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GEOLOGY OF THE GRANDE RONDE LIGNITE FIELD, ASOTIN COUNTY, WASHINGTON

By

Keith L. Stoffel

Report of Investigations

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GEOLOGY OF THE GRANDE RONDE LIGNITE FIELD, ASOTIN COUNTY, WASHINGTON

By

Keith L. Stoffel

ABSTRACT

In the Grande Ronde River-Blue Mountains region of southeastern Washington and adjacent Oregon, lignite beds up to 40 ft (12 m) thick comprise part of two sedimentary interbeds which are intercalated with flows of the Miocene Columbia River Basalt Group. Lignites analyzed range from 5,027 to 7,944 Btu/lb (as received) with low sulfur and moderate ash contents.

The sediments and peat (later converted to lignite) accumulated between approximately 13.5 and 10 million years ago, during a period of regional structural deformation punctuated by sporadic eruptions of basalt flows. This period was highlighted by the events listed below.

1. Sediments accumulated in the developing Troy basin, a structural and topographic depression which formed south and east of the Blue Mountains uplift. The tectonic evolution of this basin controlled both epiclastic sediment deposition and peat accumulation.
2. Vents for some of the basalt flows intercalated with the sediments were located within the lignite field itself, producing constructional topographic relief on the surface of some of the flows, which controlled subsequent accumulation of sediments and peat.
3. Some of the sediments and peat originally deposited were eroded by streams prior to burial by subsequent flows.
4. Some of the sediments and peat originally deposited were destroyed or displaced during the extrusion of subsequent invasive basalt flows.
5. Following the cessation of volcanism, the basalt flows and intercalated sedimentary interbeds were folded and eroded along the northern margin of the Troy basin.
6. During post-volcanism downcutting by the Grande Ronde River and its tributaries, some of the interbed sediments were reworked and redeposited, probably destroying portions of some lignite beds in the process.

These events produced complex stratigraphic relationships between Columbia River Basalt Group flows and intercalated sediments. Future exploration for lignite in the Grande Ronde lignite field must be based upon a thorough understanding of these stratigraphic complexities.

INTRODUCTION

LOCATION AND GEOGRAPHIC SETTING

The Grande Ronde lignite field is located in Asotin County of southeastern Washington and Wallowa County of northeastern Oregon. It lies along the southeastern slopes of the Blue Mountains and surrounds the Grande Ronde River canyon (fig. 1). The Washington State portion of the field (the study area of this report) stretches northeastward from Troy, Oregon for approximately 10 miles (16 km) and crops out on a series of flat to gently rolling benches 1,300 to 2,300 ft (400 to 700 m) above the Grande Ronde River (fig. 2 and plate 1). These benches, which represent the topographic expression of thick sedimentary interbeds between basalt flows, have been deeply dissected into smaller, isolated benches by the downcutting of Cougar, Cottonwood, and Menatchee Creeks (fig. 3). Since all lignites in the study area occur within the bench-

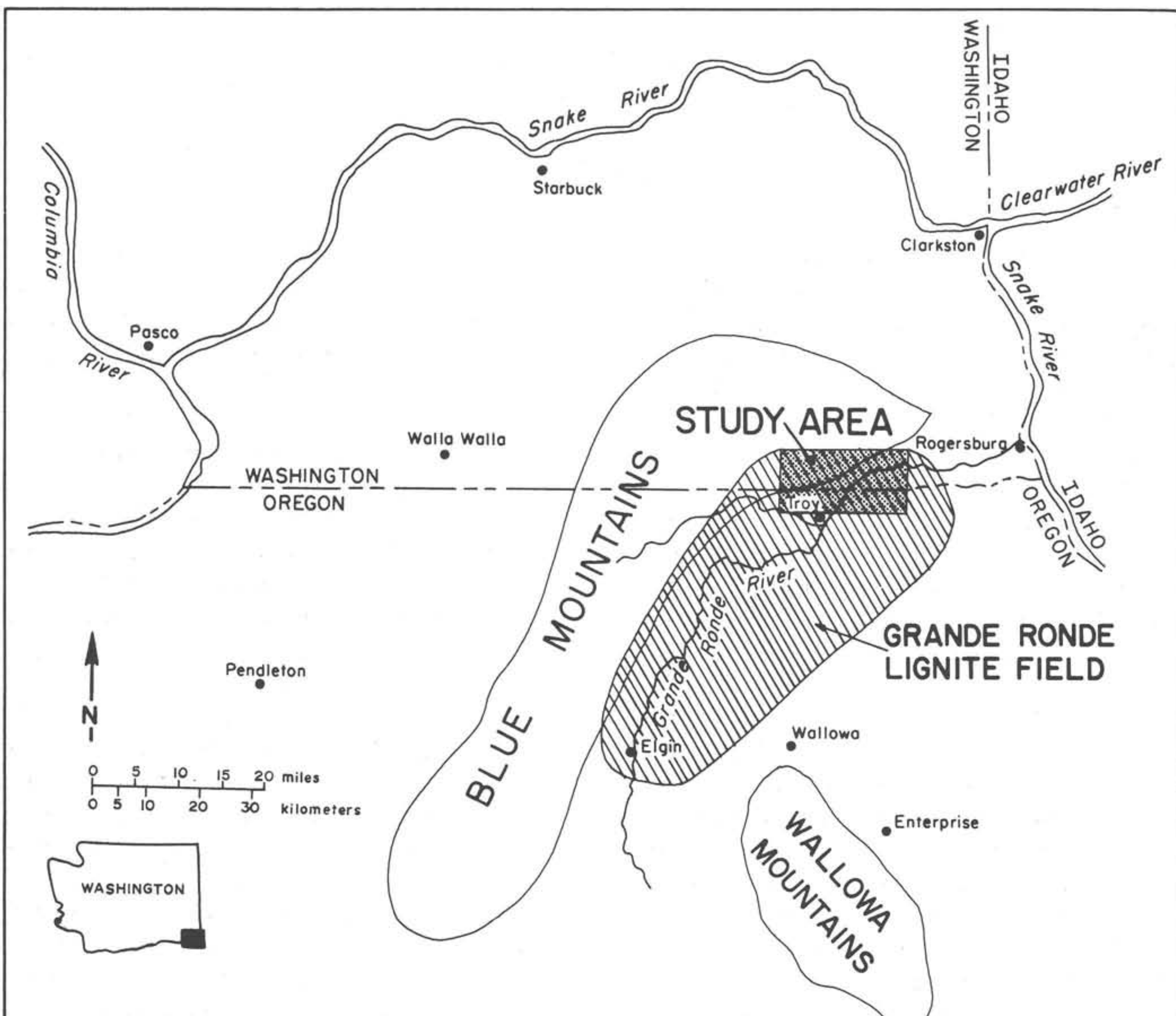


FIGURE 1. — Location map of the Grande Ronde lignite field (lined) and the study area of this report (stippled).

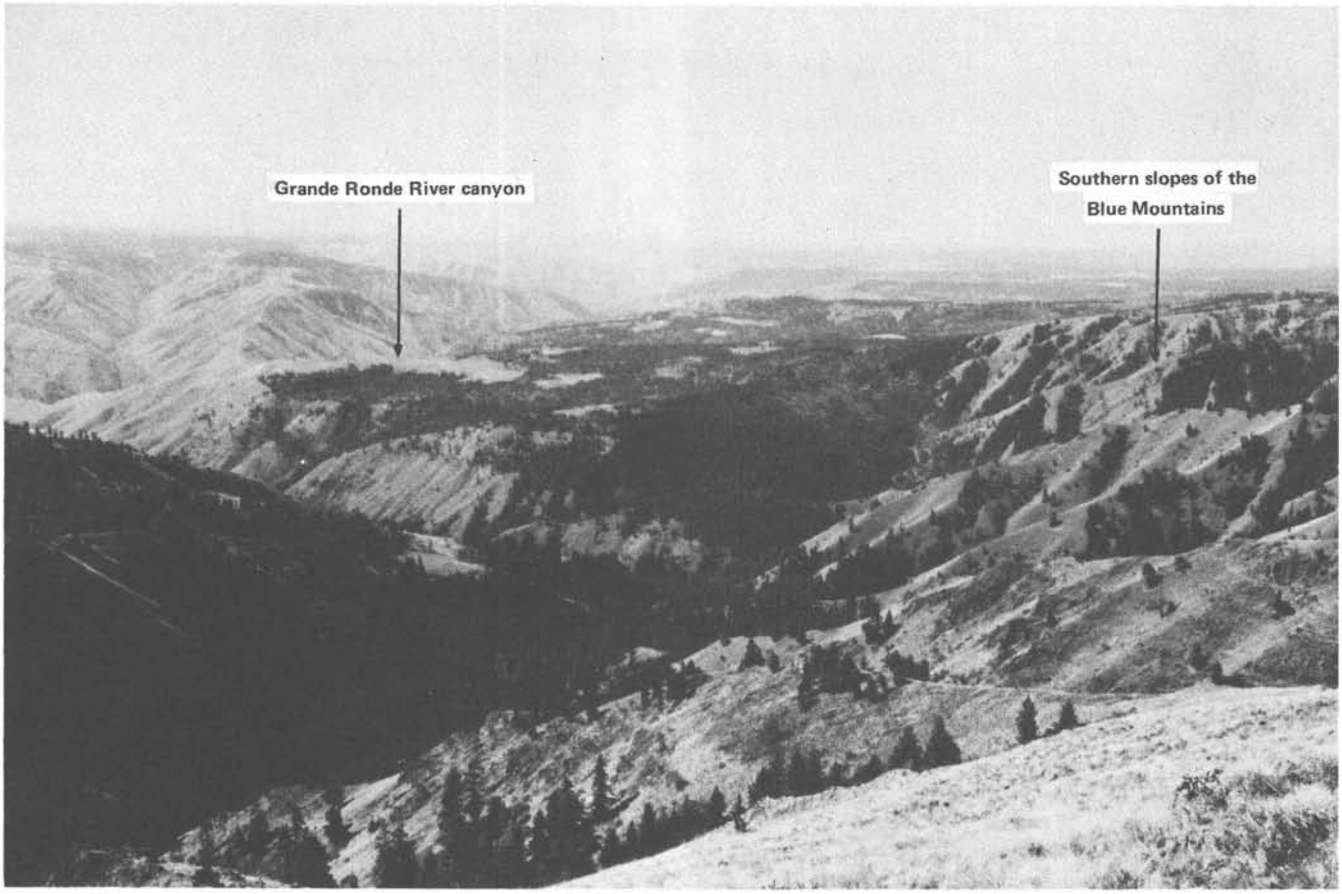


FIGURE 2. — View of the Washington State portion of the Grande Ronde lignite field from the Blue Mountains.

forming sedimentary interbeds, lignite often lies at or near the surface. Exposure of sediments and lignite on the benches is very poor; outcrops are limited to scattered roadcuts and streamcuts.

The benches in the Washington State portion of the lignite field are all accessible by well-maintained gravel roads. With the exception of a few scattered parcels of state-owned land, the benches are privately owned. At the time of this writing, several tracts of private land are under lease for coal exploration.

PURPOSE AND SCOPE OF STUDY

This report describes the stratigraphic and tectonic evolution of the Grande Ronde River-Blue Mountains region and its control on the distribution, thickness, and quality of lignite beds in the Grande Ronde lignite field. Emphasis is placed upon defining the complex stratigraphic relationships between Columbia River Basalt Group flows and intercalated sediments. Successful exploration for lignite, as well as accurate estimation of lignite reserves, depends upon recognition of these complex stratigraphic relationships and a thorough understanding of the region's geologic evolution.

This report supersedes the Division of Geology and Earth Resources Open-File Report 81-6 (Stoffel, 1981), a preliminary report on the geology of the Grande Ronde lignite field.

METHODS OF STUDY

Field mapping for this study was done during the summer and fall field seasons of 1980-1982. Portions of five 7½-minute topographic quadrangles (Mountain View, Saddle Butte, Diamond Peak, Troy, and Eden) were mapped (plate 1). The remanent magnetic polarity of

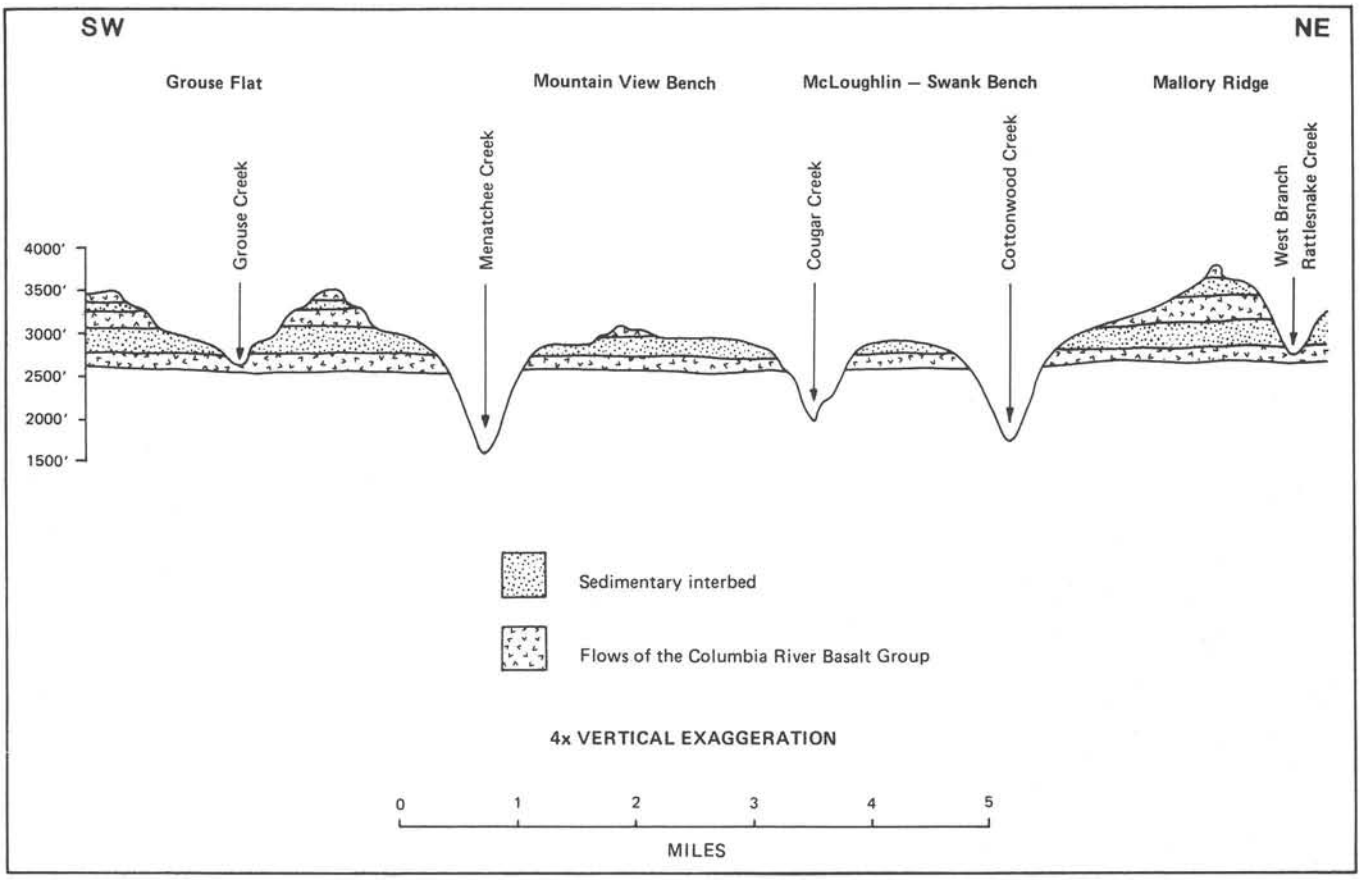


FIGURE 3. — Schematic cross section of the Washington State portion of the Grande Ronde lignite field, showing several topographic benches underlain by thick sedimentary interbeds.

each of the basalt flows in the study area was determined using a field fluxgate magnetometer.

Thin sections of 91 basalt samples were studied. All but two of the samples were analyzed by the X-ray fluorescence method (Hooper, 1981) for oxides of Si, Al, Ca, Mg, Ti, P, Na, Mn, and total Fe. Two additional basalt samples were collected and sent to a commercial laboratory for potassium-argon age dating.

Grain size analyses and heavy mineral separations were performed on 4 sediment samples. X-ray diffraction analyses of the < 2 micron fraction of nine other sediment samples were also performed.

ACKNOWLEDGMENTS

The author is grateful to the following individuals and organizations who generously contributed financial and(or) technical support for this investigation:

The ranchers in the Grande Ronde River region, especially Mike Odom (4-O Cattle Company) and Bill Goodall, graciously allowed access to their land.

Rockwell Hanford Operations and the Washington State University Geology Department provided funds for some of the X-ray fluorescence analyses, which were performed under the direction of Peter Hooper at the Washington State University Basalt Research Laboratory.

Bonnie Bunning, Peter Hooper, Bill Phillips, Steve Reidel, Martin Ross, and Terry Tolan reviewed the manuscript and offered many stimulating ideas and concepts.

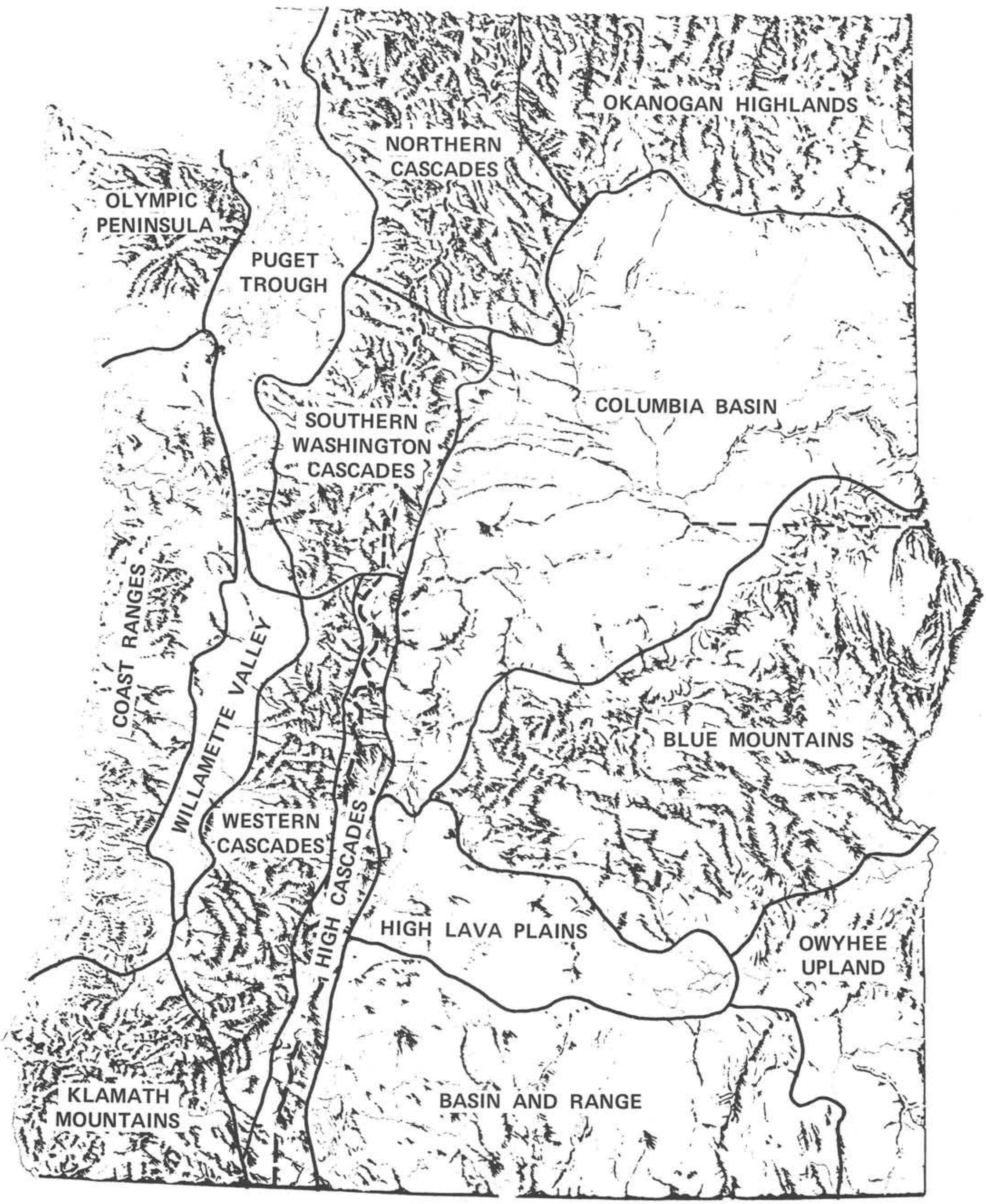


FIGURE 4. — Physiographic provinces of Washington and Oregon. From Franklin and Dyrness, 1973.

GEOLOGY OF THE COLUMBIA PLATEAU

GENERAL GEOLOGIC SETTING

The Grande Ronde lignite field lies within the Blue Mountains province, a region characterized by isolated high mountain ranges separated by broad structural valleys (fig. 4). In Washington, the province is comprised of a broad northeast-trending anticlinal arch, dominated by narrow, flat-topped ridges and deep, precipitous canyons. These structural and geomorphologic characteristics distinguish the Blue Mountains province from the adjacent Columbia Basin province, which is a structural and topographic depression.

Together the two provinces comprise one of the earth's youngest tholeiitic basalt plateaus, the Columbia Plateau, which formed between 17.5 and 6 millions years ago (Watkins and Baksi, 1974; McKee and others, 1977; McKee and others, 1981; Long and Duncan, 1982). The plateau is comprised of approximately 120 to 150 individual

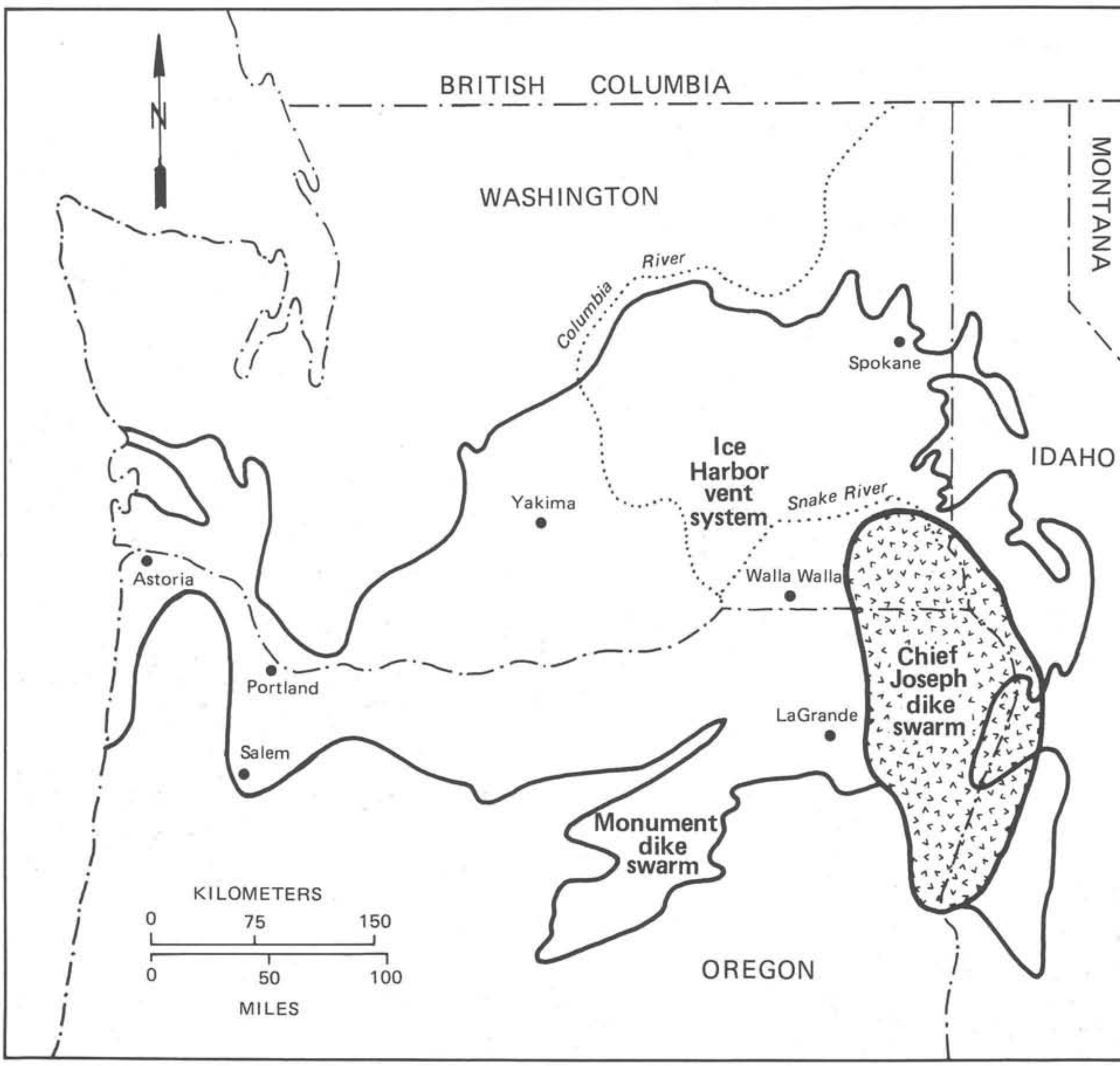


FIGURE 5. — Generalized map of the northwestern United States, showing distribution of the Columbia River Basalt Group (dark black lines). Extent of the most prominent vent system, the Chief Joseph dike swarm, is shown by pattern. Locations of the Monument dike swarm and Ice Harbor vent system are also shown. After Anderson and others, in preparation.

flows of the Columbia River Basalt Group (Hooper, 1982; Swanson and Wright, 1978), which erupted from north- northwest-trending linear fissures (fig. 5), (Waters, 1961; Taubeneck, 1970; Swanson and others, 1975). Near the center of the plateau, flows of the Columbia River Basalt Group and intercalated epiclastic and volcaniclastic sediments attain an estimated maximum thickness of 14,750 ft (4,500 m), (Reidel and others, 1982).

Individual basalt flows range from a few ft (m) to greater than 300 ft (91 m) in thickness (Swanson and others, 1979). They average 90 to 120 ft (22 to 36 m) thick. Individual flows reach maximum thickness where they filled structural depressions or river canyons. Volumes of individual flows average from 2 to 6 cu miles (10 to 29 cu km) and attain a maximum of 145 cu miles (700 cu km), (Swanson and Wright, 1978).

STRATIGRAPHIC NOMENCLATURE

COLUMBIA RIVER BASALT GROUP

Russell (1901) coined the name "Columbia River basalt" and defined it to include all Eocene to Recent basaltic lavas of the Pacific Northwest.

Waters (1961) proposed revising the name to the "Columbia River Basalt Group" and restricted its use to Miocene basalts in Washington, Oregon, and Idaho (fig. 6). He also divided the group into two formations (Yakima and Picture Gorge Basalts) and identified four dike

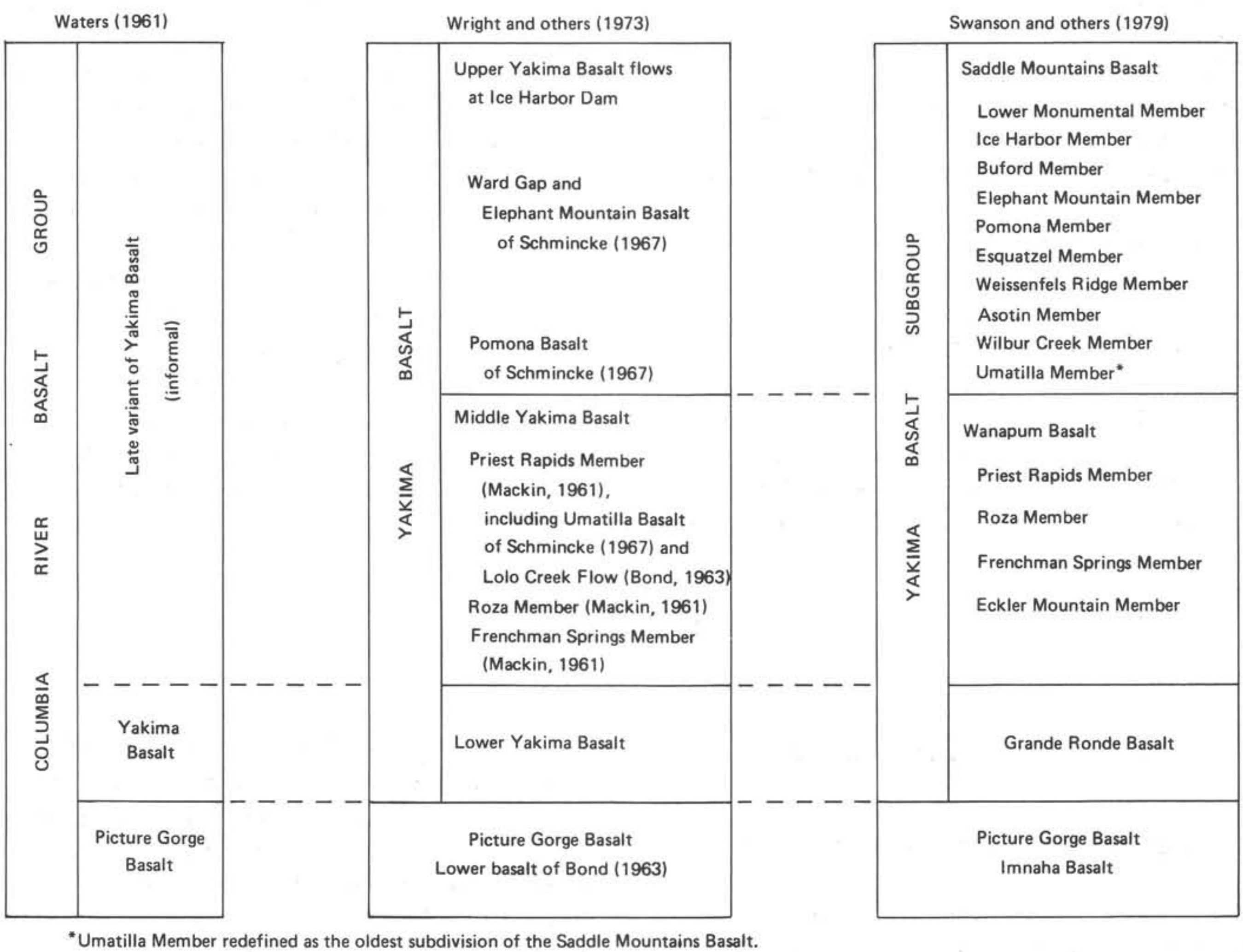


FIGURE 6. — Comparison of Columbia River Basalt Group stratigraphic nomenclature.

swarms which he believed represented vent systems for the Columbia River Basalt Group flows.

The advent and widespread use of paleomagnetics and rapid X-ray fluorescence analyses in the middle to late 1960's greatly increased the field geologist's ability to identify individual (or small groups of) Columbia River basalt flows. When mapping and correlation of flows became routine, Wright and others (1973) proposed a new informal four-fold stratigraphic subdivision of the Columba River basalt (fig. 6).

A proliferation of geologic investigations occurred in the mid-1970's, resulting in the identification of several new flows. The stratigraphic nomenclature became a mixture of formal and informal names, requiring a comprehensive revision. Utilizing some old names and introducing some new ones, Swanson and others (1979) formally revised the nomenclature (fig. 6). As suggested by Griggs (1976), they restricted the Columbia River Basalt Group to include all extrusive volcanic rocks previously assigned to the Columbia River basalt, and to exclude all formations that are largely nonbasaltic. They also subdivided the group into 1 subgroup, 5 formations, and 14 members.

ELLENSBURG AND LATAH FORMATIONS

Epiclastic and volcaniclastic sediments interbedded with, and overlying, flows of the Columbia River Basalt Group were first studied on the western margin of the Columbia Plateau. Smith (1901) named these sediments the Ellensburg Formation. Later workers excluded the suprabasalt sediments from the formation and reassigned them to other formations. In subsequent studies, workers proposed restricting the Ellensburg Formation only to sediments intercalated with flows of the Saddle Mountains Basalt Formation (Mackin, 1961) or to sediments interbedded with both the Wanapum and Saddle Mountains Basalts (Smith, 1903; Waters, 1955; Schmincke, 1964). Waitt (1979) recently proposed redefining the Ellensburg Formation to include sediments interbedded with all formations of the Columbia River Basalt Group, as well as some sediments underlying the Group.

Pardee and Bryan (1926) first assigned sediments underlying the Columbia River basalts in the northeastern portion of the Columbia Plateau to the Latah Formation. Kirkham and Johnson (1929) later proposed expansion of the formation to include sediments intercalated with the Columbia River Basalt Group, and Hosterman (1969) suggested inclusion of suprabasalt sediments as well. Griggs (1976) proposed limiting the use of the name "Latah Formation" to the Spokane River drainage only.

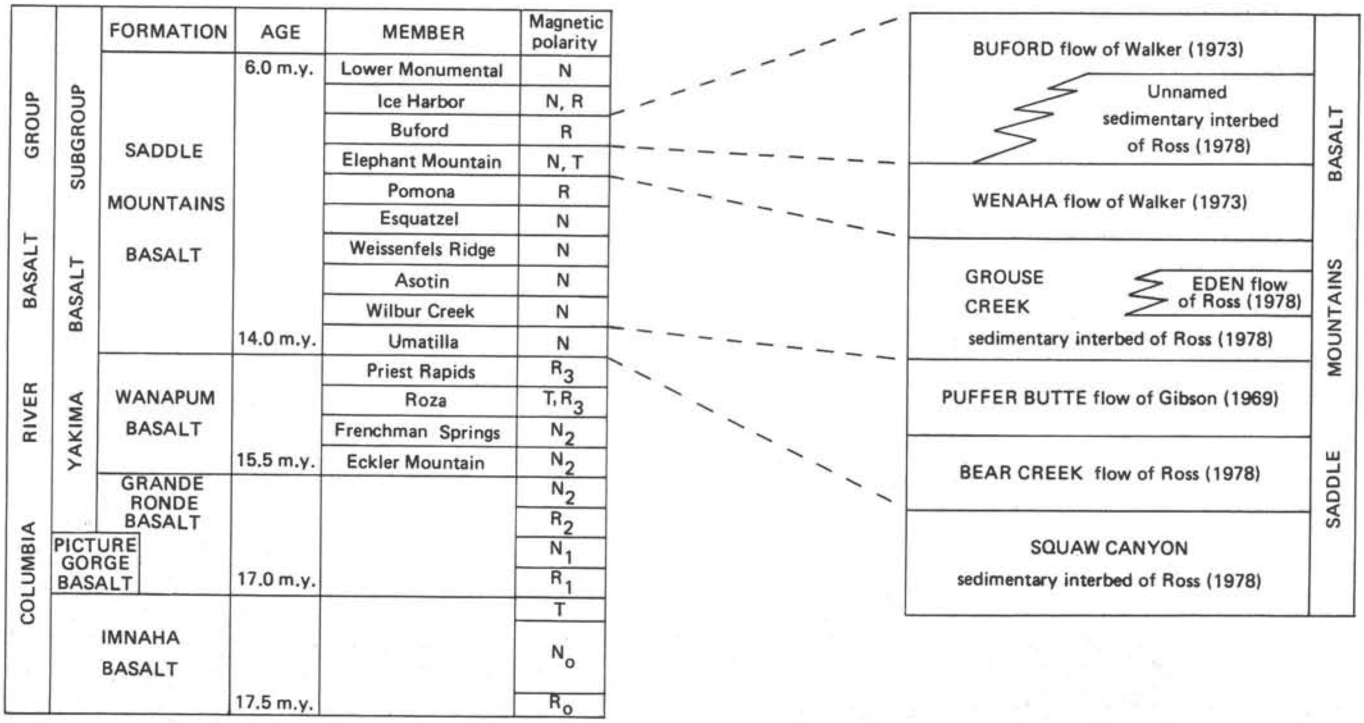
At the present time, most workers have adopted this informal nomenclature scheme. Sediments underlying and intercalated with flows of the Columbia River Basalt Group in the Spokane River drainage only are assigned to the Latah Formation. Elsewhere on the Columbia Plateau, similar sediments are assigned to the Ellensburg Formation.

STRATIGRAPHY

REGIONAL STRATIGRAPHY

IMNAHA AND PICTURE GORGE BASALTS

The oldest Columbia River Basalt Group flows in the Grande Ronde River-Blue Mountains region have been assigned to the Imnaha Basalt Formation (fig. 7). This 17.0 to 17.5 million-year-old formation (McKee and others, 1981), probably underlies the entire region, but it only crops out in the deepest canyons (Shubat, 1979; Swanson and others, 1980). Picture Gorge Basalt flows do not crop out in the region; they are restricted to north-central Oregon (Swanson and others, 1979).



(after Swanson and others, 1979)

FIGURE 7. — Correlation of the formalized stratigraphic nomenclature of the Columbia River Basalt Group (left) with the informal nomenclature of the Saddle Mountains Basalt in the Grande Ronde River-Blue Mountains region. N is normal magnetic polarity; R, reversed; and T, transitional. Polarity intervals are numbered sequentially, oldest to youngest, for the Imnaha through Wanapum Basalts. Polarity intervals are not numbered in the Saddle Mountains Basalt. Radiometric age dates from Watkins and Baksi, 1974; McKee and others, 1977; McKee and others, 1981; and Long and Duncan, 1982.

YAKIMA BASALT SUBGROUP

GRANDE RONDE BASALT

The Grande Ronde Basalt is the oldest formation of the Yakima Basalt Subgroup. Flows of Grande Ronde Basalt erupted from north- northwest-trending linear fissures in southeastern Washington and adjacent Oregon approximately 15.5 to 17 million years ago (McKee and others, 1981; Long and Duncan, 1982). Thick sections of Grande Ronde Basalt crop out in the canyons of the Grande Ronde and Wenaha Rivers and in many of the region's deeply incised creeks (plate 1), (Ross, 1978). The formation also crops out extensively in the Blue Mountains to the north, where uplift has exposed it. Steeply dipping Grande Ronde Basalt flows on the flank of the Slide Canyon monocline form the northern limit of the Grande Ronde lignite field (fig. 8 and plate 1).

