profiles is the width of the gently dipping limb. The lengths of the gently dipping limbs range from as little 5 km to as much as 35 km.

Segmentation of the anticlines is common throughout the fold belt and is defined by abrupt changes in fold geometry or by places where regional folds die out and become a series of doubly plunging anticlines. Segment lengths range from 5 to 35 km in the central plateau; some of the larger segments contain subtler changes in geometry, such as different amplitudes that could also be considered segment boundaries. Segment boundaries are marked in many places by cross or tear faults that trend from N20°W to north and display a principal component of strike-slip movement (for example, Saddle Mountains; Reidel, 1984). In the central Columbia Plateau these cross faults are confined to the anticlinal folds and nor¬mally occur only on the steeper limb, dying out onto the gentler limb. In the southwest plateau, some cross faults can be traced as far as 100 km (Swanson and others, 1979b).

Some segment boundaries are also marked by relatively undeformed areas along the fold trend where two fold segments plunge toward each other. For example, the Yakima River follows a segment boundary where it cros¬ses the RAW at the southeast termination of Rattlesnake Mountain (Fig. 2).

The steep limb of the asymmetrical anticlines in the east-central fold belt is almost everywhere faulted (Fig. 6). In the eastern portion of the Yakima Fold Belt, the steep limb is typically the northern flank, but elsewhere, as at the Columbia Hills (Swanson and others, 1979b), the south limb is faulted. Where exposed, these frontal fault zones have been found to be imbricated thrusts— for example, at Rattlesnake Mountain, Umtanum Ridge near Priest Rapids Dam (Bentley, 1977; Goff, 1981; Bentley, in Swanson and others, 1979b), the Horse Heaven Hills near Byron Road (Hagood, 1986), and the Saddle Mountains near Sentinel Gap (Reidel, 1984).

Yakima folds of the central Columbia Plateau have emergent thrust faults at the ground surface (Fig. 6). The tops of the youngest lava flows at the Earth’s surface serve as a plane that becomes a low-angle thrust fault; the structural attitude of the surface flow controls the angle of the emergent fault plane. This type of apparent structural control led many investigators to conclude that faults associated with the Yakima folds are low-angle thrust faults with detachment surfaces within the CRBG, in the sediments below the basalts, or at the basalt-sediment contact. Where erosion provides deeper exposures into the cores of folds, the frontal faults are observed to be reverse faults (as at the Columbia water gap in the Frenchman Hills, 45 degrees to the south [Grolier and Bingham, 1971]; the Columbia Hills at Rock Creek, 50-70 degrees to the north [Swanson and others, 1979b]).

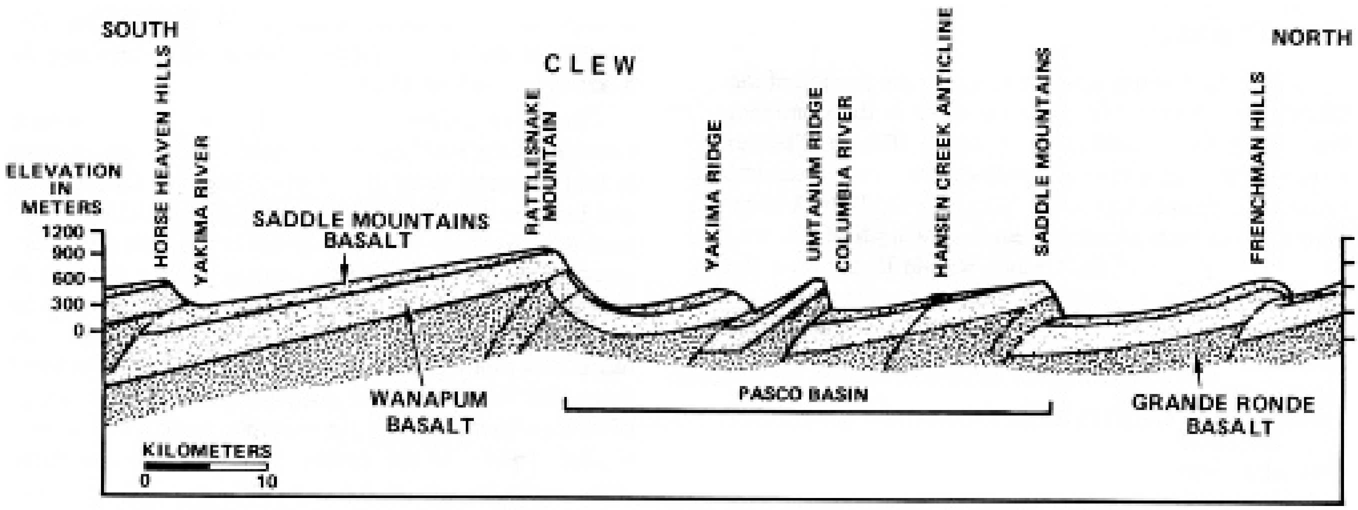

Figure 6. Schematic cross-section through the Yakima Fold Belt in the central Columbia Plateau at about long. N120°W.

Subsurface Structure

The dip of the frontal fault plane and the structure of the anticlines at depth remain controversial. A multitude of possible models (such as Suppe's [1983, 1985] fault-bend fold or fault-propagation fold, Jamison's [1987] detachment fold, and Mitchell and Woodward's [1988] kink-detachment fold) can all produce similar surface geometries and thus have provided abundant food for thought influencing many of the models that have been proposed for the fold belt. However, no clear answers have come forth because of the lack of direct observations.

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REFERENCES CITED

Barrash, W.; Bond, J. G.; Venkatakrishnan, R.;1983, Structural evolution of the Columbia Plateau in Washington and Oregon: American Journal of Science, v. 283, no. 9, p. 897-935.

Bentley, R. D., 1977, Stratigraphy of the Yakima Basalts and Structural Evolution of the Yakima Ridges in the western Columbia Plateau. In Brown, E. H.; Ellis, R. C., editors. Geology Excursions in the Pacific Northwest: Western Washington University Press, p. 339-389.

Bentley, R. D., 1980, Wrench tectonic model for the late Cenozoic evolution of Oregon and Washington [abstract]: Geological Society of America Abstracts with Programs, v. 12, no. 7, p. 385.

Bentley, R. D.; Campbell, N. P., 1983, Geologic Map of the Yakima Quadrangle, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-29, 1 pi., scale 1:48,000.

Berkman, E. A.; Orange, A.; Bergstrom, K. A.; Mitchell, T. H., 1987, Interpretation of magneto telluric data. Rattlesnake Mountain, Pasco Basin, Washington: Rockwell Hanford Operations Report SD-BWI-TI-354,31 p.

Bingham, J. W.; Lundquist, D. J.; Baltz, E. H., 1970, Geologic investigation of faulting in the Hanford Region, Washington: U.S. Geological Survey Open-file Report, 103 P-

Campbell, N. P., 1975, A geologic road log over Chinook, White Pass, and Ellensburg to Yakima highways: Washington Division of Geology and Earth Resources Information Circular 54, 81 p.

Campbell, N. P., 1988, Structural geology along the north¬western Columbia River basalt margin, Washington: Washington Division of Geology and Earth Resources Open File Report 88-5,108 p., 8 pi.

Campbell, N. P., in press, Structural and stratigraphic interpretation of the rocks under the Yakima Fold Belt based on recent surface mapping and well data. In Reidel, S. P.; Hooper, P. R. editors, Volcanism and Tectonism in the Columbia River Flood-basalt Province: Geological Society of America Special Paper 239.

Carkin, Brad, 1988, The geology and petrology of the Fifes Peak Formation in the Cliffdell area, central Cascades Washington: Western Washington University Master of Science thesis, 157 p., 2 pi. scale 1:24,000.

Carson, R. J.; Tolan, T. L.; Reidel S. P., 1987, Geology of the Vantage area, south-central Washington-An introduction to the Miocene flood basalts, Yakima Fold Belt, and Channeled Scabland. In Hill, Mason, editor. Geological Society of America Centennial Field Guide, Cordilleran Section, p. 357-362.

Catchings, R. D.; Moody, W. D., 1988, Crustal structure of the Columbia Plateau-Evidence for continental rifting: Journal of Geophysical Research, v. 19, no. Bl, p. 459-474.

Davis, G. A., 1977, Tectonic evaluation of the Pacific Northwest Pre-Cambrian to recent-Preliminary Safety Analysis Report In Washington Public Power Supply System, 1977, Washington Public Power Supply System nuclear project number 2, Preliminary Safety Analysis Report: Washington Public Power Supply System, Appendix 23, Subappcndix 2RC,p. 1-46.

Davis, G. A., 1981, Late Cenozoic tectonics of the Pacific Northwest with special reference to the Columbia Plateau. In Washington Public Power Supply System, Washington Public Power Supply System nuclear project number 2, Final Safety Analysis Report: Washington Public Power Supply System, Appendix 23, Subappendix 2.5 N, p. 1-44.

Fecht, K. R., 1978, Geology of the Gable Mountain-Gable Butte area: Rockwell Hanford Operations Report RHO-BWI-LD-5,70 p.

Fecht, K. R.; Reidel, S. P.; Tallman, A. M., 1982, Evolution of the Columbia River system in the central Columbia Plateau of Washington from Miocene to present [abstract]: Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 163.

Fecht, K. R.; Reidel, S. P.; Tallman, A. M., 1985, Paleodrainage of the Columbia River system on the Columbia Plateau of Washington State-A summary: Rockwell Hanford Operations Report RHO-BW-SA-318p, 55 p.

Fecht, K. R.; Reidel, S. P.; Tallman, A. M., 1987, Paleodrainage of the Columbia River system on the Columbia Plateau of Washington State-A summary. In Schuster, J. E., editor, Selected Papers on the Geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 219-248.

Fox, T. P.; Reidel, S. P., 1987, Stratigraphy of the Standard Kirkpatrick No. 1, Gilliam County, Oregon-New insights into Tertiary tectonism of the Blue Mountains: Oregon Geology, v. 49, no. 2, p. 15-22.

Frizzell, V. A., Jr.; Tabor, R. W.; Booth, D. B.; On, K. M.; Waitt, R. B. Jr., 1984, Preliminary geologic map of the Snoqual-mie Pass 1:100,000 quadrangle, Washington: U.S. Geological Survey Open-File Report 84-693, 43 p., 1 pi, scale 1:100,000.

Goff, F. E., 1981, Preliminary geology of eastern Umtanum Ridge, south-central Washington: Rockwell Hanford Operations Report RHO-BWI-C-21,100 p.