Uniform field, petrographic, and chemical characteristics make identification of individual flows in the Grande Ronde Basalt difficult. Fortunately, remanent magnetic polarities of the flows can be used to subdivide the Grande Ronde Basalt into four informal magnetostratigraphic units, from oldest to youngest, R_1, N_1, R_2, N_2, where N stands for normal and R for reversed polarity (fig. 7).

WANAPUM BASALT

Flows of the Wanapum Basalt were erupted from fissures in southeastern Washington between approximately 14 and 15.5 million years ago (Watkins and Baksi, 1974; Long and Duncan, 1982). In the Grande Ronde River-Blue Mountains region, Wanapum Basalt flows are generally exposed near the top of deep canyons.

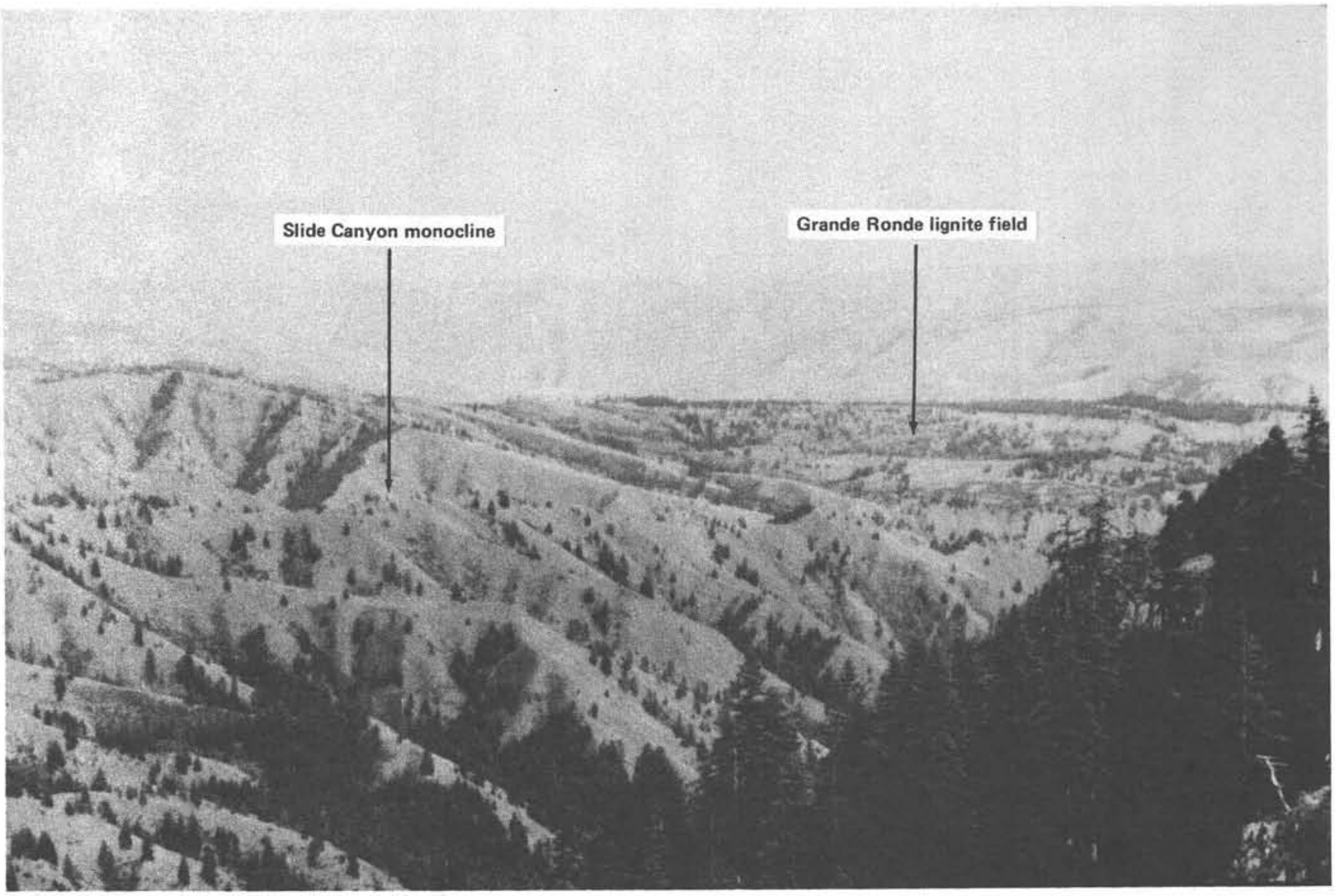


FIGURE 8. — View from the northwest of the steeply dipping south limb of the Slide Canyon monocline, which forms the northern limit of the Grande Ronde lignite field.

Since individual flows of the Wanapum Basalt are identifiable by field, petrographic, and chemical characteristics, the formation has been subdivided into several mappable members (fig. 7). All members of Wanapum Basalt, except the Priest Rapids Member, occur in the Grande Ronde River-Blue Mountains region (Swanson and others, 1979; 1980). The Grande Ronde and Wanapum Basalts are separated by a thick saprolitic soil throughout much of the region, which provides an excellent marker horizon and correlation tool (Ross, 1978).

SADDLE MOUNTAINS BASALT

During the late stages of Yakima Basalt Subgroup volcanism, between approximately 6 and 14 million years ago (Watkins and Baksi, 1974; McKee and others, 1977), flows of the Saddle Mountains Basalt erupted from fissures in south-central and southeastern Washington and western Idaho. During this period of waning volcanism, thick sediments accumulated in the developing Troy basin (fig. 9). The quiescence dominated by sediment deposition was punctuated by sporadic, short-lived eruptions. As a result, flows of the Saddle Mountains Basalt are intercalated with three major sedimentary interbeds in the Grande Ronde River-Blue Mountains region.

Since many of the individual flows of the Saddle Mountains Basalt are petrographically and chemically distinct, the formation has been subdivided into ten members (fig. 7), (Swanson and others, 1979). The thickest section of the Saddle Mountains Basalt and intercalated sediments is found in the northern Troy basin (fig. 9), (Ross, 1978, 1979). The formation thins toward basin margins.

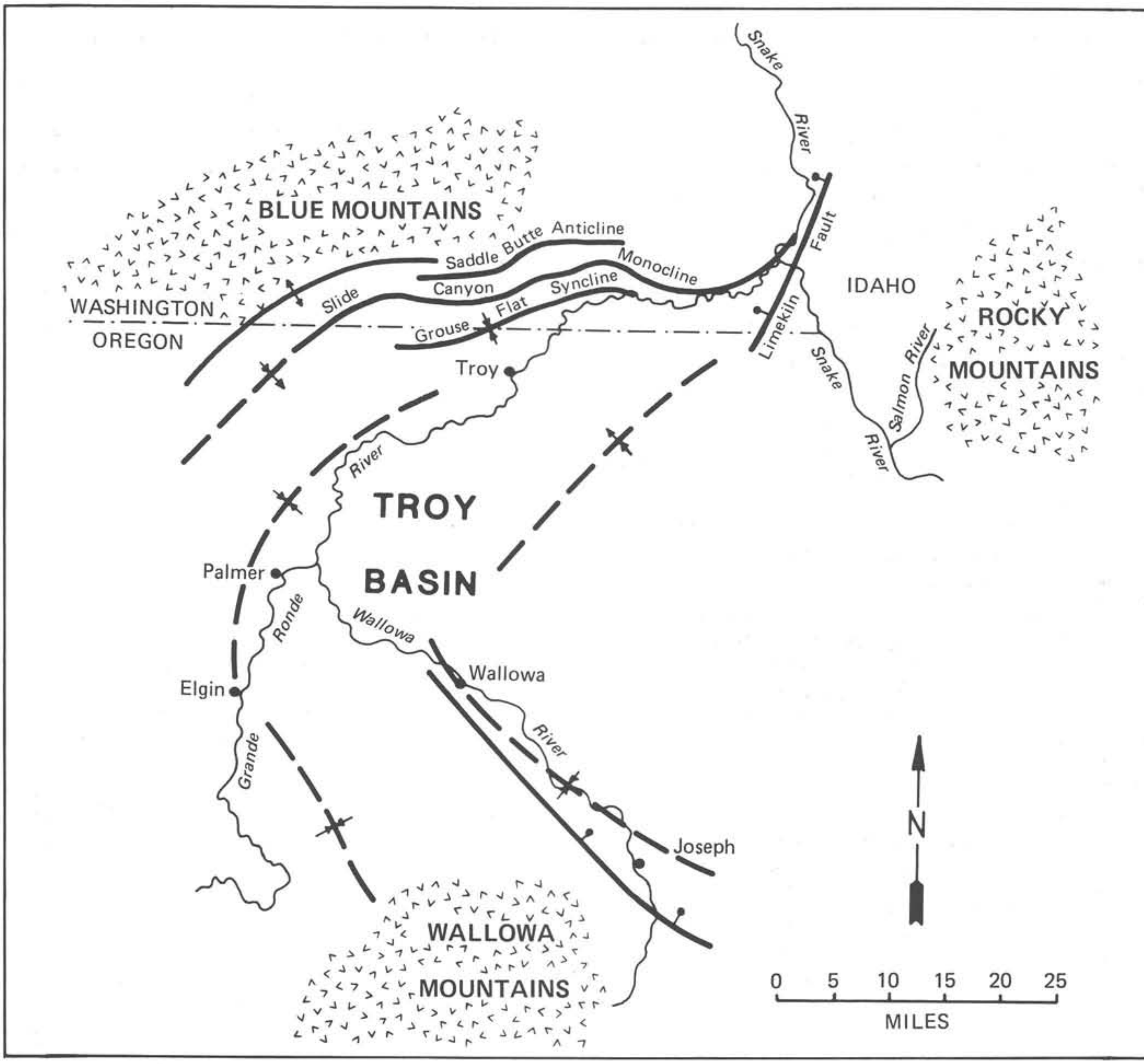


FIGURE 9. — Generalized structure map of northeastern Oregon and adjacent Washington.

STRATIGRAPHY OF THE GRANDE RONDE LIGNITE FIELD

The lignite beds in the Grande Ronde River-Blue Mountains region occur within thick sedimentary interbeds between flows of the Saddle Mountains Basalt. In the vicinity of the lignite field, Saddle Mountains Basalt was first identified by Waters (1961), who described a single flow capping 250 ft (76 m) of sediments on a ridge east of Buford Creek in Wallowa County, Oregon. He assigned this flow to his "late textural and mineralogic variant of the Yakima Basalt," which was later named the Saddle Mountains Basalt (Swanson and others, 1979), (fig. 6). Subsequently, Gibson (1969) described a vent complex of feeder dikes and scoriaceous lava flows near the northeast end of the Blue Mountains, and suggested correlation of these "Puffer Butte" flows with the Umatilla flow of the Saddle Mountains Basalt (fig. 7). Walker (1973) described two additional Saddle Mountains Basalt flows in the area and informally named them the Wenaha and Buford flows (fig 7). Walker (1979) later mapped the regional distribution of the Saddle Mountains Basalt and intercalated sediments in the Oregon part of the Grande Ronde lignite field.

Utilizing the informal nomenclature previously proposed by Gibson (1969) and Walker (1973) and introducing some informal names of his own, Ross (1978) studied and mapped the Saddle Mountains Basalt and intercalated sediments in a portion of the lignite field along the Washington-Oregon border. A correlation of Ross' informal stratigraphy of the Saddle Mountains Basalt in the Grande Ronde River-Blue Mountains region with the formal Columbia River Basalt Group stratigraphic nomenclature is given in fig. 7.

Detailed mapping of Saddle Mountains Basalt flows in this study has shown that a revision of Ross' stratigraphic nomenclature is necessary. Field evidence indicates that two flows of the Buford Member interfinger with two flows of the Elephant Mountain Member in the study area. The author's proposed informal stratigraphy of the Saddle Mountains Basalt in the Washington State portion of the lignite field is given in fig. 10.

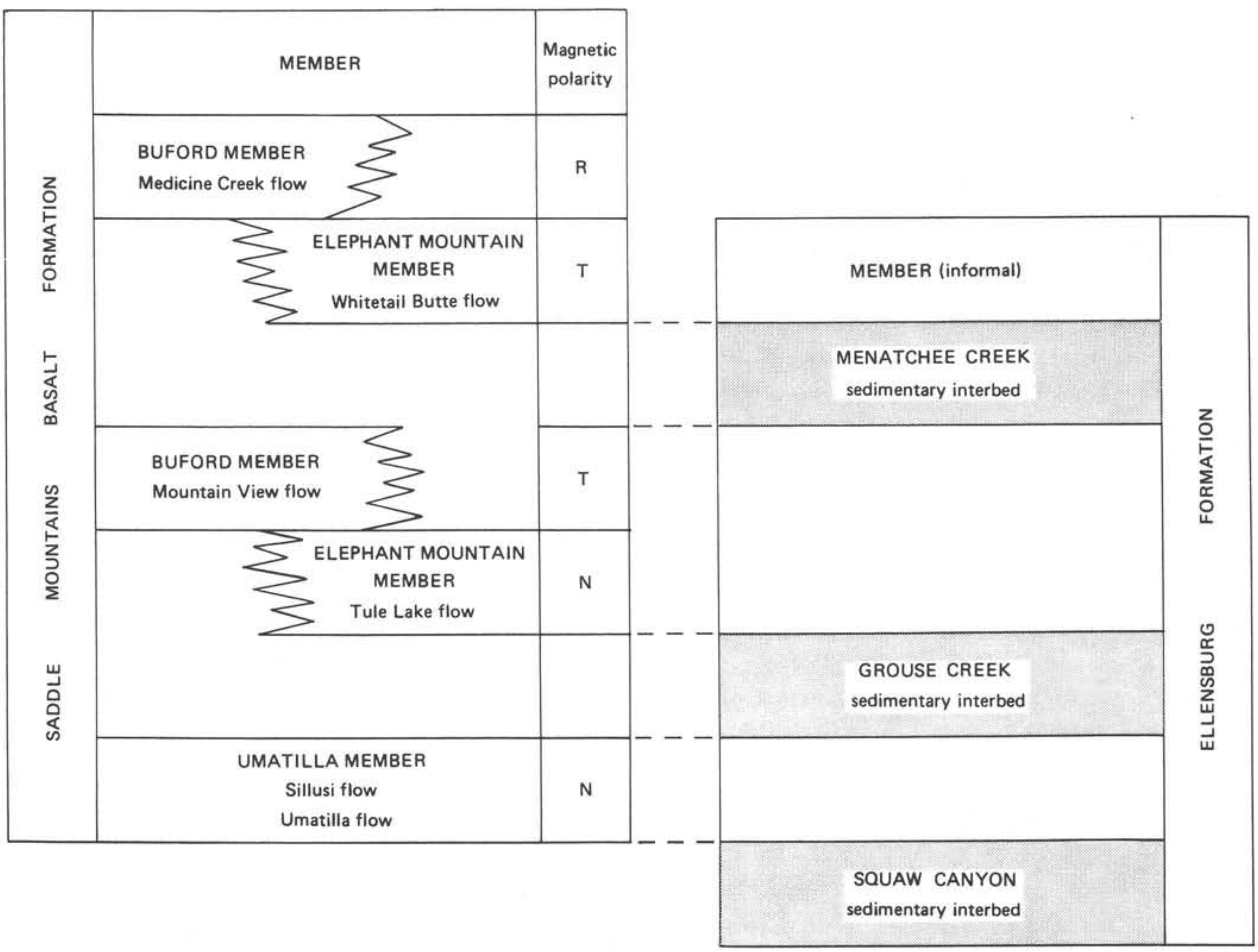


FIGURE 10. — Proposed stratigraphy of the Saddle Mountains Basalt in the Washington State portion of the Grande Ronde lignite field. N is normal magnetic polarity; R, reversed; and T, transitional.

STRUCTURE

EVOLUTION OF THE BLUE MOUNTAINS PROVINCE

The Columbia Plateau was created between 17.5 and 6 million years ago by the eruption of scores of basalt flows of the Columbia River Basalt Group. Concurrent with and subsequent to eruption of the flows, the southeast part of the plateau was uplifted, tilted, gently folded, and faulted. Regional deformation produced four major structural elements: (1) A regional paleoslope dipping west away from the eastern margin of the plateau (Bond, 1963; Swanson and others, 1975); (2) large wavelength folds with east-west trending axes (Camp, 1976; Ross, 1978; Swanson and others, 1980); (3) dikes with a remarkably consistent north-northwest-south-southeast trend (Waters, 1961; Gibson, 1969; Taubeneck, 1970; Price, 1977); and (4) a regional fault system with northwest-southeast, northeast-southwest, and north-south trends (Camp, 1976; Reidel, 1978; Ross, 1978; Shubat, 1979).

These structural elements of the Blue Mountains province can best be explained by a tectonic model (Hooper and Camp, 1981) which includes: (1) Regional east-west tilting (Swanson and others, 1975); (2) a stress regime with an axis of maximum compression in a horizontal north-northwest-south-southeast direction and an axis of maximum tension in a horizontal east-northeast-west-southwest direction (Ross, 1978); and (3) reactivation of the pre-basalt structural grain, consisting of northwest-southeast, northeast-southwest, and north-south fractures (Hooper and Camp, 1981).

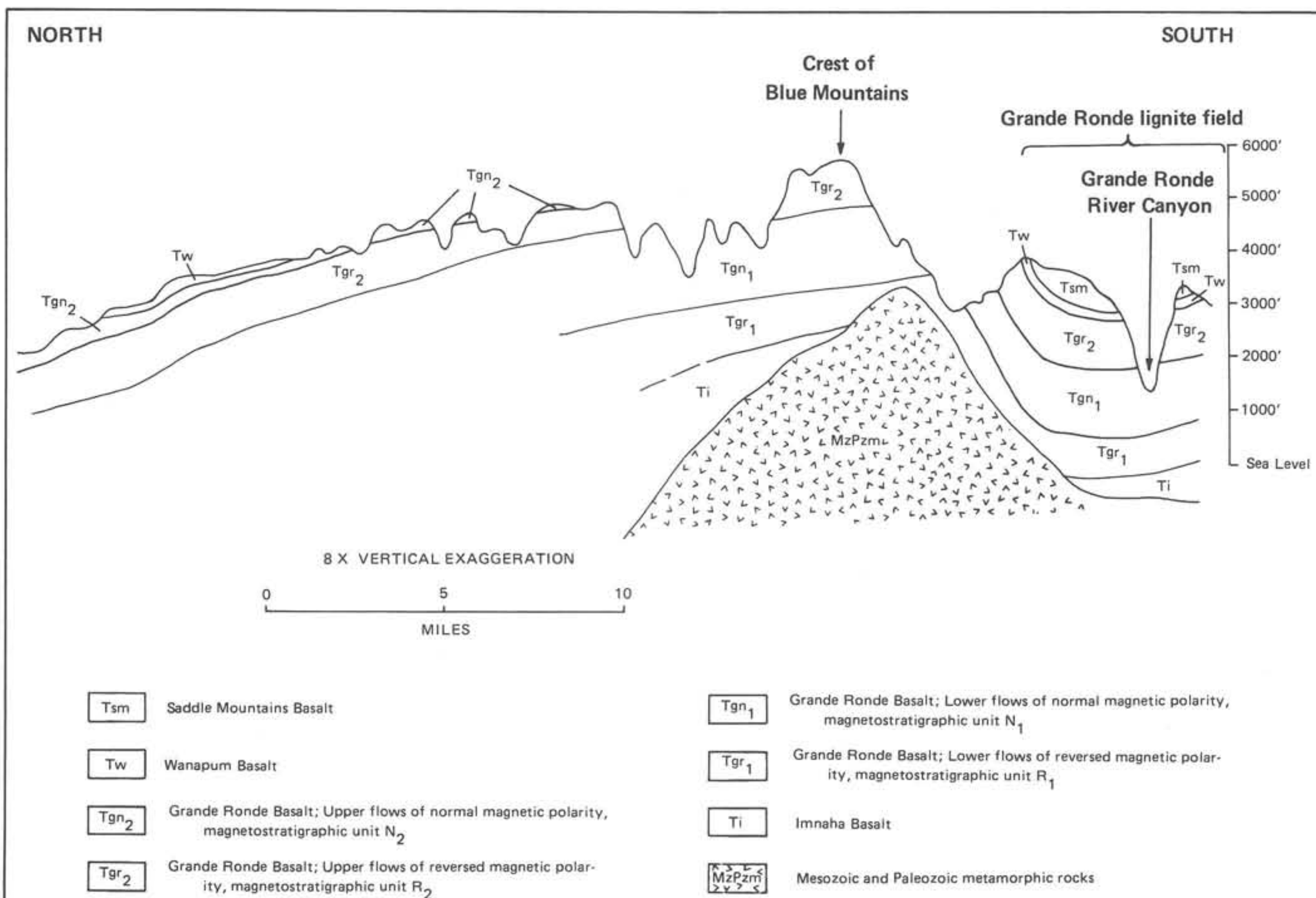


FIGURE 11. — Schematic cross section of the Blue Mountains in southeastern Washington. After Swanson and others, 1980.

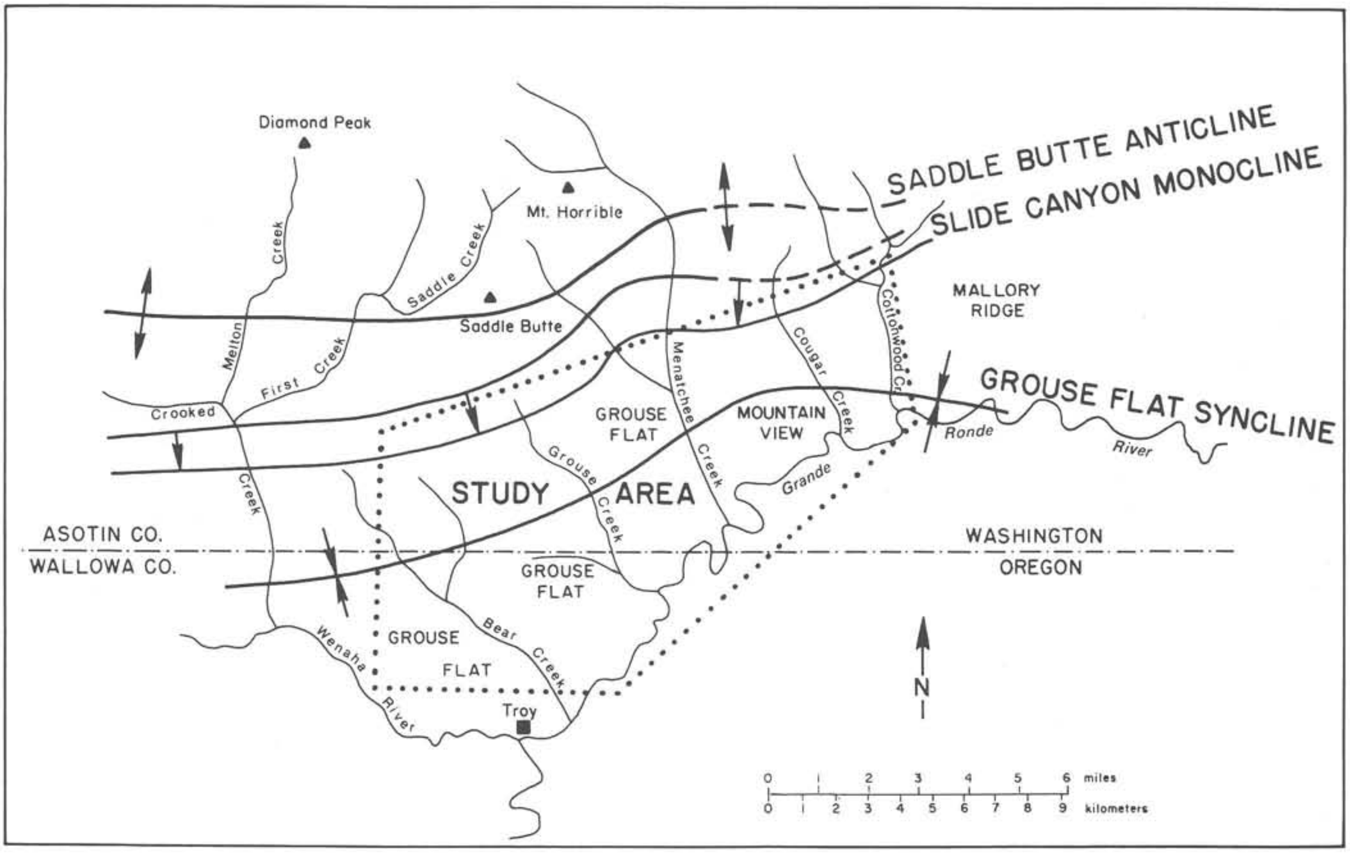


FIGURE 12. — Structure map of the Grande Ronde River-Blue Mountains region. After Ross, 1978. See plate 1 for more precise location of structures.

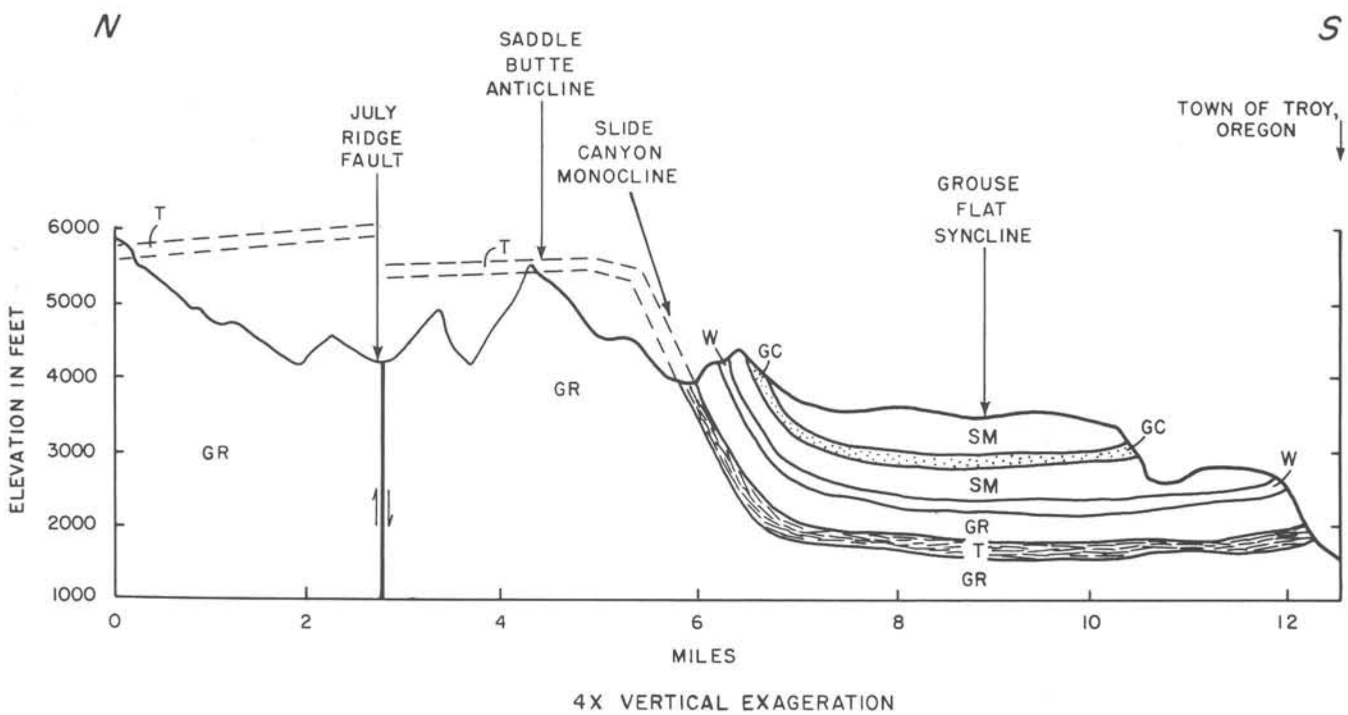


FIGURE 13. — Cross section through the Grande Ronde River-Blue Mountains region. After Ross, 1978.
GR = Grande Ronde Basalt, includes T = Troy flow (informal)
W = Wanapum Basalt
SM = Saddle Mountains Basalt, with intercalated GC = Grouse Creek sedimentary interbed

The tectonic regime was regional in scope and remained essentially unchanged throughout middle and late Miocene time.

STRUCTURAL GEOLOGY OF THE GRANDE RONDE RIVER-BLUE MOUNTAINS REGION

The Blue Mountains are a broad anticlinal arch uplifted during the late Cenozoic. The folded and faulted arch consists of a core of Paleozoic and Mesozoic metamorphic rocks mantled by flows of the Columbia River Basalt Group (fig. 11). All formations of the Columbia River Basalt Group (except the Picture Gorge Basalt) crop out in the Blue Mountains arch, but exposures of the metamorphic core rocks and the Imnaha Basalt are rare. The structural elements present in the Grande Ronde River-Blue Mountains region are discussed below (Ross, 1978, 1979, 1980).

FOLDS

In the northeasternmost portion of the arch, the axis of the Blue Mountains uplift coincides with the axis of the Saddle Butte anticline. This asymmetrical anticline has a broad, flat hinge zone and gently dipping limbs (figs. 12 and 13). The north limb dips 2° to 3° and the south limb dips up to 9°, but the south limb of the anticline abruptly steepens and becomes the Slide Canyon monocline (figs. 12 and 13). Monoclinal dips reach a maximum of 49°, although 25° to 30° dips are more common. To the south, the steeply dipping monocline abruptly flattens and merges with the north limb of the Grouse Flat syncline, a structure with very gently dipping limbs (3° to 6°) and a broad, flat hinge zone (figs. 12 and 13). Maximum structural relief on the Saddle Butte anticline-Grouse Flat syncline complex is approximately 2,800 ft (850 m).

FAULTS

Most of the prominent faults in the Grande Ronde River-Blue Mountains region are assigned to the Grande Ronde Fault System, an 18-mile-long (29 km) system of four en echelon faults trending N. 20° E. and one conjugate fault trending N. 40° W. (fig. 14 and plate 1). All faults in the system exhibit vertical dip-slip movement with downthrown blocks on the northwest side of the en echelon faults. Left-lateral strike-slip movement has also occurred on the Powatka Ridge and Courtney Creek faults. Only minor offsets have been identified north of the Grande Ronde River, suggesting that the Grande Ronde Fault System dies out in the vicinity of the river.

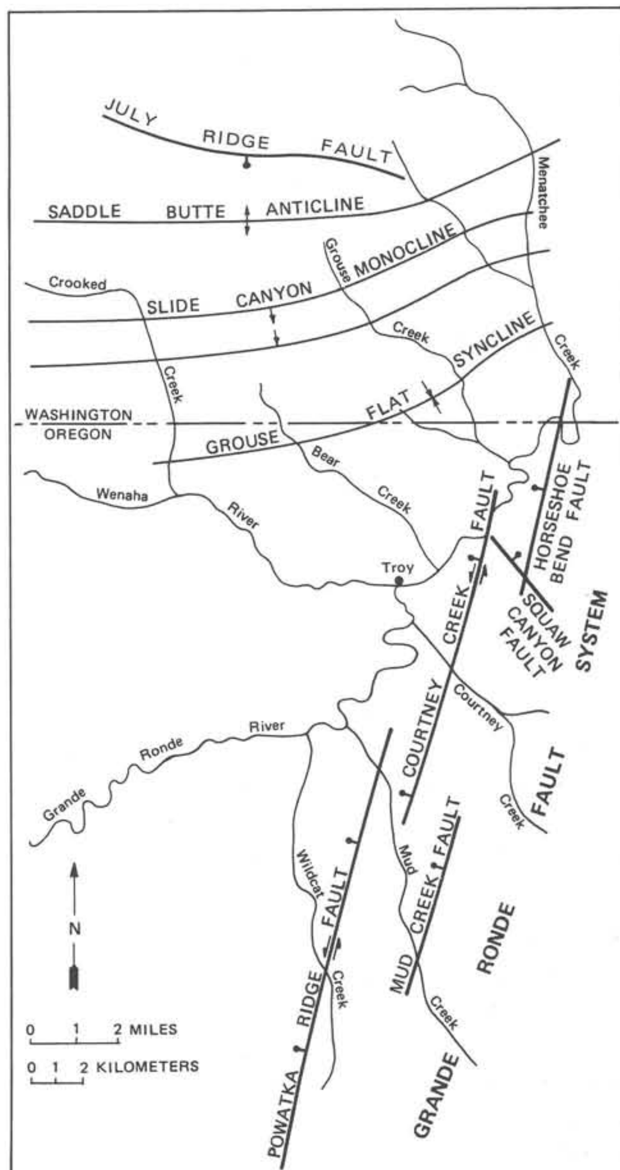


FIGURE 14. — Map of the Grande Ronde Fault System. Ball and bar on downthrown side of faults. After Ross, 1978.

AGE OF TECTONISM

The geographic distribution and thickness variation of Grande Ronde Basalt magnetostratigraphic units indicate that folding in the Grande Ronde River-Blue Mountains region probably initiated in late Grande Ronde time (Ross, 1978; Camp and Hooper, 1981; Hooper and Camp, 1981). Development of the Troy basin did not begin until late Wanapum time (Swanson and Wright, 1983). The presence of sedimentary interbeds between thick flows of Saddle Mountains Basalt, and the restriction of the Saddle Mountains Basalt and intercalated sediments to the Troy basin documents continued structural deformation during Saddle Mountains time (Ross, 1978).

Although the age of strike-slip movement of the Grande Ronde Fault System has not been accurately determined, it is known that strike-slip faulting in the region initiated sometime between eruptions of the Umatilla and Elephant Mountain Members of the Saddle Mountains Basalt (Swanson and Wright, 1983), and that it preceded dip-slip movement (Ross, 1978). Equal vertical displacement of flows of the Grande Ronde, Wanapum, and Saddle Mountains Basalts indicate that dip-slip movement of the Grande Ronde Fault System is post-Elephant Mountain in age (Ross, 1978).

GEOLOGY OF THE WASHINGTON STATE PORTION OF THE GRANDE RONDE LIGNITE FIELD

DESCRIPTION OF STRATIGRAPHIC UNITS

BASALT FLOWS

Flows of Saddle Mountains Basalt in the Grande Ronde lignite field have diverse field, petrographic, and chemical characteristics. Detailed descriptions of the flows, which follow, include discussion of the following properties:

Field characteristics. – Include stratigraphic position, thickness, hand specimen appearance, weathering characteristics, flow structures (jointing and flowtop characteristics), and magnetic polarity. The remanent magnetic polarity (normal, reversed, or transitional) of each of the basalt flows in the study area was determined in the field using a Model 70 (Calex Mfg. Co., Inc.) fluxgate magnetometer. Measurements were made on oriented samples, following the procedure of Doell and Cox (1962; 1967). Four or five samples were taken at each outcrop. Where possible, the samples were taken from the oxidized tops of the flows, since the quickly chilled portions of flows have proven to give the most reliable readings (Hooper, 1981). When outcrops of oxidized flow tops were not available, polarity measurements were made at the base of the flows. Since overprint of reversed polarity flows by the present-day normal magnetic field is common (Watkins and Baksi, 1974), and unstable magnetic components are not removed before field measurements, the reported magnetic polarities should be considered tentative.

Petrography. – Includes discussion of the mineralogy and texture of each basalt flow.

Chemistry. – Major element compositions of the flows were determined by the X-ray fluorescence method in the Basalt Research Laboratory at Washington State University. Samples were analyzed for oxides of Si, Al, Ti, Fe, Mn, Ca, Mg, K, Na, and P (Appendix B). Analyses were plotted on six variation diagrams and polygonal fields were drawn around chemical types (Appendix B). All flows of Saddle Mountains Basalt in the Grande Ronde lignite field belong to one of three chemical types (Umatilla, Elephant Mountain, or Buford) defined by previous workers (Walker, 1973; Wright and others, 1973).

UMATILLA MEMBER

The Umatilla Member consists of two flows in the Washington State portion of the Grande Ronde lignite field. The flows are named, from older to younger, the Umatilla and Sillusi flows, to conform to the stratigraphic nomenclature of the Umatilla Member established by Laval (1956) and formalized by Swanson and others, 1979). This nomenclature supersedes the myriad of informal names previously assigned to flows of the Umatilla Member in the Grande Ronde River-Blue Mountains region (fig. 7). To clarify the confusion, the following correlations are herein established:

Sillusi flow = Puffer Butte flow of Gibson (1969); Umatilla flow of Ross (1978)

Umatilla flow = Bear Creek flow of Ross (1978); Sopher Ridge flow of Hooper (1981)

The Umatilla Member overlies the Squaw Canyon sedimentary interbed throughout much of the study area, but where the sediments are absent, it overlies flows of the Wanapum Basalt (figs. 7 and 10). The Umatilla Member is overlain by the Grouse Creek sedimentary interbed throughout the Grande Ronde lignite field. Maximum thickness of each Umatilla Member flow in the lignite field is approximately 200 ft (60 m), (Ross, 1978).

FIELD CHARACTERISTICS

Fresh basalt of the Umatilla flow is dark blue-black, fine to medium grained, and equigranular. It weathers to an orange-brown color. The flow is best exposed in the cliffs along Bear Creek (plate 1), where it consists of a thick basal colonnade with moderately well-formed vertical columns, an upper zone characterized by blocky joints, and a thin, vesicular flow top. The Umatilla flow has a normal magnetic polarity (Ross, 1978).