Grolier, M. J.; Bingham, J. W., 1971, Geologic map and sections of parts of Grant, Adams and Franklin Counties, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map 1-589, 6 sheets, scale 1:62,500.

Hagood, M. A., 1986, Structure and evolution of the Horse Heaven Hills, south-central Washington: Rockwell Hanford Operations Report RHO-BW-SA-344, 176 p., 1 pi., scale 1:24,000.

Hammond, P. E., 1963, Structure and stratigraphy of the Keechelus volcanic group and associated Tertiary rocks of the west-central Cascade Range, Washington: University of Washington Doctor of Philosophy thesis, 294 p., 2 pi.

Hooper, P. R.; Camp, V. E., 1981, Deformation of the southeast part of the Columbia Plateau: Geology, v. 9, no. 7, p. 323-328.

Keinle, C. F.; Bentley, R. D.; Anderson, J. L., 1977, Geologic reconnaissance in the Cle Elum-Wallula Lineament and re¬lated structures. In Washington Public Power Supply System, 1977, Washington Public Power Supply System nuclear project number 2, Preliminary Safety Analysis Report Washington Public Power Supply System, v. 2A, Amendment 23, Subappendix 2R D, p. 1-33.

Jamison, W. R., 1987, Geometric analysis of fold development in overthrust terranes: Journal of Structural Geology, v. 9, no. 2, p. 207-220.

Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: University of Washington Doctor of Philosophy thesis, 221 p.

Mackin, J. H., 1961, A stratigraphic section in the Yakima Basalt and Ellensburg Formations in south-central Washington: Washington Division of Mines and Geology Report of Investigations 19, 45 p.

Mangan, M. T.; Wright, T. L.; Swanson, D. A.; Byerly, G. R., 1986, Regional correlation of Grande Ronde Basalt flows, Columbia River Basalt Group, Washington, Oregon, and Idaho: Geological Society of America Bulletin, v. 97, no. 11, p. 1300-1318.

McMillian, Kent; Cross, R. W.; Long, P. E., 1987, Two-stage vesiculation in the Cohassett flow of the Grande Ronde Basalt, south central Washington: Geology, v. 15, no. 9, p. 809-812.

Mitchell, M. M.; Woodward, N. B., 1988, Kink detachment fold in the southwest Montana fold and thrust belt: Geology, v. 16, no. 2, p. 162-165.

Myers, C. W.; and others, 1979, Geologic Studies of the Columbia Plateau - A status report: Rockwell Hanford Operations Report RHO-BWI-ST-4,326 p., 10 pi.

Price, E. H., 1982, Structural geology, strain distribution, and tectonic evolution of Umtanum Ridge at Priest Rapids Dam, and a comparison with other selected localities within the Yakima Fold Belt structures, south-central Washington: Rockwell Hanford Operations Report RHO-BWI-SA-138, 197 p., 3 pi.

Raisz, E., 1945, The Olympic-Wallowa Lineament: American Journal of Science, v. 243-a, no. 5, p. 479-485.

Reidel, S. P., 1983, Stratigraphy and petrogenesis of the Grande Ronde Basalt from the deep canyon country of Washington, Oregon and Idaho: Geological Society of America Bulletin, v. 94, no. 4, p. 519-542.

Reidel, S. P., 1984, The Saddle Mountains-the evolution of an anticline in the Yakima Fold Belt: American Journal of Science, v. 284, no. 8, p. 942-978.

Reidel, S. P.. 1988[1989], Geologic Map of the Saddle Mountains, south central Washington: Washington Division of Geology and Earth Resources Geologic Map GM-38, 5 pi., scale 1:48,000.

Reidel, S. P.; Fecht, K. R., 1986, The Huntzinger flow-Evidence of surface mixing of the Columbia River Basalt Group and its petrogenetic implications: Geological Society of America Bulletin, v. 98, no. 6, p. 664-667.

Reidel, S. P.; Fecht, K. R.; Hagood, M. A.; Tolan, T. L., in press (a). Geologic evolution of the central Columbia Plateau. In Reidel, S. P.; Hooper, P. R., editors, Volcanism and Tectonism in the Columbia River Flood-basalt Province: Geological Society of America Special Paper 239.

Reidel, S. P.; Long, P. E.; Myers, C. W.; Mase, Jack, 1982, New evidence for greater than 3.2 kilometers of Columbia River basalt beneath the central Columbia Plateau: Eos (Transactions of American Geophysical Union), v. 63, no. 8, p. 173.

Reidel, S. P.; Scott, G. R.; Bazard, D. R.; Cross, R. W.; Dick, B., 1984, Post-12 million year clockwise rotation in the central Columbia Plateau, Washington: Tectonics, v. 3, no. 2, p. 251-273.

Reidel, S. P.; Tolan, T. L.; Hooper, P. R.; Beeson, M. H.; Fecht, K. R.; Anderson, J. L.; and Bentley, R. D., in press (b), The Grande Ronde Basalt, Columbia River Basalt Group-Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho. In Reidel, S. P.; Hooper, P. R., editors, Volcanism and Tectonism in the Columbia River Flood-basalt Province: Geological Society of America Special Paper 239.

Ross, M. E., 1978, Stratigraphy, structure, and petrology of Columbia River basalt in a portion of the Grande Ronde-Blue Mountains area of Oregon and Washington: University of Idaho Doctor of Philosophy thesis, 407 p., 1 pi.

Schmincke, H.-U., 1964, Petrology, paleocurrents, and stratigraphy of the Ellensburg Formation and interbedded Yakima Basalt flows, south-central Washington: The Johns Hopkins University Doctor of Philosophy thesis, 384 p.

Schmincke, H.-U., 1967, Flow direction in Columbia River basalt flows and paleocurrents of interbedded sedimentary rocks, south-central Washington: Geologisches Rundschau, v. 56, no. 3, p. 992-1019.

Shannon & Wilson, Inc., 1973, Geologic studies of the Columbia River basalt structures and age of deformation: Report to Portland General Electric Company, Portland, Oregon, 45 p.

Smith, G. A., 1989, Neogene synvolcanic and syntectonic sedimentation in central Washington: Geological Society of America Bulletin, v.100, no. 9, p. 1479-1492.

Smith, G. A., 1988b, Sedimentology of proximal to distal volcaniclastics dispersed across an active fold belt-Ellensburg Formation (late Miocene), central Washington: Sedimentology, v. 35, no. 6, p. 953-977.

Smith, G. A.; Campbell, N. P.; Deacon, M. W.; Muhammad Shafiquallah, 1988, Eruptive style and location of volcanic centers in the Miocene Washington Cascade Range-Reconstruction from the sedimentary record: Geology, v. 16, no. 4, p. 337-340.

Smith, G. O., 1903, Anticlinal mountain ridges in central Washington: Journal of Geology, v. 11, no. 2, p. 166-177.

Suppe, J., 1983, Geometry and kinematics of fault-bend folding: American Journal of Science, v. 283, no. 7, p. 648-721.

Suppe, J., 1985, Principles of Structural Geology: Prentice-Hall, Inc., N. J., 537 p.

Swanson, D. A.; Wright, T. L., 1976, Field Guide to field trip between Pasco and Pullman, Washington, emphasizing stratigraphy, vent areas, and intracanyon flows of the Yakima Basalt. In Proceedings, Geological Society of America Cordilleran Section meeting, Pullman, Washington, Field Guide

Swanson, D. A.; Wright, T. L.; Hooper, P. R.; Bentley, R. D., 1979a, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Swanson, D. A.; Anderson, J. L.; Bentley, R. D.; Camp, V. E.; Gardner, J. N.; Wright, T. L., 1979b, Reconnaissance geologic map of the Columbia River Basalt Group in Washington and adjacent Idaho: U.S. Geological Survey Open-file Report 79-1363, 7 pi., scale 1:250,000.

Swanson, D. A.; Wright, T. L.; Camp, V. E.; Gardner, J. N.; Helz, R. T.; Price, S. M.; Reidel, S. P.; Ross, M. E., 1980, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Map 1-1139, 2 sheets, scale 1:250,000.

Tabor, R. W.; Frizzell, V. A., Jr.; Vance, J. A.; Naeser, C. W., 1984, Ages and stratigraphy of Lower and Middle Tertiary sedimentary and volcanic rocks of the central Cascades, Washington-Application to the tectonic history of the Straight Creek fault: Geological Society of America Bulletin, v. 95, no. 1, p. 26-44.

Tolan, T. L.; Reidel, S. P.; Anderson, J. L.; Beeson, M. H.; Fecht, K. R.; Swanson, D. A., in press. Revisions to the area! extent and volume of the Columbia River Basalt Group. In Reidel, S. P.; Hooper, P. R., editors, Volcanism and Tectonism in the Columbia River Flood-basalt Province: Geological Society of America Special Paper 239.

Vance, J. A.; Clayton, G. A.; Mattinson, J. M.; Naeser, C. W., 1987, Early and Middle Cenozoic stratigraphy of the Mount Rainier-Tieton River area, southern Washington Cascades. In Schuster, J. E., editor. Selected Papers on the Geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 269-290.

Walsh, T. J.; Korosec, M. A.; Phillips, W. M.; Logan, R. L.; Schasse, H. W., 1987, Geologic Map of Washington-Southwest quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-34, 28 p., 2 pi., scale 1:250,000.

Waters, A. C., 1961, Stratigraphy and lithologic variations in the Columbia River basalt: American Journal of Science, v. 259, p. 583-611.

Road Log

The route covered by the road log is shown in Figure 7. Swanson and others (1979b) and Walsh and others (1987) provide geologic maps that include areas covered by this field guide. More detailed maps are available for parts of the areas described below: the western margin of the Columbia Plateau (Campbell, 1988); the Yakima area (Bentley and Campbell, 1983); the Saddle Mountains (Reidel, in press); out of date but useful color maps by Myers and others (1979) for the Pasco Basin and Grolier and Bingham (1971) for Franklin and Grant Counties. Bentley (1977), Campbell (1975), and Carson and others (1987) provide guides for portions of the Yakima Fold Belt.

Cumulative mileage is given on the left below; interval mileage is in parentheses.

Day 1: Columbia River Basalt Group Margin in the Naches River Drainage

Yakima to the Naches River area

0.0 Begin at Red Lion Inn parking lot. Turn right (north) on 1st Street. Stay in the right lane.

0.4 (0.4) Take U.S Highway 12 (west) turnoff toward Naches (sharp turn just beyond underpass). Pro ceed west on U.S. 12.

1.6 (1.2) 16th Avenue overpass.

1.7 to 2.5 (0.1) Cliffs on the right of the highway are in Columbia River Basalt Group (CRBG) and were exposed by breaching of the Yakima Ridge an¬ticline by the Naches River. The bench above the river level marks the Vantage interbed. Grande Ronde Basalt (N2 msu) flows below and Wanapum Basalt above the Vantage. The Pomona Member of the Saddle Mountains Basalt is exposed on the skyline (Fig. 3).

3.8 (1.3) The highway and Naches River cut diagonally through the Yakima Ridge anticline here. At 11 o'clock is the termination of the Tieton Ande-site flow at Painted Rocks. (Direction notation in this guide uses a clock format.) The Tieton Andesite is a single flow that erupted from a volcano in the Goat Rocks area about 980,000 yr ago (Shannon & Wilson, Inc., 1973). Painted Rocks features numerous petroglyphs, restored for public viewing.

4.5 (0.7) Cross the Naches River at Twin Bridges. Cleman Mountain anticline is visible at 12 o'clock.

8.0 (3.5) Eschback Road intersection. Tieton Andesite forms cliffs at 9 o'clock. The flow traveled down the Tieton River canyon and filled the paleovalley of the Naches River just south of U.S. 12. The Naches River was forced to cut a new valley to the north. With a length

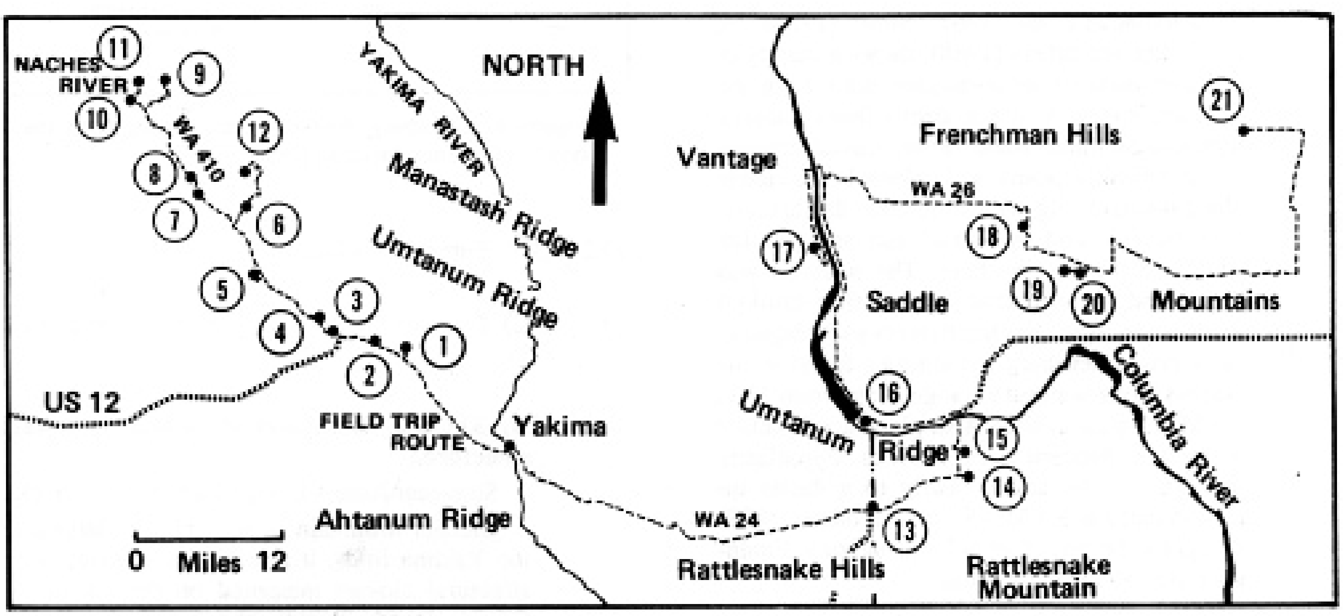

Figure 7. Fieldtrip route. Circled numbers locate trip stops. WA, Washington State Route (SR in text)

exceeding 80 km, this flow may be the longest andesite flow in the world.

9.5 (1.5) Yakima Water Treatment Plant at 9 o'clock. The two interbeds exposed at 2 o'clock are the Selah and Vantage. Wanapum flows thin rapidly to the west in this area; at Cleman Mountain only one Wa napum flow remains.

10.8 (1.3) Cleman Mountain anticline at 12 o'clock. The type section of the Ellensburg Formation is exposed at 3 o'clock. Although Smith (1903) first described the Ellensburg Formation in the Kittitas Valley, the Naches section is the thickest known. About 366 m is exposed along these cliffs, and a nearby well penetrated 579 m of Ellensburg Formation before reaching basalt. There is nearly 1,930 m of structural relief between the Grande Ronde Basalt in the Naches syncline here and the Grande Ronde Basalt on top of the Cleman Mountain anticline.

12.3 (1.5) Turn right on Allan Road at Allan Brothers ware house.

13.3 (1.0) Stop sign at Old Naches Highway. Continue straight ahead.

14.2 (0.9) **STOP 1. Upper Ellensburg Formation.**

Stop on the top of the Wenas Grade.
The Ellensburg Formation, described in detail by Schmincke (1964, 1967), Smith (1988a, b), and Smith and others (1988), shows a variety of volcanic-induced sedimentation units from the Cascade Range. Volcanic debris flows (lahars), hyperconcentrated flood flows, fluvial channel and overbank deposits, and paleosols are visible along the road (Fig. 8). Hornblende-dacite clasts plus air-fall and reworked ash and pumice dominate the section here.

The material was deposited by volcanic events that choked streams (ancestral Naches River?) with fragmental debris. Ellensburg pyroclastics found in the Naches River watershed range in age from 13 to 7.4 Ma (Smith, 1988a). A single volcanic center may have deposited these rocks. Pyroclastic deposits can be traced nearly to a dacite intrusion dated at 8.8 Ma (Smith and others, 1988) thought to be part of an old volcano near Bumping Lake, 50 km to the west. Return to U.S. 12 and continue west.

17.2 (3.0) Entering Naches.

17.4 (0.2) Blinking yellow light. Continue west on U.S. 12.

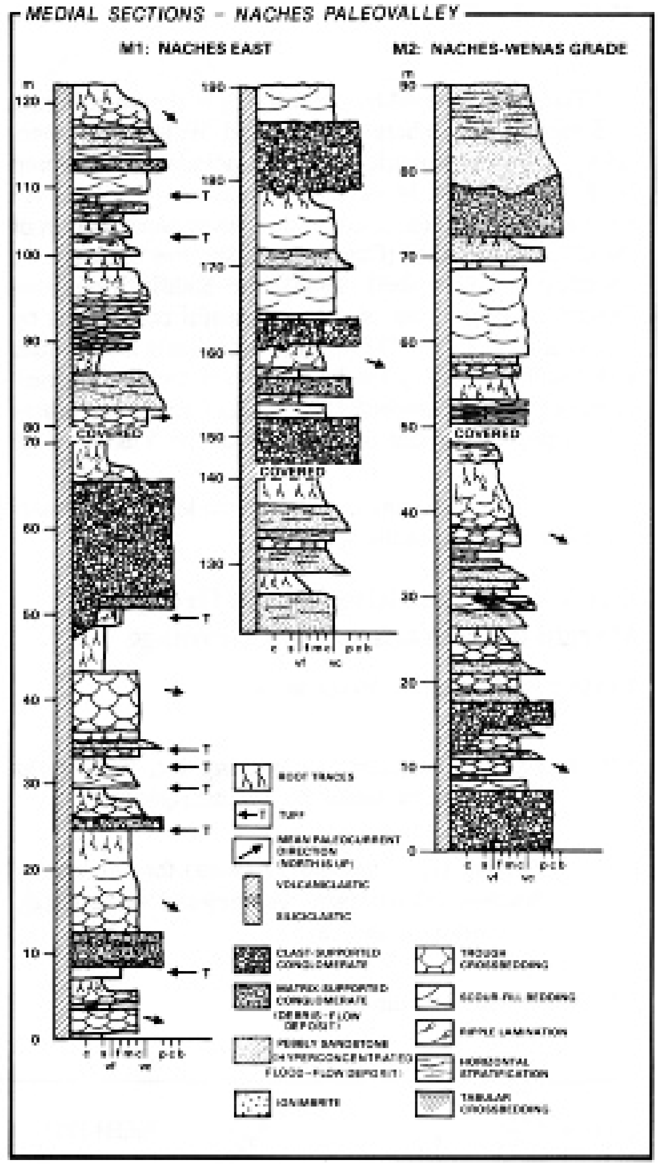

Figure 8. Ellensburg Formation stratigraphy from the type locality (from Smith and others, 1988).

18.0 (0.6) **STOP 2. Discussion of Cleman Mountain structure.**

Stop near Rose's Cafe, which is at 9 o'clock. Cleman Mountain is not only the largest of the Yakima folds, it also has the greatest west structural closure measured on the top of the Grande Ronde Basalt, about 610 m. Cleman Mountain is unusual in other respects as well. A folded thrust fault on its south limb places the Grande Ronde Basalt R2 msu over the Na msu flows that form the steeply dipping rocks at 1 o'clock (Fig. 9). At 3 o'clock, the folded thrust may be overturned and displaced southward by a second thrust fault. Although a second thrust may exist just above road level, the folded thrust crosses

U.S. 12 a few miles west of here. This large-scale fold and thrust of Cleman Mountain has deformed and perhaps covered part of the Naches syncline here (Fig. 9B).

Continue west on U.S. 12.

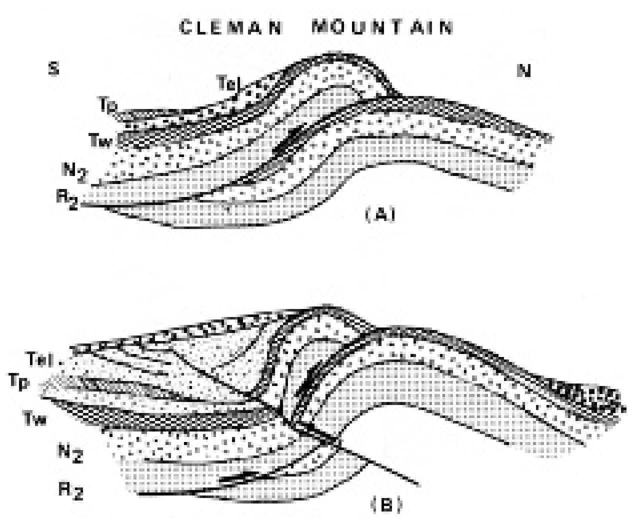

Figure 9. Generalized cross-sections of the Cleman Mountain structure (R. D. Bentley and N. P. Campbell, unpublished data). (A) is the interpreted structure at post-Wanapum time. (B) is the interpreted structure at post-Saddle Mountains time. Tel, Ellensburg Formation; Tp, Pomona Member; Tw, Wanapum Formation; N2 and R2, second normal and second reversed polarity intervals, respectively, of the Grande Ronde Basalt.