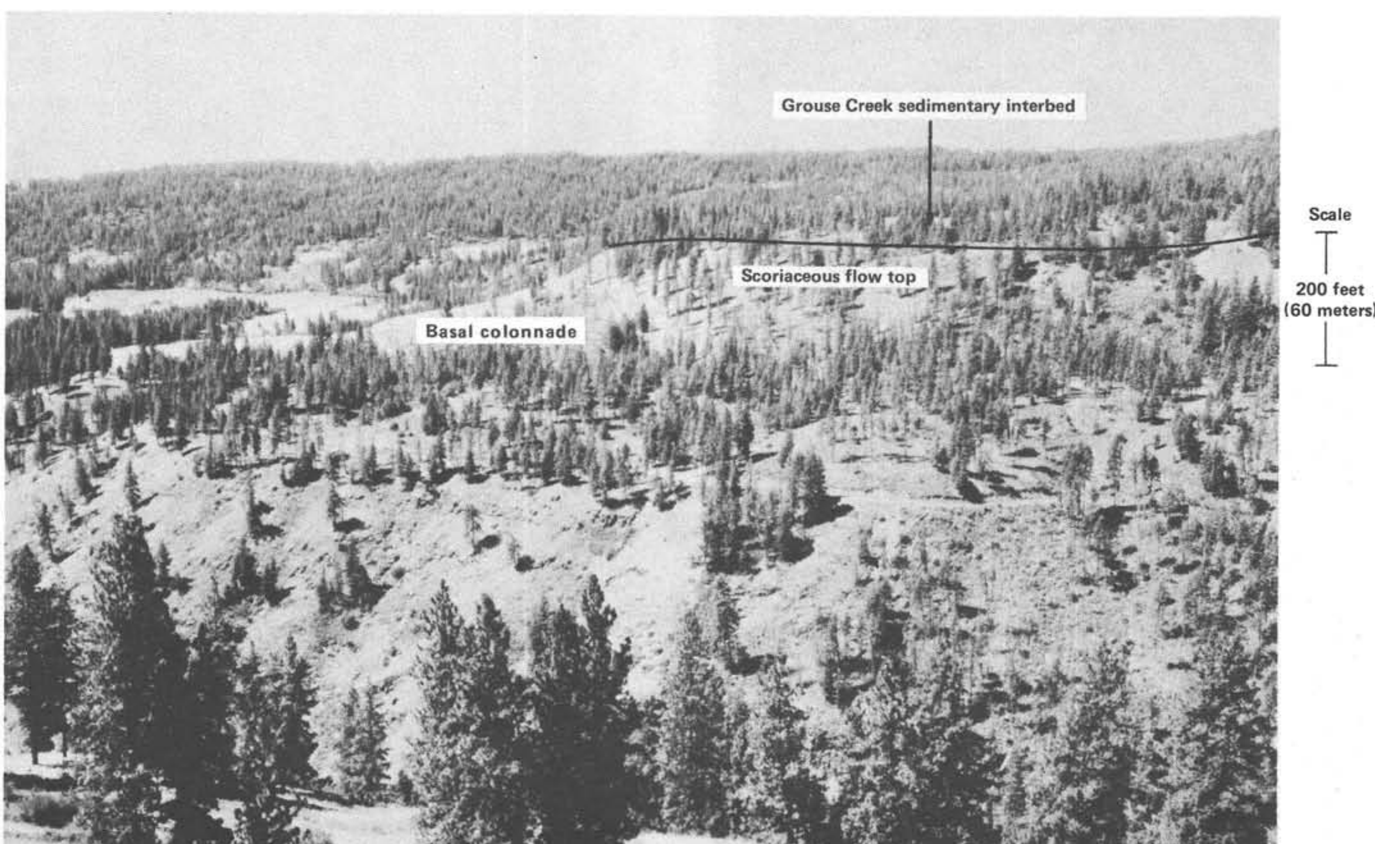


FIGURE 15. — The Sillusi flow in Grouse Creek (sec. 15, T. 6 N., R. 43 E). Gentle slopes of the flow's scoriaceous top overlie steeper slopes of the basal colonnade. The flow is overlain by the Grouse Creek sedimentary interbed.

Fresh basalt of the Sillusi flow is dark gray and extremely fine grained, with abundant plagioclase microphenocrysts (up to 2.0 mm long) in an aphanitic groundmass. It weathers to a pale yellow-brown or pale orange-brown color. The flow commonly displays a basal colonnade of moderately well-formed vertical columns, a middle vesicular zone, and a thick, scoriaceous flow top characterized by pale brownish-yellow weathering and siderite and goethite-filled vesicles. In canyon exposures, the scoriaceous flow top often forms gentle slopes overlying steeper slopes of the basal colonnade (fig. 15). The Sillusi flow has a normal magnetic polarity (Ross, 1978), (this report).

PETROGRAPHY
(after Ross, 1978)

The Umatilla flow is essentially equigranular and fine grained throughout its thickness. Microphenocrysts of plagioclase and clinopyroxene are rare. Intergranular texture is best developed in the more crystalline portions of the flow containing less than 25 percent glass. Intersertal texture is dominant in about the upper 10 percent of the flow containing over 25 percent glass plus opaques. Subophitic texture is rare.

The Sillusi flow is microporphyritic with plagioclase slightly more abundant than clinopyroxene (fig. 16). The microphenocrysts are mostly isolated, but a few occur in microglomeroporphyritic clusters. Groundmass is intersertal with interstices filled with glass, mineraloid, and sometimes carbonate. Intersertal texture occurs in samples containing 20 percent to 50 percent glass while more crystalline samples (glass less than 20 percent) are intergranular. The glassy (over 50 percent glass) vesicular to scoriaceous

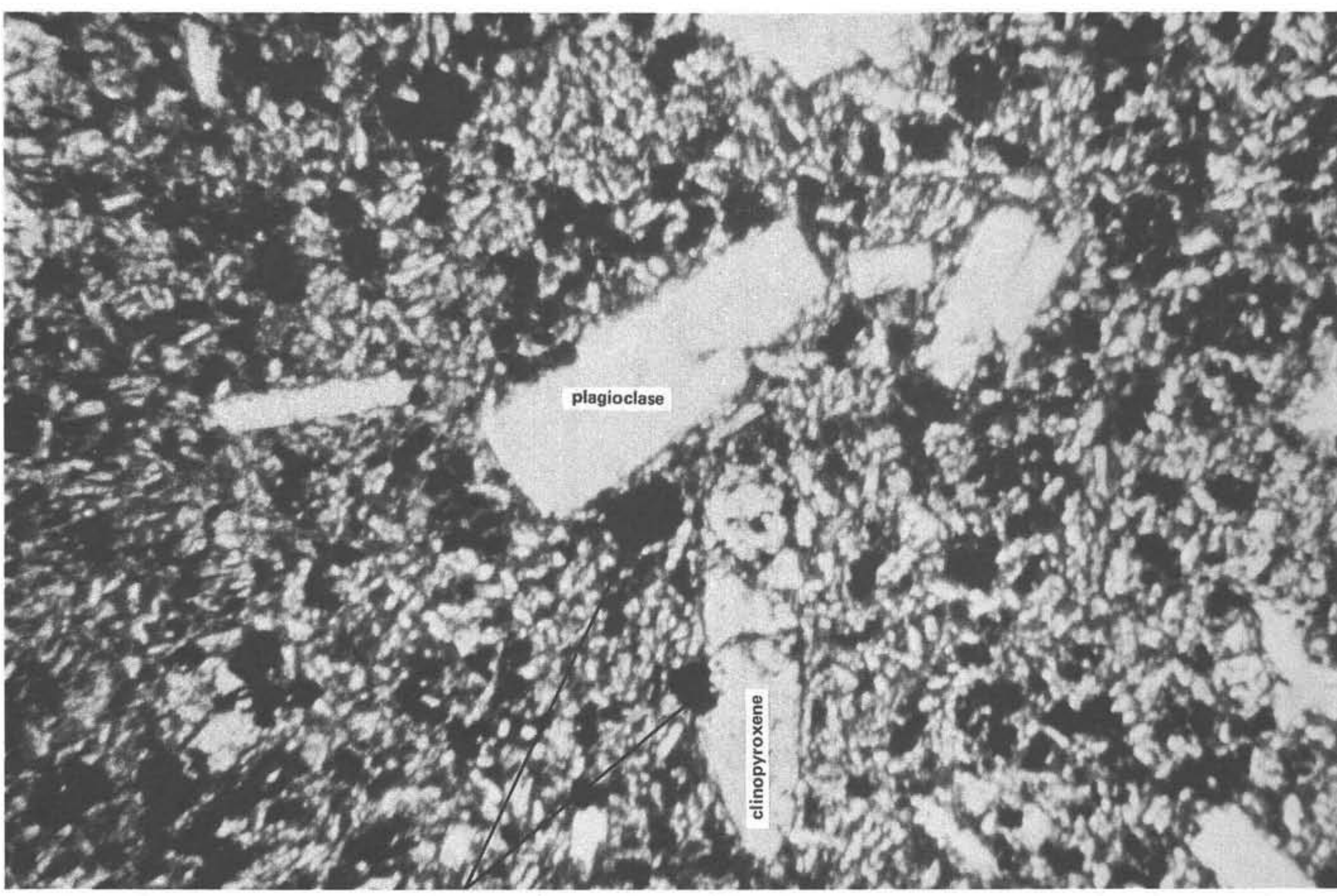


FIGURE 16. — Photomicrograph illustrating the microporphyritic texture of the Sillusi flow. Sample GRB-10. Plane light. 50 X.

upper portion of the flow exhibits hyaloophitic texture. Lens-shaped vesicles up to 18.0 X 4.5 mm are present in thin sections from the vesicular to scoriaceous portions of the flow. Most of the vesicles are lined with goethite.

CHEMISTRY

Umatilla Member flows are distinguished from other flows in the Grande Ronde lignite field by their higher P_2O_5 and K_2O and lower CaO and MgO contents (Appendix B). The two flows of the Umatilla Member are chemically very similar, but the Umatilla flow can be distinguished from the Sillusi flow by its slightly lower P_2O_5, SiO_2, and K_2O contents (Laval, 1956; Ross, 1978). For the purpose of this report, it is sufficient to consider the two flows of the Umatilla Member as one chemical type (Appendix B).

ELEPHANT MOUNTAIN MEMBER

In the Washington State portion of the Grande Ronde lignite field, the Elephant Mountain Member consists of two flows, the Tule Lake and Whitetail Butte flows (fig. 10 and plate 1):

TULE LAKE FLOW (NEW)

The Tule Lake flow is informally named herein for cliff outcrops on the west side of Tule Lake, in the E½NW¼ sec. 9, T. 6N., R. 43 E. (fig. 17). The Tule Lake flow overlies the Grouse Creek sedimentary interbed throughout the study area (fig. 10). It is in turn overlain by the Whitetail Butte flow (Elephant Mountain Member) in the western portion of the study area, the Menatchee Creek sedimentary interbed in the central part, and the Mountain View flow (Buford

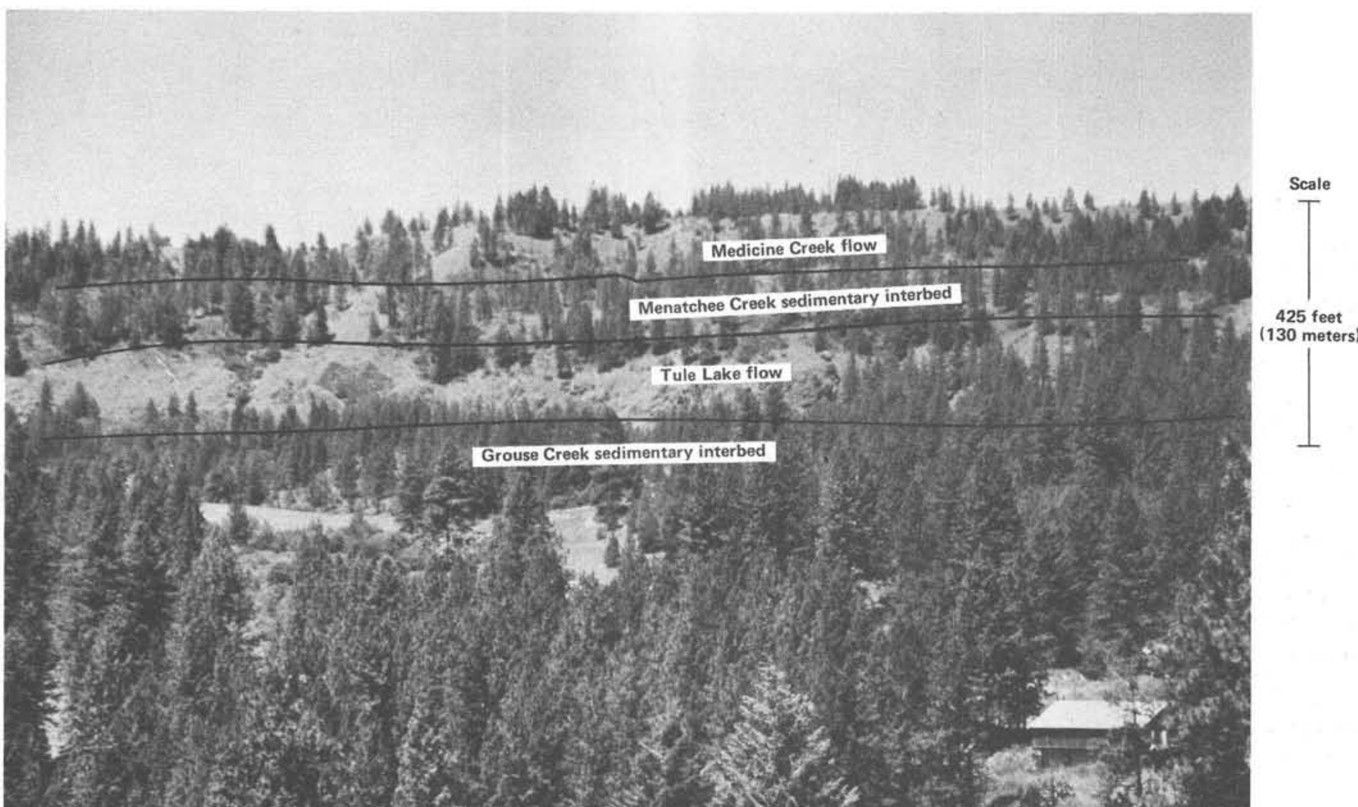


FIGURE 17. — Proposed type locality of the Tule Lake flow (Elephant Mountain Member) in E½NW¼ sec. 9, T. 6 N., R. 43 E. The flow forms the base of the prominent cliff at the back of a narrow bench eroded into the Grouse Creek sedimentary interbed.

Member) in the eastern portion (plate 1). The Tule Lake flow is approximately 150 ft (45 m) thick.

WHITETAIL BUTTE FLOW (NEW)

The Whitetail Butte flow is informally named herein for outcrops on the 3,536-ft summit of Whitetail Butte, in the NW¼NW¼ sec. 31, T. 7 N., R. 44 E. (fig. 18). At this locality, the Whitetail Butte flow overlies the Menatchee Creek sedimentary interbed (plate 1). On the south side of Grouse Flat, it overlies the Tule Lake flow. In other localities, the Whitetail Butte flow fills canyons eroded into the Menatchee Creek sedimentary interbed and the Tule Lake (Elephant Mountain Member) and Mountain View (Buford Member) flows (figs. 19 and 20). The Whitetail Butte flow is overlain by the Medicine Creek flow (Buford Member) throughout the study area, except where the Medicine Creek flow has been removed by erosion (plate 1). Since the Whitetail Butte flow is a sheet flow in the western third of the study area, and an intracanyon flow in the eastern part, the thickness of the flow is highly variable. On Grouse Flat, the sheet flow is approximately 250 ft (75 m) thick. Remnants of the intracanyon flow are greater than 400 ft (120 m) thick.

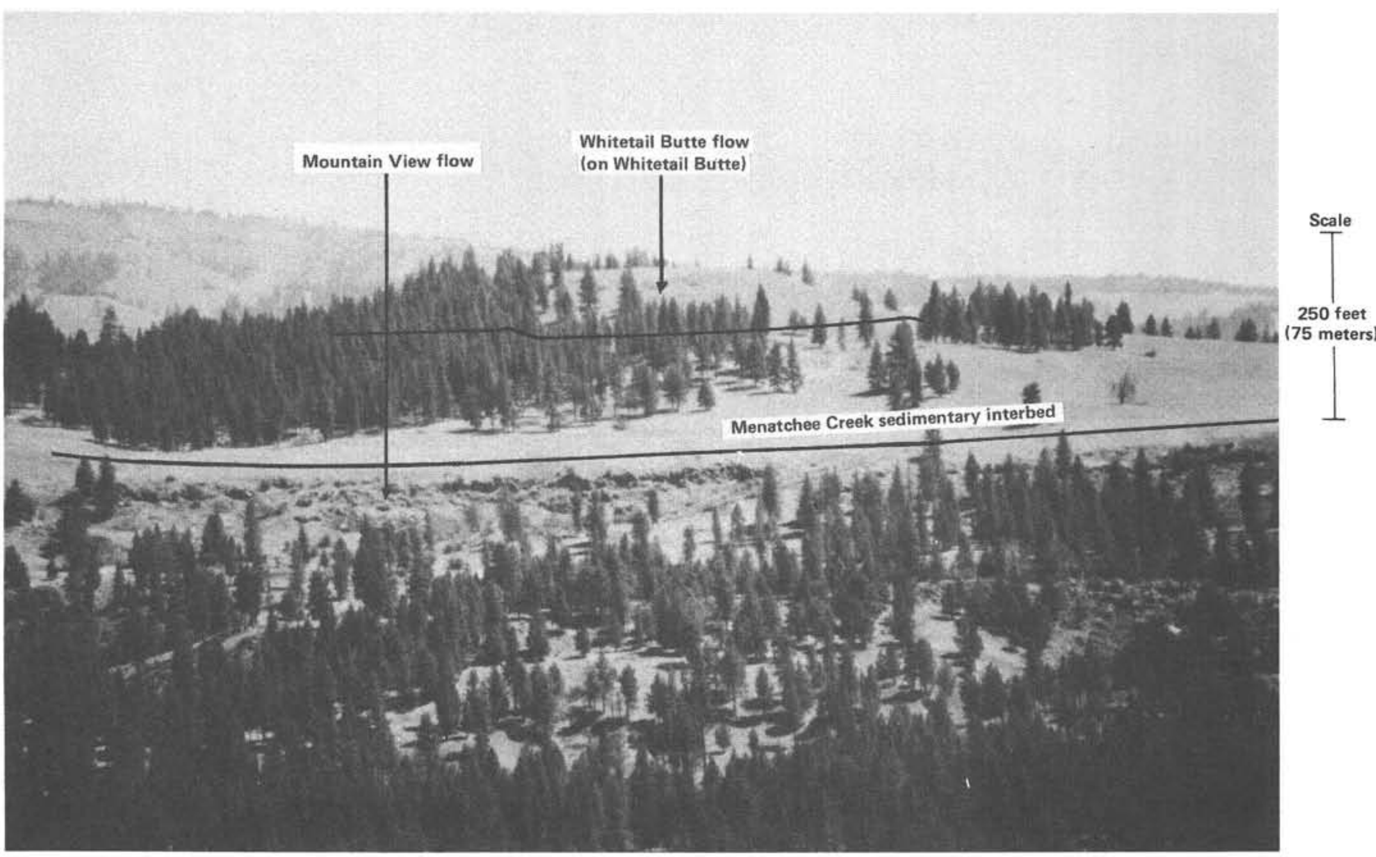


FIGURE 18. — Proposed type locality of the Whitetail Butte flow (Elephant Mountain Member) on the summit of Whitetail Butte in NW¼NW¼ sec. 31, T. 7 N., R. 44 E.

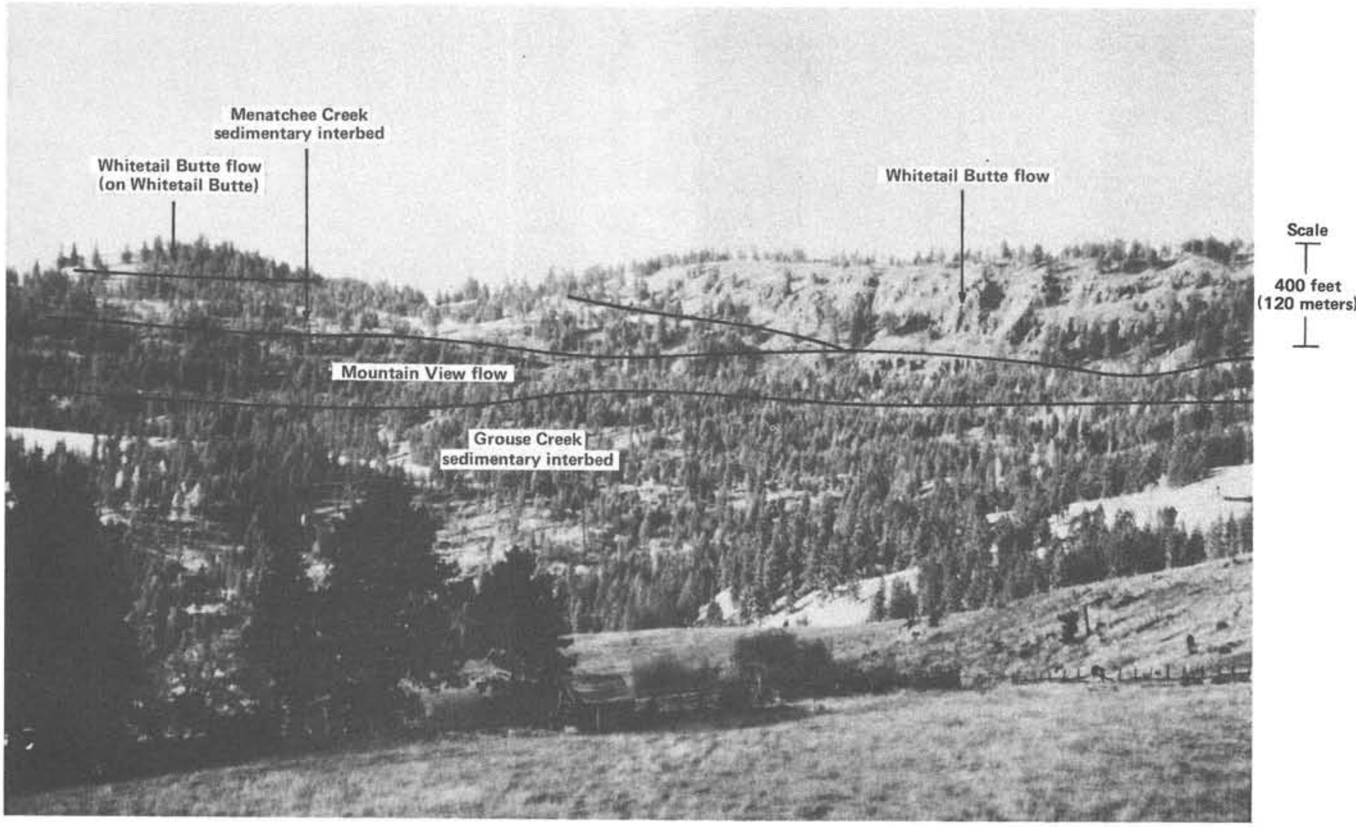


FIGURE 19. — The Whitetail Butte flow (Elephant Mountain Member) fills an erosional channel cut into the Menatchee Creek sedimentary interbed and the Mountain View flow (Buford Member) on the east side of "The Bench" in the W½ sec. 30, T. 7 N., R. 44 E.

FIELD CHARACTERISTICS

The Tule Lake flow generally consists of a basal colonnade of crudely formed vertical columns and a thin, vesicular flow top. Fresh outcrops of Tule Lake basalt are fine to medium grained, and equigranular. It weathers to a red-brown color.

The most distinctive field characteristic of the Whitetail Butte flow is its complex, chaotic jointing. Most outcrops of the flow are characterized by intricate, elaborate joint patterns produced by the abrupt lateral and vertical change of horizontal and vertical columnar joints into blocky, platy, or fan joints (fig. 21). Fresh exposures of Whitetail Butte basalt are black, fine to medium grained, and equigranular. It weathers to a red-brown color. The Whitetail Butte flow cannot be distinguished from the Tule Lake flow in hand specimen, but the Whitetail Butte flow has a transitional magnetic polarity while the Tule Lake flow has a normal magnetic polarity.

PETROGRAPHY

(after Ross, 1978)

The two flows of the Elephant Mountain Member cannot be differentiated in thin section. Basalt of both flows is equigranular, with scattered microphenocrysts of plagioclase, clinopyroxene, and more rarely, opaques (fig. 22). Textures in the flows vary, dependent upon glass plus opaques content, as follows: intergranular if less than 25 percent, intersertal if 25 percent to 40 percent, and hyaloophitic if over 40 percent. Intersertal to intergranular, or more commonly, intersertal to hyaloophitic textures occur within a single thin section. Ophitic and subophitic textures are best developed in the flow interiors, where clinopyroxenes attain their broadest dimensions and more

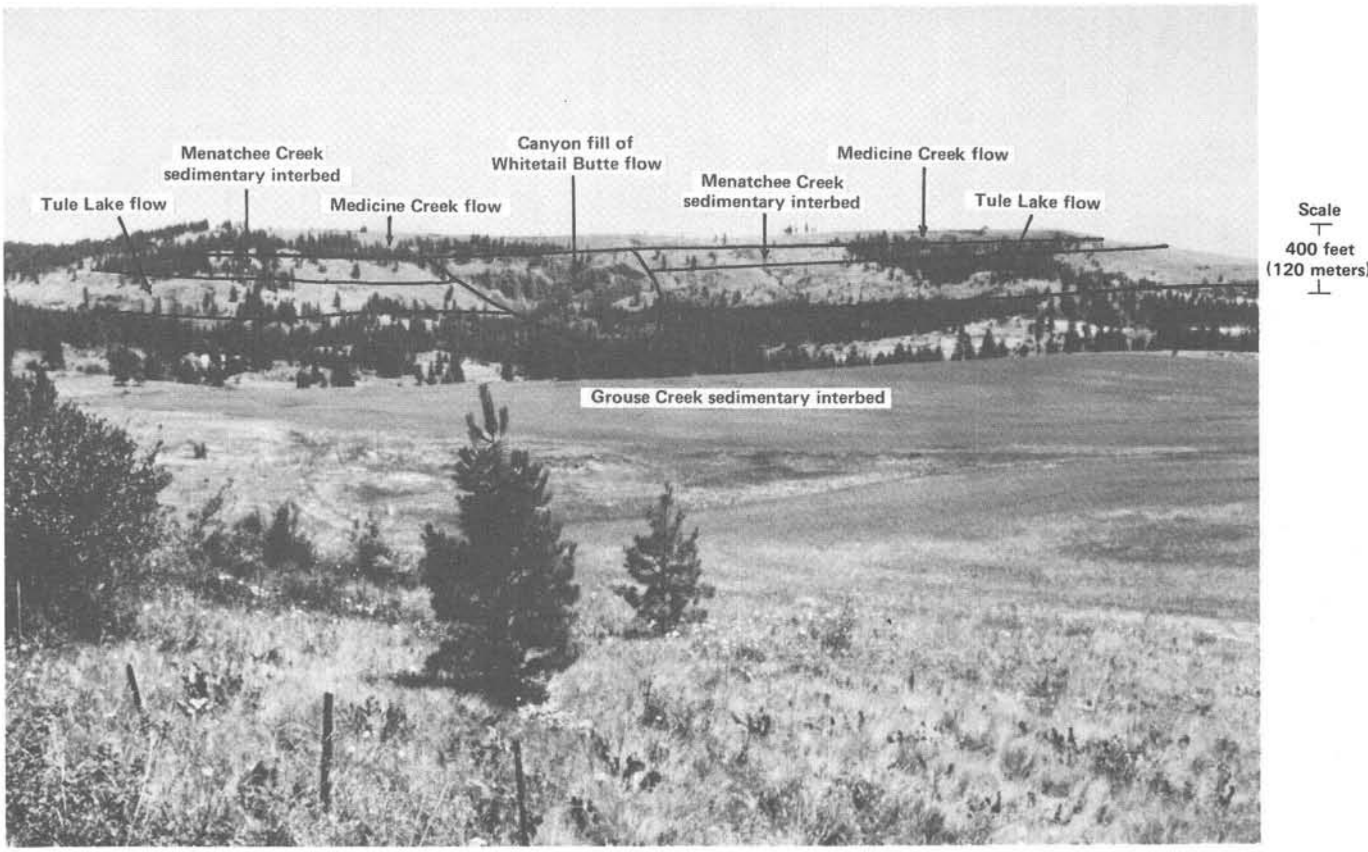


FIGURE 20. — View of the cliffs at the head of Grouse Creek (SW¼ sec. 3, T. 6 N., R. 43 E.), where the Whitetail Butte flow (Elephant Mountain Member) fills a canyon eroded into the Menatchee Creek sedimentary interbed and the Tule Lake flow (Elephant Mountain Member).

readily enclose plagioclase groundmass grains. No distinct flow banding is developed and vesicles are nearly all circular in cross section. The vesicles generally are completely filled with mineraloids or carbonate. In cross section, many vesicles are rimmed with small, lath-shaped grains of plagioclase arranged end-to-end, tangentially around the edge of individual vesicles.

CHEMISTRY

Major element chemistries of the Tule Lake and Whitetail Butte flows (Appendix B) are very similar to each other and to the Elephant Mountain chemical type defined by Wright and others (1973). For this reason, it is assumed that the flows are correlative with the Elephant Mountain Member in the central Columbia Plateau (Swanson and others, 1979). In the study area, flows of the Elephant Mountain Member are distinguished from flows of the Umatilla and Buford Members by their higher TiO_2 and lower SiO_2 contents (Ross, 1978) (Appendix B of this report).

Six samples of Whitetail Butte basalt are anomolously high in SiO_2 and TiO_2 and low in FeO and MgO (Appendix B). All of these samples are from portions of the Whitetail Butte flow which invaded sediments of the Menatchee Creek interbed (discussed later).

RADIOMETRIC AGE DATES

One sample of each flow of the Elephant Mountain Member was collected during this investigation and sent to Geochron Laboratories (Kreuger Enterprises, Inc.) for potassium-argon age dating. The samples were fresh, holocrystalline, nonvesicular, and nonamygdaloidal basalt.

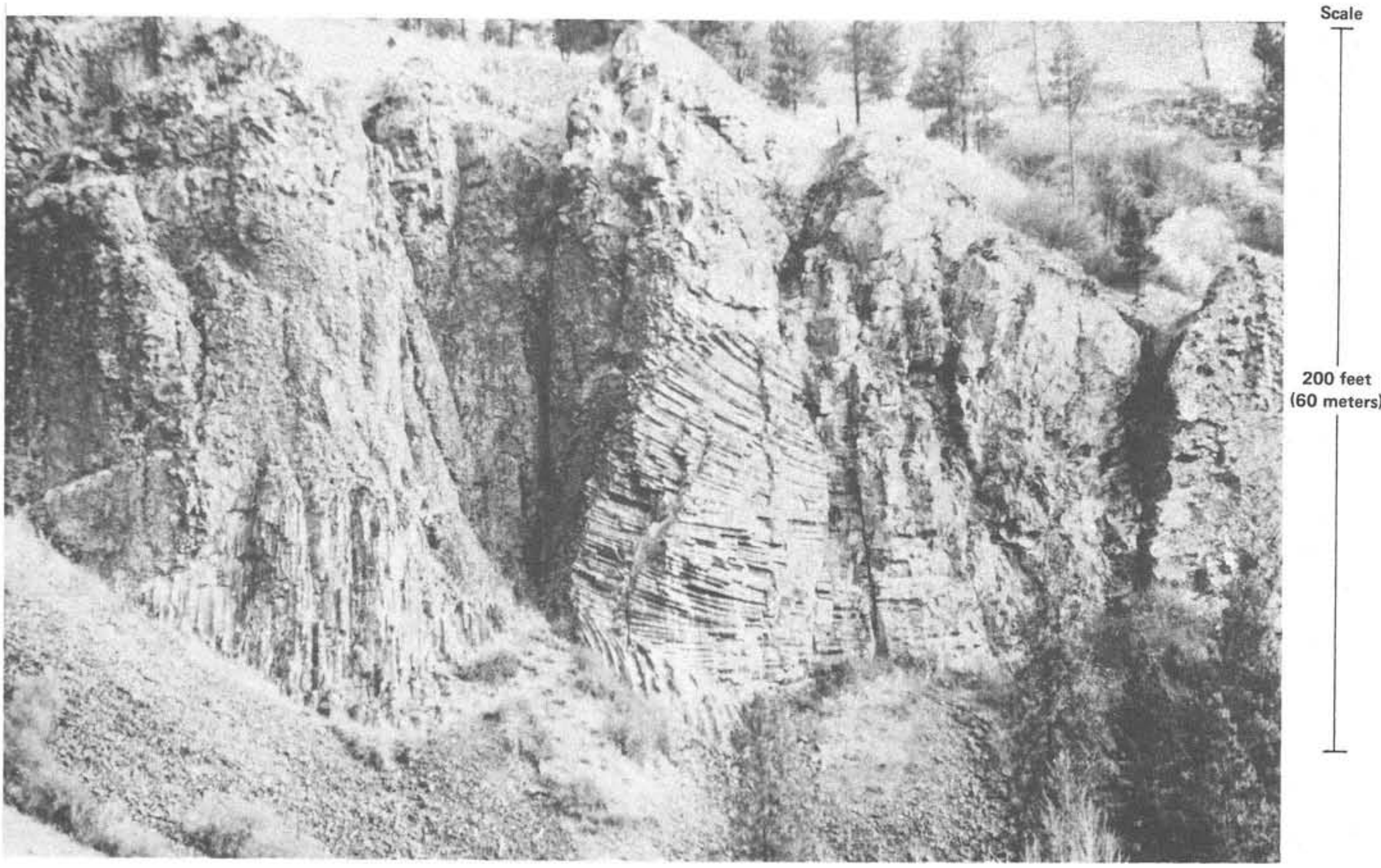


FIGURE 21. — Complex, chaotic jointing of the Whitetail Butte flow (Elephant Mountain Member) is exposed in the cliff at the head of Grouse Creek (SW¼SW¼ sec. 3, T. 6 N., R. 43 E.).

Before sending the samples to the Geochron Laboratory, they were pretreated as follows, in the Division of Geology and Earth Resources laboratory, to remove nonradiogenic argon trapped mechanically in the lattice structure of clay minerals:

1. Sample crushed to 80 mesh
2. Sample sieved and washed with water
3. Sample washed in 14 percent HNO_3 for 30 minutes
4. Sample washed in 5 percent HF for 1 minute
5. Sample washed in an ultrasonic cleaner for 15 minutes
6. Sample dried under a heat lamp

The following age dates were reported by the Geochron laboratory:

SAMPLE WI2

Tule Lake flow 9.4 ± 0.7 m.y.b.p.
From outcrop of 3-foot-diameter vertical columns at 3,110 ft in the NE¼SE¼SE¼ sec. 4, T. 6 N., R. 43 E.

SAMPLE WII2

Whitetail Butte flow 10.7 ± 0.8 m.y.b.p.
From outcrop of 4-foot-diameter vertical columns at 3,280 ft in the NE¼NW¼SW¼ sec. 30, T. 7 N., R. 44 E.

These dates agree well with the Elephant Mountain Member age dates of 9.5 and 10.5 m.y.b.p. reported by Atlantic Richfield Hanford Co. (1976) and McKee and others (1977), respectively.

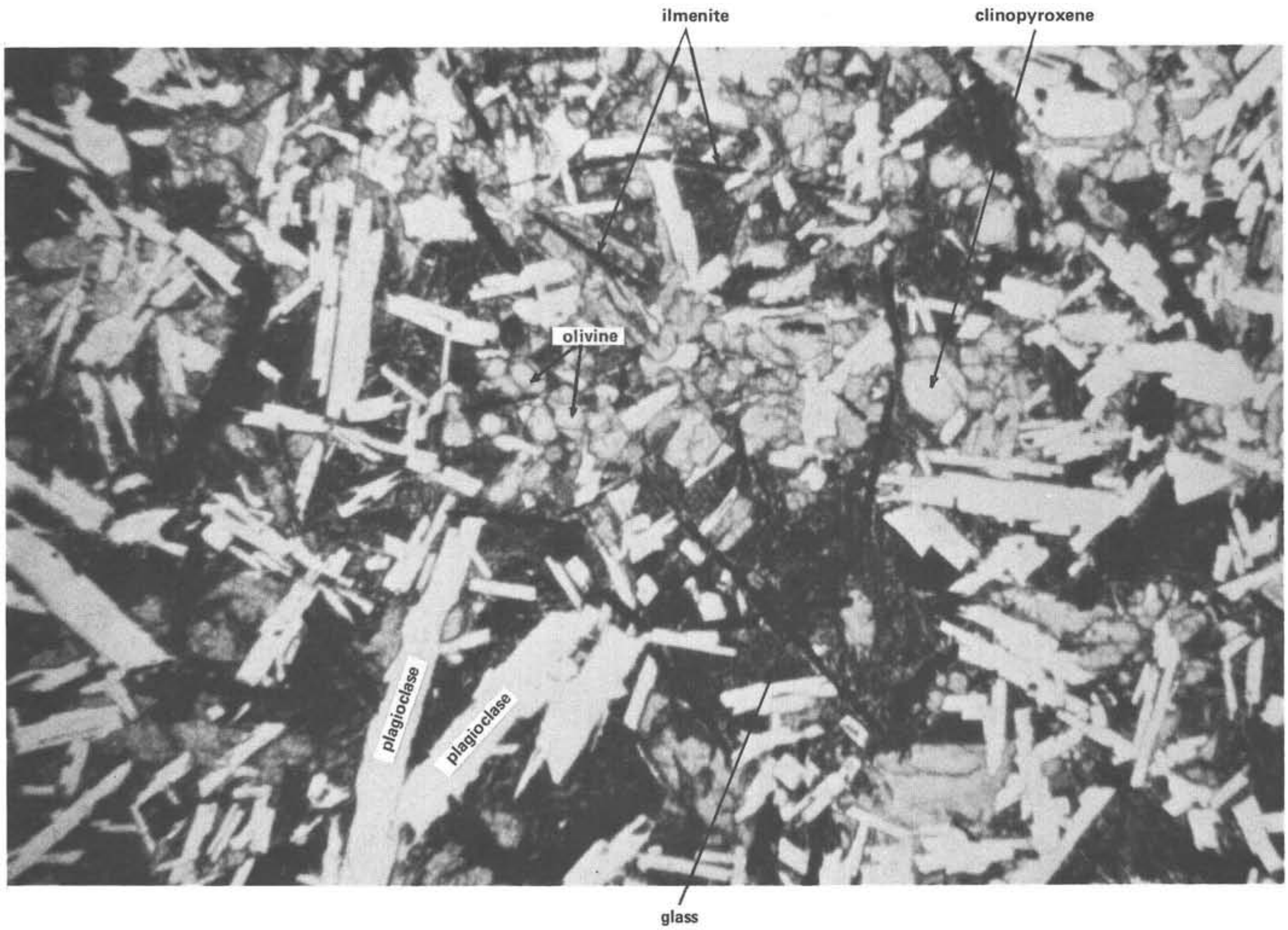


FIGURE 22. — Photomicrograph illustrating the equigranular texture of the Whitetail Butte flow (Elephant Mountain Member). Sample GRB-34. Plane light. 50 X.

BUFORD MEMBER

In the Washington State portion of the Grande Ronde lignite field, the Buford Member consists of two flows, the Mountain View and Medicine Creek flows (fig. 10 and plate 1).

MOUNTAIN VIEW FLOW (NEW)

The Mountain View flow is informally named herein for cliff outcrops in the E½ sec. 36, T. 7 N., R. 43 E., one mile west of Mountain View (fig. 23). In the eastern half of the study area, the flow conformably overlies the Grouse Creek sedimentary interbed, and in the west half it fills a canyon eroded into the Tule Lake flow (Elephant Mountain Member). It is overlain by the Menatchee Creek sedimentary interbed throughout most of the study area. In the vicinity of the type locality, the Mountain View flow averages 250 ft (75 m) thick.

MEDICINE CREEK FLOW (NEW)

The Medicine Creek flow is informally named herein for cliff outcrops on the southwest side of Medicine Creek in the W½NW¼ sec. 30, T. 7 N., R. 44 E. (fig. 24). Throughout the study area, the Medicine Creek flow overlies either the Whitetail Butte flow (Elephant Mountain Member) or the Menatchee Creek sedimentary interbed (plate 1). The Medicine Creek flow is the youngest Columbia River Basalt Group flow present in the Washington State portion of the lignite field.

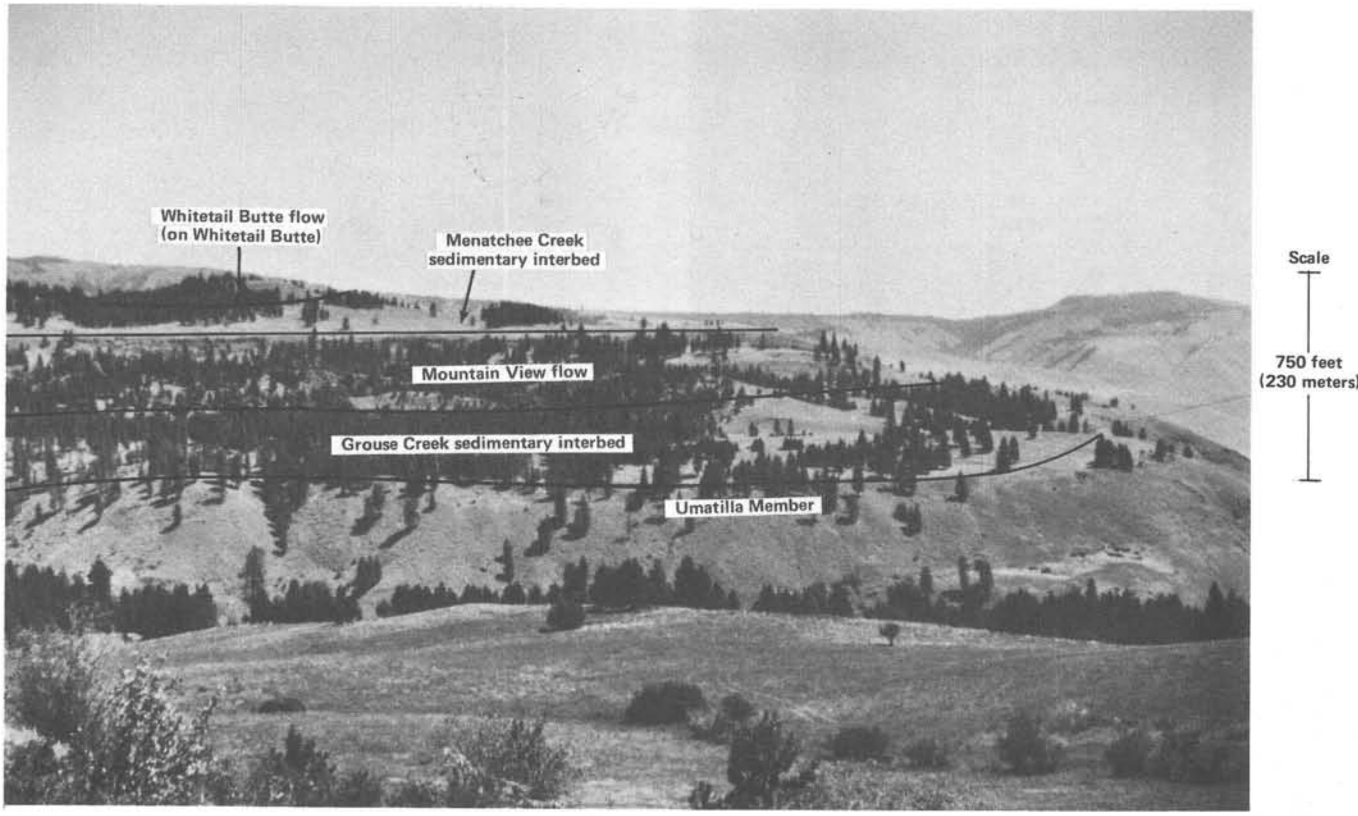


FIGURE 23. — View across Menatchee Creek to the proposed type localities of the Mountain View flow (Buford Member) and Menatchee Creek sedimentary interbed on the south end of "The Bench" (sec. 36, T. 7 N., R. 43 E.). The Menatchee Creek and Grouse Creek sedimentary interbeds crop out on topographic benches between flows of Saddle Mountains Basalt.

Outcrops north of Swank Springs (SW¼ sec. 20, T. 7 N., R. 44 E.) indicate that the original thickness of the Medicine Creek flow was approximately 160 ft (50 m) in the study area. Elsewhere, much of the flow has been removed by erosion, and flow thickness cannot be determined.

FIELD CHARACTERISTICS

The Mountain View flow consists of a basal colonnade of moderately well-formed vertical columns and an overlying vesicular zone which grades into a scoriaceous flow top. Vesicles are commonly filled with botryoidal goethite. The Mountain View flow has a transitional magnetic polarity.

The lower half of the Medicine Creek flow displays a basal colonnade of crudely formed vertical columns, which are broken into large blocks by widely spaced horizontal joints. A thick vesicular zone separates the basal colonnade from the flow's scoriaceous top. The Medicine Creek flow has a reversed magnetic polarity (Ross, 1978; Swanson and others, 1980).

The Mountain View flow cannot be distinguished from the Medicine Creek flow in hand specimen. The basalts are black, fine grained, and plagioclase-phyric when fresh, but all natural outcrops of both flows are deeply weathered. The weathered basalt is characterized by translucent to chalky white feldspar phenocrysts surrounded by a weathered light-gray groundmass, which is "peppered" by abundant minute black opaque grains. Weathering rinds are a pale orange-brown color.

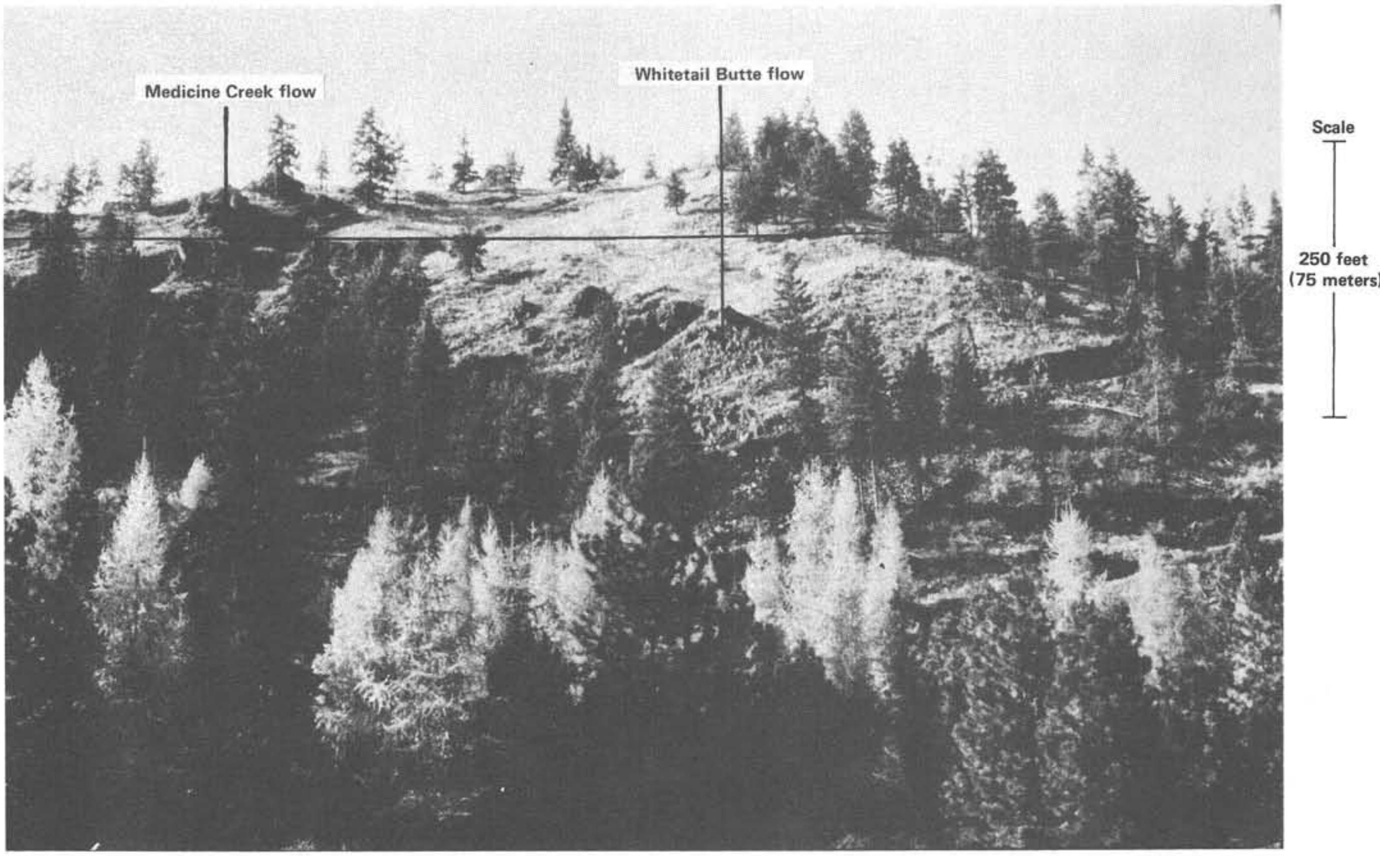


FIGURE 24. — Proposed type locality of the Medicine Creek flow (Buford Member) in the W½NW¼ sec. 30, T. 7 N., R. 44 E. View west to the east side of "The Bench" shows the Medicine Creek flow overlying the Whitetail Butte flow (Elephant Mountain Member).

PETROGRAPHY

(after Ross, 1978)

Both flows of the Buford Member are microporphyritic (fig. 25), with their groundmass textures grading from intergranular to intersertal to hyaloophitic as the glass content increases toward the top of the flows. Ophitic and subophitic textures are well developed, especially in the intergranular portions of the flows. Microphenocrysts commonly form microglomeroporphyritic clots. Scattered plagioclase phenocrysts and rare clinopyroxene phenocrysts are present.

CHEMISTRY

Major element chemistries of the Mountain View and Medicine Creek flows (Appendix B) are very similar to each other and to the Buford chemical type defined by Walker (1973). For this reason, the flows are assigned to the Buford Member. In the study area, flows of the Buford Member are distinguished from flows of the Umatilla and Elephant Mountain Members by their lower P_2O_5, TiO_2, and total Fe contents (Ross, 1978; Appendix B of this report).

SEDIMENTARY INTERBEDS

In the Washington State portion of the Grande Ronde lignite field, three sedimentary interbeds are intercalated with flows of the Saddle Mountains Basalt (fig. 10). Only the upper two, the Grouse Creek and Menatchee Creek interbeds, were mapped in this investigation. In the study area, these two interbeds are indistinguishable, except by stratigraphic position.

FIGURE 25. — Photomicrograph illustrating the microporphyritic texture of the Mountain View flow (Buford Member). Sample GRB-19. Plane light. 50 X.

GROUSE CREEK SEDIMENTARY INTERBED

The Grouse Creek interbed (Ross, 1978) overlies flows of the Umatilla Member and underlies the Tule Lake and Mountain View flows (fig. 10 and plate 1). The interbed varies in thickness from less than 50 ft (15 m) on the southwest side of the study area to 250 ft (75 m) along the axis of the Grouse Flat syncline.

MENATCHEE CREEK SEDIMENTARY INTERBED (NEW)

The Menatchee Creek interbed is informally named herein for outcrops on a narrow bench below Whitetail Butte (fig. 23), 1½ miles (2.4 km) east of Menatchee Creek (W½NW¼ sec. 31, T. 7 N., R. 44 E.). The interbed overlies the Tule Lake and Mountain View flows (fig. 10), and underlies the Whitetail Butte and Medicine Creek flows. It reaches a maximum thickness of 200 ft (61 m) in the vicinity of the type locality.

INTERBED CONSTITUENTS

Sediments are poorly exposed in the study area. Outcrops are limited to scattered roadcuts, streamcuts, and borrow pits, which expose subarkosic sandstone and siltstone, diatomite, carbonaceous shale, lignite, massive siltstone and claystone, and hyaloclastite.

Microscopic examination of the subarkosic sandstones and X-ray diffraction analyses of the < 2 micron fraction of the subarkosic sandstones and siltstones, indicate they are composed predominantly of quartz, with variable amounts of feldspar, muscovite and biotite mica, hornblende, and kaolinite. Subarkosic sandstone, the most common lithology in the sedimentary interbeds, is very fine to coarse grained (Appendix C), poorly to moderately well sorted, friable to moderately indurated, and locally cross bedded. It contains sparse fragments of basalt, quartzite, and crystalline rocks. Individual mineral grains and rock fragments in the sandstone are subrounded to subangular. The combination of positive skewness and high sorting values calculated from the grain size distribution curves in Appendix C suggest that the sandstones were deposited in a fluvial environment (Friedman, 1967).

Diatomite in the study area is white when pure, but it commonly grades into black, quartz-rich carbonaceous shale (Appendix D). The carbonaceous shale often grades into lignite.

X-ray diffraction analyses of the massive siltstone and claystone (Appendix D) indicate that their primary constituent is kaolinite; they also contain abundant fragments of dark-brown organic debris. The origin of the siltstone and claystone is uncertain; they may represent either *in situ* weathering of feldspar-rich sediments or deposition of detrital kaolinite.

Hyaloclastite is a glassy sand formed by the phreatic brecciation of basaltic lava as it suddenly chilled upon contact with water (McDonald, 1972). It is composed of thousands of minute plates of basaltic glass which are often altered to palagonite.

The Menatchee Creek interbed does contain one distinctive lithologic horizon which is apparently not present in the Grouse Creek interbed. At two widely separated outcrops*, subarkosic sandstone beds at the base of the Menatchee Creek interbed are composed of approximately 5 to 10 percent glass shards. The glass is dark brown, fresh, angular, and vesicular and has a refractive index of 1.498, indicative of a volcanic glass of rhyolitic composition (Williams and others, 1954). It must be a product of explosive volcanism from outside of the study area.

* Roadcut at 3,220 ft elevation in the NW¼SE¼SE¼ sec. 4, T. 6 N., R. 43 E.; roadcut at 3,290 ft elevation in the NE¼SW¼ NW¼ sec. 30, T. 7 N., R. 44 E.

SOURCE OF INTERBED SEDIMENTS

Two size fractions (80 mesh and 120 mesh) of five samples of subarkosic sandstone from the Grouse Creek and Menatchee Creek interbeds were analyzed to determine their heavy mineral compositions. The principal heavy minerals present in both fractions of all samples are garnet (almandite or spessartite), epidote, and black opaques (magnetite and ilmenite). Hornblende is abundant in one sample but sparse in the others; trace amounts of actinolite, sphene, rutile, and zircon are also present. This heavy mineral assemblage is characteristic of granitic and contact metamorphic rocks.

The source area(s) for the sandstones in the interbeds could have been either the Wallowa Mountains of Oregon or the Rocky Mountains of western Idaho (or both) (fig. 9). The northern Wallowa Mountains are a complex assemblage of Paleozoic and Mesozoic limestones, shales, sandstones, and greenstones intruded by Cretaceous granodiorite of the Wallowa batholith (Ross, 1938; Smith and Allen, 1941). Epidote and garnet are the major constituents of tactites found there. Tactites are rocks formed by the contact metamorphism of limestone. Hornblende is a principal constituent and magnetite and sphene are prominent accessory minerals in the Wallowa batholith granodiorite. Mesozoic shales, limestones, and dolomites intruded by Cretaceous granitic batholiths crop out in the Rocky Mountains of western Idaho as well (Bond and others, 1978). They are composed of similar mineral constituents.

From their source area(s), the detrital sediments were swept into the Troy basin and deposited with tuffaceous sediments derived from pyroclastic eruptions outside of the basin and with diatomite, carbonaceous shale, and peat of intrabasin origin.

GRANDE RONDE LIGNITES

DISTRIBUTION AND THICKNESS

Lignite is very poorly exposed in the Grande Ronde lignite field, but limited outcrops are found in springs, creeks, and roadcuts. Four exposures of lignite in the Grouse Creek interbed are known:

1. Mountain View mine: SW¼SW¼SW¼ sec. 31, T. 7 N., R. 44 E.

2. McLoughlin Spring: NE¼NE¼SE¼ sec. 29, T. 7 N., R. 44 E.

3. Medicine Creek: SE¼SW¼NE¼ sec. 30, T. 7 N., R. 44 E.

4. Sheep Creek: NW¼NE¼NW¼ sec. 22, T. 6 N., R. 43 E.

Of these localities, lignite thickness is known only from the abandoned Mountain View mine, where a 300-ft-long adit was driven to expose lignite more than 27 ft (8 m) thick (Washington Division of Geology and Earth Resources unpublished data), and from McLoughlin Spring, where an excavation exposed lignite more than 16 ft (5 m) thick (Russell, 1901). Logs of exploration holes drilled by private energy companies show that the lignite in the Grouse Creek interbed underlies most of the study area and reaches a maximum thickness of 40 ft (12 m). This thick lignite bed lies at or near the base of the Grouse Creek interbed, just above the contact between the sediments and the underlying Umatilla Member flows. Springs commonly emerge where the lignite crops out (fig. 26).

Lignite beds in the Menatchee Creek interbed crop out at only two localities:

1. East Grouse Flat: NE¼NE¼SE¼ sec. 3, T. 6 N., R. 43 E.

2. Grouse Creek: SE¼SW¼NE¼ sec. 4, T. 6 N., R. 43 E.

The lignite is very poorly exposed at both of these localities. Thickness and distribution of lignite beds in the Menatchee Creek interbed are poorly known.

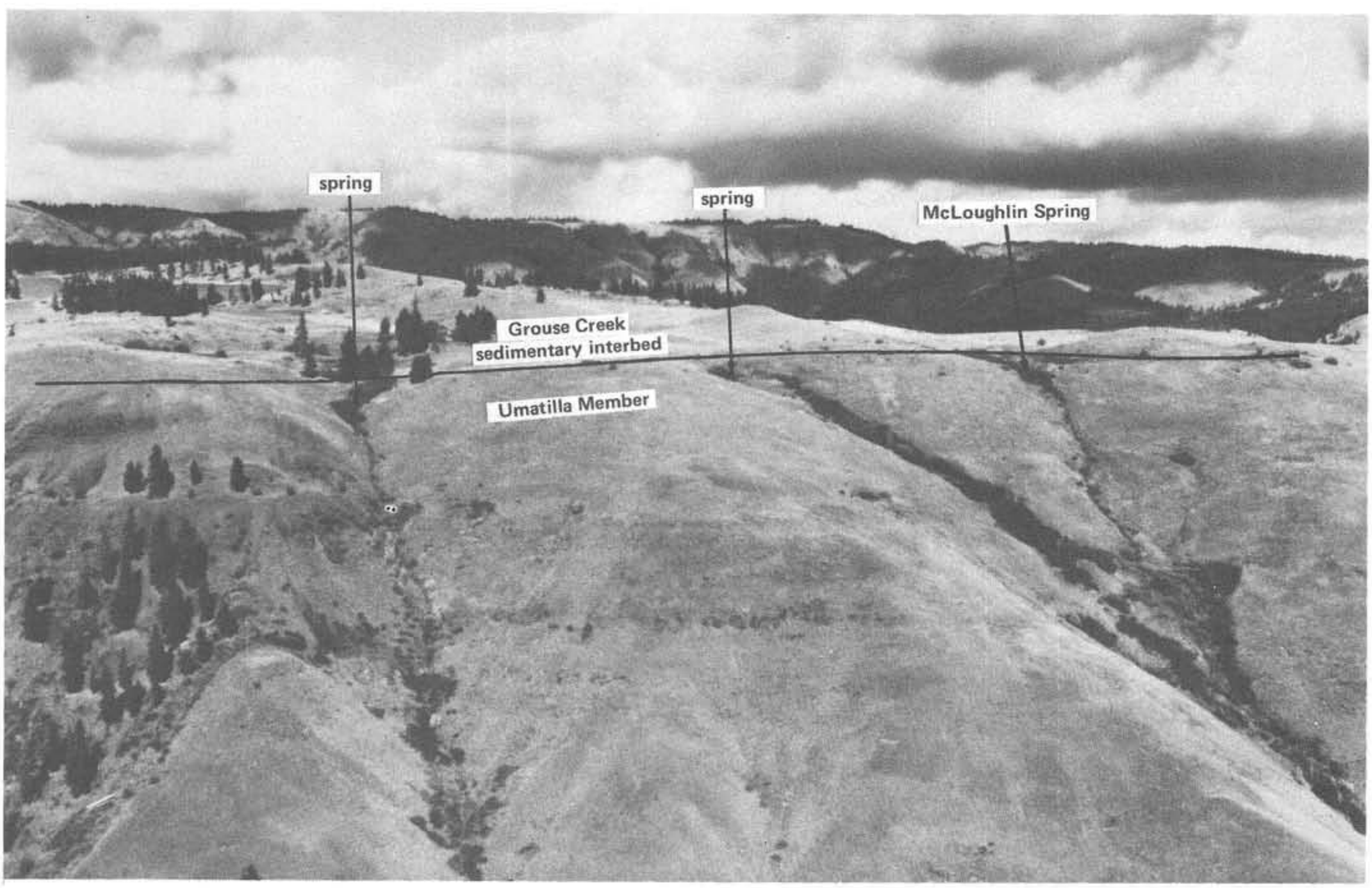


FIGURE 26. — View north to McLoughlin Spring and two other unnamed springs on a narrow bench eroded into the Grouse Creek sedimentary interbed. Springs commonly emerge where lignite crops out, just above the contact between the Umatilla Member and the Grouse Creek interbed.

QUALITY

Analyses of four lignite samples from scattered localities in the Grande Ronde lignite field are given in table 1. Samples nos. 1, 2, and 3 were collected from highly weathered outcrops in the study area. Sample no. 4 was collected from a fresh roadcut southeast of the study area.

All samples were analyzed by the U.S. Department of Energy except sample no. 1, which was analyzed by the U.S. Bureau of Mines. The lignites have a maximum Btu/lb value of 7,944 (as received) and a maximum fixed carbon value of 39.6 percent (as received). Sulfur content is less than 0.5 percent in all four samples, while ash content ranges from 5.7 to 16.7 percent (as received).

DEPOSITIONAL ENVIRONMENT

Outcrop and borehole data indicate that accumulation of the thick peat at the base of the Grouse Creek interbed (later converted to lignite) was preceded only by the deposition of diatomite and(or) carbonaceous shale. This implies that the peat was deposited in bog lakes which formed on the surface of the Umatilla Member. Formation of these lakes was closely related to the initiation of the Blue Mountains uplift and the development of the Troy basin (see next section).

The depositional environment of the lignite in the Menatchee Creek interbed cannot be determined from the limited outcrops available for study.

TABLE 1. — *Analyses of Grande Ronde lignites*

AR - as received
MF - moisture free
MAF - moisture and ash free

		1	2	3	4
PROXIMATE ANALYSIS	Moisture (AR)	15.8	36.8	33.4	12.5
	Volatile matter (AR)	31.8	24.0	35.0	43.9
	Volatile matter (MF)	37.8	37.9	52.5	50.2
	Volatile matter (MAF)	44.6	51.5	57.4	60.9
	Fixed carbon (AR)	39.6	22.5	25.9	28.2
	Fixed carbon (MF)	47.0	35.6	38.9	32.1
	Fixed carbon (MAF)	55.4	48.5	42.6	39.1
	Ash (AR)	12.8	16.7	5.7	15.4
	Ash (MF)	15.2	26.5	8.6	17.7
ULTIMATE ANALYSIS	Hydrogen (AR)	4.4	6.0	7.0	5.4
	Hydrogen (MF)	3.1	3.1	4.9	4.6
	Hydrogen (MAF)	3.7	4.2	5.3	5.5
	Carbon (AR)	49.6	31.3	40.5	46.6
	Carbon (MF)	58.9	49.6	60.8	53.2
	Carbon (MAF)	69.5	67.4	66.5	64.6
	Nitrogen (AR)	0.6	0.4	0.4	0.5
	Nitrogen (MF)	0.7	0.6	0.6	0.5
	Nitrogen (MAF)	0.8	0.8	0.7	0.7
	Sulfur (AR)	0.3	0.1	0.2	0.4
	Sulfur (MF)	0.4	0.2	0.3	0.4
	Sulfur (MAF)	0.4	0.2	0.3	0.5
	Oxygen (AR)	32.2	45.4	46.2	31.7
	Oxygen (MF)	21.6	20.1	24.8	23.6
	Oxygen (MAF)	25.5	27.3	27.2	28.6
	Ash (AR)	12.8	16.7	5.7	15.4
	Ash (MF)	15.2	26.5	8.6	17.7
Btu/lb	BTU (AR)	7,815	5,027	6,697	7,944
	BTU (MF)	9,263	7,949	10,053	9,078
	BTU (MAF)	10,953	10,809	10,998	11,024

1 (DGER No. 5-76) SW¼NE¼ sec. 30, T. 7 N., R. 44 E. - Medicine Creek
2 (DGER No. 8-77) SW¼NE¼ sec. 30, T. 7 N., R. 44 E. - Medicine Creek
3 (DGER No. 9-77) NE¼SE¼ sec. 29, T. 7 N., R. 44 E. - McLoughlin Spring

4 (DGER No. 11-80) NE¼NE¼ sec. 35, T. 6 N., R. 44 E. - Buford Creek, Oregon

DISCUSSION OF COMPLEX STRATIGRAPHIC RELATIONSHIPS

Saddle Mountains Basalt time in the Grande Ronde lignite field was dominated by the tectonic evolution of the Blue Mountains and Troy basin, the accumulation of sediments and peat, and the sporadic eruption of basalt flows. The synchroneity of these events produced complex stratigraphic relationships between flows and sediments (plate 1) that must be understood before lignite reserves can be accurately estimated.

SEDIMENT DEPOSITION

Sediment deposition in the Grande Ronde lignite field during Saddle Mountains Basalt time was controlled by the two conditions discussed below.

DEVELOPMENT OF THE TROY BASIN

Sediments of the Grouse Creek and Menatchee Creek interbeds were deposited in the Troy basin, a structural depression which formed south and east of the Blue Mountains uplift (fig. 9). The tectonic evolution of this basin controlled epiclastic sediment deposition and, more importantly, peat accumulation.

In early Saddle Mountains Basalt time, two flows of the Umatilla Member erupted from vents near the Washington-Oregon border and flowed west down a broad river valley to the central Columbia Plateau (fig. 27). Shortly after eruption

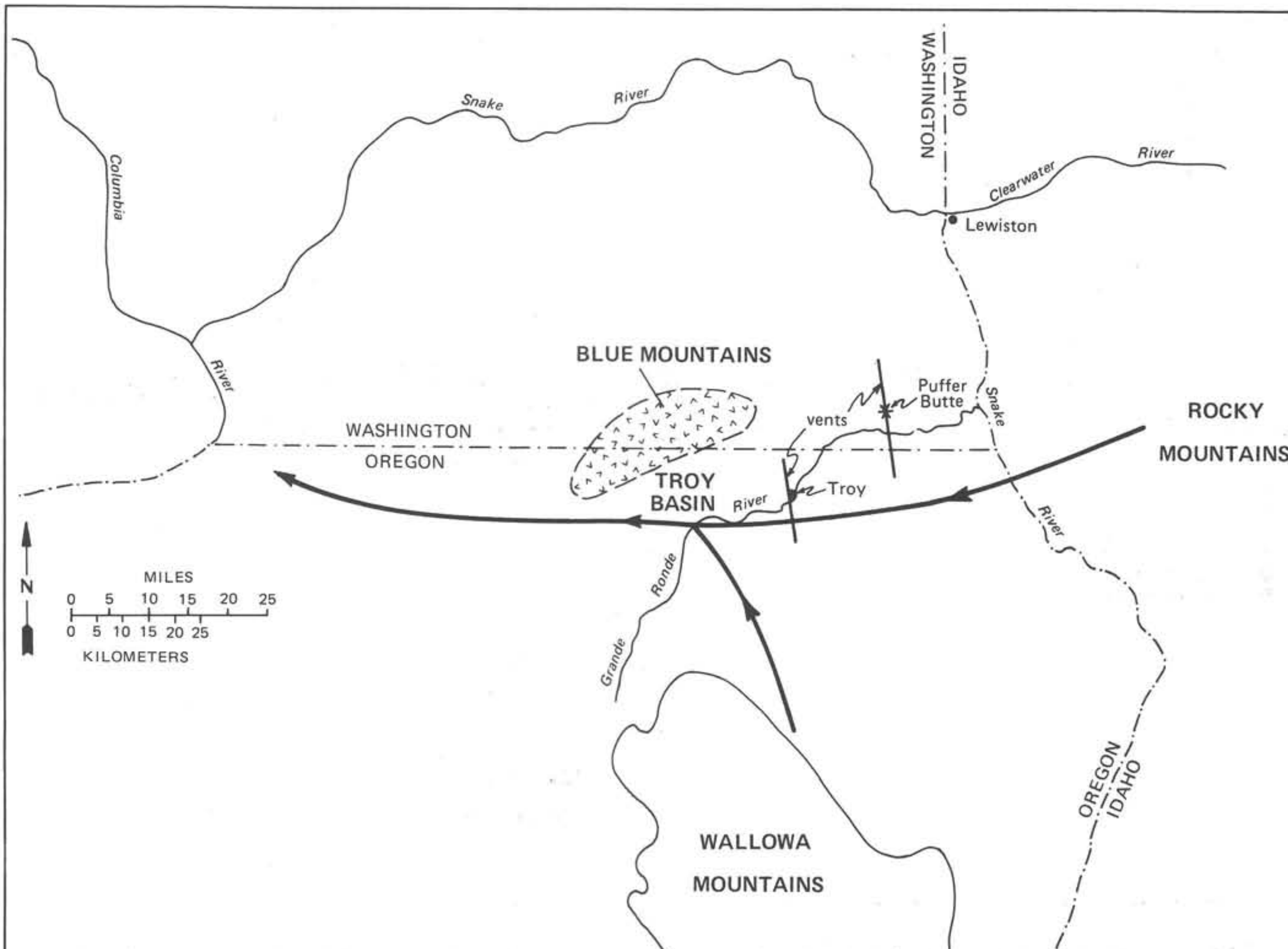


FIGURE 27. — Probable drainage pattern (dark black arrows) in the Grande Ronde River-Blue Mountains region during early Saddle Mountains Basalt time. Umatilla Member flows erupted from vents near Puffer Butte and Troy, Oregon, and flowed west to the central Columbia Plateau. Present locations of the Columbia, Snake, Clearwater, and Grande Ronde Rivers shown for reference only.

of these flows, uplift of the Blue Mountains blocked the westward flow of this river (Swanson and Wright, 1983), causing bog lakes to form and peat to accumulate throughout the Troy basin (fig. 28). As uplift of the Blue Mountains to the north and west continued, a northeasterly dipping paleoslope developed and a new river system began to form (fig. 29). Once this river system became established, the lakes and bogs in the Troy basin were drained, peat accumulation ended, and deposition of Grouse Creek interbed epiclastic sediments began. Soon after, flows of the Elephant Mountain Member erupted and flowed northeastward down this ancestral Grande Ronde River valley to the present-day site of Lewiston, Idaho, where they turned west and flowed to the central Columbia Plateau (fig. 29).

The thickest sediments in the Grouse Creek and Menatchee Creek interbeds occur near the center of the Troy basin; sediment thickness decreases toward basin margins. However, well logs indicate that the interbeds in the study area do not thin substantially toward the Slide Canyon monocline to the north. This implies that the northern limit of the depositional basin was once farther north than the present site of the hinge zone between the Slide Canyon monocline and the Grouse Flat syncline (figs. 12 and 13).

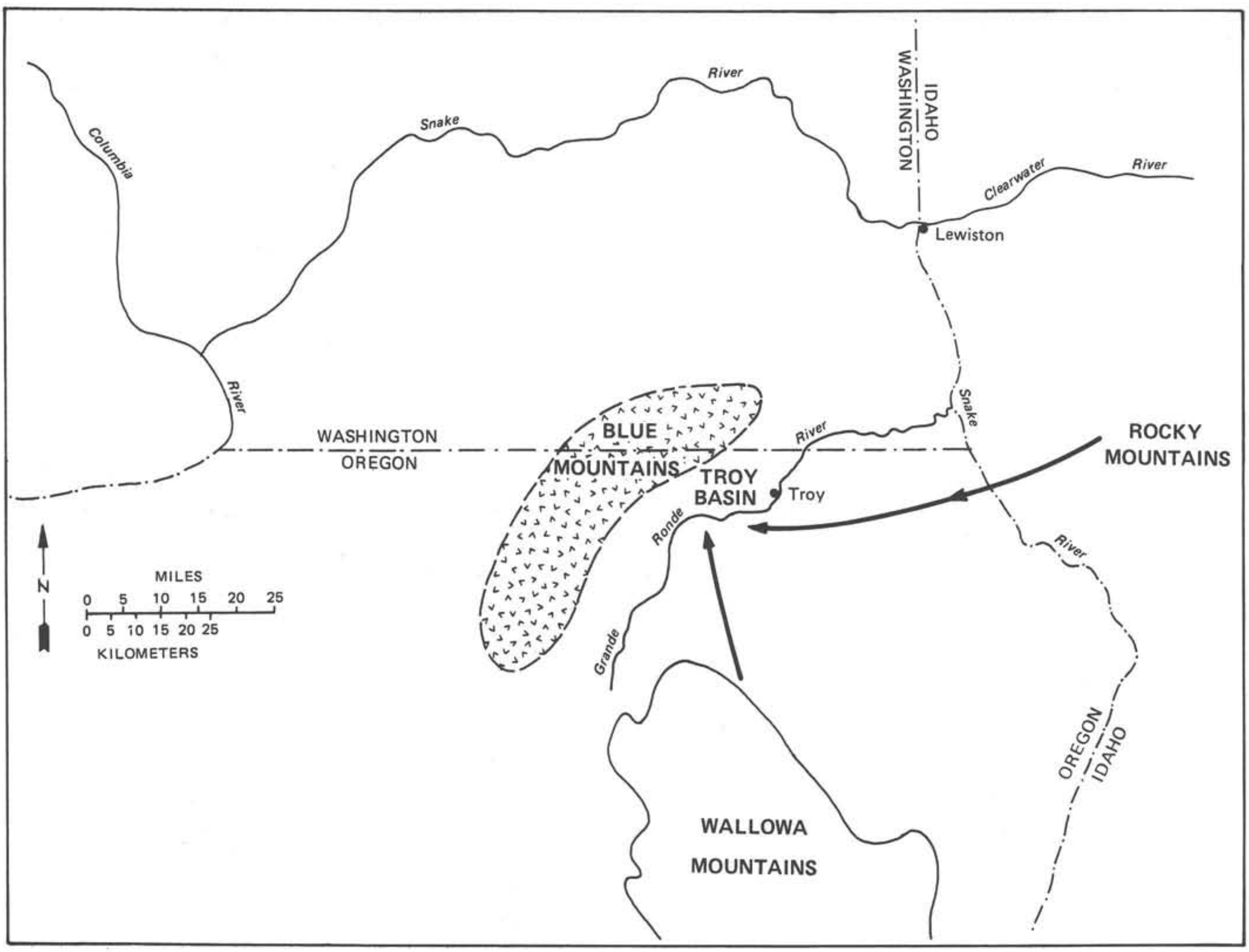


FIGURE 28. — Probable drainage pattern (dark black arrows) in the Grande Ronde River-Blue Mountains region during accumulation of the thick peat (now lignite) at the base of the Grouse Creek sedimentary interbed. Bog lakes occupied the poorly drained Troy basin at this time. Present locations of the Columbia, Snake, Clearwater, and Grande Ronde Rivers shown for reference only.