21.4 (3.4) Approaching the Chinook Pass-White Pass junc tion. Note steeply dipping, brecciated flows on the south limb of the Cleman Mountain fold at 3 o'clock.

21.8 (0.4) Junction of Highways U. S. 12 and Wash¬ington State Route (SR) 410. Proceed straight ahead on SR 410 toward Chinook Pass.

23.6 (1.8) STOP 3. View of fault breccia and thrust fault.

Turn right onto a small road and park. Here the folded thrust seen at Stop 2 crosses SR 410. N2 Grande Ronde basalt flows are exposed just west of this stop, whereas mostly sheared R2 flows (?) crop out to the east. This is typical of many thrust faults in Columbia River basalt where the upper plate is highly brecciated and the overridden block is nearly undeformed. At 9 o'clock across the Naches River, N2 Grande Ronde basalt flows, an interbed between the N2 and R2 basalt, R2 basalt, and the trace of the thrust fault can be seen. This thrust fault presumably continues up the valley but has not been traced there to date.

Continue west on SR 410.

24.1 (0.5) Fault breccia associated with back thrust visible at 12 o'clock.

24.3 (0.2) **OPTIONAL STOP 4. Discussion of thrust fault and Sanford Pasture landslide.**

Turn off onto the wide shoulder and park.
The gray mass of breccia across the river at 9 o'clock is at the edge of an extremely large landslide known as the Sanford Pasture landslide. The breccia may be associated with the landslide, fault breccia transported by the landslide, or part of the Cleman Mountain folded thrust. Detailed mapping or trenching is needed to resolve this problem. The Sanford Pasture landslide continues upriver for more than 8 km.
Continue west on SR 410.

25.0 (0.7) Landslide debris at 3 o'clock in the road cut. Grande Ronde Basalt in cliffs at 9 o'clock across the Naches River.

26.6 (1.6) Steeply dipping basalt in the Nile syncline (?) at 11 o'clock across the Naches River.

29.2 (2.6) Roadcut at 3 o'clock exposes pillows of Grande Ronde Basalt resting on a gravel interbed.

30.1 (0.9) Turn left (southeast) onto Rattlesnake Road.

30.3 (0.2) Cross the Naches River.

30.5 (0.2) N2 flows at 9 o'clock.

30.9 (0.4) **STOP 5. View of Nile syncline and Cleman Mountain structure.**

Pull off along the road.

At 9 o'clock, the sediments in the Rattlesnake Creek section of the Ellensburg Formation near the axis of the Nile syncline (Fig. 5) are much coarser than those of the Naches section. Block- and ash-flow deposits, as well as rapid lateral clast-size changes, suggest that the source was only a few kilometers to the west.

Cleman Mountain anticline at 12 o'clock shows both steeply southwest-dipping Nz Grande Ronde basalt flows and almost flat-lying R2 basalt. The R? msu has probably moved southward as an in-place block, giving the false appearance of a tear fault.

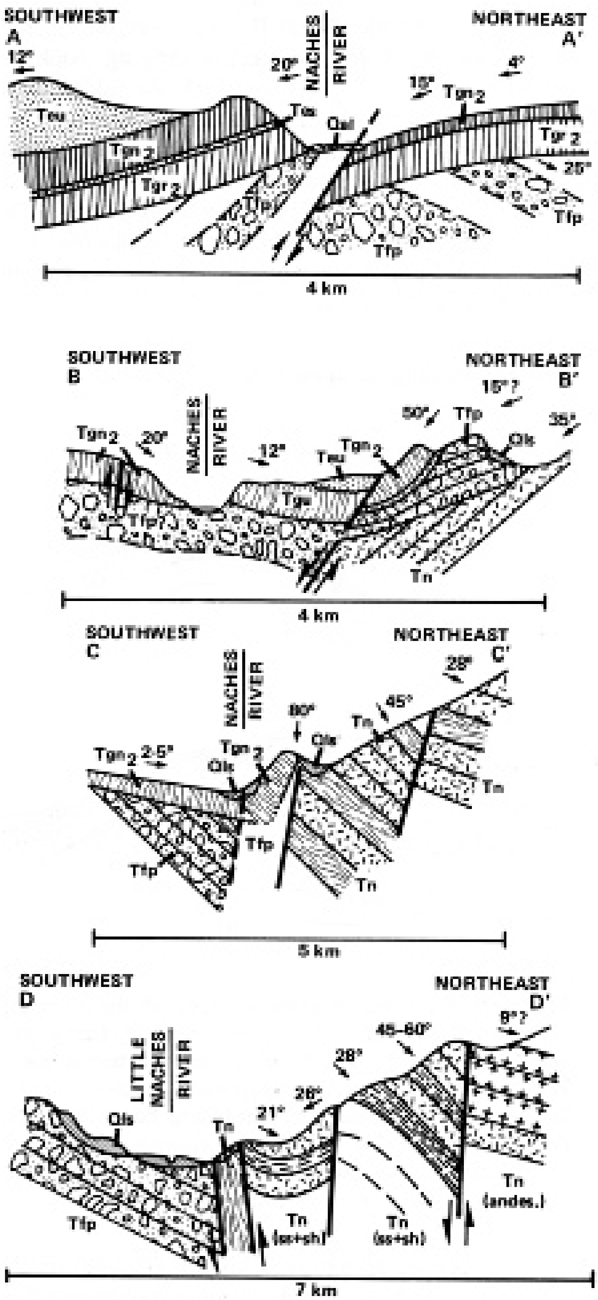

Figure 10. Diagrammatic sections across the Naches River-White River fault zone trend at selected locations along the Naches-Little Naches River canyon (not to scale; from Campbell, 1988). (A) at Rock Creek; (B) near Sawmill Flat; (C) at Longmire Meadow; and (D) west of profile (C) and beyond the margin of the Columbia River basalt Tfp, Fifes Peak Formation; Tn, Naches Formation [ss, sandstone; sh, shale; andes., andesite]; Tel, Ellensburg Formation; N2 and Rz, second normal and reversed polarity units, respectively, of the Grande Ronde Basalt; Qls, landslide. Arrows with numbers indicate dip angle.

folded thrust described at Stop 2 and may die out a few kilometers to the east.

36.6 (0.6) The stratigraphic section at 9 o'clock consists of both N2 and Rz Grande Ronde Basalt flows. These exposures are structurally high compared to the flows north of the road; offset occurs on a fault that parallels the road at this locality (Fig. 10, section a).

37.1 (0.5) Bald Mountain Road at 3 o'clock.

37.7 (0.6) **OPTIONAL STOP 6. Discussion of White River-Naches River fault zone.**

Fault breccia and slickensides in Columbia River basalt at 3 o'clock. This exposure is near the basalt margin. This fault is one of the few faults that can be found displacing basalt at the margin of the Columbia Plateau. The fault is thought to be part of the larger White River-Naches River fault zone and suggests that movement along this structure continued in post-basalt time. The fault here aligns with, and is related to the thrust described at trip mile 30.3. West of the basalt margin, the fault has been difficult to trace into the Fifes Peak Formation.

38.0 (0.3) Rock Creek turnoff at 3 o'clock. Up this road is a good view of the west-plunging Cleman structure; we will stop here late in the day when the light is best.

38.7 (0.7) Andesites, breccias, and tuffs of the Fifes Peak Formation are exposed here along cliffs at the sharp bend of the road.

39.2 (0.5) Across the river at 9 o'clock are steeply dipping volcanic rocks of the Edgar Rock vol cano, a partly dissected cone of the Fifes Peak Formation (23-26 Ma). This is the southeast edge of the Edgar Rock volcano; the Naches River canyon cuts diagonally through the cone for the next 8 km. Fifes Peak rocks along this part of the Cascade Range are associated with these partly preserved volcanoes. Only rocks that are part of the Edgar Rock volcano will be seen on this field trip.

39.3 (0.1) Volcanic breccia and channel fill in Fifes Peak volcanics. The Edgar Rock volcano has both a cone facies (coarse breccias, andesite flows) and an apron facies (ash-flow tuffs and finer pyroclastics), but SR 410 exposes mainly cone facies.

folded thrust described at Stop 2 and may die out a `few kilometers to the east.

36.6 (0.6) The stratigraphic section at 9 o'clock consists of both N2 and R2 Grande Ronde Basalt flows. These exposures are structurally high compared to the flows north of the road; offset occurs on a fault that parallels the road at this locality (Fig. 10, section a).

37.1 (0.5) Bald Mountain Road at 3 o'clock.

37.7 (0.6) **OPTIONAL STOP 6. Discussion of White River-Naches River fault zone.**

Fault breccia and slickensides in Columbia River basalt at 3 o'clock. This exposure is near the basalt margin. This fault is one of the few faults that can be found displacing basalt at the margin of the Columbia Plateau. The fault is thought to be part of the larger White River-Naches River fault zone and suggests that move-ment along this structure continued in post-basalt time. The fault here aligns with, and is related to the thrust described at trip mile 30.3. West of the basalt margin, the fault has been difficult to trace into the Fifes Peak Formation. 38.0 (0.3) Rock Creek turnoff at 3 o'clock. Up this road is a good view of the west-plunging Cleman structure; we will stop here late in the day when the light is best.

38.7 (0.7) Andesites, breccias, and tuffs of the Fifes Peak Formation are exposed here along cliffs at the sharp bend of the road.

39.2 (0.5) Across the river at 9 o'clock are steeply dipping volcanic rocks of the Edgar Rock volcano, a partly dissected cone of the Fifes Peak Forma¬tion (23-26 Ma). This is the southeast edge of the Edgar Rock volcano; the Naches River can¬yon cuts diagonally through the cone for the next 8 km. Fifes Peak rocks along this part of the Cascade Range are associated with these partly preserved volcanoes. Only rocks that are part of the Edgar Rock volcano will be seen on this field trip.

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\
39.6 (0.3) The Pond Restaurant at 3 o'clock.
\
40.4 (0.8) Passing through Forest Service work camp.