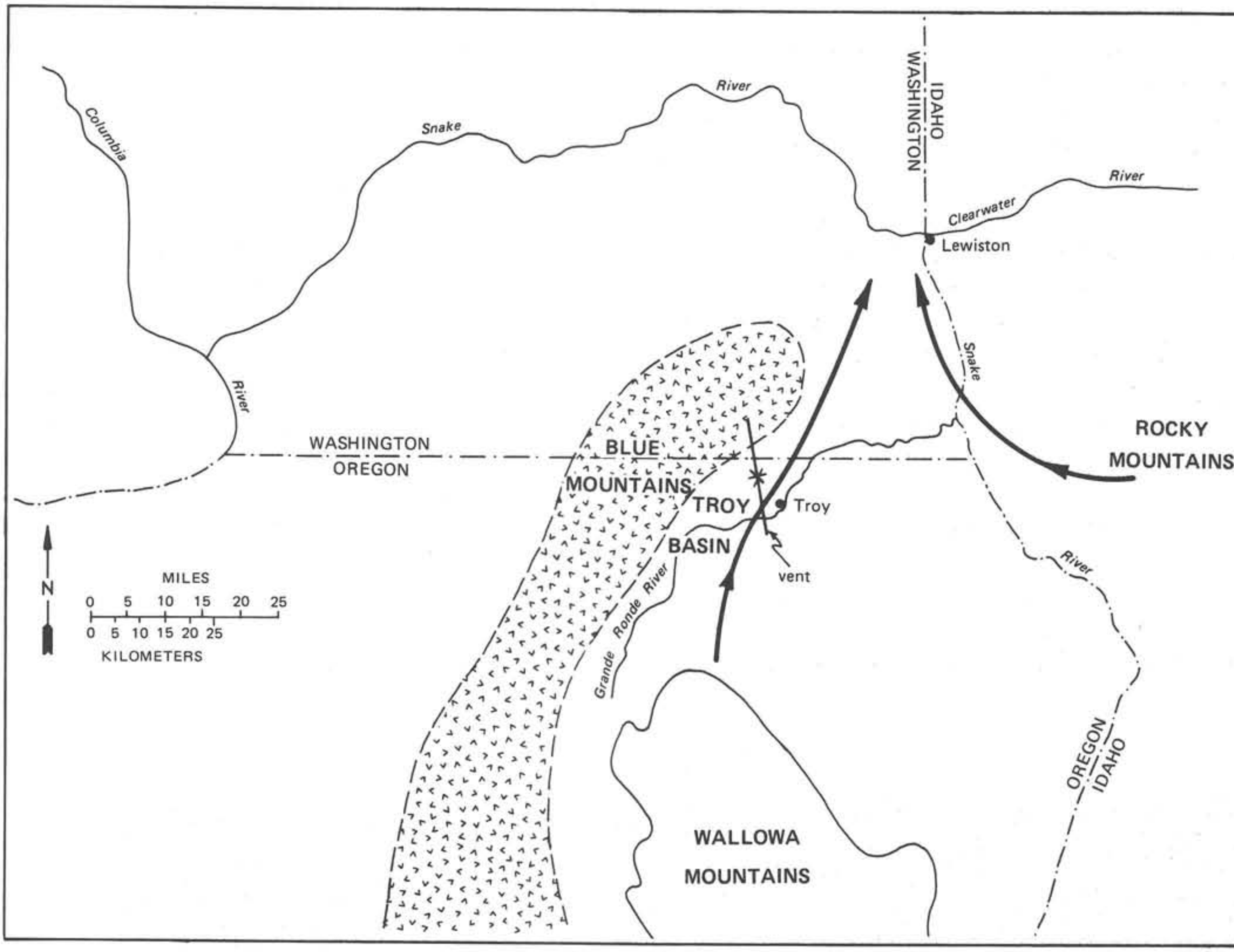


FIGURE 29. — Probable drainage pattern (dark black arrows) in the Grande Ronde River-Blue Mountains region during middle Saddle Mountains Basalt time. Elephant Mountain Member flows erupted from vents near Troy, Oregon, and flowed northeast down an ancestral Grande Ronde River valley to the Lewiston basin then west to the central Columbia Plateau. Present locations of the Columbia, Snake, Clearwater, and Grande Ronde Rivers shown for reference only.

FLOW SURFACE TOPOGRAPHY

Topographic relief on the surfaces of the Saddle Mountains Basalt flows in the Grande Ronde lignite field is often substantial. Field evidence indicates this relief is constructional topography formed by the building of cinder and spatter cones and low shield volcanoes at the vents of some of the Saddle Mountains Basalt flows in the lignite field.

Price (1977) described a lava cone complex at Puffer Butte, 6 miles northeast of the study area, and determined it was the vent for the Sillusi flow (Umatilla Member). Stratigraphic relationships suggest that the vent for the Umatilla flow (Umatilla Member) may have been located in the vicinity of Bear Creek, just northeast of Troy, Oregon (plate 1). Ross (1978) identified and mapped a complex of north- northwest-trending feeder dikes along the west edge of Grouse flat, which marks the location of the vent for at least one flow of the Elephant Mountain Member. No vents for the flows of the Buford Member have been positively identified, but since the flows were restricted to a relatively small area in the vicinity of the Grande Ronde River, the vents for these flows must have also been located there.

Interbed sediments deposited on flows near topographically high vent areas are significantly thinner than those away from vent areas. The Grouse Creek interbed thins substantially just east of the eastern border of the study area, near the Sillusi flow (Umatilla Member) vent at Puffer Butte. The Menatchee Creek interbed apparently thins significantly and may disappear altogether on the west side of Grouse Flat, near the Elephant Mountain Member vent. Since the thickest lignite deposits in the interbeds of the Grande Ronde lignite field occur near the base of the interbeds, topographic highs on the surfaces of the basalt flows underlying the interbeds probably prevented peat accumulation in some areas.

SEDIMENT DESTRUCTION

Several geologic events, which followed the deposition of each of the interbeds in the study area, destroyed or displaced much of the sediment which was originally deposited. The events discussed below substantially reduced the volume of sediments and lignite present in the Grande Ronde lignite field today.

INVASIVE FLOWS

Invasive basalt flows, lava flows which burrowed into sediments as they overrode them, have been described at numerous localities on the Columbia Plateau (Schmincke, 1964). Within coarse-grained sediments, these flow intrusions generally form sheets, tongues, or globular masses of unfragmented basalt. Invasion of finer-grained sediments formed basalt-sediment breccias known as peperites, intimate mixtures of fragmented basalt and shattered sediments which resulted from the hot liquid lava churning up wet, unconsolidated sediments (Schmincke, 1965). Several examples of invasive flows are well exposed in

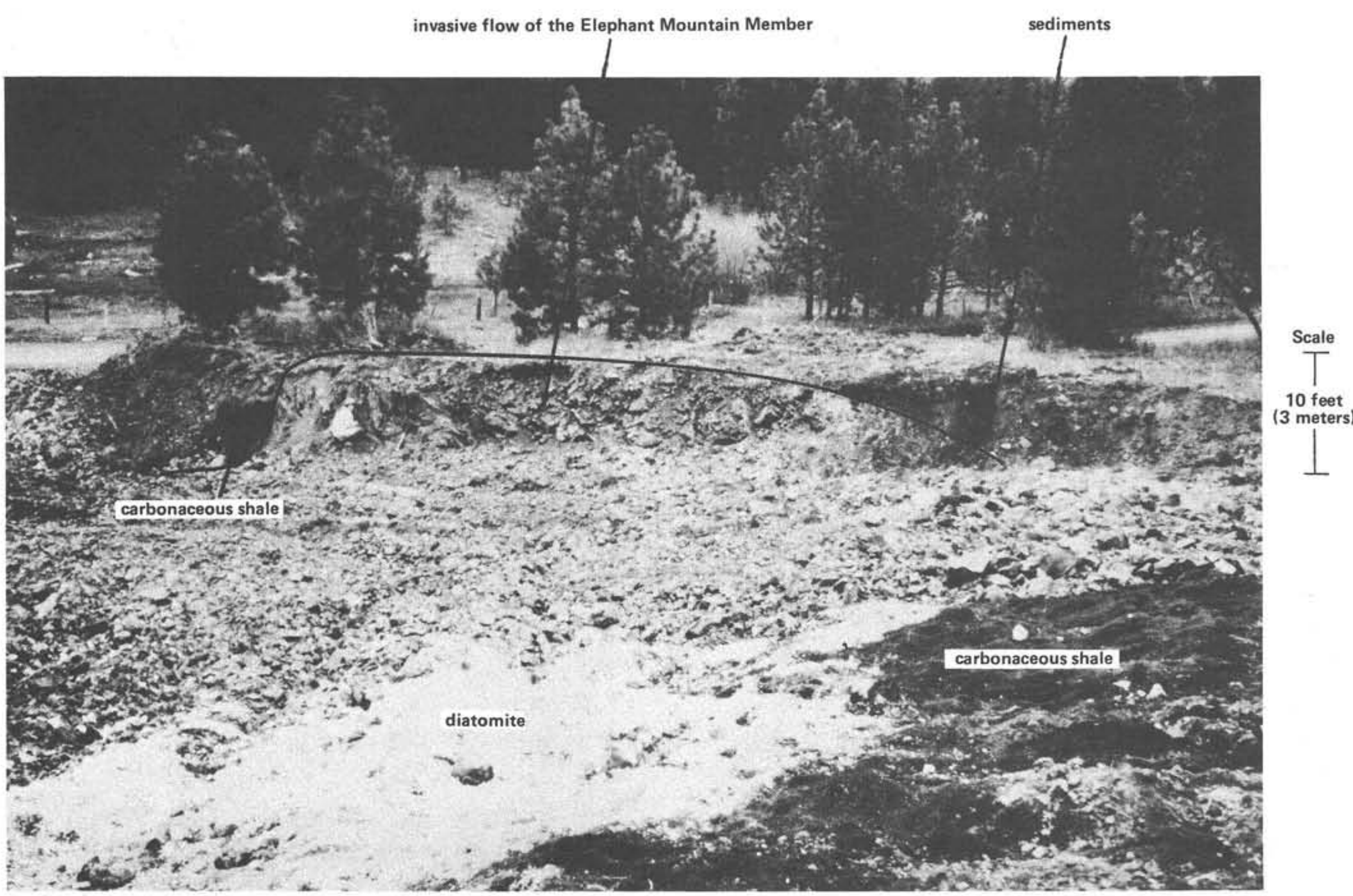


FIGURE 30. — An invasive flow of the Elephant Mountain Member exposed in a borrow pit on Grouse Flat (NW¼NW¼ SW¼ sec. 8, T. 6 N., R. 43 E.). The flow invaded diatomite and organic mud (now carbonaceous shale).

borrow pits and roadcuts in the Grande Ronde lignite field:

1. An excellent three-dimensional exposure occurs in a borrow pit on Grouse Flat (NW¼NW¼ SW¼ sec. 8, T. 6 N., R. 43 E.), where a flow of the Elephant Mountain Member intrudes sediments of a thin interbed (fig. 30). At this locality, the lava apparently flowed into a swampy lake underlain by diatomite and organic debris. Upon contact with the water, the lava suddenly chilled and brecciated, forming a glassy sand (hyaloclastite). As the lava overrode the lake, it stirred up the unconsolidated sediments, producing an intimate mixture of diatomite, organic debris, and hyaloclastite. The lava then burrowed into the sedimentary pile, forming a large intrusion from which numerous small dikes emanated.

2. Outcrops in a borrow pit near Grouse Creek (SE¼NW¼NE¼ sec. 9, T. 6 N., R. 43 E.) expose basalt of the Tule Lake flow which has invaded sediments of the Grouse Creek interbed (fig. 71). During invasion, the lava shoved competent beds of subarkosic sandstone and siltstone into a vertical position.

3. A roadcut near Swank Springs (SE¼SW¼ SW¼ sec. 20, T. 7 N., R. 44 E.) exposes basalt of the Mountain View flow which invaded sediments of the Grouse Creek interbed. A thin peperite marks the contact between the flow and the sediments.

Field relationships in the study area (plate 1) indicate that as the Tule Lake and Mountain View flows overrode unconsolidated sediments of the Grouse Creek interbed, the flows invaded the sediments. Younger flows which overrode sediments of the Menatchee Creek interbed invaded those sediments as well. Evidence for this "burrowing" is abundant on the interbed benches in the study area, where erosional remnants of invasive structures crop out as small basalt hills sur-

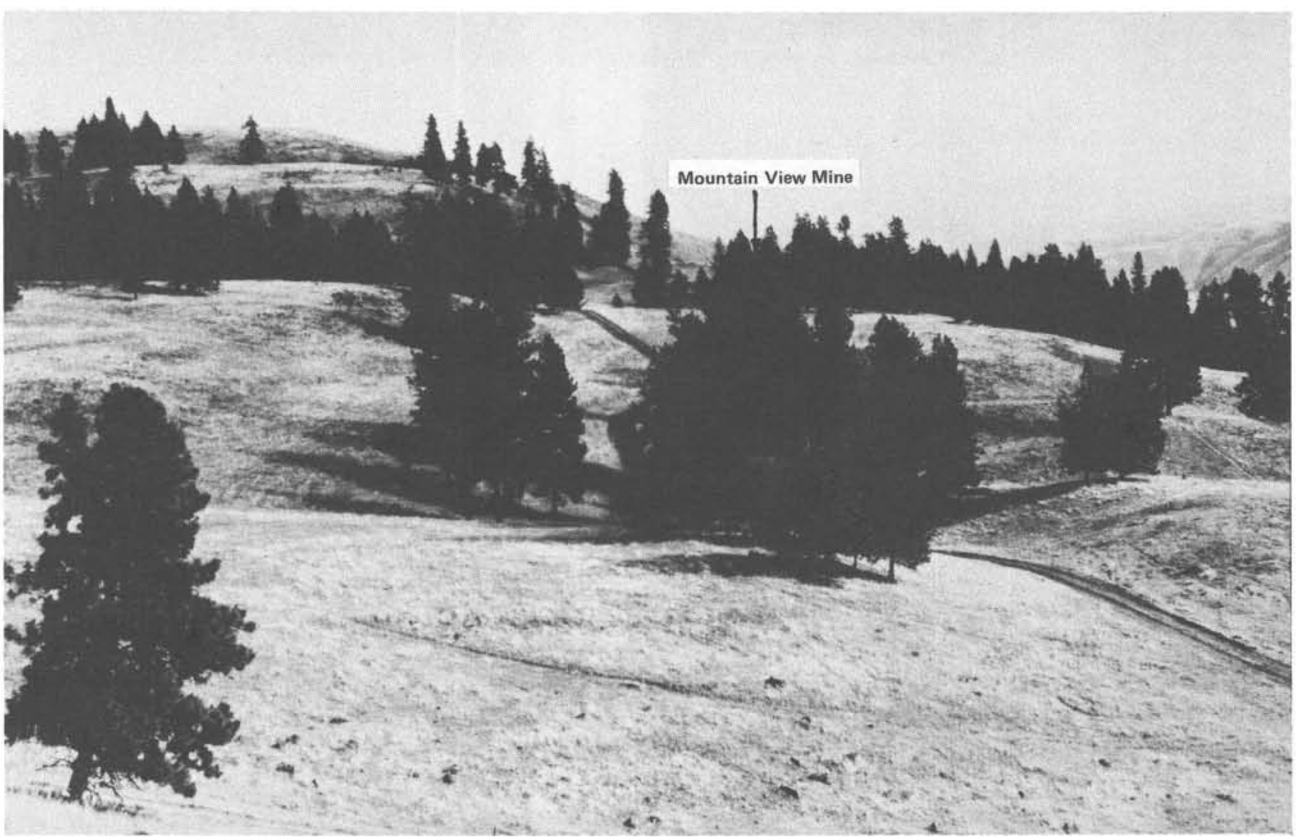


FIGURE 31. — Erosional remnants of invasive structures formed at the base of the Mountain View flow crop out as small basalt hills on the Grouse Creek interbed bench near the south end of "The Bench" (sec. 36, T. 7 N., R. 43 E.).

FIGURE 32. — Details of the small basalt hills shown in fig. 31.

rounded by sediments (figs. 31 and 32).

In places, the invasive basalt flows burrowed completely through the interbeds and are in direct contact with the underlying basalt flows. Good examples are exposed at the Medicine triangulation station on Hanson Ridge (NE¼SW¼SW¼ sec. 28, T. 7 N., R. 44 E.) and along an unnamed ridge on the southwest side of Cougar Creek (SE¼NE¼NW¼ sec. 32, T. 7 N., R. 44 E.) where basalt of the Mountain View flow directly overlies the scoriaceous flow top of the Sillusi flow (fig. 33).

Invasive basalt flows in the Grande Ronde lignite field displaced great volumes of sediment during the process of invasion. More importantly, where the flows burrowed completely through the sediments, they destroyed some of the thick lignite beds near the base of the interbeds. This is evident at McLoughlin Spring (NE¼NE¼SE¼ sec. 29, T. 7 N., R. 44 E.), where 30 ft (9 m) of lignite lies at the base of the Grouse Creek interbed. Small hills adjacent to the spring are composed of basalt of the Mountain View flow, which burrowed through approximately 250 ft (75 m) of Grouse Creek sediments and destroyed some of the lignite bed which crops out at the spring (fig. 34).

CANYON CUTTING

Canyon cutting and the extrusion of basalt flows both accompanied structural deformation in the Grande Ronde River-Blue Mountains region during Saddle Mountains Basalt time. For this reason, intracanyon flows of Saddle Mountains age are common in the Grande Ronde lignite field (plate 1).

In the study area, the best exposure of intracanyon basalt is located in the cliffs at the head of Grouse Creek (SW¼SW¼ sec. 3, T. 6 N., R. 43 E.). At that locality, the Whitetail Butte flow fills a canyon eroded into the Menatchee

FIGURE 33. — View southwest to a linear ridge of basalt of the Mountain View flow that overlies the Sillusi flow (SE¼ NE¼NW¼ sec. 32, T. 7 N., R. 44 E.). At this locality, the Mountain View flow "burrowed" completely through the 250-ft-thick Grouse Creek sedimentary interbed.

Creek interbed and the Tule Lake flow (figs. 20 and 65). Another exposure of the Whitetail Butte intracanyon flow crops out on the east side of "The Bench" (W½ sec. 30, T. 7 N., R. 44 E.), where the flow fills a broad canyon eroded into the Menatchee Creek interbed and the underlying Mountain View flow (fig. 19). Still another Whitetail Butte flow canyon fill crops out in cliffs on the west side of Grouse Creek (N½NW¼ sec. 9, T. 6 N., R. 43 E.), (figs. 63 and 64).

Field relationships observed in roadcuts and streamcuts along Sheep Creek (plate 1) indicate that at that locality the Mountain View flow occupies a canyon eroded into the Tule Lake flow (fig. 64). The base of the canyon was apparently eroded into the Grouse Creek interbed.

Where basalt flows filled canyons eroded into interbed sediments, lava often invaded the canyon walls during filling. Outcrops at two localities in the study area expose basalt of the Whitetail Butte flow that intruded canyon walls composed of Menatchee Creek sediments:

1. Roadcuts on the east side of "The Bench" (SW¼NW¼ sec. 30, T. 7 N., R. 44 E.), (figs. 58 and 69).
2. A roadcut at the head of Grouse Creek (NW¼SE¼SE¼ sec. 4, T. 6 N., R. 43 E.), (figs. 35 and 70).

The combination of sediment erosion during canyon cutting and basalt invasion of sediments during canyon filling has destroyed a significant volume of sediments in the Grande Ronde lignite field. Lignite beds probably have also been removed by these processes.

FOLDING

Following their deposition, the interbeds and intercalated basalt flows in the study area were folded during the continued development

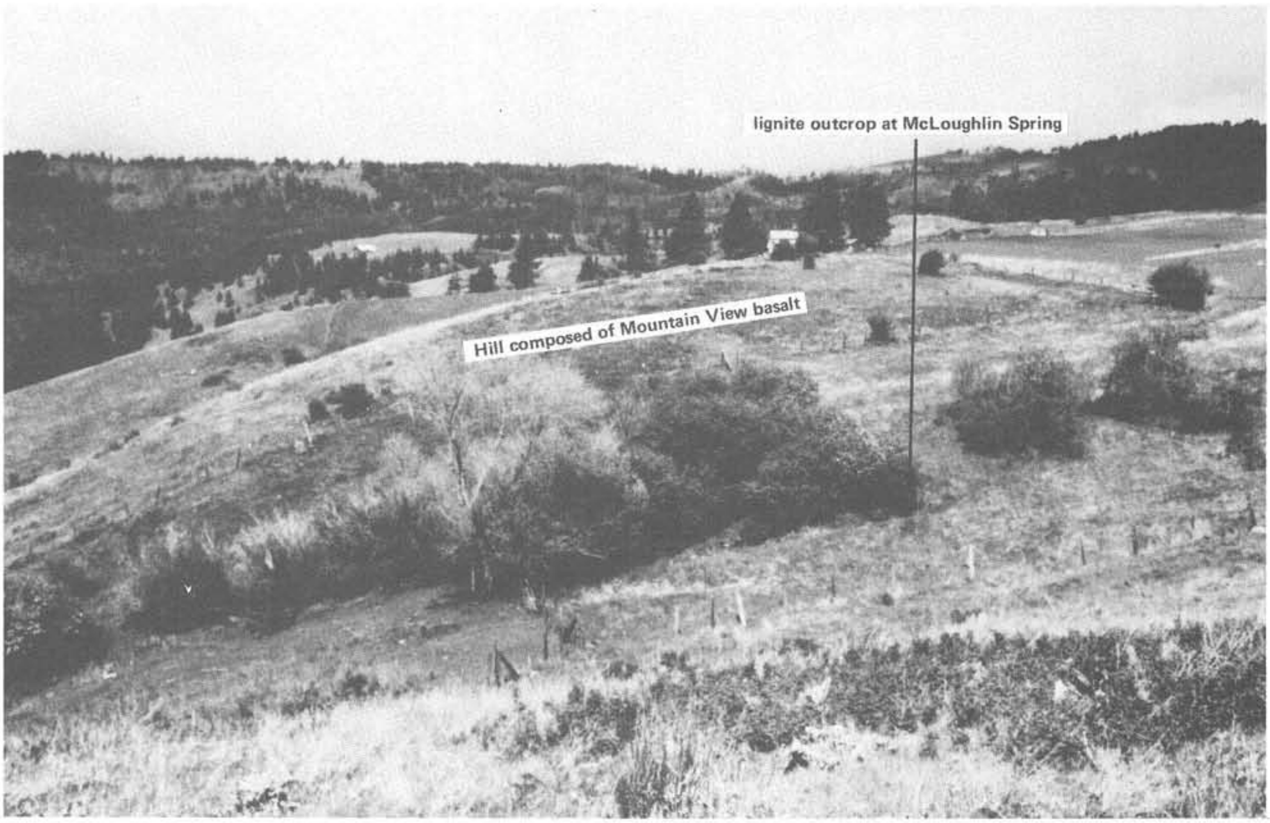


FIGURE 34. — View of McLoughlin Spring (NE¼NE¼SE¼ sec. 29, T. 7 N., R. 44 E.). Small hill adjacent to spring is composed of basalt of the invasive Mountain View flow.

of the Saddle Butte anticline-Grouse Flat syncline complex (figs. 12 and 13). As a result of this folding, the sedimentary interbeds rise gently from the Grouse Flat synclinal axis to the southern limb of the Slide Canyon monocline, where dips abruptly steepen (fig. 68). North of the hinge zone, the interbeds have been eroded from the steeply dipping monocline. It is impossible to determine the volume of sediments eroded from the monocline, since the original northern limit of the interbeds is unknown.

DEVELOPMENT OF BENCHES

In response to regional uplift following Columbia River Basalt Group volcanism, the Grande Ronde River and its tributaries cut down through the thick pile of basalt flows and intercalated sediments. When the easily erodable interbeds were encountered, the streams eroded laterally, forming benches. As lateral erosion occurred, interbed sediments were reworked and, in places, deposited as fluvial sand and gravel (fig. 36). In some localized areas within the Grande Ronde lignite field, large volumes of interbed sediments have apparently been reworked and redeposited, probably destroying lignite beds in the process.

During development of the benches, lateral erosion by rivers and streams undercut the cliffs at the back of the benches, triggering landslides. In places where the cliffs at the back of the benches are partially composed of water-bearing sediments, landslides are still active. Recent landslide blocks which slid out onto the benches are easy to recognize, but identification of older, partially eroded landslide deposits on the benches is more difficult. Landslides have not significantly

FIGURE 35. — A roadcut at 3,220-ft elevation, in the NW¼SE¼ sec. 4, T. 6 N., R. 43 E., exposes a dike of the Whitetail Butte flow, which has intruded subarkosic sandstone at the base of the Menatchee Creek sedimentary interbed. The dike is approximately 1 ft (0.3 m) thick and has a thin, glassy selvage.

reduced the volume of interbed sediments present on the benches, but their deposits often cover the base of the cliffs and the back of the benches. An excellent example of a recent landslide is located on the east side of Grouse Creek (N½ sec. 10, T. 6 N., R. 43 E.), (plate 1).

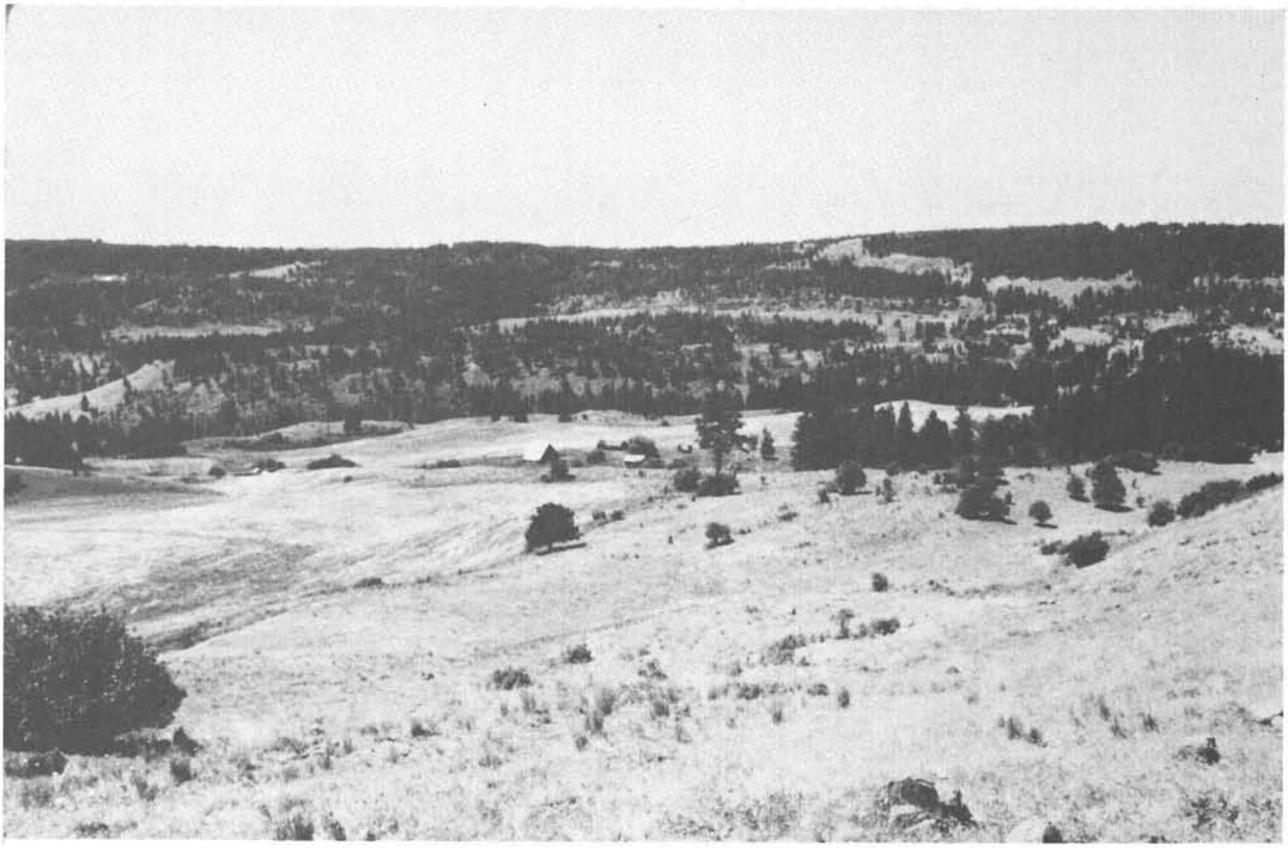


FIGURE 36. — View of a broad bench eroded into the Grouse Creek interbed on the east side of Grouse Creek (center of sec. 10, T. 6 N., R. 43 E.). During the bench-forming erosion some of the interbed sediments were apparently reworked by stream activity and redeposited on the benches as younger fluvial deposits.

SUMMARY

GEOLOGIC HISTORY

Structural deformation and sediment deposition dominated the late stages of Columbia River Basalt Group volcanism in the Grande Ronde lignite field. During long periods of volcanic quiescence between approximately 14 and 10 million years ago, sediments derived from surrounding highlands were transported into the developing Troy basin where they accumulated with sediments of intrabasin origin. Sediment deposition was punctuated by sporadic, short-lived eruptions of Saddle Mountains Basalt.

In the Washington State portion of the Grande Ronde lignite field, Saddle Mountains Basalt time began with the accumulation of organic mud and peat in lakes and bogs and detrital sand, silt, and clay in streams. Collectively, these sediments are informally named the Squaw Canyon interbed (Ross, 1978). They attain a maximum thickness of 50 ft (15 m) in the study area.

Approximately 13.5 million years ago (Rockwell Hanford Operations unpublished data) the Umatilla flow (Umatilla Member) erupted from a vent in the western part of the Troy basin (Hooper, 1981, personal communication) and flowed west to the central Columbia Plateau. Soon after, the Sillusi flow (Umatilla Member) erupted from a vent in the eastern part of the Troy basin (Gibson, 1969) and also flowed west to the central plateau (Anderson and others, in preparation).

Uplift of the Blue Mountains soon blocked the westward flow of the river whose valley the Umatilla Member flows had occupied, apparently causing lakes and bogs to form throughout much of the Troy basin. Thick peat (later converted to lignite) accumulated in these bogs before a new drainage system developed. The peat was then buried by the influx of epiclastic sediments. Informally named the Grouse Creek interbed by Ross (1978), the lignite and sediments reach a maximum thickness of 250 ft (75 m) in the study area.

Approximately 10 million years ago, the Tule Lake flow (Elephant Mountain Member) erupted from a vent in the Troy basin. As the flow overrode unconsolidated sediments of the Grouse Creek interbed, it invaded them, destroying or displacing sediments and lignite. The Tule Lake flow never inundated the eastern part of the study area. Instead, it flowed northeastward out of the Troy basin into the Lewiston basin, in a valley eroded by an ancestral Grande Ronde River (Price, 1977).

In response to continued structural deformation, broad canyons or valleys were eroded into the surface of the Tule Lake flow. These valleys were filled during the subsequent eruption of the Mountain View flow (Buford Member). In the eastern portion of the study area, where the Tule Lake flow is absent, the Mountain View flow is a 250-ft-thick (75 m) sheet flow. In that area, the Mountain View flow overrode unconsolidated sediments of the Grouse Creek interbed and invaded them, destroying or displacing sediments and lignite.

Deposition of sediments in the Troy basin continued following the eruption of the Mountain View flow. Up to 150 ft (45 m) of sediments similar to those of the Squaw Canyon and Grouse Creek interbeds accumulated on the Tule Lake and Mountain View flows. These sediments are informally named the Menatchee Creek interbed.

Throughout most of the study area, canyons were then eroded through the Menatchee Creek sediments, often into the basalt flows which underlie them. These canyons were subsequently filled by the Whitetail Butte intracanyon flow (Elephant Mountain Member). In the western part of the study area where sediment erosion was apparently more complete (or the original thickness of the Menatchee Creek interbed sediments was much less), the Whitetail Butte flow is a sheet flow. Like the Tule Lake flow, the Whitetail Butte flow apparently flowed northeastward down an ancestral Grande Ronde River valley into the Lewiston basin, then westward to the central Columbia Plateau (Swanson and others, 1979).

The Medicine Creek flow (Buford Member) represents the last eruption of the Columbia River Basalt Group in the Grande Ronde River region. It was apparently restricted to the Troy basin, but erosion of the flow has made reconstruction of its original distribution difficult.

Following the cessation of volcanism in the region, the Blue Mountains and Troy basin continued to evolve. Saddle Mountains Basalt flows and intercalated sediments were folded and eroded during the development of the Saddle Butte anticline-Grouse Flat syncline structural complex.

Meanwhile, the Grande Ronde River and its tributaries established meandering courses through the Troy basin. In response to regional uplift, the meandering streams became entrenched and canyons formed. When the easily erodable sedimentary interbeds were encountered, the streams eroded laterally, forming broad valleys. Once the river and its tributaries had eroded through the interbed sediments, they again became entrenched into the basalt flows and cut narrow, deep canyons. The broad valleys, which had been eroded into the interbed sediments, were left abandoned as topographic benches, high above the present Grande Ronde River.

LIGNITE RESERVES AND SUGGESTIONS FOR EXPLORATION

Lignites in the Washington State portion of the Grande Ronde lignite field are poorly exposed. Thickness of some of the lignite beds has been measured, but the scarcity of subsurface information prohibits defining their lateral extent. For this reason, estimation of lignite reserves in the Grande Ronde lignite field is impossible at this time.

Future exploration in the Washington State portion of the lignite field should begin with drilling to determine the lateral extent of the thickest known lignite bed, a 40-ft-thick (12 m) bed at the base of the Grouse Creek interbed. Several square miles of Grouse Creek sediments crop out on easily accessible benches in the study area (plate 1).

Another target for future exploration should be the bench underlain by the Menatchee Creek interbed sediments at the south end of "The Bench" (plate 1). Although no lignite crops out on this bench, thick diatomaceous earth beds do. If stratigraphic relationships in this interbed are similar to those observed elsewhere in the lignite field, lignite may be associated with the diatomite.

Finally, the flat plateau surface of Grouse Flat should be investigated (plate 1). Because of time constraints, this area was not mapped during this investigation, but several outcrops of diatomite and carbonaceous shale were observed. Preliminary mapping should be undertaken to determine if the sediments there belong to a thin, discontinuous sedimentary interbed or to a thicker, more extensive one.

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APPENDIX A

SAMPLE LOCATIONS

TABLE 2. — *Basalt and sediment sample locations*

Sample no.[1]	State	County	Quadrangle (USGS 7½')	Location [2]	Location shown on figure . . . [3]
Grb 1	Wash.	Asotin	Mountain View	Sec. 2 (7-44E); 4,888-ft elev.; summit of Anatone Butte	not shown
Grb 2	Wash.	Asotin	Saddle Butte	NW¼NW¼NW¼ sec. 10 (6-43E); 2,900-ft elev.; cliff of chaotically oriented columns	38
Grb 3	Wash.	Asotin	Saddle Butte	SW¼NW¼SE¼ sec. 8 (6-43E); 3,430-ft elev.; roadcut	38
Grb 4	Wash.	Asotin	Saddle Butte	SW¼NW¼SW¼ sec. 8 (6-43E); 3,600-ft elev.; hillslope outcrop	38
Grb 5	Wash.	Asotin	Saddle Butte	SE¼NW¼NE¼ sec. 9 (6-43); 2,850-ft elev.; gravel pit - basalt in vertical contact with steeply dipping sediments	38
Grb 6	Wash.	Asotin	Saddle Butte	SW¼NE¼SW¼ sec. 10 (6-43E); 2,720-ft elev.; roadcut of vesicular to scoriaceous basalt	38
Grb 7	Wash.	Asotin	Saddle Butte	NW¼SW¼NW¼ sec. 10 (6-43E); 2,850-ft elev.; hillslope outcrop	38
Grb 8	Wash.	Asotin	Saddle Butte	NE¼SW¼SW¼ sec. 3 (6-43E); 3,300-ft elev.; cliff outcrop of chaotically oriented columns	38
Grb 9	Wash.	Asotin	Saddle Butte	SE¼NW¼SW¼ sec. 3 (6-43E); 3,475-ft elev.; hillslope outcrop	38
Grb 10	Ore.	Wallowa	Troy	NW¼NW¼SE¼ sec. 31 (6-43E); 2,880-ft elev.; hillslope outcrop	39
Grb 11	Ore.	Wallowa	Troy	SE¼NW¼SW¼ sec. 31 (6-43E); 2,880-ft elev.; hillslope outcrop	39
Grb 12	Ore.	Wallowa	Troy	SE¼NE¼SW¼ sec. 32 (6-43E); 2,750-ft elev.; roadcut	39
Grb 13	Ore.	Wallowa	Eden	SW¼NW¼NE¼ sec. 36 (6-42E); 2,930-ft elev.; hillslope outcrop	39
Grb 14	Ore.	Wallowa	Eden	NE¼NE¼SW¼ sec. 25 (6-42E); 2,920-ft elev.; roadcut of crudely developed vertical columns	39
Grb 15	Ore.	Wallowa	Troy	SE¼SE¼NE¼ sec. 36 (6-42E); 3,070-ft elev.; roadcut below abandoned shack	39
Grb 16	Ore.	Wallowa	Eden	SE¼SW¼SE¼ sec. 25 (6-42E); 3,120-ft elev.; roadcut of vesicular to scoriaceous basalt	39
Grb 17	Wash.	Garfield	Diamond Peak	SE¼NE¼SE¼ sec. 4 (6-42E); 3,960-ft elev.; road ditch	39
Grb 18	Wash.	Garfield	Saddle Butte	NW¼SW¼NW¼ sec. 12 (6-42E); 3,640-ft elev.; roadcut	39
Grb 19	Wash.	Asotin	Mountain View	SE¼SE¼NE¼ sec. 20 (7-44E); 3,150-ft elev.; cliff outcrop	37
Grb 20	Wash.	Asotin	Mountain View	SW¼SW¼SW¼ sec. 16 (7-44E); 2,960-ft elev.; roadcut of platy basalt	37
Grb 21	Wash.	Asotin	Mountain View	NW¼SE¼SW¼ sec. 20 (7-44E); 3,340-ft elev.; hillslope outcrop of vesicular to scoriaceous basalt	37
Grb 22	Wash.	Asotin	Mountain View	SW¼NW¼SW¼ sec. 20 (7-44E); 3,290-ft elev.; hillslope outcrop of platy basalt	37
Grb 23	Wash.	Asotin	Mountain View	SW¼NW¼SW¼ sec. 20 (7-44E); 3,300-ft elev.; cliff outcrop of large vertical columns	37
Grb 24	Wash.	Asotin	Mountain View	SE¼SW¼SW¼ sec. 20 (7-44E); 3,035-ft elev.; roadcut below barn	37
Grb 25	Wash.	Asotin	Mountain View	NE¼NW¼NW¼ sec. 29 (7-44E); 2,810-ft elev.; hillslope outcrop of basalt below sediments	37
Grb 26	Wash.	Asotin	Mountain View	NE¼SW¼SW¼ sec. 28 (7-44E); 2,710-ft elev.; hillslope outcrop	37
Grb 27	Wash.	Asotin	Mountain View	SE¼NW¼SW¼ sec. 28 (7-44E); 2,824-ft elev.; hilltop outcrop at Medicine tringulation station	37
Grb 28	Wash.	Asotin	Mountain View	SE¼NW¼SE¼ sec. 19 (7-44E); 3,080-ft elev.; roadcut of vesicular to scoriaceous basalt	37
Grb 29	Wash.	Asotin	Mountain View	NW¼NW¼SW¼ sec. 29 (7-44E); 2,800-ft elev.; narrow ravine outcrop of platy basalt underlying sediment	37
Grb 30	Wash.	Asotin	Mountain View	SW¼SE¼NE¼ sec. 30 (7-44E); 2,890-ft elev.; roadcut of crudely developed vertical columns	37
Grb 31	Wash.	Asotin	Mountain View	SE¼NE¼NW¼ sec. 32 (7-44E); 2,780-ft elev.; hillslope outcrop	37
Grb 32	Wash.	Asotin	Mountain View	SE¼NE¼NW¼ sec. 32 (7-44E); 2,750-ft elev.; hillslope outcrop of vesicular to scoriaceous basalt	37
Grb 33	Wash.	Asotin	Mountain View	NE¼NW¼NW¼ sec. 31 (7-44E); 3,525-ft elev.; outcrop on top of Whitetail Butte	37
Grb 34	Wash.	Asotin	Mountain View	SE¼NW¼NW¼ sec. 30 (7-44E); 3,360-ft elev.; roadcut of large, vertical columns	37
Grb 35	Wash.	Asotin	Mountain View	NE¼SW¼NW¼ sec. 30 (7-44E); 3,340-ft elev.; roadcut of basalt intruding sandstone; sample from 1-ft-thick dike	37
Grb 36	Wash.	Asotin	Mountain View	NW¼SE¼NW¼ sec. 30 (7-44E); 3,290-ft elev.; roadcut of basalt intruding sandstone; sample from platy dike	37
Grb 37	Wash.	Asotin	Mountain View	NW¼SE¼NW¼ sec. 30 (7-44E); 3,260-ft elev.; roadcut of large vertical columns	37
Grb 38	Wash.	Asotin	Mountain View	SE¼SE¼SE¼ sec. 36 (7-43E); 2,920-ft elev.; hillslope outcrop of crudely developed vertical columns	37
Grb 39	Wash.	Asotin	Mountain View	SW¼NW¼NE¼ sec. 1 (6-43E); 2,910-ft elev.; hillslope outcrop	37
Grb 40	Ore.	Wallowa	Troy	NW¼NE¼SE¼ sec. 14 (6-43E); 2,740-ft elev.; roadcut	38
Grb 41	Wash.	Asotin	Troy	NW¼NE¼NE¼ sec. 15 (6-43E); 2,860-ft elev.; hillslope outcrop	38
Grb 42	Wash.	Asotin	Saddle Butte	NE¼SE¼SE¼ sec. 10 (6-43E); 2,990-ft elev.; hillslope outcrop	38
Grb 43	Wash.	Asotin	Saddle Butte	NE¼SE¼SW¼ sec. 10 (6-43E); 2,780-ft elev.; hillslope outcrop	38
Grb 44	Wash.	Asotin	Saddle Butte	SE¼NE¼SW¼ sec. 10 (6-43E); 2,850-ft elev.; hilltop outcrop, along crest of narrow, linear hill	38

[1] Grb- basalt sample number; Grs- sediment sample number.