40.9 (0.5) Rocks at 3 o'clock for the next mile are altered volcanics of unknown age, possibly Fifes Peak Formation.

41.8 (0.9) Gold Creek Station and Cafe. This is the ap proximate center of the old Edgar Rock volcano, which probably exceeded 2,400 m in elevation.

42.0 (0.8) Edgar Rock at 12 o'clock is the northwestern flank of the old volcano.

42.7 (0.7) **STOP 7. Edgar Rock volcano and older(?) volcanic rocks.**

At 9 o'clock, Edgar Rock marks the highest remaining part of the Edgar Rock cone. At 3 o'clock the roadcut exposes sheared and altered older(?) rocks. Tuffs here gave a K-Ar age of 25.7 Ma (Neil Johnson, Shell Oil Company, oral commun., 1986) or in the age range of the Fifes Peak Formation, but the altered condition of the rock makes the date suspect. The shears and faults here are part of the White River-Naches River fault zone. Dips of more than 60 degrees in the rocks in the cone facies at Edgar Rock suggest tilting of the old cone due to faulting, but other evidence for faulting across this area has yet to be demonstrated.

Continue west on SR 410.

43.4 to 43.5 **(0.7) OPTIONAL STOP 8. Fifes Peak cone facies.**

Steeply dipping cone facies of the Fifes Peak Formation of the Edgar Rock volcano; we are now passing through the northwest edge of the old volcano.

44.0 (0.5) Entering Cliffdell.

45.0 (1.0) Old River Road at 9 o'clock.

45.1 (0.1) Columbia River basalt in cliffs \along the road at 3 o'clock. Columbia River basalt flowed around the old Edgar Rock cone and continued up a palcodrainagc that parallels the present Little Naches River.

47.7 (2.6) Milk Creek Road at 3 o'clock.

48.2 (0.5) Approaching the Little Naches Road. Prepare to exit SR 410.

52.4 (4.2) Right turn on U.S. Forest Service Road (FSR) 19, Little Naches River Road.

53.0 (0.6) We are now traveling westward on Columbia River basalt along Little Naches River syncline. There are four or five N2 Grande Ronde basalt flows and one R2 flow exposed. The White River-Naches River fault zone is north of the highway along the north limb of the syncline.

54.3 (1.3) FSR 1901 at 3 o'clock. Turn right and proceed to Optional Stop 9.

56.5 (2.2) Junction with FSR 1903; continue on FSR 1901.

57.2 (0.7) Beginning of exposures of Naches Forma¬tion in the roadcut at 3 o'clock.

57.4 (0.2) Kaner Flat Trail at 3 o'clock.

58.4 (1.1) Naches Formation at 3 o'clock.

58.5 (0.1) Rhyolite dome in the Naches Formation at 11 o'clock.

58.7 (0.1) FSR 1901-726 junction; stay left.

60.7 (2.0) Quartz Creek Trail, FSR 1916. Bear left downgrade.

60.8 to 61.5 (0.1) Section in the Naches Formation.

61.6 (0.1) **OPTIONAL STOP 9. Naches Formation and southern splay of Straight Creek fault.**
The Naches Formation has several different facies and probably should be subdivided into members. Several rhyolite dome-like masses are present in the Little Naches River drainage. The section exposed south of the fault contains both basalt flows and fluvial elastics. The fault observed here is the southernmost splay of the Straight Creek fault (Fig. 4), and it forms the south boundary of the Cabin Creek block of Tabor and others (1984).

Return to the main FSR 19 and continue west.

69.8 (8.2) FSR 1902 to Ravens Roost at 9 o'clock. 70.0 (0.2) Crossing Quartz Creek.

70.8 (0.8) Crossing the Little Naches River. Rapids are in N2 Grande Ronde Basalt.

71.5 (0.7) FSR 750 at 3 o'clock. Turn right onto FSR 750 for Stops 10 and 11.

71.8 (0.3) At 9 o'clock N2 Grande Ronde Basalt flows.

72.5 (0.7) **STOP 10. White River structure.**
Columbia River basalt flows are nearly verti¬cal along the north edge of the Little Naches River syncline (Fig. 11). The main White River fault of Frizzell and others (1984) passes just to the north and may have as much as 1,000 m of north-side-up throw (Fig. 10, section D, and Fig. 11). No evidence for strike-slip movement is known from anywhere along the White River-Naches River structure. The main fault is not ex¬posed, but small shears probably associated with it cut the basalt.

Continue on FSR 750 for Stop 11.

73.6 to 74.4 (1.1) Naches Formation in road cuts.

74.5 (0.1) **STOP 11. Sandstone facies of the Naches Formation.**
The stratigraphy of the Naches Formation is not well known. It is possible that the thickness (1,500 to 3,000 m, Tabor and oth ers, 1984) of the Naches is much less than published estimates due to stratigraphic duplication by faulting.

Return to FSR 19.

76.5 (2.0) Junction of FSR 750 and 19. Turn east onto FSR 19 (Little Naches Highway).

81.0 (4.5) Junction of FSR 19 and SR 410. Turn left onto SR 410.

91.4 (10.4) Turn north onto Rock Creek Road (FSR 1702/625) for Stop 12.

91.5 to 94.5 (0.1) We are traveling along Fifes Peak Formation at the margin of the Co lumbia River basalt.

95.2 (0.7) Junction with FSR 1720; bear left on FSR 1702.

97.2 (2.0) Junction with FSR 1721; bear left to FSR 1721.

98.4 (1.2) Good exposures of Fifes Peak Formation for the next mile.

99.8 (1.4) Unmarked road junction; bear left on the lower road.

100.9 (1.1) Junction of FSR 1721 and 559; bear

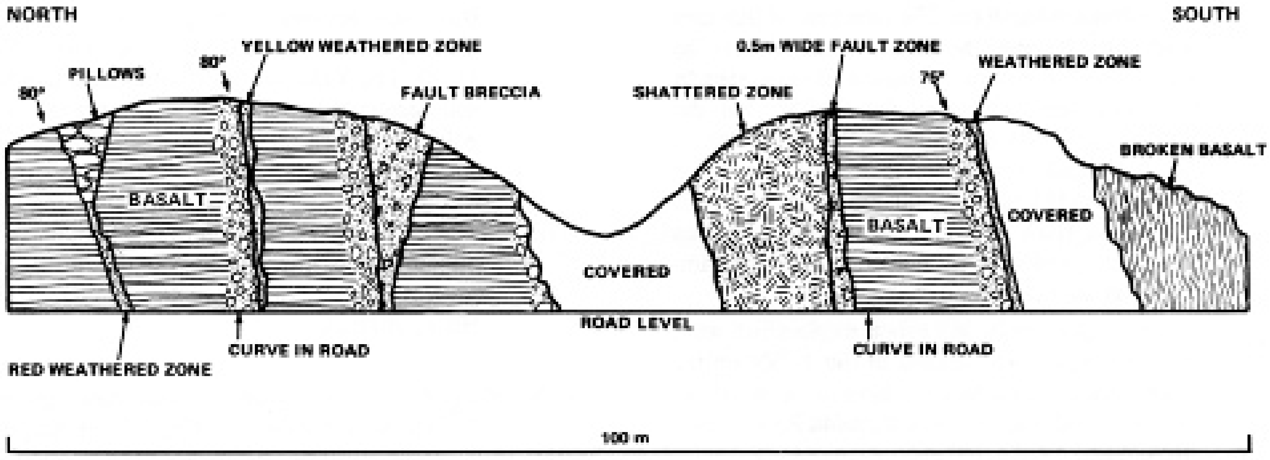

Figure 11. Sketch of near-vertical Columbia River basalt at Longmire Meadow, Little Naches River (from Campbell, 1988).

left on FSR 559.

102.1 (1.2) Bear right on the upper logging road.

102.3 (0.2) **STOP 12. Cleman Mountain anticline.**
End of the road; park.
It is best to view this stop in the late afternoon. This stop provides an excellent view of the west-plunging Cleman Mountain anticline, the basalt margin, and the underlying Fifes Peak Formation. The Cleman anticline is typical of most Yakima folds in that the fold dies out before reaching the basalt margin. Clearly, pre-basalt structures here do not align with those in the Columbia River basalt (Campbell, 1988). Columbia River basalt is offset at the Little Naches River where the plateau margin is offset along the Naches River-White River fault zone.

Return to SR 410 and drive back to Yakima.

95.2 (0.7) Junction with FSR 1720; bear left on FSR 1702.

97.2 (2.0) Junction with FSR 1721; bear left to FSR 1721.

98.4 (1.2) Good exposures of Fifes Peak Formation for the next mile.

99.8 (1.4) Unmarked road junction; bear left on the lower road.

100.9 (1.1) Junction of FSR 1721 and 559; bear left on FSR 559.

102.1 (1.2) Bear right on the upper logging road.

102.3 (0.2) **STOP 12. Cleman Mountain anticline.**

End of the road; park.

It is best to view this stop in the late after¬noon. This stop provides an excellent view of the west-plunging Cleman Mountain anticline, the basalt margin, and the underlying Fifes Peak Formation. The Cleman anticline is typical of most Yakima folds in that the fold dies out before reaching the basalt margin. Clearly, pre-basalt structures here do not align with those in the Columbia River basalt (Campbell, 1988). Columbia River basalt is offset at the Little Naches River where the plateau margin is offset along the Naches River-White River fault zone.

Return to SR 410 and drive back to Yakima.

Day 2: Yakima Fold Belt, Columbia Plateau Yakima to Spokane

0.0 Leave Red Lion Motel in Yakima. Reset odometer. Turn right on 1st Street and take Interstate Highway 82 southbound.

3.7 (3.7) Take exit 34 to Moxee. Turn left (east) on SR 24.

6.2 (2.5) Konnowock Pass in the Rattlesnake Hills anticline at 2 o'clock. This is an ancestral (late Miocene) water gap of the Yakima River through the Rattlesnake Hills (Smith, 1988).

23.4 (17.2) Mile marker 19. Road narrows.

26.0 (2.6) Approximate crest of the Hog Ranch-Naneum Ridge anticline (Fig. 2). The structural relief of the anticline exposed at the surface progressively decreases south from where it enters the Columbia Plateau near Wenatchee. The prominent ridge at 12 o'clock is the part of the Rattlesnake Hills anticline that extends northeast of the main trend.

35.2 (9.2) **STOP 13. Discussion of the western Pasco Basin.**
Pull into the parking lot of the Silver Dollar Cafe. The Hog Ranch-Naneum Ridge anticline marks the western boundary of the Pasco Basin (Fig. 2). From the western boundary of the basin, the Yakima folds plunge gently eastward toward the Palouse paleoslope. The structure of this area is complex because the CLEW trends across the area. To the north, Yakima Ridge trends northwest and is part of the CLEW, but the Rattlesnake Hills anticline to the south trends east-west and is separate from this zone. The Rattlesnake Hills display the typical geometry of a Yakima fold, whereas this part of Yakima Ridge is a series of en echelon folds superimposed on the main trend.

The first deep hydrocarbon exploration well, RSH-1 (Fig.4), was drilled in the 1950s on the Rattlesnake Hills east of here to a depth of 10,660 ft and was still in Columbia River basalt (Reidel and others, 1982).

35.5 (0.3) Benton County line. Pomona Member (Fig. 3) exposed on the left. The hill crest ahead is one of the en echelon anticlines that make up this segment of the Yakima Ridge anticline.

37.6 (2.1) Crest of another en echelon anticline on Yakima Ridge. Sediments of the Rattlesnake Ridge interbed at 3 o'clock. The Rattlesnake Ridge interbed is the packet of sediments of the Ellensburg Formation between the Pomona (12 Ma) and Elephant Mountain (10.5 Ma) Members (Fig. 3). The white layer is ash.

37.8 (0.2) The Saddle Mountains form the prominent ridge to the north; Gable Mountain is to the east. The highest point visible on the Saddle Moun¬tains is Wahatis Peak, a channel fill of basalt of the Asotin Member (Reidel and Fecht, 1986).

40.3 (2.5) Cold Creek Road at 9 o'clock. Vineyards of Chateau Ste. Michelle on the left.

40.5 (0.2) Touchet beds along both sides of the road.

43.4 (2.9) STOP 14. Central Pasco Basin.
Junction of SR 24 and SR 240. The barricade at 12 o'clock is one of the entrances to the U.S. Department of Energy's Hanford Site. Proceed to the parking area before the guard station.

From here the eastward plunge of the Yakima folds is very apparent. In the distance only Gable Butte and Gable Mountain of the Umtanum Ridge anticline protrude above the sediment-filled basin (Fig. 2). A buried ridge east of Gable Mountain, called the Southeast anticline, marks the eastward termination of the Umtanum Ridge structural trend. Gable Mountain and Gable Butte are second-order en echelon anticlines developed on the Umtanum anticline (Fecht, 1978). The Yakima Ridge anticline also plunges southeast and is buried by sediments of the Ringold Formation and Hanford formation. To the south is the intersection of the east-trending Rattlesnake Hills and northwest-trending Rattlesnake Mountain. Both anticlines appear to terminate at this intersection. On the north side of Rattlesnake Mountain is the old Rattlesnake Hills gas field.

43.6 (0.2) Return to the main highway; turn right on SR 24. The road follows the Cold Creek bar, which contains multiple flood deposits from cataclysmic flood waters during the Pleistocene.

45.4 (1.8) **OPTIONAL STOP 15. Northern Pasco Basin**.
Pull over at the curve in the road near the top of the hill at Hanford Gate 122A.

The crest of this hill also marks the crest of Umtanum Ridge (Fig. 2), which is plunging to the east. The prominent basalt flow that we are on is the Pomona flow.

This stop provides a view of the northern part of the Pasco Basin. At 12 o'clock is the Sentinel Gap segment of the Saddle Mountains, at 2 o'clock is the Smyrna Bench segment. The geometry of the Saddle Mountains anticline changes here from an open fold in the Sentinel Gap segment to a box fold in the Smyrna Bench segment. Farther east in the Saddle Gap segment, the fold geometry is that of an open fold. At about 12 o'clock on the crest of the Saddle Mountains is the site where Shell and ARCO drilled the BN 1-9 wildcat well (Fig. 4). This well penetrated about 11,500 ft of basalt and bottomed (at more than 17,000 ft) in the Chumstick Formation of Eocene age (Campbell, in press).

The well had subcommercial gas shows.

46.1 (0.7) Quarry in the Umatilla Member, Saddle Mountains Basalt, at 3 o'clock.

47.2 (1.1) Midway Road at 9 o'clock. From the bottom of the hill the road is on flood gravels of the Hanford formation. At 3 o'clock is Gable Butte, an en echelon anticline along the Umtanum Ridge structural trend that has been breached by Pleistocene catastrophic flood waters.

48.4 (1.2) Rest area.

48.6 (0.2) Return to the main road.

48.9 (0.3) Cross the Columbia River.

49.4 (0.5) Turn left on SR 243 toward Vantage.

50.6 (1.2) At 10 o'clock is a large landslide on Umtanum Ridge above the town of Midway; at about 12 o'clock is the large McCoy Canyon slide block.

53.2 (2.6) Road O-SW. Note the change from the north-dipping basalt flows along the north limb of Umtanum Ridge to overturned, south-dipping basalt flows farther west (at 12 o'clock).

54.2 (1.0) Type locality for the Umtanum flow, Grande Ronde Basalt at 3 o'clock. The Umtanum flow is the uppermost low-Mg flow, N2 msu of the
\ Grande Ronde Basalt in the area. It has a TiOi content (-2.3 wt %) that makes it fairly distinct and an important marker flow.

55.2 (1.0) Gravel pit in the Hanford formation. 58.2 (3.0) Turn left at Priest Rapids Dam Road.

59.6 (1.4) Where the main road bends to the right, continue straight on the asphalt/gravel road to the area below the dam. Stop at the river overlook.

59.9 (0.3) **STOP 16. Umtanum Ridge.**
Umtanum Ridge extends about 100 km from near the western margin of the Columbia Plateau to the Palouse paleoslope. The structural relief gradually decreases eastward to Gable Butte, where it becomes a series of en echelon anticlines. In the Priest Rapids Dam area the north limb is overturned and dips 40 degrees to the south. An upper fault, the Buck thrust, and a lower fault, the Umtanum fault, define the overturned flows of the fold (Price, 1982). The Buck thrust dies out to both the east and west, but the Umtanum fault has been inferred to extend from the western edge of the anticline to just east of Midway. Drilling has constrained the angle of the Umtanum fault in the near surface to be¬tween 30 and 60 degrees.
\

61.7 (1.8) Return to SR 243 and continue north (left). Glacial erratics left by catastrophic flood waters `occur alone the road side for the next mile.

63.0 (1.3) Desert Aire Resort. Pomona Member at 3 o'clock.

63.4 (0.4) At 9 o'clock north of Umtanum Ridge, an inter bed of the Ellensburg Formation forms the white exposures (ash) across the Columbia River. The basalt flows in this area have been folded into a series of low-amplitude, east-trend¬ing anti clines and synclines.

64.3 (0.9) Sentinel Gap at 11 o'clock. Sentinel Gap is a water gap through the Saddle Mountains. In-tra canyon flows and mainstream facies sedi¬ments indicate that the Columbia River flowed through this water gap from at least the middle to late Miocene (Reidel, 1984).

65.8 (1.5) Glacial erratics at 9 o'clock. Across the river is the Hanson Creek anticline (Fig. 2).

67.1 (1.3) Mattawa turnoff. At 10 o'clock on the west side of the river is the Huntzinger flow, a 13 Ma flow that filled an ancestral channel of the Colum bia River (Reidel and Fecht, 1986).

67.7 (0.6) Glacial erratics form a boulder train from the Sentinel Gap area.

69.1 (1.4) At 2 o'clock in the quarry are exposures of the type locality of the Beverly interbed (Swan-son and others, 1979a). The Elephant Mountain Member lies above, and the Priest Rapids Member below the interbed. Just east of the quarry, the Pomona is invasive into the Beverly interbed (Schmincke, 1967). This area is also the type locality for the Saddle Mountains Basalt (Swan-son and others, 1979a).

70.9 (1.8) Entering Sentinel Gap.
\

71.1 (0.2) Cohassett flow, Grande Ronde Basalt, in road cuts. The internal vesicle zone of the flow is ex posed along the road (McMillian and others, 1987).

71.3 (0.2) Sentinel Gap, Saddle Mountains. This is Site 6 of Carson and others (1987).

72.1 (0.8) Flow top of the Umtanum flow, Grande Ronde Basalt, at 3 o'clock. The entablature is at 10 o'clock near the river level.

72.9 (0.8) Crab Creek. Saddle Mountains fault is inferred to pass through this area (Reidel, 1984, in press).

74.4 (1.5) Crab Creek Road at 3 o'clock.

75.2 (0.8) Beverly-Burke Road at 3 o'clock.

77.6 (2.4) Wanapum Dam turnout. The exposures of the Priest Rapids, Roza, and Frenchman Springs Members along the Columbia River near here (Mackin, 1961) form the type locality for the Wanapum Basalt (Swanson and others, 1979a). The Rosalia flow of the Priest Rapids Member is at 3 o'clock.

77.9 (0.3) Frenchman Springs Member at road level.

79.1 (1.2) Roza Member at 1 o'clock.

81.8 (2.7) Stop sign. Turn left on SR 26. Prepare to enter Interstate Highway 90 (1-90) westbound. At 12 o'clock from bottom to top on the cliff are the Ginkgo, Sand Hollow, and Sentinel Gap flows of the Frenchman Springs Member.

82.7 (0.9) Take the Seattle entrance on 1-90.

84.7 (2.0) Take Exit 136 to Vantage.

85.0 (0.3) Turn right on Huntzinger Road. The white sedi ment is ash of the May 18, 1980, Mount St. Helens eruption. The basalt flows along the road for the next 2 mi are the Frenchman Springs Member.

87.9 (2.9) Wanapum State Park at 9 o'clock.

88.5 (0.6) Exposed from 15 to 30 m above the road at 3 o'clock is a south-dipping, northwest-striking thrust fault. In the creek and along the roadcuts is a series of thin (1-2-cm thick) breccia zones that parallel the fault (Fig. 2).

90.3 (1.8) Wanapum Dam abutment.

90.8 (0.5) The road climbs through the Frenchman Springs, Roza, and Priest Rapids members of Wanapum Basalt.

92.3 (1.5) Old railroad track crossing, now known as the John Wayne Trail.

92.4 (0.1) **STOP 17. The Saddle Mountains fault zone and core of the anticline.**
Turn right on the gravel road toward Doris and stop. Because it would take about 4 hours to walk through the entire exposure, we will examine it in two parts. For the first part (Fig. 12, area 1) we will observe one of the few places where the core of the Saddle Mountains anticline is well exposed. For the second part (Fig. 12, area 2) we will see the Saddle Mountains thrust fault.