[2] Land descriptions are abbreviated and given to the nearest 64th section; for example, NW¼NW¼NW¼ sec. 10 (6-43E) written in full would be the northwest quarter of the northwest quarter of the northwest quarter of section 10, township 6 north, range 43 east, Willamette meridian and base.

[3] The locations of the samples are shown on the maps in figure 37-39.

TABLE 2. – *Basalt and sediment sample locations* – Continued

Sample no.[1]	State	County	Quadrangle (USGS 7½')	Location [2]	Location shown on figure . . . [3]
Grb 45	Wash.	Asotin	Saddle Butte	SE¼SW¼NW¼ sec. 10 (6-43E); 2,900-ft elev.; hillslope outcrop of tilted, elongate columns	38
Grb 46	Wash.	Asotin	Troy	NW¼NE¼NE¼ sec. 15 (6-43E); 2,840-ft elev.; hilltop outcrop	38
Grb 47	Wash.	Asotin	Saddle Butte	SW¼SE¼NE¼ sec. 10 (6-43E); 3,100-ft elev.; gravel pit	38
Grb 48	Wash.	Asotin	Saddle Butte	NE¼SW¼NW¼ sec. 11 (6-43E); 3,100-ft elev.; hilltop outcrop	38
Grb 49	Wash.	Asotin	Saddle Butte	NW¼NE¼NW¼ sec. 11 (6-43E); 3,089-ft elev.; hilltop outcrop	38
Grb 50	Wash.	Asotin	Saddle Butte	NW¼SW¼NE¼ sec. 11 (6-43E); 2,870-ft elev.; hillslope outcrop	38
Grb 51	Wash.	Asotin	Saddle Butte	SW¼SE¼NE¼ sec. 11 (6-43E); 2,820-ft elev.; hillslope outcrop	38
Grb 52	Wash.	Asotin	Saddle Butte	NE¼SW¼NW¼ sec. 11 (6-43E); 3,080-ft elev.; hillslope outcrop	38
Grb 53	Wash.	Asotin	Saddle Butte	NW¼SE¼SE¼ sec. 4 (6-43E); 3,200-ft elev.; roadcut of basalt intruding sandstone; sample from 1-ft-thick dike	38
Grb 54	Wash.	Asotin	Saddle Butte	SW¼NE¼NW¼ sec. 9 (6-43E); 3,200-ft elev.; cliff of chaotically oriented columns	38
Grb 55	Wash.	Asotin	Saddle Butte	SW¼NE¼NW¼ sec. 9 (6-43E); 3,190-ft elev.; cliff outcrop of large, vertical columns	38
Grb 56	Wash.	Asotin	Saddle Butte	SW¼NE¼NW¼ sec. 9 (6-43E); 3,400-ft elev.; hillslope outcrop of large, vertical columns broken into smaller blocks	38
Grb 57	Ore.	Wallowa	Troy	SW¼NW¼SE¼ sec. 32 (6-43E); 2,740-ft elev.; roadcut of vesicular to scoriaceous basalt	39
Grb 58	Ore.	Wallowa	Troy	NW¼SW¼NW¼ sec. 32 (6-43E); 2,940-ft elev.; roadcut of vesicular to scoriaceous basalt	39
Grb 59	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,550-ft elev.; gravel pit; basalt intruding sediments	38
Grb 60	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 3 (6-43E); 3,180-ft elev.; hillslope outcrop of platy basalt	38
Grb 61	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 3 (6-43E); 3,210-ft elev.; hillslope outcrop of basalt intruding quartzose siltstone	38
Grb 62	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 3 (6-43E); 3,200-ft elev.; cliff outcrop of chaotically oriented columns	38
Grb 63	Wash.	Asotin	Saddle Butte	SE¼NE¼SE¼ sec. 31 (7-43E); 3,860-ft elev.; roadcut of massive to vesicular basalt	38
Grb 64	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 32 (7-43E); 3,810-ft elev.; roadcut	38
Grb 65	Wash.	Asotin	Saddle Butte	NW¼SE¼SW¼ sec. 32 (7-43E); 3,670-ft elev.; roadcut of vesicular to scoriaceous basalt	38
Grb 66	Wash.	Asotin	Mountain View	SE¼SW¼NW¼ sec. 30 (7-44E); 3,450-ft elev.; cliff outcrop of vesicular basalt	37
Grb 67	Wash.	Asotin	Mountain View	SE¼SW¼NW¼ sec. 30 (7-44E); 3,470-ft elev.; cliff outcrop near the top of "The Bench"	37
Grb 68	Wash.	Asotin	Mountain View	NW¼SE¼NW¼ sec. 31 (7-44E); 3,240-ft elev.; hillslope outcrop of vesicular basalt	37
Grb 69	Wash.	Asotin	Mountain View	NW¼SE¼SW¼ sec. 30 (7-44E); 3,240-ft elev.; roadcut of vesicular to scoriaceous basalt	37
Grb 70	Wash.	Asotin	Mountain View	NE¼NW¼SW¼ sec. 25 (7-43E); 3,260-ft elev.; hilltop outcrop of small, horizontal columns	37
Grb 71	Wash.	Asotin	Mountain View	NE¼NW¼SW¼ sec. 25 (7-43E); 3,240-ft elev.; hillslope outcrop of small, horizontal columns	37
Grb 72	Wash.	Asotin	Mountain View	NW¼NW¼SW¼ sec. 25 (7-43E); 3,150-ft elev.; roadcut	37
Grb 73	Wash.	Asotin	Mountain View	SW¼NE¼SW¼ sec. 30 (7-44E); 3,220-ft elev.; cliff outcrop of large, vertical columns	37
Grb 74	Wash.	Asotin	Mountain View	NE¼SE¼NW¼ sec. 30 (7-44E); 3,200-ft elev.; hillslope outcrop	37
Grb 75	Wash.	Asotin	Mountain View	SW¼NE¼NE¼ sec. 20 (7-44E); 3,410-ft elev.; roadcut of vesicular to scoriaceous basalt	37
Grb 76	Wash.	Asotin	Mountain View	SE¼SE¼NW¼ sec. 30 (7-44E); 3,130-ft elev.; hillslope outcrop	37
Grb 77	Wash.	Asotin	Mountain View	SE¼SE¼NW¼ sec. 30 (7-44E); 3,120-ft elev.; hillslope outcrop of platy basalt	37
Grb 78	Wash.	Asotin	Mountain View	NE¼SE¼NW¼ sec. 21 (7-44E); 2,920-ft elev.; hillslope outcrop	37
Grb 79	Wash.	Asotin	Saddle Butte	SE¼NW¼NE¼ sec. 9 (6-43E); 2,920-ft elev.; hillslope outcrop	38
Grb 80	Wash.	Asotin	Saddle Butte	NE¼NW¼NE¼ sec. 16 (6-43E); 2,880-ft elev.; hillslope outcrop	38
Grb 81	Wash.	Asotin	Saddle Butte	NW¼NE¼NE¼ sec. 17 (6-43E); 3,340-ft elev.; roadcut	38
Grb 82	Wash.	Asotin	Troy	SE¼NE¼NE¼ sec. 17 (6-43); 3,270-ft elev.; roadcut of vesicular to scoriaceous basalt	38
Grb 83	Ore.	Wallowa	Troy	NW¼NW¼SE¼ sec. 15 (6-43E); 2,820-ft elev.; hillslope outcrop	38
Grb 84	Wash.	Asotin	Saddle Butte	SE¼NW¼SE¼ sec. 8 (6-43E); 3,520-ft elev.; hilltop outcrop along flat ridge top	38
Grb 85	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 9 (6-43E); 3,420-ft elev.; hillslope outcrop	38
Grb 86	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 9 (6-43E); 3,250-ft elev.; hillslope outcrop of vesicular basalt	38
Grb 87	Wash.	Asotin	Saddle Butte	NW¼SW¼SW¼ sec. 9 (6-43E); 3,270-ft elev.; hillslope outcrop of large, horizontal columns	38
Grb 88	Ore.	Wallowa	Troy	SE¼SW¼SW¼ sec. 15 (6-43E); 3,190-ft elev.; hillslope outcrop	38
Grb 89	Ore.	Wallowa	Troy	SE¼NE¼SE¼ sec. 22 (6-43E); 3,150-ft elev.; hillslope outcrop	38
Grb 90	Ore.	Wallowa	Troy	NW¼NE¼NW¼ sec. 22 (6-43E); 3,120-ft elev.; roadcut of platy basalt overlying sediments	38
Grb 91	Wash.	Asotin	Mountain View	SW¼SE¼NW¼ sec. 30 (7-44E); 3,250-ft elev.; hillslope outcrop of basalt scoria	37

TABLE 2. – *Basalt and sediment sample locations* – Continued

Sample no.[1]	State	County	Quadrangle (USGS 7½')	Location [2]	Location shown on figure . . . [3]
Grs 1	Wash.	Asotin	Saddle Butte	SW¼NE¼SW¼ sec. 9 (6-43E); 3,040-ft elev.; roadcut	38
Grs 2	Wash.	Asotin	Saddle Butte	NW¼SE¼SW¼ sec. 9 (6-43E); 3,040-ft elev.; roadcut	38
Grs 3	Ore.	Wallowa	Troy	NW¼NW¼NE¼ sec. 22 (6-43E); 2,970-ft elev.; roadcut	38
Grs 4	Ore.	Wallowa	Troy	NE¼NW¼NE¼ sec. 29 (6-43E); 2,960-ft elev.; roadcut	38
Grs 5	Ore.	Wallowa	Troy	SE¼NW¼NW¼ sec. 28 (6-43E); 2,950-ft elev.; roadcut	38
Grs 6	Ore.	Wallowa	Troy	SE¼NW¼NE¼ sec. 28 (6-43E); 2,920-ft elev.; roadcut	38
Grs 7	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 8	Wash.	Asotin	Saddle Butte	SE¼SE¼SE¼ sec. 4 (6-43E); 2,975-ft elev.; trail cut	38
Grs 9	Wash.	Asotin	Mountain View	NW¼SE¼NW¼ sec. 31 (7-44E); 3,320-ft elev.; ravine outcrop	37
Grs 10	Wash.	Asotin	Saddle Butte	NE¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 11	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 12	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 13	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 14	Wash.	Asotin	Saddle Butte	NW¼NW¼SW¼ sec. 8 (6-43E); 3,540-ft elev.; gravel pit	38
Grs 15	Wash.	Asotin	Mountain View	NE¼NW¼SW¼ sec. 21 (7-44E); 2,950-ft elev.; roadcut	37
Grs 16	Wash.	Asotin	Mountain View	NW¼NE¼SE¼ sec. 20 (7-44E); 3,220-ft elev.; roadcut	37
Grs 17	Wash.	Asotin	Mountain View	SE¼SE¼NE¼ sec. 20 (7-44E); 3,100-ft elev.; roadcut	37
Grs 18	Wash.	Asotin	Mountain View	SE¼SW¼SW¼ sec. 20 (7-44E); 3,080-ft elev.; roadcut	37
Grs 19	Wash.	Asotin	Mountain View	SW¼NE¼SE¼ sec. 19 (7-44E); 3,100-ft elev.; roadcut	37
Grs 20	Wash.	Asotin	Mountain View	SE¼SW¼NE¼ sec. 30 (7-44E); 2,900-ft elev.; roadcut	37
Grs 21	Wash.	Asotin	Mountain View	NE¼SE¼SE¼ sec. 30 (7-44E); 2,800-ft elev.; roadcut	37
Grs 22	Wash.	Asotin	Mountain View	SE¼NW¼NW¼ sec. 31 (7-44E); 3,490-ft elev.; hillslope outcrop	37
Grs 23	Wash.	Asotin	Mountain View	SW¼SE¼SW¼ sec. 30 (7-44E); 3,350-ft elev.; roadcut	37
Grs 24	Wash.	Asotin	Mountain View	SE¼NW¼NW¼ sec. 20 (7-44E); 3,330-ft elev.; roadcut	37
Grs 25	Wash.	Asotin	Mountain View	NE¼SW¼NW¼ sec. 30 (7-44E); 3,290-ft elev.; roadcut	37

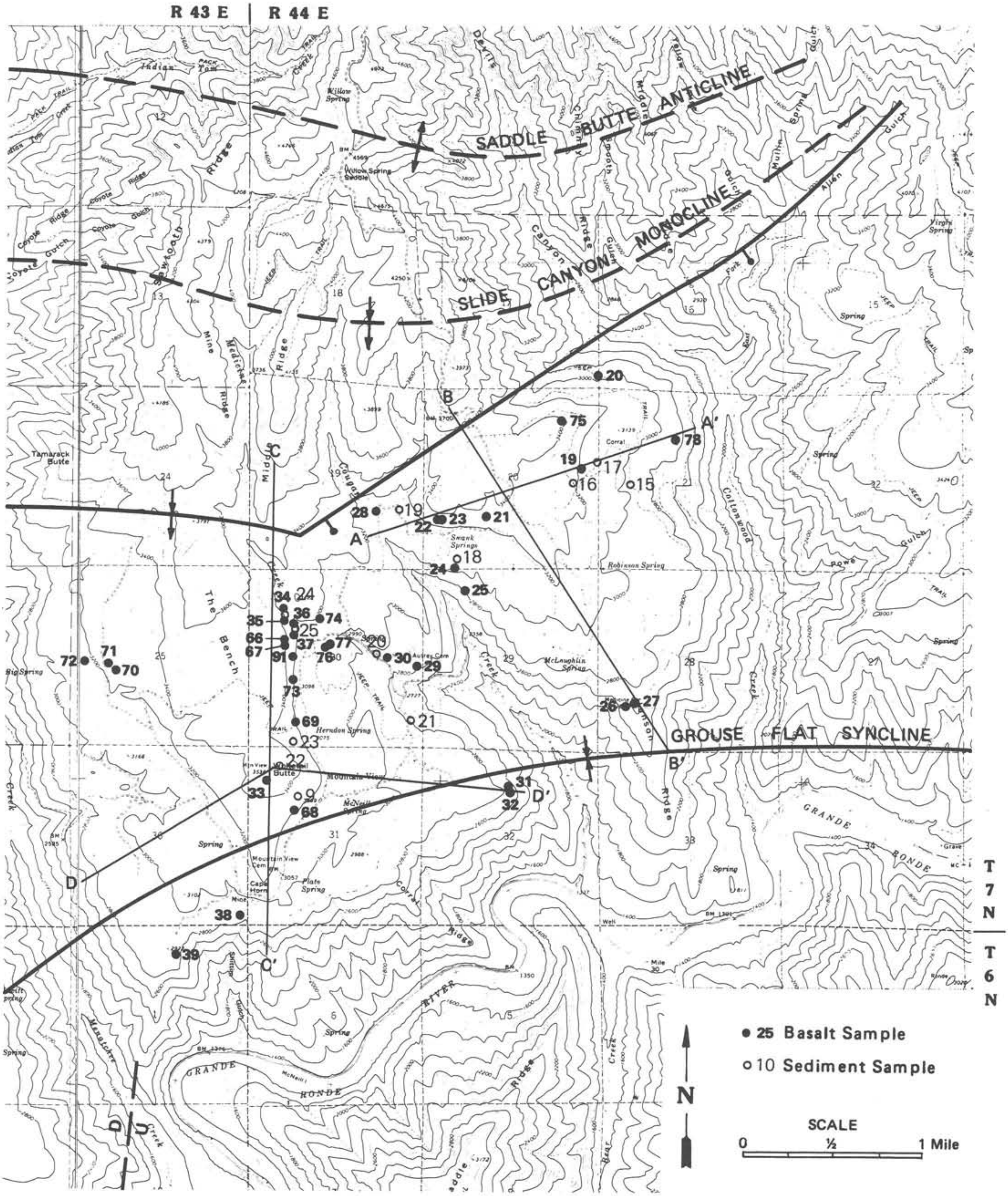


FIGURE 37. — Basalt and sediment sample locations map (see table 2).

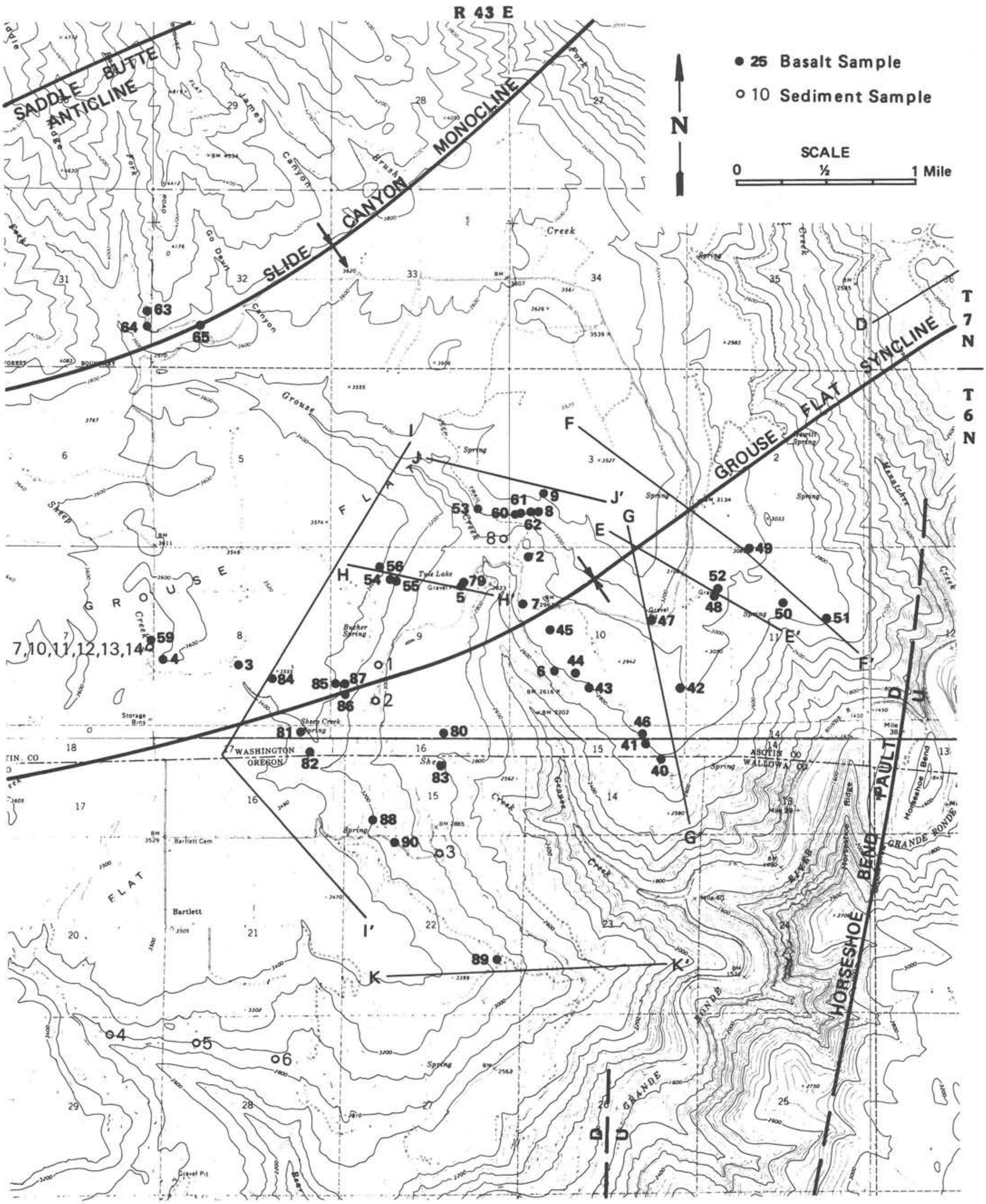


FIGURE 38. — Basalt and sediment sample locations map (see table 2).

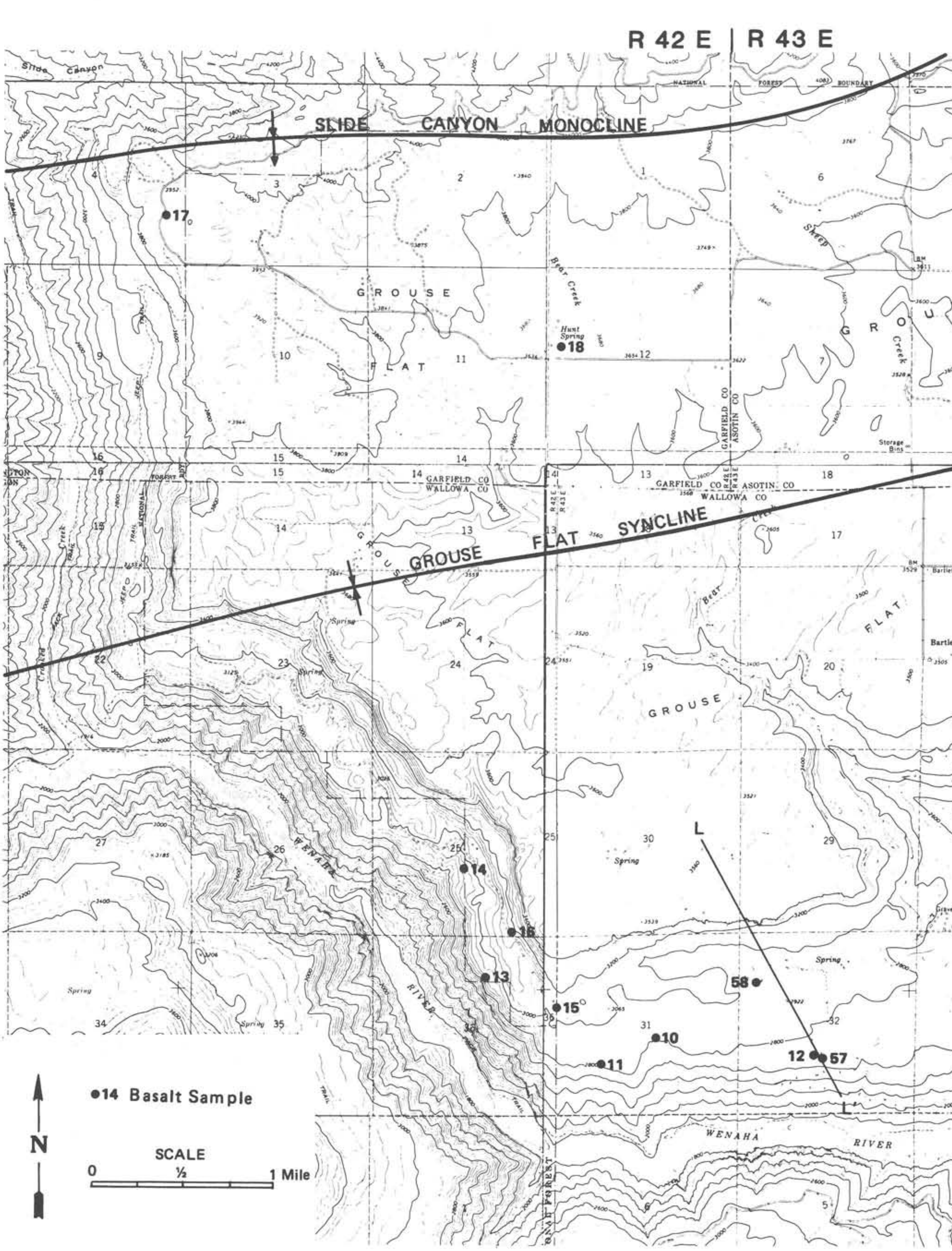


FIGURE 39. — Basalt and sediment sample locations map (see table 2).

APPENDIX B

BASALT GEOCHEMISTRY

Eighty-nine of the ninety-one basalt samples collected in this study were analyzed by the X-ray fluorescence method for oxides of Si, Al, Ca, Mg, Ti, K, P, Na, Mn, and total Fe. The analyses were performed in the Washington State University Basalt Research Laboratory under the direction of Dr. Peter Hooper.

The samples were crushed to a fine powder by a hydroloc press, jaw crusher, and shatter box. For each sample, one part of the powder was mixed with two parts of lithium tetraborate, poured into a carbon crucible, and fused into a glass bead by placing the mixture into a 1,000°C oven for 5 minutes. The glass beads were then crushed and fused a second time, in order to minimize all grain size effects.

After polishing, the beads were analyzed on a Phillips PW-1411 X-ray fluorescence unit with standard generator and recording units and a paper-tape printout, which is fed directly into a computer. Several crystals were used to analyze the various elements:

Lithium Fluoride (LiF) analyzing crystal: for Fe, Mn, Ti, Ca, K

Pentaerythritol (PET) analyzing crystal: for Si, Al

Germanium (GE) analyzing crystal: for P

Ammonium Dihydrogen Phosphate (ADP) analyzing crystal: for Mg

Potassium Acid Phthalate (KAP) analyzing crystal: for Na

Standard corrections for absorption were made on the raw data. The corrected values were normalized on a volatile-free basis with Fe_2O_3 assumed to be 2.0 percent by weight (table 3). The analyses were plotted on six variation diagrams and polygonal fields were drawn around chemical types (figs. 40 through 45). All flows analyzed belong to one of the following three chemical types defined by previous workers (Walker, 1973; Wright and others, 1973): B = Buford chemical type; EM = Elephant Mountain chemical type; U = Umatilla chemical type.

GEOCHEMICAL DATA

TABLE 3. – *Major and minor oxide data for Columbia River Basalt Group flows in Grande Ronde lignite field, Asotin County, Washington*

Sample	Type	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Total
GRB2	EM	51.30	14.37	3.48	2.00	13.05	0.22	8.55	4.46	1.09	0.99	0.49	100.00
GRB3	EM	51.69	13.96	3.49	2.00	13.01	0.22	8.28	4.37	1.10	1.43	0.46	100.01
GRB4	B	54.28	15.65	2.14	2.00	9.84	0.26	8.54	4.70	1.45	0.85	0.30	100.01
GRB5	EM	52.06	14.15	3.43	2.00	13.09	0.20	7.97	4.16	1.11	1.34	0.48	99.99
GRB6	U	55.40	15.14	2.81	2.00	10.34	0.23	6.28	2.92	2.85	1.24	0.80	100.01
GRB7	EM	51.84	14.23	3.44	2.00	12.97	0.21	8.19	4.30	1.06	1.31	0.46	100.01
GRB8	EM	51.94	14.52	3.64	2.00	13.19	0.24	8.35	3.94	1.19	0.49	0.50	100.00
GRB9	B	54.52	15.27	2.16	2.00	9.73	0.18	8.52	4.94	1.23	1.16	0.27	99.98
GRB10	U	54.67	15.48	2.65	2.00	10.91	0.20	6.07	2.91	2.64	1.63	0.84	100.00
GRB12	EM	51.90	14.39	3.42	2.00	12.80	0.24	8.77	4.46	1.06	0.53	0.42	99.99
GRB13	U	54.69	15.07	2.72	2.00	11.53	0.21	6.04	2.70	2.55	1.71	0.78	100.00
GRB14	U	54.29	15.00	2.70	2.00	11.15	0.22	6.16	2.73	2.78	2.09	0.88	100.00
GRB15	U	54.35	15.28	2.61	2.00	11.73	0.23	6.05	2.26	2.82	1.82	0.86	100.01
GRB16	U	54.27	15.05	3.15	2.00	11.14	0.20	6.95	2.93	2.31	1.33	0.69	100.02
GRB17	B	54.79	15.48	2.14	2.00	9.24	0.20	8.58	4.64	1.42	1.21	0.30	100.00
GRB18	EM	52.77	14.81	3.73	2.00	11.51	0.16	8.65	3.42	1.22	1.21	0.52	100.00
GRB19	B	54.17	15.13	2.20	2.00	10.48	0.20	8.37	4.75	1.36	1.05	0.29	100.00
GRB20	U	55.57	15.49	2.72	2.00	11.58	0.16	5.15	1.80	2.80	1.84	0.89	100.00
GRB21	B	54.08	16.16	2.22	2.00	9.83	0.18	8.45	4.40	1.22	1.17	0.30	100.01
GRB22	B	54.66	15.40	2.12	2.00	9.56	0.19	8.32	4.88	1.31	1.28	0.29	100.01
GRB23	B	54.71	15.57	1.99	2.00	9.12	0.19	8.62	5.10	1.34	1.09	0.26	99.99
GRB24	B	54.97	15.37	2.21	2.00	8.95	0.18	8.30	4.79	1.37	1.57	0.30	100.01
GRB25	U	54.96	15.04	2.71	2.00	11.08	0.20	5.90	3.21	2.54	1.57	0.78	99.99
GRB26	U	55.04	15.17	2.56	2.00	10.87	0.19	5.73	3.49	2.56	1.57	0.82	100.00
GRB27	B	54.80	15.78	2.15	2.00	8.85	0.24	8.58	4.79	1.43	1.07	0.29	99.98
GRB28	U	54.75	15.04	2.62	2.00	10.94	0.24	6.27	2.45	3.19	1.64	0.87	100.01
GRB29	U	55.37	15.34	2.65	2.00	10.52	0.26	6.14	2.32	2.98	1.54	0.87	99.99
GRB30	EM	52.29	14.75	3.50	2.00	12.13	0.19	8.32	4.39	1.13	0.80	0.49	99.99
GRB31	B	54.82	14.97	2.12	2.00	9.92	0.20	8.38	4.82	1.51	0.97	0.28	99.99
GRB32	U	56.26	15.56	2.70	2.00	9.45	0.25	6.19	2.38	3.04	1.30	0.88	100.01
GRB33	EM	52.11	14.06	3.59	2.00	13.19	0.21	7.94	4.03	1.16	1.22	0.50	100.01
GRB34	EM	50.46	14.15	3.40	2.00	15.05	0.24	8.11	4.38	1.00	0.73	0.49	100.01
GRB35	EM	52.65	14.81	3.84	2.00	13.81	0.21	7.23	2.33	1.25	1.34	0.53	100.00
GRB36	EM	55.44	16.35	4.16	2.00	8.66	0.11	7.65	2.07	1.40	1.59	0.57	100.00
GRB37	EM	53.54	14.71	3.69	2.00	9.95	0.20	8.93	4.14	1.23	1.11	0.50	100.00
GRB38	B	54.43	15.55	2.20	2.00	9.46	0.21	8.71	4.85	1.32	0.98	0.30	100.01
GRB39	B	55.14	15.15	2.19	2.00	9.04	0.19	8.57	4.93	1.36	1.14	0.30	100.01
GRB40	U	54.83	15.58	3.04	2.00	9.71	0.19	5.78	2.21	2.73	3.14	0.80	100.01
GRB41	EM	51.37	14.48	3.56	2.00	11.81	0.18	8.25	3.85	1.24	2.75	0.51	100.00
GRB42	B	53.98	15.51	2.23	2.00	8.94	0.19	8.34	4.71	1.56	2.22	0.31	99.99
GRB43	EM	51.31	14.56	3.66	2.00	11.91	0.20	8.27	3.83	1.26	2.46	0.52	99.98
GRB44	B	53.53	15.49	2.20	2.00	9.22	0.19	8.36	4.76	1.54	2.42	0.30	100.01
GRB45	EM	51.54	14.40	3.68	2.00	11.99	0.20	8.23	3.72	1.33	2.39	0.52	100.00

EXPLANATION OF CHEMICAL TYPE:

EM=ELEPHANT MOUNTAIN
B= BUFORD.
U= UMATILLA.