Part 1. Deformation in the core of the Saddle Mountains anticline.
From the road walk due west toward the hummocky lower slope of the Saddle Mountains. The Columbia River has exposed a zone of complex folding and faulting in the core of the Saddle Mountains anticline. Above the main fault, the Saddle Mountains fault, is an upper fault that does not penetrate the upper layers of basalt. The basalt flows between the two faults (the hummocky exposures) are vertical and strike west. The flows are shattered and brec-ciated, but their chemical compositions permit identification of the individual flows. The Cohassett and Umtanum flows are part of this group of flows. Above the upper fault, the flows are relatively intact but folded. The upper fault has about 100 m of offset measured on the Umtanum flow. Total shortening across this part of the Saddle Mountains anticline is about 3 km.
To reach Part 2, one can either walk north up through the stratigraphic section or return to the parking area and take the gravel road north.

93.0 (0.6) Follow the gravel road north to the quarry in Hanford formation gavels and then take the left fork.

93.4 (0.4) **Part 2. The Saddle Mountains fault.** Drive up to the fence line and park by the gate.

The Saddle Mountains fault is covered along most of its length, but at this locality Wanapum Basalt is thrust northward over the Ringold Formation. The basalt flows are steeply north dipping to vertical south of the fault, and the Ringold sediments are nearly horizontal north of it. The youngest faulting here is older than the youngest

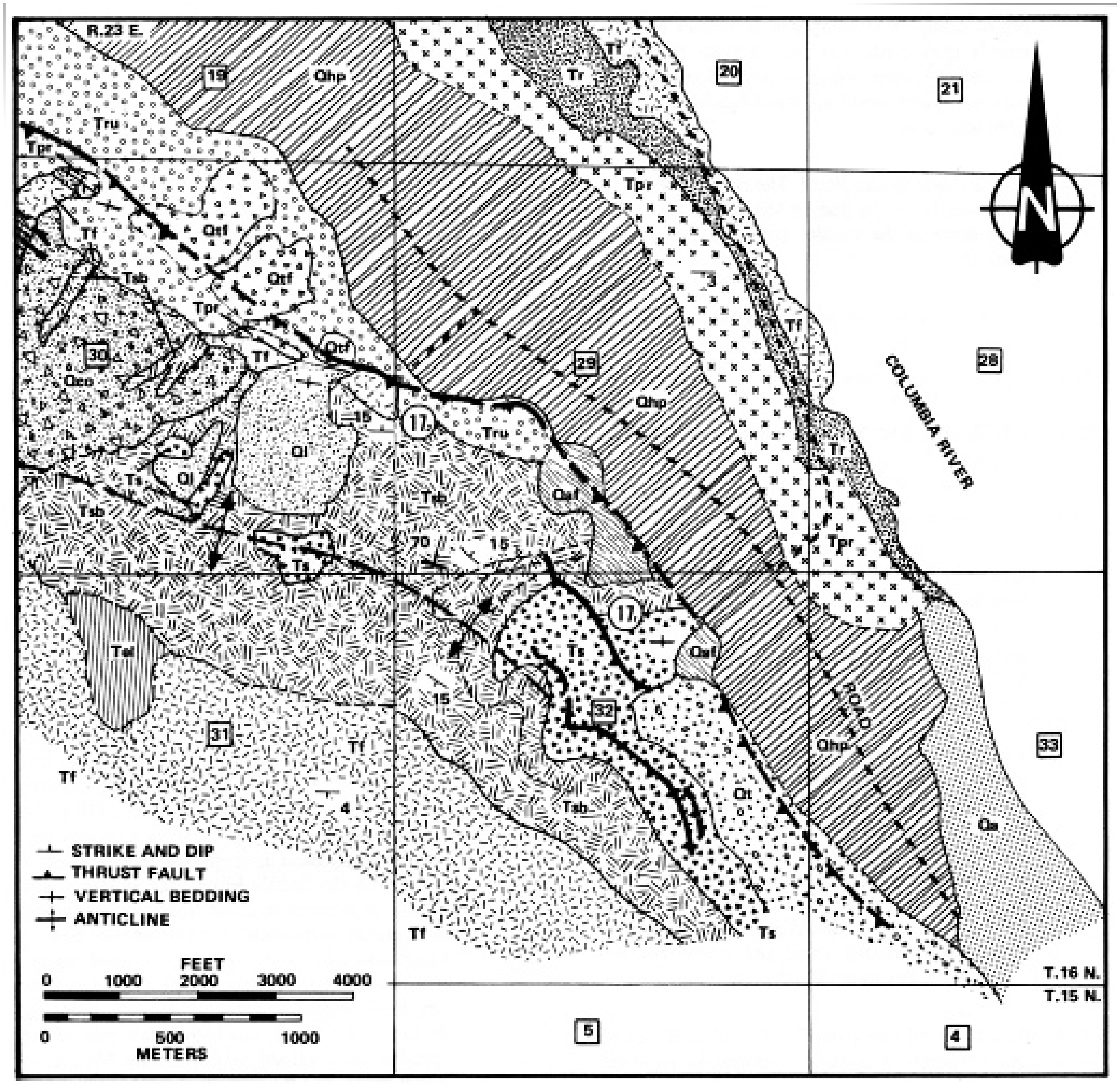

Figure 12. Geologic map of the west side of Sentinel Gap, Saddle Mountains (from Reidel, in press). The area covered by Part 1 of Stop 17 is indicated by 17i and Part 2 is indicated by 1?2. See Figure 3 for explanation of stratigraphic unit symbols. Numbers in squares refer to sections.

catastrophic flooding (13,000 yr) because apparently undisturbed Hanford formation gravels overlie the fault.

93.8 (0.4) Return to the quarry.

94.3 (0.5) Return to Huntzinger Road and retrace the route to 1-90.

101.0 (6.7) Enter 1-90 and proceed east toward Spokane.

103.2 (2.2) Exit 1-90 onto SR 26 and proceed east toward Colfax and Pullman.

104.6 (1.4) Pillow complex of Ginkgo flow, Frenchman Springs Member. This is a classic locality to exam ine pillow complexes and has been described in several field guides (for example, Site 5 of Carson and others, 1987). This pillow complex is composed of foreset beds of basalt that built out into a lake that had developed during Vantage time. Some of the best fossilized wood in Washington has come from this zone.

110.4 (5.8) Beverly-Burke Road. The route now heads east, parallel to the Saddle Mountains anticline. Note some of the smaller scale folds along the north face.

119.1 (8.7) Caliche horizon in the Ringold Formation.

121.1 (2.1) Royal City tumoff.

122.8 (1.6) Road E-SW, Brown's Comer. Turn right to Smyrna.

123.0 (0.2) Cross railroad tracks.

123.1 (0.1) **OPTIONAL STOP 18. View of Smyrna Bench.**
At 12 o'clock are dissected alluvial fans col¬lectively known as Smyrna Bench. Smyrna Bench consists of several alluvial fans that developed as the Smyrna Bench segment of the Saddle Mountains anticline grew and was simultaneously eroded. Flood waters from the Pleistocene catastrophic floods removed much of the fan from Crab Creek coulee, which parallels the north side of the Saddle Mountains. Several trenches have been dug on Smyrna Bench in the past two decades to determine the youngest age of faulting (for example Bingham and others, 1970). Evidence to date suggests the youngest faulting is older then the most recent catastrophic flooding (13,000 yr).

123.4 (0.3) Descend into Crab Creek coulee. Basalt of the Elephant Mountain Member is exposed along roadcuts.

125.5 (1.1) Pomona Member outcrop at 8 o'clock. This is the easternmost exposure of the Pomona north of the Saddle Mountains.

126.9 (1.4) Turn left on Crab Creek Road. Cross the railroad tracks. Elephant Mountain Member and Ringold Formation at 3 o'clock.

130.3 (3.9) Roadcuts through the Elephant Mountain Member. Leaving Crab Creek coulee.

130.5 (0.2) CAUTION! Very rough cattle guard crossing.

130.8 (0.3) Top of the Elephant Mountain Member; Ringold Formation ahead and to the right. The Corfu landslide can be seen at 1 o'clock. The Corfu landslide resulted when catastrophic flood waters removed the north-dipping basalt along the Saddle Mountains, allowing the remaining basalt to slide on the interbed above the Priest Rapids Member.

132.1 (1.3) Turn right onto Smyrna Bench Road (gravel road).

132.3 (0.2) Cross the railroad tracks. On the right, the Asotin and Pomona Members form a small anticline with a thrust fault along the north side.

132.9 (0.6) View of the east side of Smyrna Bench. We will stop here on our return route.

133.6 (0.7) Road triple junction; bear left and then right (east) and stop at the top of the hill.

133.95 (0.35) STOP 19. Smyrna Bench "graben".
This low depression on Smyrna Bench in front of the Saddle Mountains (Fig. 13) has had many interpretations over the past several decades. (See Bingham and others, 1970.) The interpretations receiving the most attention are: (1)the depression is a graben that developed along with the Saddle Mountains anticline, and (2) the depression resulted from gravity sliding of Ringold sediments away from the Saddle Mountains after the catastrophic flood waters removed the northern part of Smyrna Bench. A structural origin is currently favored. Mapping by Reidel (in press) has shown that part of the "graben" is confined to the Saddle Mountains basalt flows and thick intercalated sediments of the Ellensburg Formation. Steep, north-dipping to overturned flows probably were extended during folding, allowing the "graben" to form as basalt flows slid along interbedded sediments.One of the most important questions is: How young is the movement? Evidence from recent trenching by Michael West and Associates suggests that there may be young scarps of unknown age but, unfortunately, the evidence is not conclusive.

(0.05) Continue down the hill and turn around by the corral. Return by the same route to the road triple junction. We are at trip mile 134.5.