TABLE 3. — *Major and minor oxide data for Columbia River Basalt Group flows in Grande Ronde lignite field, Asotin County, Washington* — Continued

Sample	Type	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Total
GRB46	B	54.43	16.07	2.27	2.00	7.42	0.16	8.43	4.51	1.51	2.89	0.31	100.00
GRB47	EM	50.86	14.30	3.49	2.00	12.43	0.21	8.18	4.18	1.35	2.51	0.49	100.00
GRB48	B	53.76	15.27	2.24	2.00	8.86	0.18	8.39	4.79	1.56	2.63	0.32	100.00
GRB49	EM	51.19	14.46	3.58	2.00	12.28	0.21	8.16	4.05	1.33	2.23	0.51	100.00
GRB50	B	53.40	15.36	2.25	2.00	9.60	0.19	8.33	4.68	1.48	2.39	0.32	100.00
GRB51	B	52.99	15.98	2.31	2.00	9.42	0.17	8.50	4.49	1.21	2.57	0.36	100.00
GRB52	B	53.36	15.58	2.21	2.00	9.92	0.17	8.02	4.39	1.40	2.65	0.31	100.01
GRB53	EM	53.75	16.09	4.10	2.00	9.58	0.19	7.75	1.92	1.51	2.57	0.54	100.00
GRB54	EM	52.03	14.92	3.82	2.00	11.40	0.19	7.88	3.16	1.39	2.68	0.54	100.01
GRB55	EM	49.84	13.83	3.71	2.00	13.24	0.21	8.19	4.25	1.36	2.85	0.51	99.99
GRB56	B	53.75	15.36	2.21	2.00	9.39	0.18	8.08	4.58	1.70	2.43	0.32	100.00
GRB57	U	54.98	15.83	2.88	2.00	10.04	0.14	5.41	1.82	2.75	3.27	0.89	100.01
GRB58	U	53.72	15.19	2.92	2.00	11.17	0.24	6.18	2.23	2.81	2.78	0.77	100.01
GRB59	EM	53.01	15.53	4.07	2.00	10.76	0.12	8.12	2.07	1.00	2.75	0.57	100.00
GRB60	EM	50.94	14.08	3.54	2.00	12.66	0.26	7.88	3.98	1.25	2.93	0.50	100.02
GRB61	EM	51.65	14.86	3.69	2.00	11.30	0.25	7.98	3.32	1.35	3.03	0.58	100.01
GRB62	EM	50.92	14.15	3.49	2.00	12.49	0.21	8.07	4.00	1.21	2.97	0.49	100.00
GRB63	U	55.89	15.90	2.90	2.00	7.54	0.19	6.24	2.47	2.82	3.18	0.86	99.99
GRB64	EM	51.72	14.53	3.65	2.00	11.33	0.20	8.22	3.81	1.41	2.63	0.51	100.01
GRB65	B	55.35	16.37	2.43	2.00	7.39	0.13	7.84	3.78	1.56	2.83	0.33	100.01
GRB66	EM	51.27	14.27	3.57	2.00	12.24	0.19	8.05	3.84	1.36	2.70	0.51	100.00
GRB67	B	52.93	15.92	2.33	2.00	9.74	0.17	8.21	4.62	1.10	2.68	0.31	100.01
GRB68	B	53.68	15.35	2.21	2.00	9.48	0.18	8.11	4.67	1.51	2.50	0.31	100.00
GRB69	B	53.77	15.78	2.26	2.00	8.20	0.19	8.39	4.83	1.62	2.65	0.31	100.00
GRB70	EM	51.83	15.22	3.69	2.00	9.79	0.18	8.75	4.04	1.20	2.79	0.51	100.00
GRB71	B	53.49	15.47	2.23	2.00	9.45	0.18	7.96	4.65	1.47	2.80	0.31	100.01
GRB72	EM	51.63	14.20	3.54	2.00	11.78	0.19	8.04	4.07	1.22	2.83	0.50	100.00
GRB73	B	54.09	15.33	2.29	2.00	8.88	0.23	8.21	4.64	1.47	2.54	0.31	99.99
GRB74	B	53.16	15.48	2.17	2.00	9.52	0.18	8.16	4.83	1.49	2.71	0.30	100.00
GRB75	EM	51.18	14.41	3.80	2.00	11.43	0.20	8.48	3.86	1.27	2.83	0.55	100.01
GRB76	B	52.57	15.20	2.58	2.00	10.05	0.21	8.11	4.30	1.90	2.71	0.36	99.99
GRB77	EM	50.25	14.19	3.61	2.00	12.58	0.19	8.40	4.15	1.25	2.87	0.51	100.00
GRB78	B	53.65	15.28	2.16	2.00	9.64	0.19	8.20	4.63	1.57	2.36	0.31	99.99
GRB79	B	53.94	15.50	2.22	2.00	8.76	0.19	8.22	4.78	1.70	2.37	0.31	99.99
GRB80	B	53.68	15.39	2.14	2.00	9.32	0.19	8.22	4.82	1.62	2.32	0.30	100.00
GRB81	EM	50.33	13.82	3.71	2.00	13.13	0.22	8.16	4.15	1.28	2.69	0.53	100.02
GRB82	B	53.62	15.60	2.21	2.00	9.53	0.18	7.98	4.52	1.45	2.57	0.32	99.98
GRB83	B	53.84	15.52	2.17	2.00	9.16	0.18	8.26	4.75	1.48	2.34	0.31	100.01
GRB84	B	53.66	15.67	2.18	2.00	8.90	0.19	8.38	4.79	1.50	2.42	0.30	99.99
GRB85	EM	50.11	13.63	3.63	2.00	13.14	0.21	8.44	4.08	1.36	2.86	0.54	100.00
GRB86	B	54.47	15.54	2.23	2.00	7.92	0.18	8.61	4.85	1.52	2.34	0.33	99.99
GRB87	EM	50.04	13.79	3.54	2.00	13.17	0.21	8.53	4.35	1.29	2.58	0.50	100.00
GRB88	B	53.31	15.33	2.14	2.00	9.79	0.25	8.28	4.76	1.54	2.29	0.32	100.01
GRB89	EM	50.11	14.20	3.26	2.00	12.47	0.22	8.78	4.79	1.17	2.54	0.45	99.99
GRB90	EM	50.19	13.67	3.71	2.00	13.32	0.22	8.18	4.17	1.27	2.76	0.51	100.00
GRB91	B	53.61	15.51	2.27	2.00	9.80	0.23	8.02	4.48	1.58	2.19	0.31	100.00

VARIATION DIAGRAMS

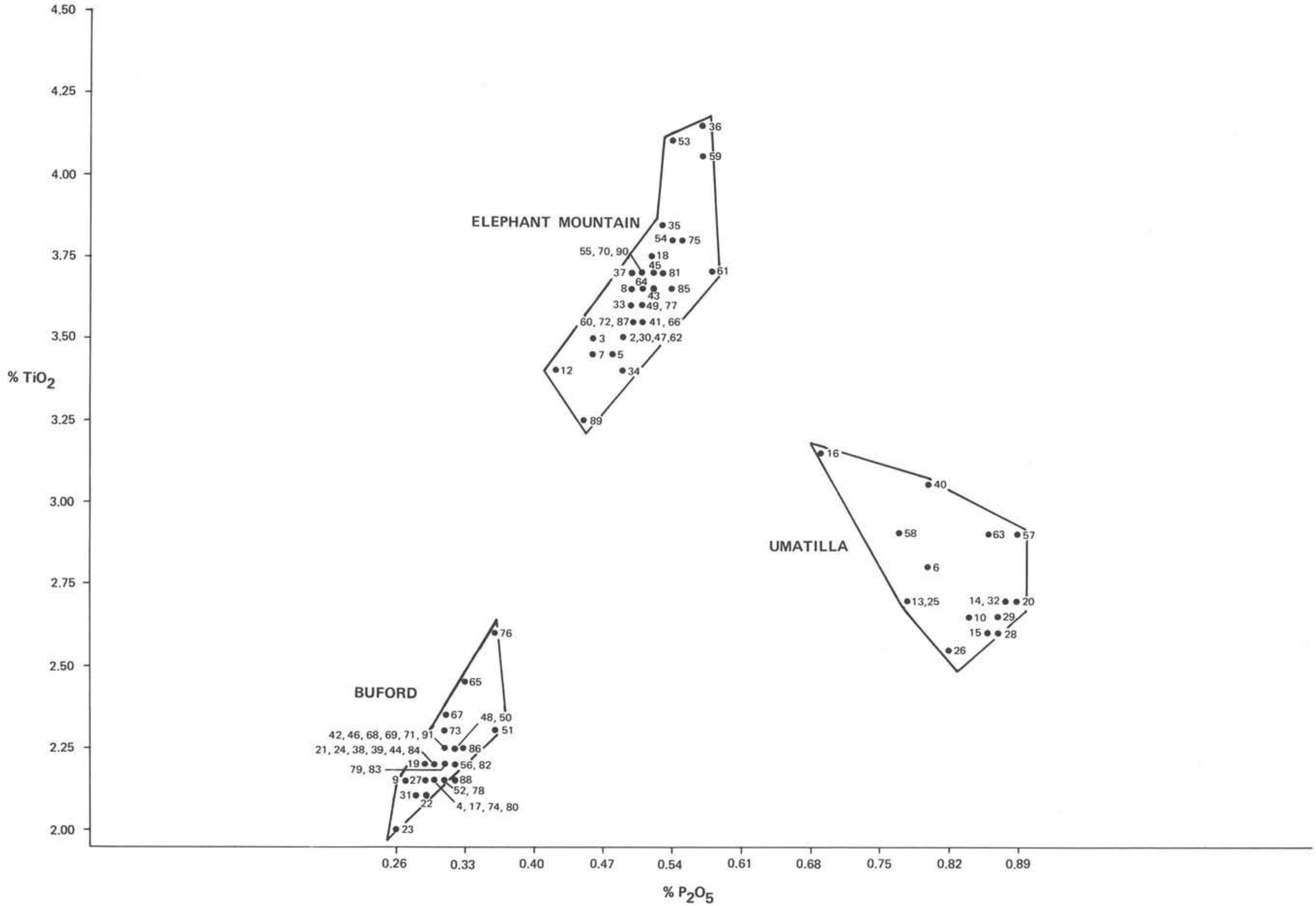


FIGURE 40. — TiO_2/P_2O_5 diagram of basalt flows in the Grande Ronde lignite field.

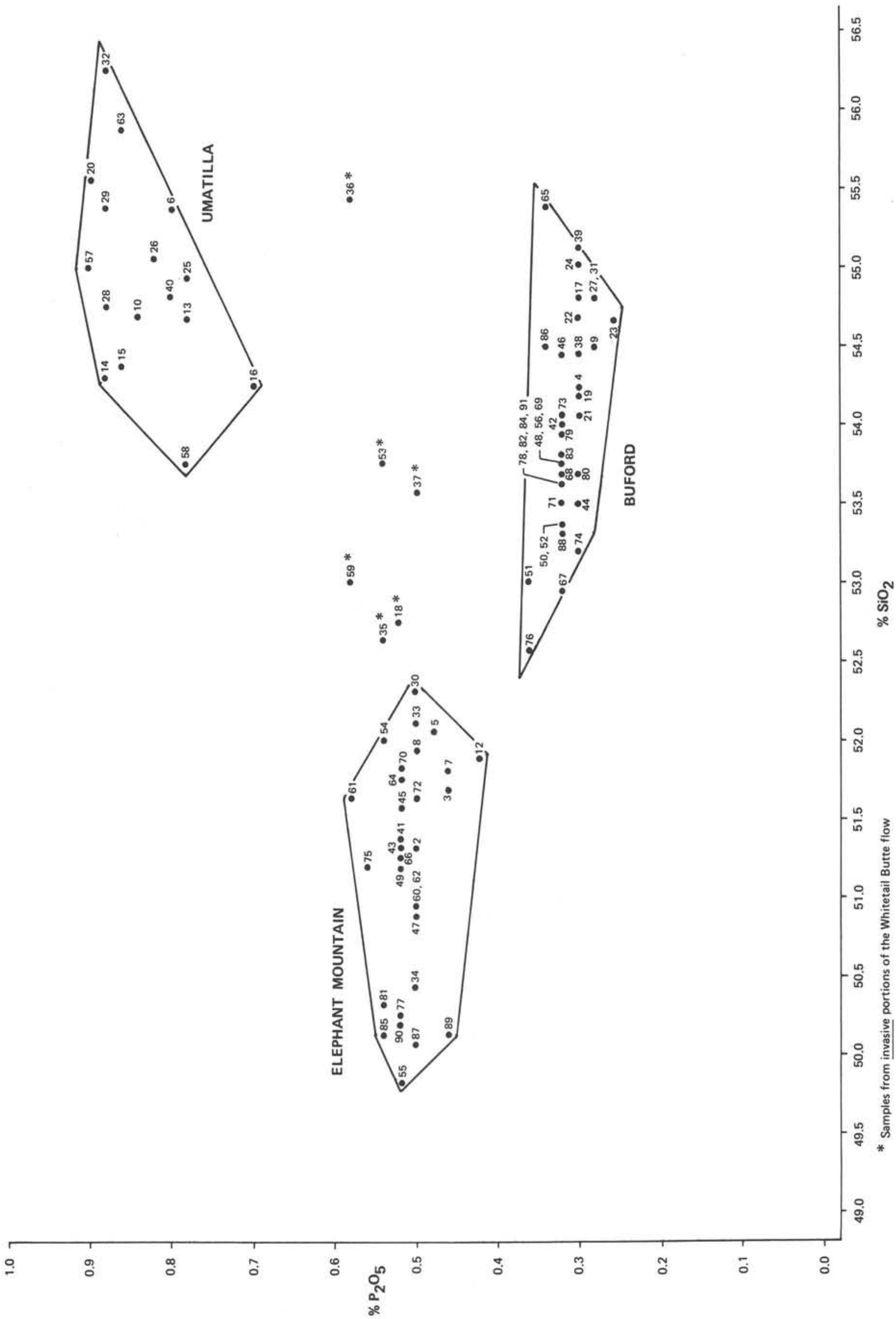


FIGURE 41. — P_2O_5/SiO_2 diagram of basalt flows in the Grande Ronde lignite field.

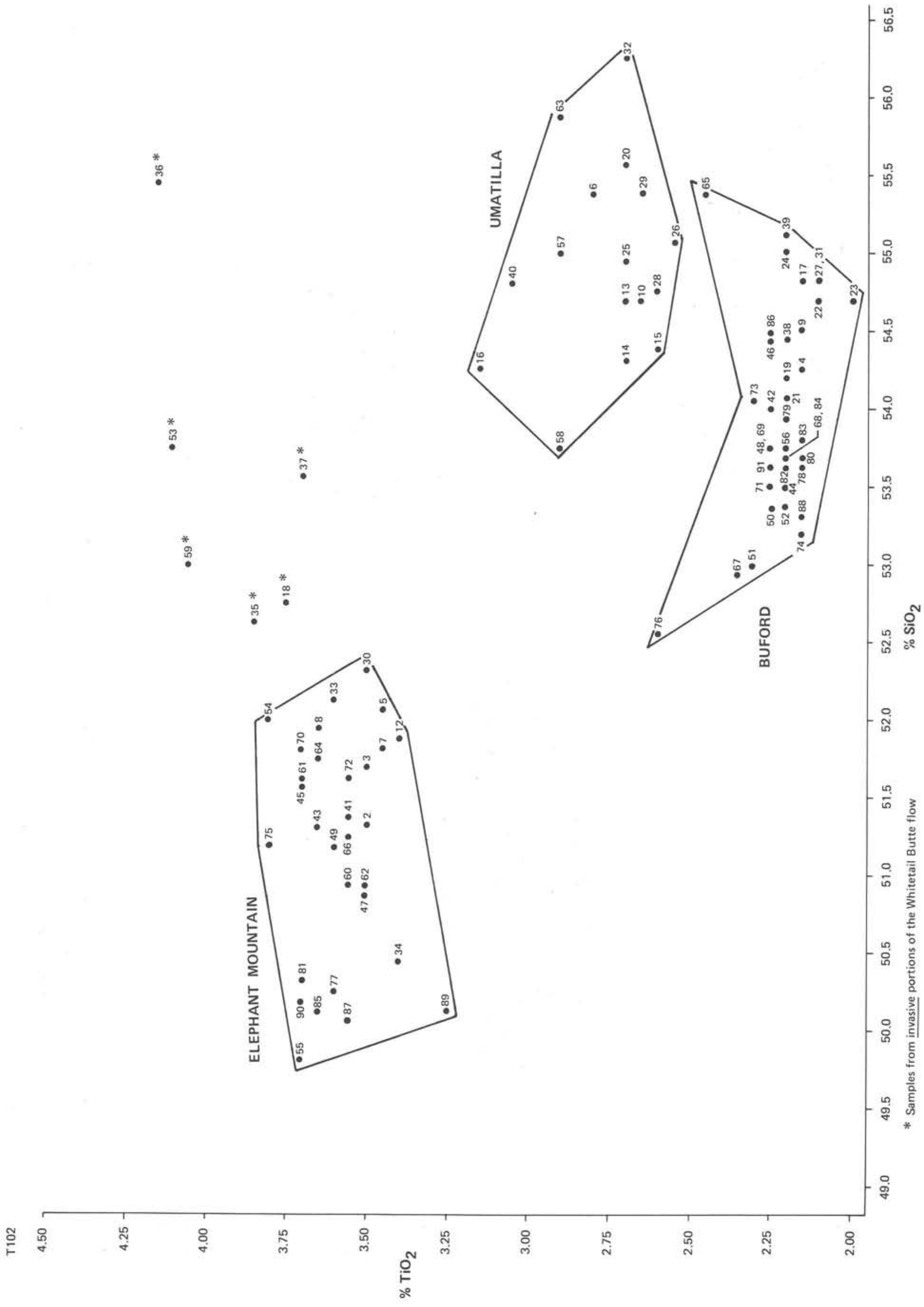


FIGURE 42. — TiO_2/SiO_2 diagram of basalt flows in the Grande Ronde lignite field.

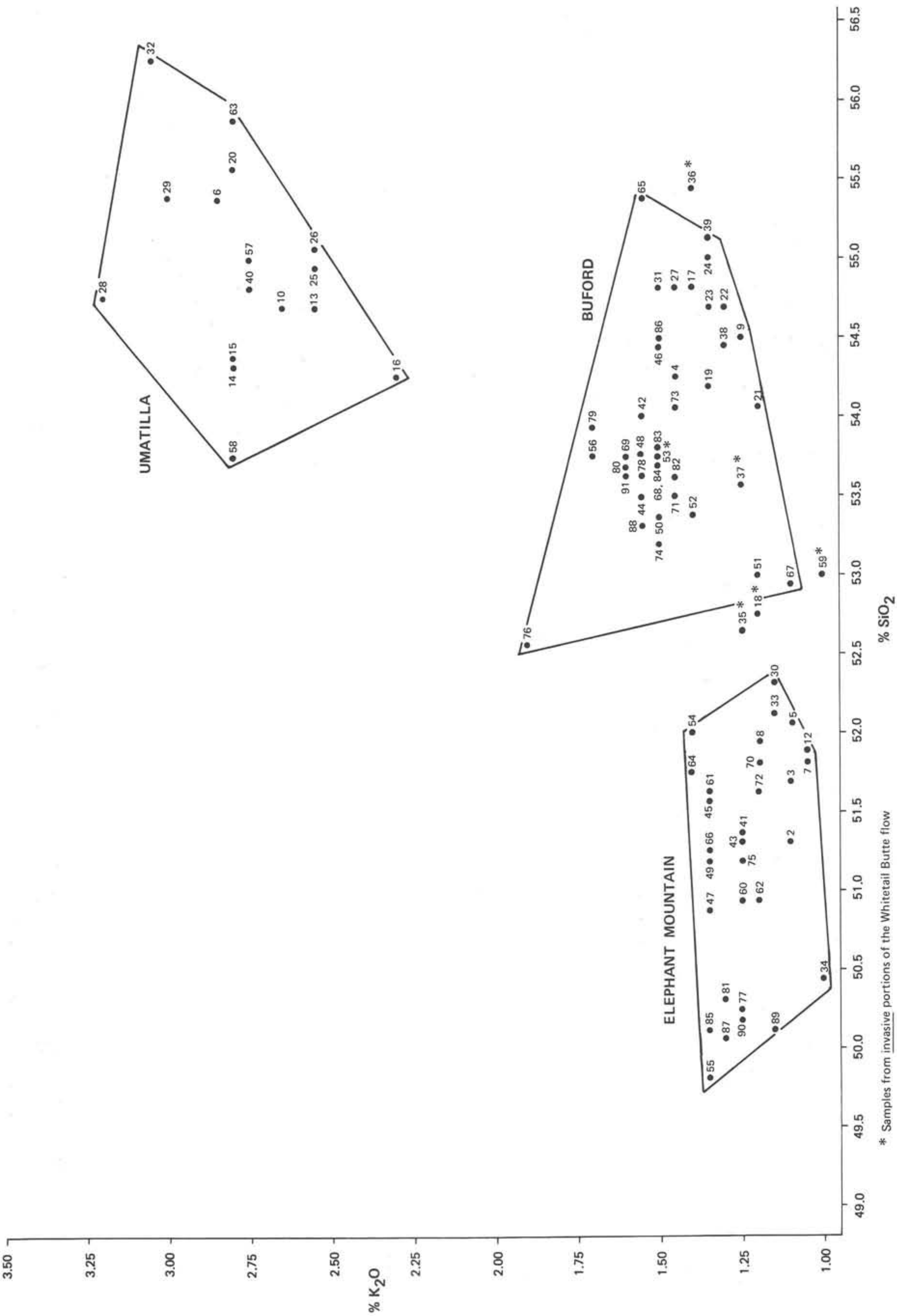


FIGURE 43. — K_2O/SiO_2 diagram of basalt flows in the Grande Ronde lignite field.

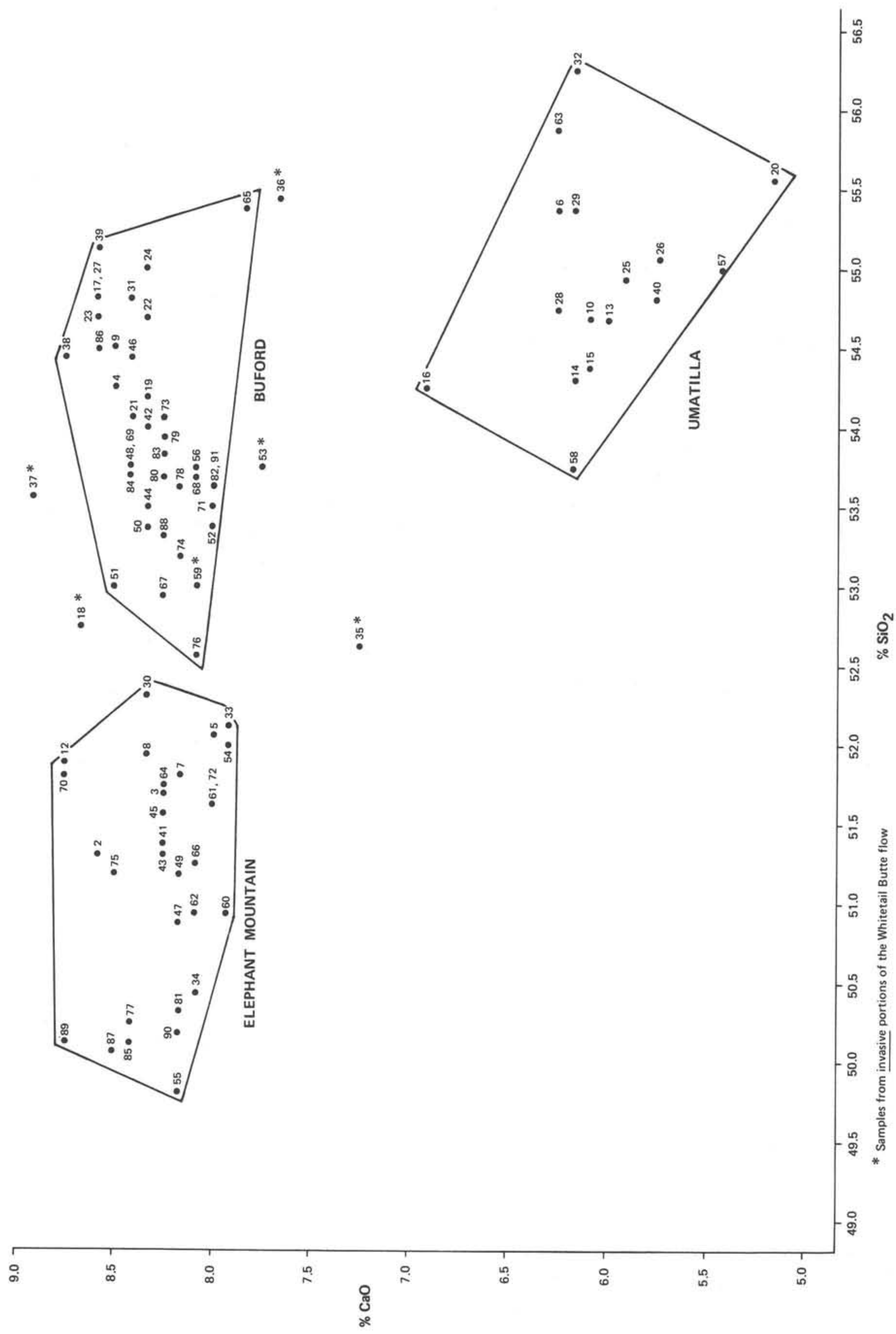
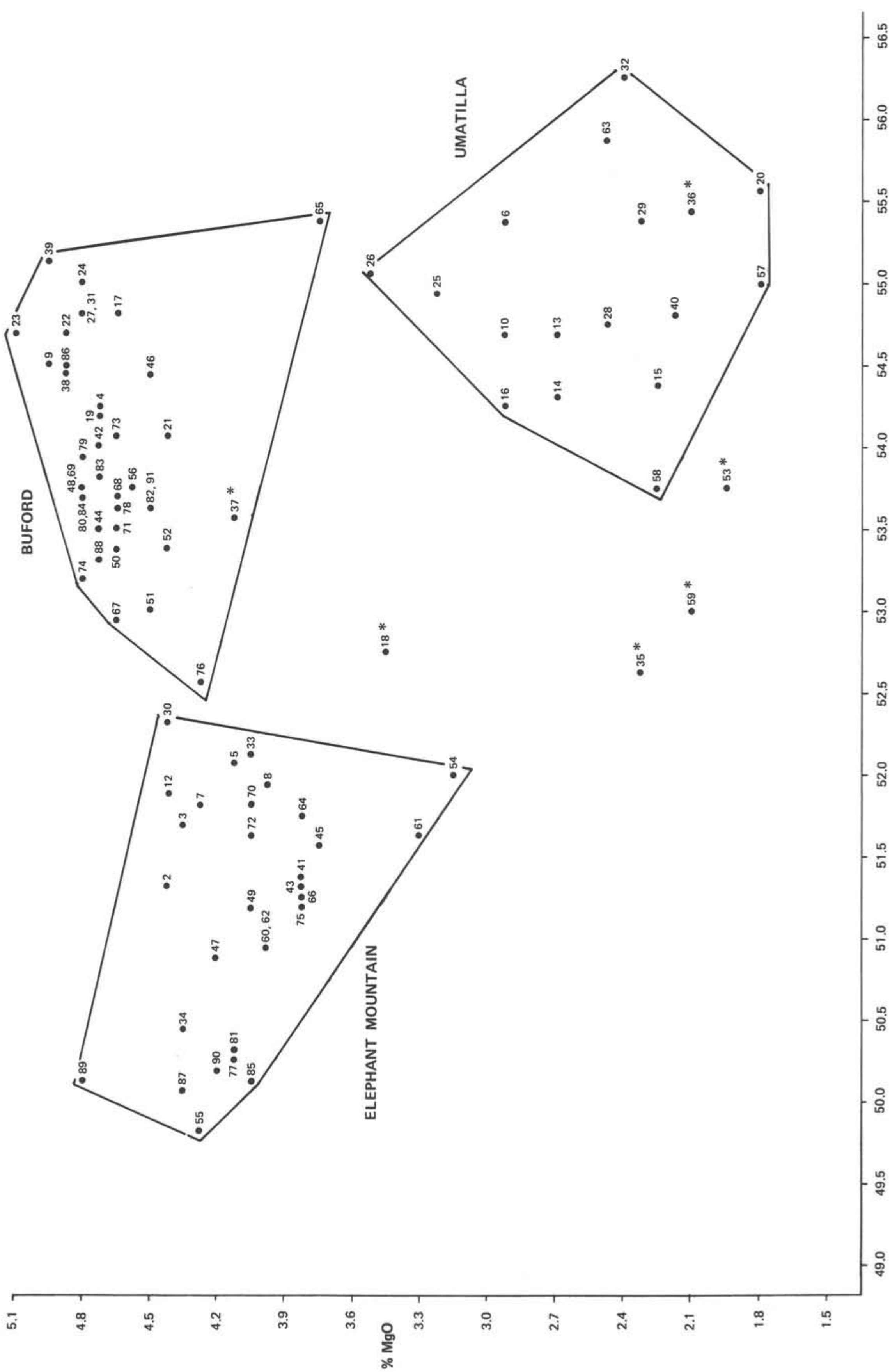


FIGURE 44. — CaO/SiO_2 diagram of basalt flows in the Grande Ronde lignite field.



* Samples from invasive portions of the Whitetail Butte flow

FIGURE 45. — MgO/SiO_2 diagram of basalt flows in the Grande Ronde lignite field.

APPENDIX C

GRAIN SIZE ANALYSES OF SEDIMENTS

GRAIN SIZE DISTRIBUTION CURVES

Using the procedures outlined by Bowles (1970) and Folk (1968), four samples of subarkosic sandstone from the Grouse Creek and Menatchee Creek sedimentary interbeds were sieved to determine their grain size distribution. The sands were passed through a sieve stack with ½Ø intervals. Data were plotted on grain size distribution curves (fig. 46), and the following statistical parameters (Folk, 1968) were calculated, in an effort to determine the depositional environment of the sands.

GRAPHIC MEAN

A measure of the average grain size of the sediment sample. Calculated by the following equation:

$$M_z = \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3}$$

GRAPHIC STANDARD DEVIATION

A measure of the uniformity or sorting of the sediment sample. When the sample contained less than 5 percent silt and clay, it was calculated by the following equation:

$$\sigma_I = \frac{\emptyset 16 - \emptyset 84}{4} + \frac{\emptyset 5 - \emptyset 95}{6.6}$$

When the sample contained more than 5 percent silt and clay, it was calculated by this equation:

$$\sigma_G = \frac{\emptyset 16 - \emptyset 84}{2}$$

GRAPHIC SKEWNESS

A measure of the amount of excess fine material (positive skewness) or coarse material (negative skewness) present in the sediment sample. When the sample contained less than 5 percent silt and clay, it was calculated by the following equation:

$$Sk_I = \frac{\emptyset 84 + \emptyset 16 - 2\emptyset 50}{2(\emptyset 16 - \emptyset 84)} + \frac{\emptyset 95 + \emptyset 5 - 2\emptyset 50}{2(\emptyset 5 - \emptyset 95)}$$

When the sample contained more than 5 percent silt and clay, it was calculated by this equation:

$$Sk_G = \frac{\emptyset 84 + \emptyset 16 - 2\emptyset 50}{\emptyset 16 - \emptyset 84}$$

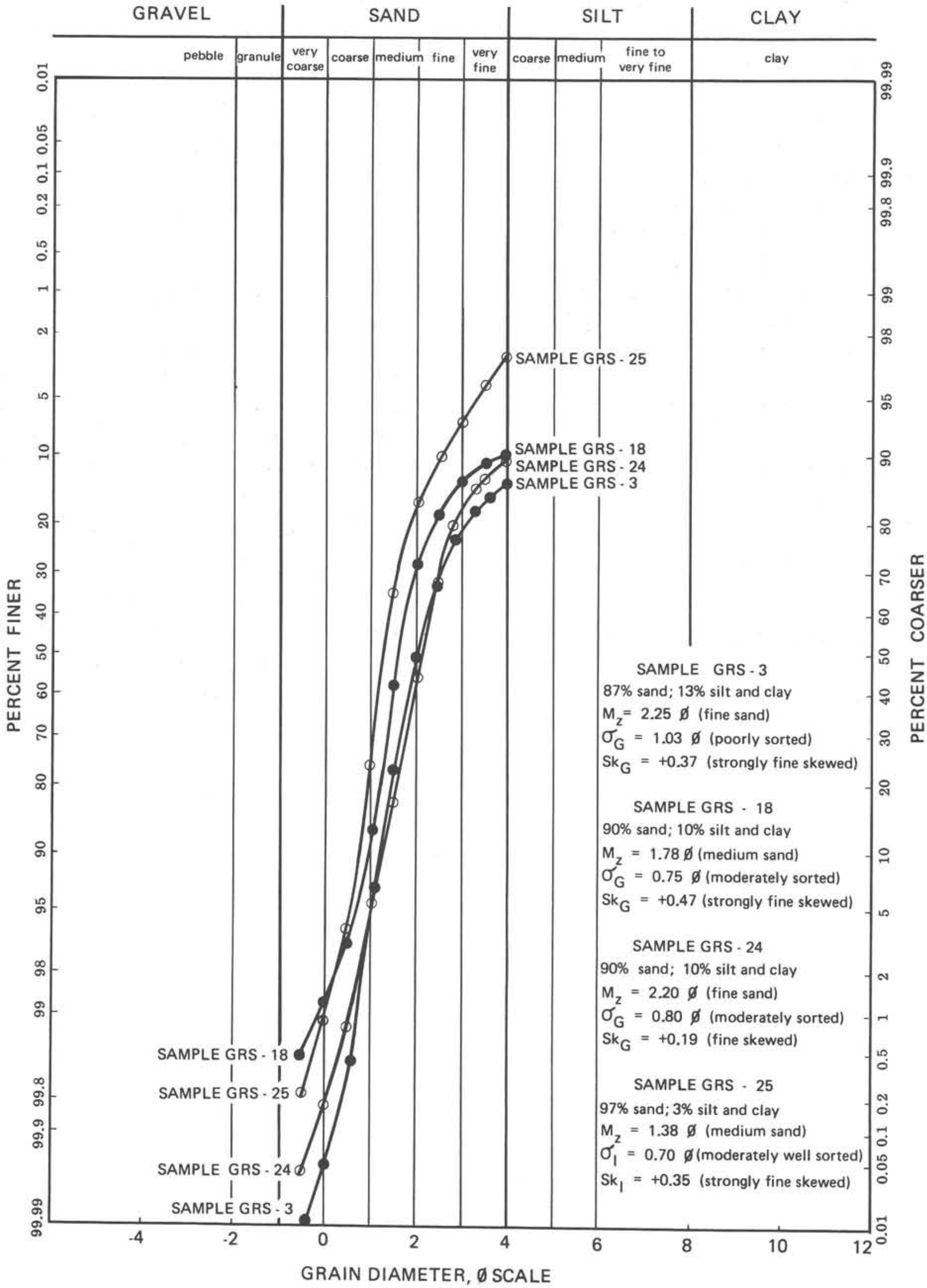


FIGURE 46. — Grain size distributions for samples GRS-3, GRS-18, GRS-24, and GRS-25.

APPENDIX D

CLAY MINERALOGY OF SEDIMENTS

X-RAY DIFFRACTION PATTERNS

Nine sediment samples of lithologies representative of the Grouse Creek and Menatchee Creek interbeds were analyzed by the X-ray diffraction method, to determine the mineralogic composition of their < 2 micron size fraction. Air-dried and glycolated samples were prepared for analysis by the procedure outlined by Carroll (1970). The samples were then irradiated on a diffraction unit consisting of a Phillips goniometer (model no. 42202) and generator (model no. 12045b) in the Division of Geology and Earth Resources laboratory. Diffraction patterns were obtained on runs from 32° 2θ to approximately 2° 2θ, using CuK α radiation with a Ni filter, a scanning speed of 1°/minute, and generator settings of 36 Kv and 16mA (figs. 47 through 55).

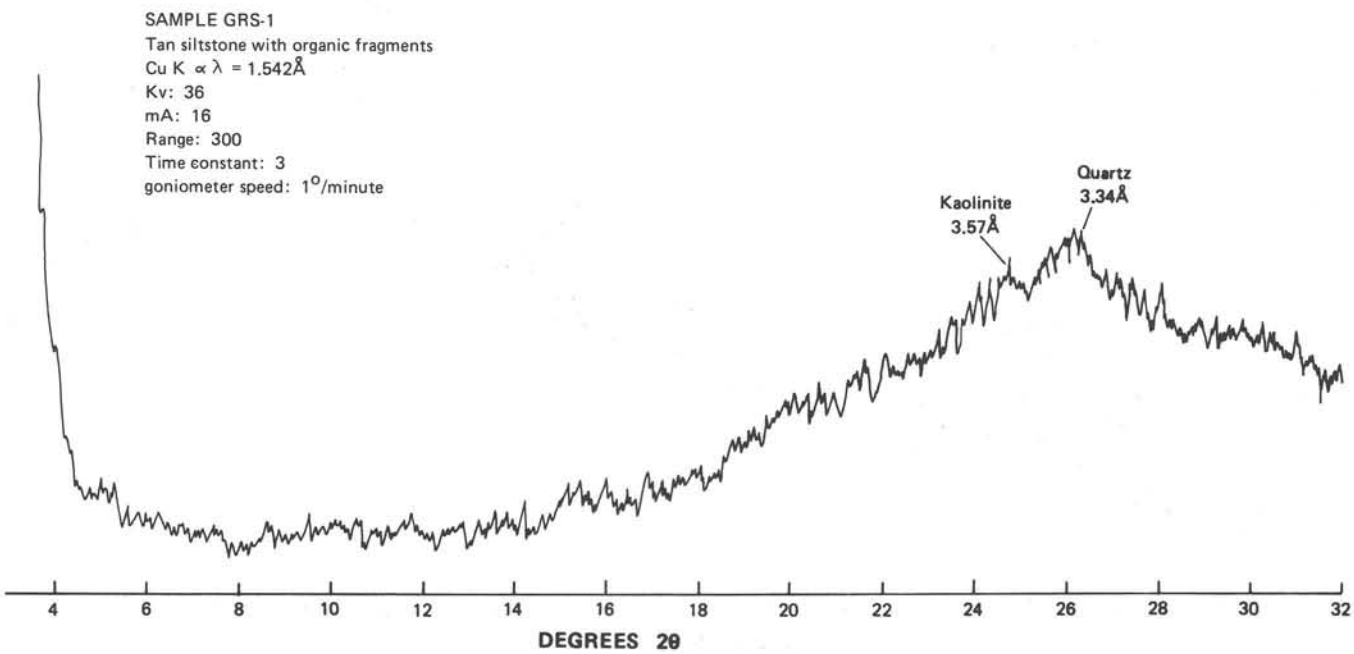


FIGURE 47. — X-ray diffraction pattern of sample GRS-1.

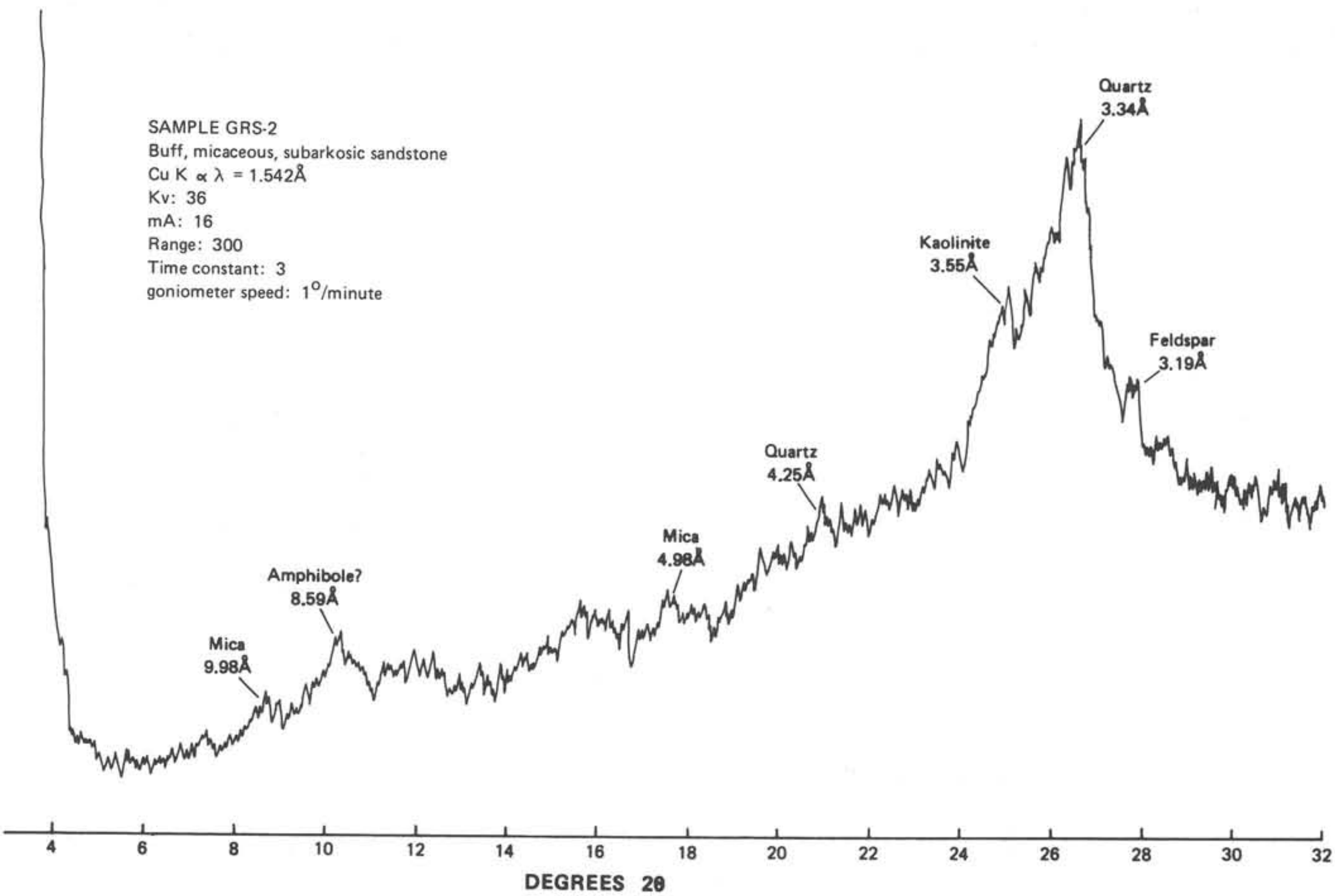


FIGURE 48. — X-ray diffraction pattern of sample GRS-2.