135.1 (1.1) **STOP 20. East side of Smyrna Bench.**
The east side of Smyrna Bench is geologically complex (Fig. 13). It marks the junction

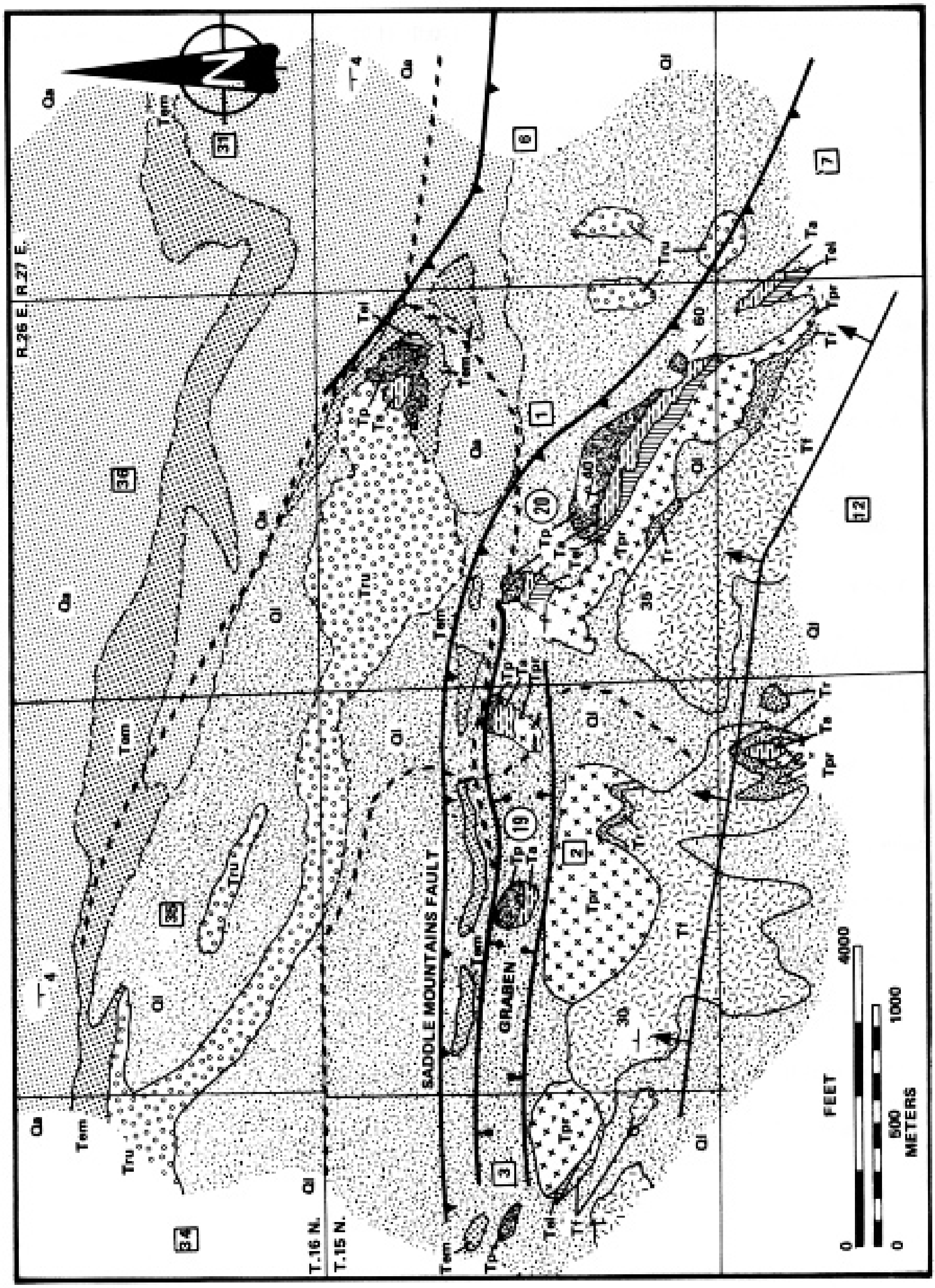

Figure 13. Geologic map of the west side of the Smyrna Bench area. Saddle Mountains. Shown are the location of the Smyrna Bench graben (Stop 19) and the junction between the Smyrna Bench and Saddle Gap segments (Stop 20) (from Reidel, in press). See Figure 3 for explana¬tion of stratigraphic unit symbols and Figure 12 for explanation of structure and other symbols.

of two distinct segments, the Smyrna Bench seg¬ment on the west and the Saddle Gap segment on the east. The Saddle Mountains shows some of the most dramatic changes in geometry and style of folding across this segment boundary. The structure changes from a box fold with overturned beds that strike west in the Smyrna Bench segment to northeast-dipping and north west-striking flows. Minor structures such as kink folds and small faults are well exposed in this area. We will ex amine both the large- and small-scale structures by walk ing about 2 km through the area where the two segments intersect.

135.9 (0.8) Return to Crab Creek Road. Turn right.
\

137.8 (1.9) Road B-SE, the Corfu Road. Turn left and proceed to SR 26. At 1 o'clock note the dipping basalt just above the road level. At this locality the Pomona Member has 25 degrees of clockwise rotation recorded by its magnetic declination (Reidel and others, 1984).

140.3 (2.5) Rood bar.

140.8 (0.5) SR 26. Turn right toward Othello. Corfu landslide at 2 o'clock.

145.6 (4.8) Adams County line.

155.3 (9.7) Junction with SR 240.

157.3 (2.0) Turn left on SR 17.

158.3 (1.0) Othello tumoff. Cunningham Road.

163.3 (5.0) Railroad underpass.

169.0 (5.7) Warden Road.

170.0 (1.0) Turn left on Potholes State Park Road and toward O'Sullivan Dam.

174.2 (4.2) Road M-SE. A Roza flow in the roadcuts.

174.6 (0.4) Turn right onto the dirt road that leads toward Lind Coulee.

174.7 (0.1) **OPTIONAL STOP 21. Lind Coulee fault.**

Grolier and Bingham (1971) mapped a reverse fault along the north side of the Frenchman Hills in Lind Coulee (Fig. 14). Their mapping shows that the fault cuts sediments that overlie the Roza Member in several places. Recent studies by Michael West and Associates for the Bureau of Reclamation show that Pleistocene loess is faulted and that still younger loess and flood deposits overlying the basalt are unfaulted. Although their study was not avail¬able at the time of the writing of this guidebook, it appears that movement occurred on the fault during the Pleistocene but that the latest movement is older than the most recent catastrophic floods. Loess that overlies the fault and is younger than the last fault movement is similar to loess dated at about 500,000 yr by Rockwell Hanford Operations (unpub. data) using paleomagnetic techniques. Although the trenches that Michael West and Associates dug are now filled in, there are several excellent ex¬posures (A and B, Fig. 14) where the relations between faults and the overlying sediments can be seen.

Retrace the route to SR 17.

179.4 (4.7) SR 17. Turn left on SR 17 and proceed to Moses Lake. 1-90 passes through Moses Lake and provides the most direct route to Spokane.

End of Road Log.

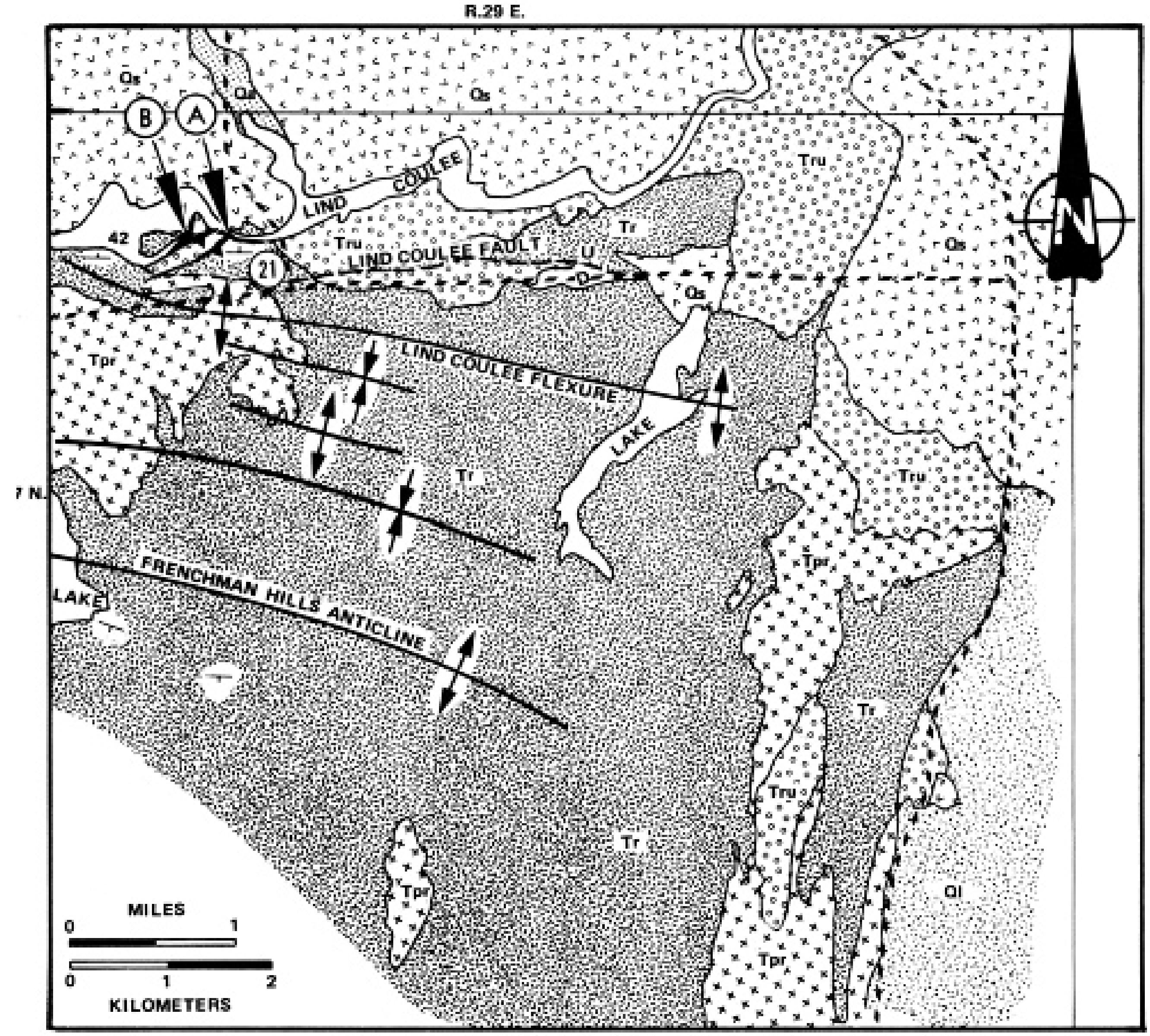

Figure 14. Geologic map of the area near Stop 21, the Frenchman Hills anticline and the Lind Coulee fault (from Grolier andBingham, 1971). See Figure 3 for explanation of stratigraphic unit symbols and Figure 12 for explanation of struc¬tural and other symbols. Locations of good exposures of faults are shown by arrows; A is a northeast-facing exposure on the south side of Lind Coulee, and B is a northwest-facing exposure along the lake.