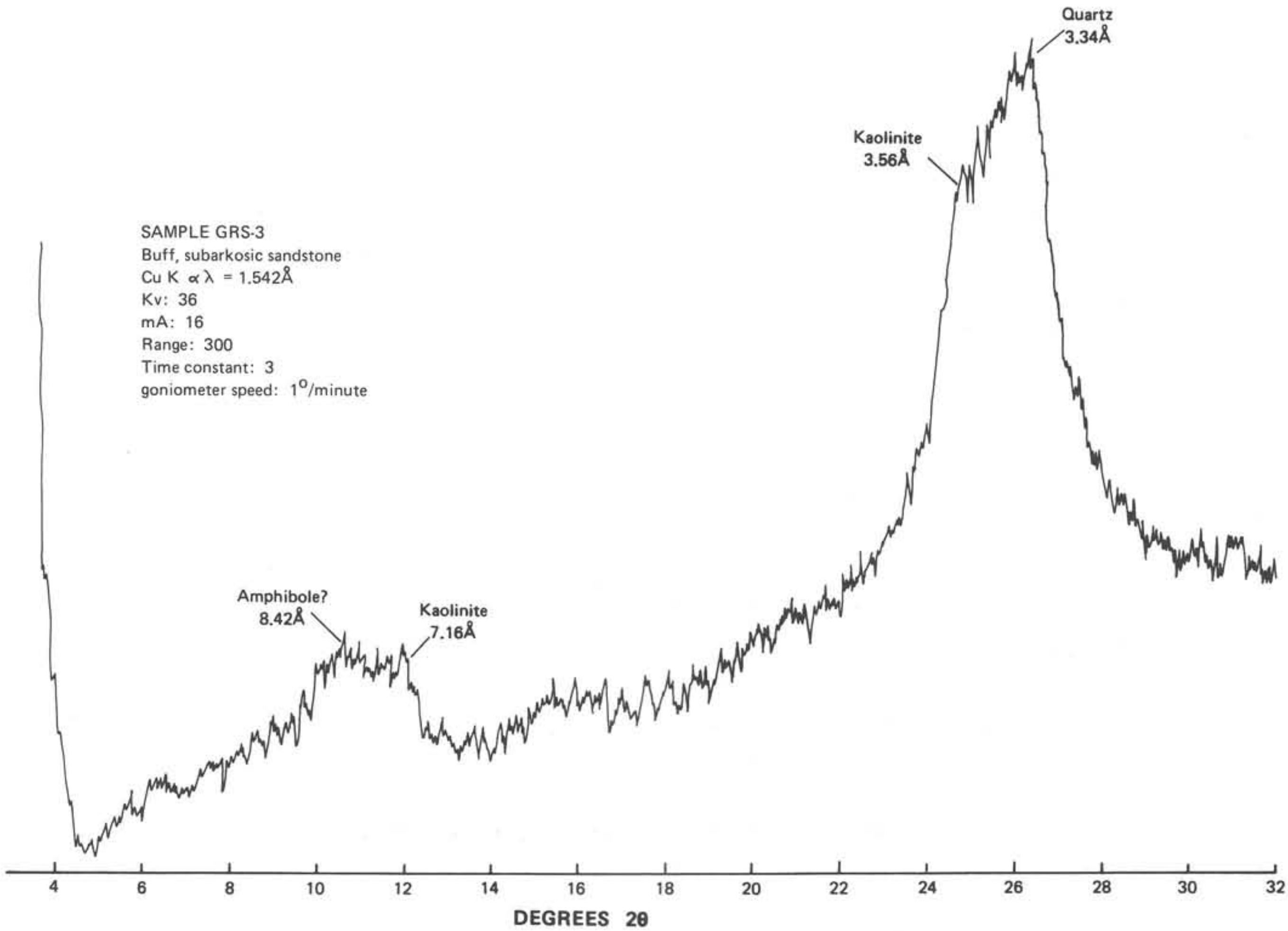


FIGURE 49. — X-ray diffraction pattern of sample GRS-3.

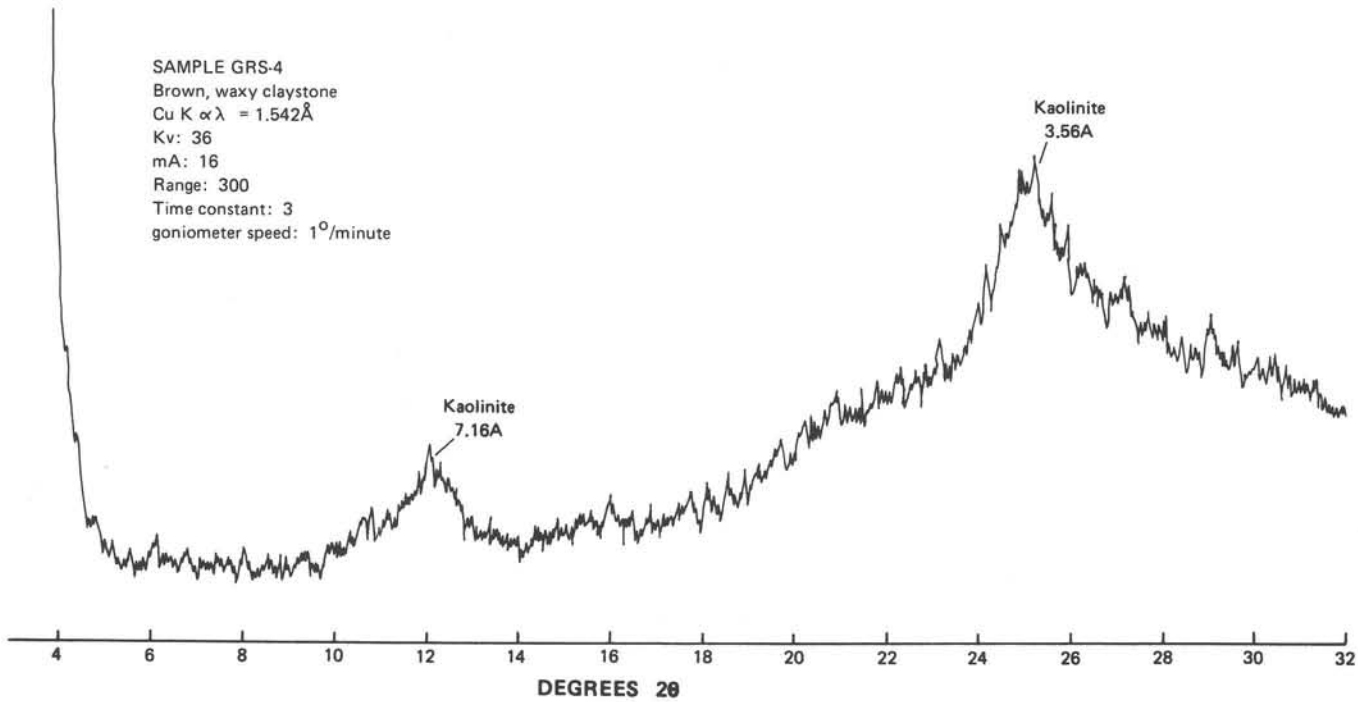


FIGURE 50. — X-ray diffraction pattern of sample GRS-4.

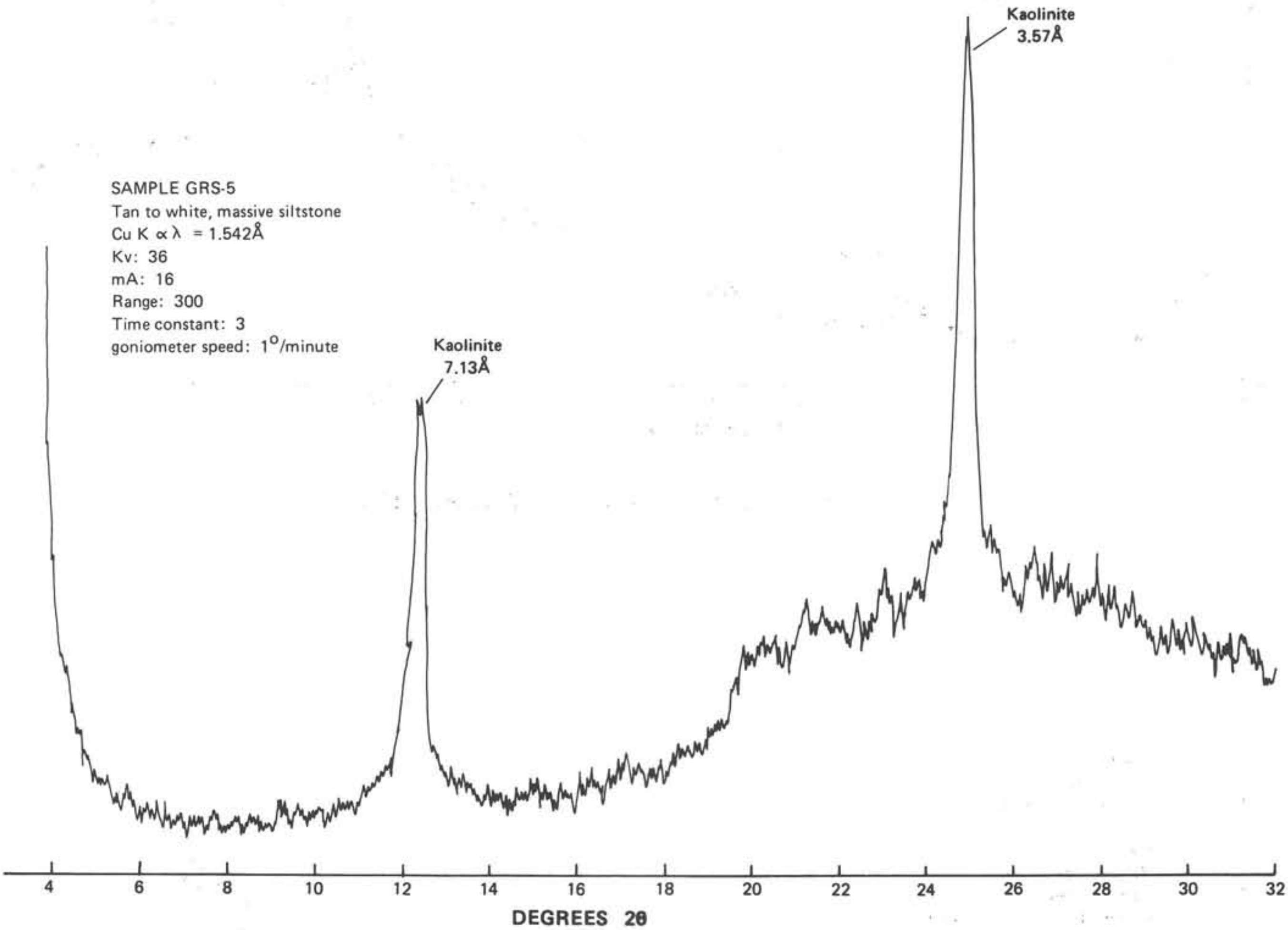


FIGURE 51. — X-ray diffraction pattern of sample GRS-5.

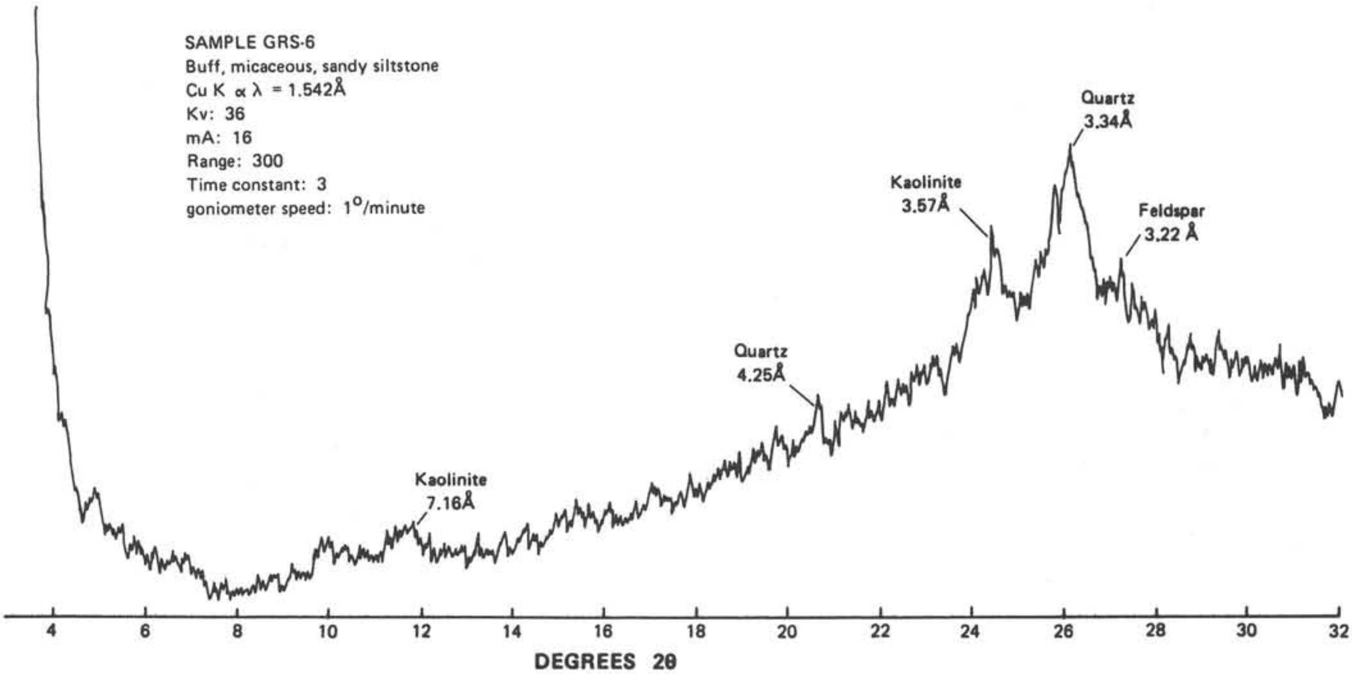


FIGURE 52. — X-ray diffraction pattern of sample GRS-6.

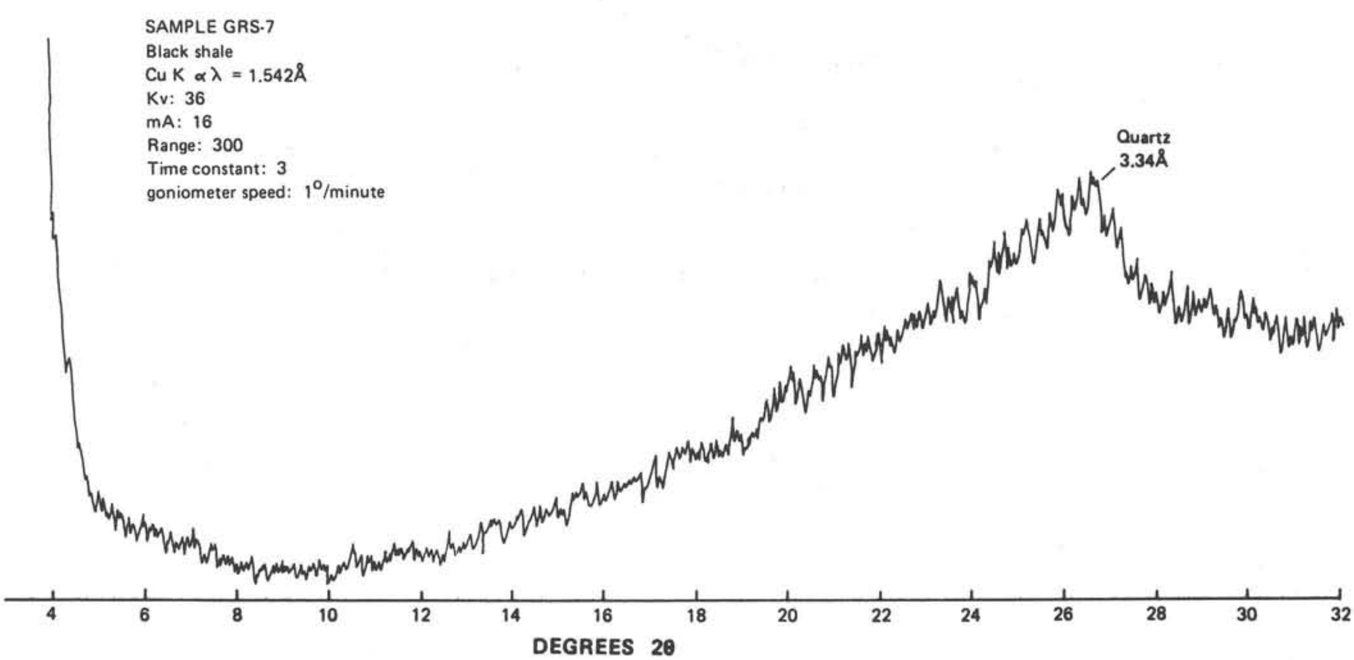


FIGURE 53. — X-ray diffraction pattern of sample GRS-7.

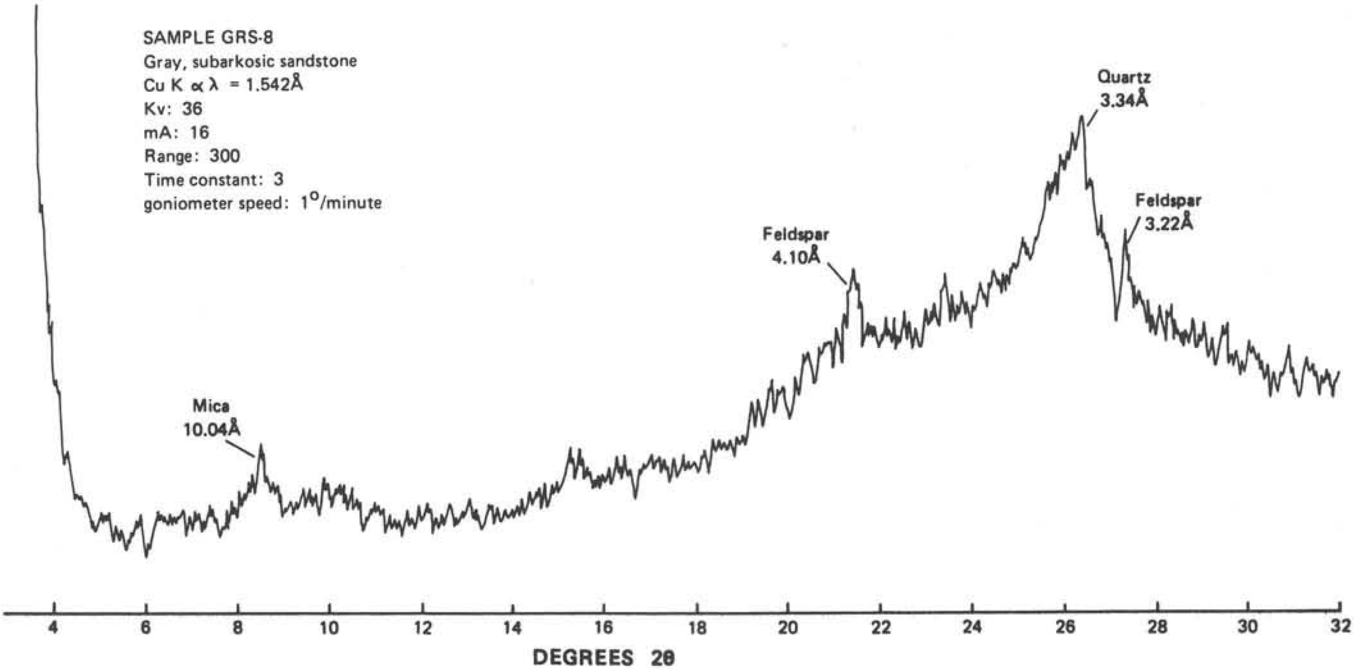


FIGURE 54. — X-ray diffraction pattern of sample GRS-8.

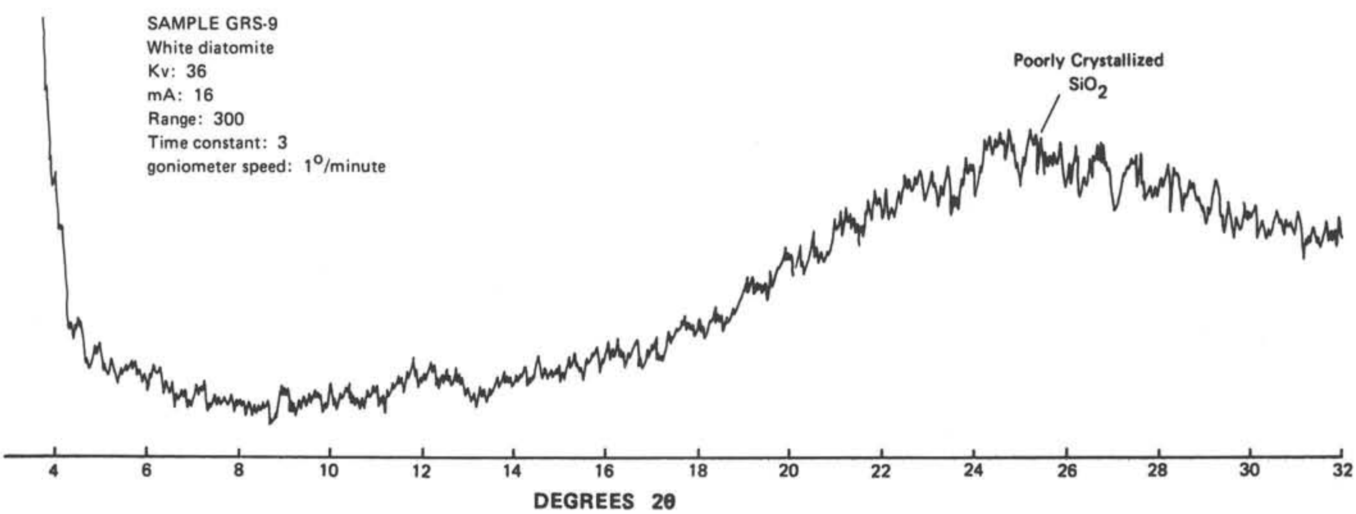


FIGURE 55. — X-ray diffraction pattern of sample GRS-9.

REPORT OF INVESTIGATIONS 27, PLATE 1

GEOLOGIC MAP OF THE GRANDE RONDE LIGNITE FIELD, ASOTIN COUNTY, WASHINGTON

STATE OF WASHINGTON
DEPARTMENT OF NATURAL RESOURCES

BRIAN J. BOYLE, Commissioner of Public Lands
ART STEARNS, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES
RAYMOND LASMANIS, State Geologist

CROSS SECTIONS

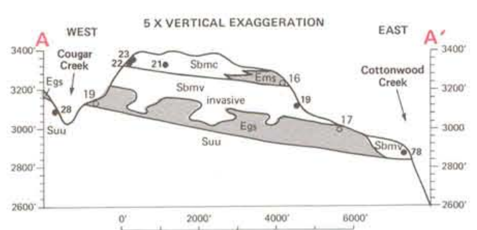


FIGURE 56. — Cross section A to A'.

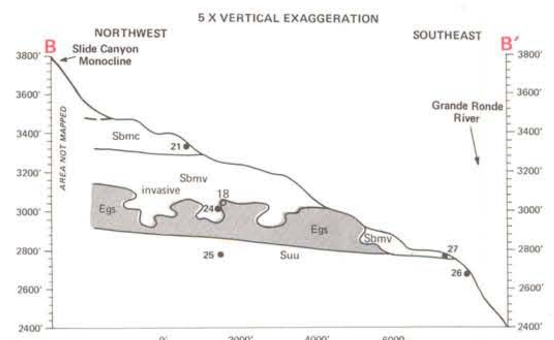


FIGURE 57. — Cross section B to B'.

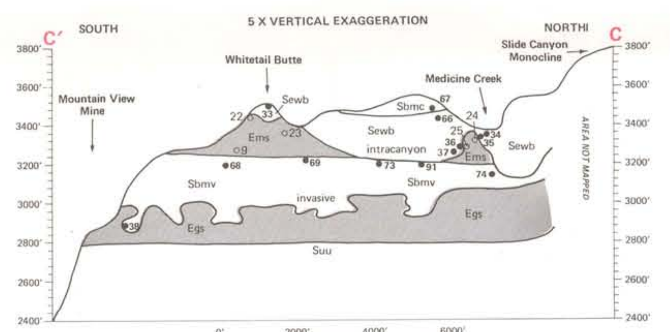


FIGURE 58. — Cross section C to C'.

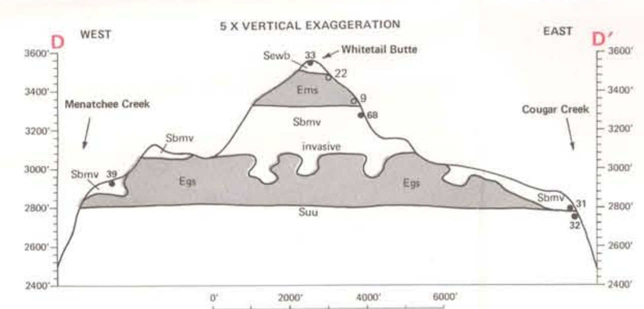


FIGURE 59. — Cross section D to D'.

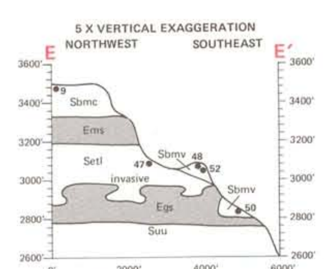


FIGURE 60. — Cross section E to E'.

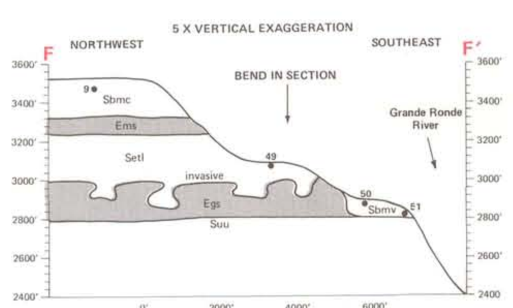


FIGURE 61. — Cross section F to F'.

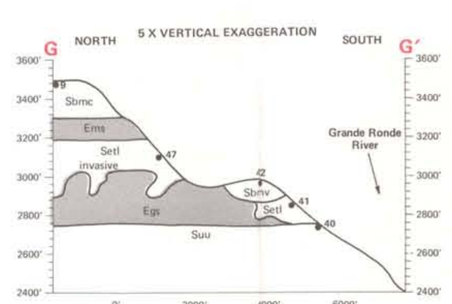


FIGURE 62. — Cross section G to G'.

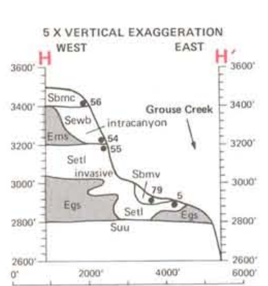


FIGURE 63. — Cross section H to H'.

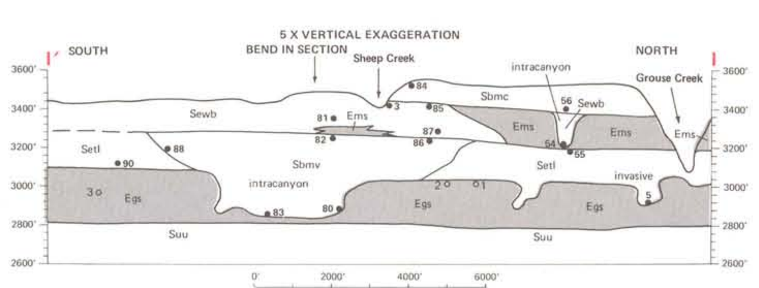


FIGURE 64. — Cross section I to I'.

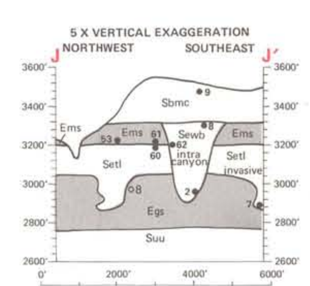


FIGURE 65. — Cross section J to J'.

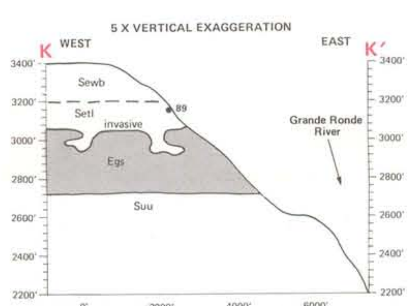


FIGURE 66. — Cross section K to K'.

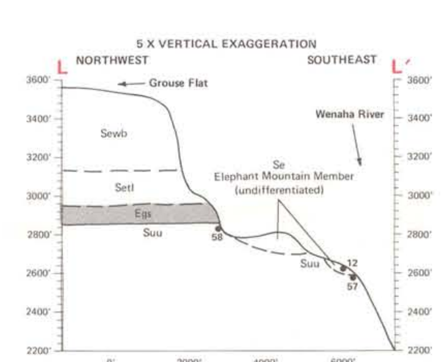


FIGURE 67. — Cross section L to L'.

Note: The small hills composed of the Elephant Mountain Member undifferentiated (Se) are not shown on the accompanying geologic map.

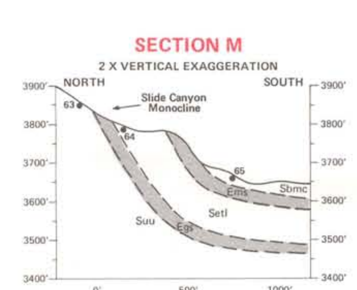


FIGURE 68. — Section M.

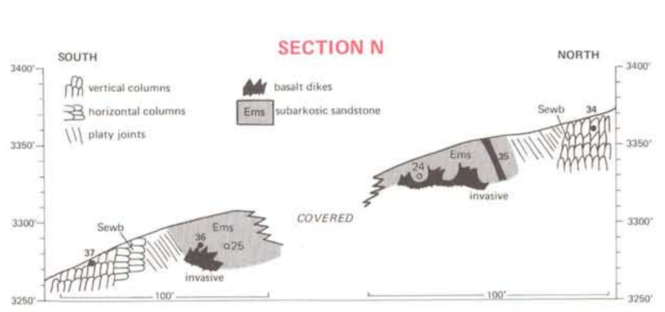


FIGURE 69. — Section N.

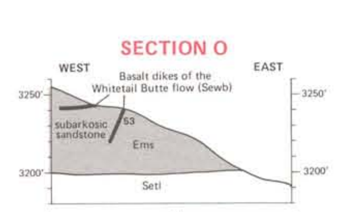


FIGURE 70. — Section O.

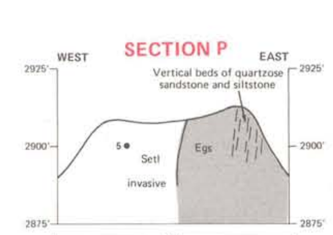
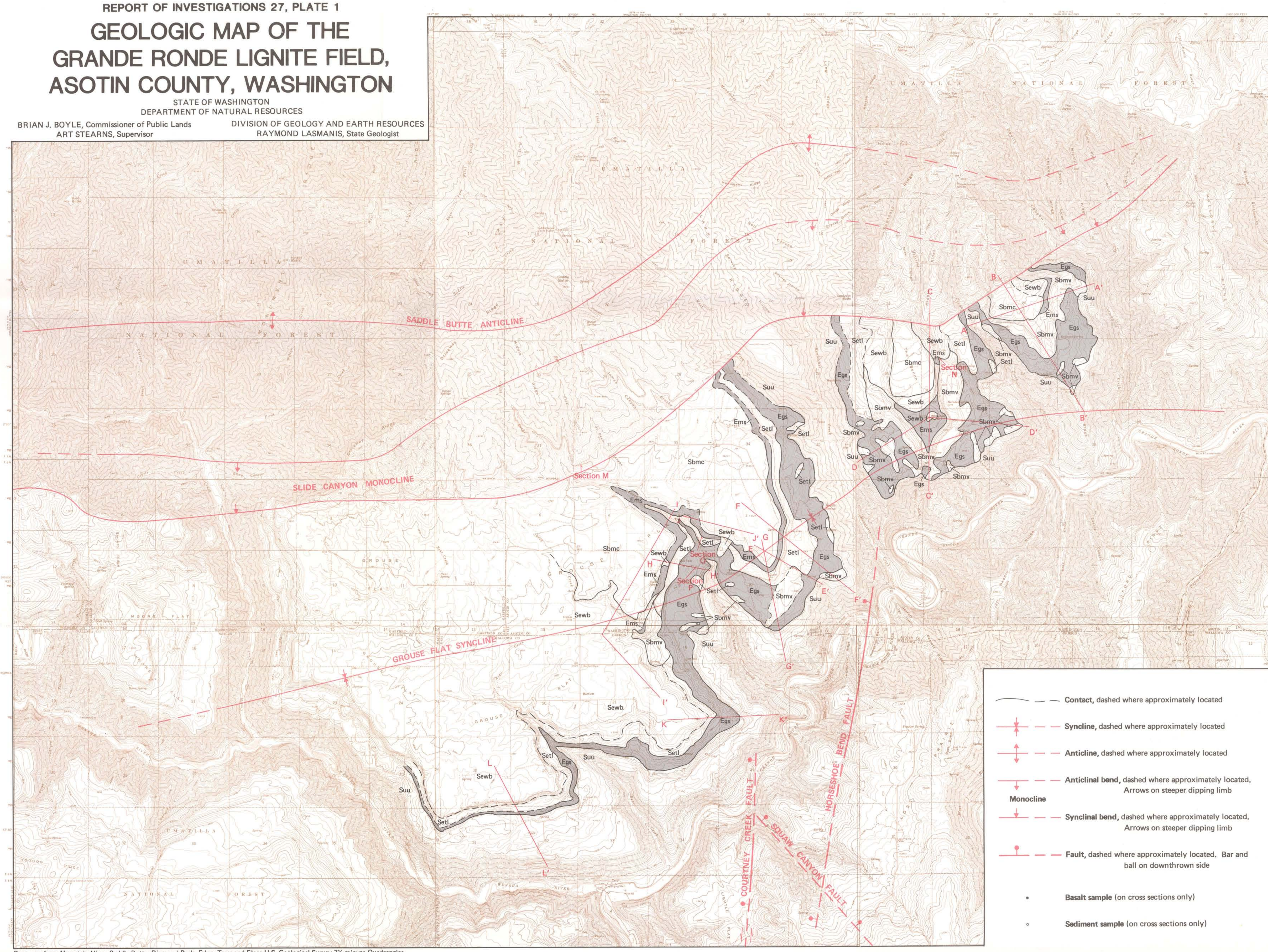


FIGURE 71. — Section P.



Base map from Mountain View, Saddle Butte, Diamond Peak, Eden, Troy and Flora U.S. Geological Survey 7½ minute Quadrangles.

Contact, dashed where approximately located

Syncline, dashed where approximately located

Anticline, dashed where approximately located

Monocline

Anticlinal bend, dashed where approximately located. Arrows on steeper dipping limb

Synclinal bend, dashed where approximately located. Arrows on steeper dipping limb

Fault, dashed where approximately located. Bar and ball on downthrown side

Basalt sample (on cross sections only)

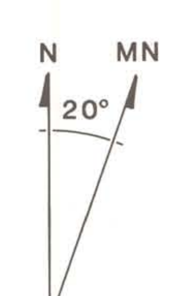
Sediment sample (on cross sections only)

SCALE 1:48,000

0 1 2 3 4 MILES

0 1 2 3 4 KILOMETERS

0 2000 4000 6000 8000 FEET



SEDIMENTARY ROCKS

Ellensburg Formation

Menatchee Creek sedimentary interbed — Ems

Subarkosic sandstone and siltstone, diatomite, carbonaceous shale, lignite, and massive kaolinite-rich siltstone and claystone. Reaches a maximum of 200 feet (60 meters) thick

Grouse Creek sedimentary interbed — Egs

Subarkosic sandstone and siltstone, diatomite, carbonaceous shale, lignite, and massive kaolinite-rich siltstone and claystone. Lignite bed at the base of the interbed reaches a maximum known thickness of 40 feet (12 meters). Interbed is 250 feet (75 meters) thick

EXTRUSIVE IGNEOUS ROCKS

Miocene — Columbia River Basalt Group — Saddle Mountains Basalt

Medicine Creek flow (BUFORD MEMBER) — Sbmc

When fresh, the basalt is black, fine-grained and microporphyritic with plagioclase microphenocrysts more abundant than clinopyroxene. All natural outcrops of the flow are deeply weathered and fresh basalt is seldom exposed. Weathered basalt is characterized by translucent to chalky white feldspar phenocrysts surrounded by a light gray groundmass which is "peppered" by abundant minute black opaque grains. Reversed magnetic polarity Approximately 160 feet (50 meters) thick

Whitetail Butte flow (ELEPHANT MOUNTAIN MEMBER) — Sewb

Black, fine to medium-grained, equigranular basalt with scattered microphenocrysts of plagioclase, clinopyroxene, and more rarely opaques. Weathers to a red-brown color. Transitional magnetic polarity. Varies from 250 feet (75 meters) to 400 feet (120 meters) thick

Mountain View flow (BUFORD MEMBER) — Sbmv

When fresh, the basalt is black, fine-grained, and microporphyritic with plagioclase microphenocrysts more abundant than clinopyroxene. All natural outcrops of the flow are deeply weathered and fresh basalt is seldom exposed. Weathered basalt is characterized by translucent to chalky white feldspar phenocrysts surrounded by a light gray groundmass which is "peppered" by abundant minute black opaque grains. Transitional magnetic polarity. 250 feet (75 meters) thick

Tule Lake flow (ELEPHANT MOUNTAIN MEMBER) — Setl

Black, fine to medium-grained, equigranular basalt with scattered microphenocrysts of plagioclase, clinopyroxene, and more rarely opaques. Weathers to a red-brown color. Normal magnetic polarity. 150 feet (45 meters) thick

UMATILLA MEMBER (undifferentiated) — Suu

Consists of two flows. The Umatilla flow, the older flow, is dark blue-black, fine to medium-grained, and equigranular. It weathers to an orange-brown color. The Sillusi flow is dark gray, extremely fine-grained, and microporphyritic with plagioclase microphenocrysts slightly more abundant than clinopyroxene. The Sillusi flow weathers to a pale yellow-brown color and has a thick goethite-rich scoriaceous flowtop. Each flow has a normal magnetic polarity and reaches a maximum thickness of approximately 200 feet (60 meters)