1978

Stratigraphy and petrography of the Selah member of the Ellensburg formation in south-central Washington and north-central Oregon

Mavis Hensley Kent
Portland State University

AN ABSTRACT OF THE THESIS OF Mavis Hensley Kent for the Master of Science in Geology presented May 19, 1978.

Title: Stratigraphy and Petrography of the Selah Member of the Ellensburg Formation in south-central Washington and north-central Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Paul E. Hammond, Chairman

[redacted]

Robert O. VanAtta

[redacted]

Marvin H. Beeson

The Selah Member of the Ellensburg Formation is a sedimentary interbed within lava flows of Yakima Basalt and occurs in south-central Washington and north-central Oregon. The Selah Member is overlain by the Pomona Member of the Saddle Mountains Basalt, and underlain by the Priest Rapids Member of the Wanapum Basalt. The Selah Member has been studied in detail within the southwestern portion of

the Columbia Plateau, in the Roosevelt-Arlington basin, an east-west trending structure which parallels the axis of the Dalles-Umatilla syncline. The Roosevelt-Arlington basin is bounded by the Horse Heaven Hills anticline to the north, and the Willow Creek monocline to the south.

Within the Roosevelt-Arlington basin the Selah Member is divided into three lithologic and petrographic units. The lowermost unit, I, consists of air-fall tuff, accretionary lapilli tuff, pumicite, and minor volcanic lith-arenite and siltstone. The middle unit, II, is subdivided into: 1) a northern part consisting primarily of volcanic lith-arenite, feldspathic volcanic lith-arenite and basaltic conglomerate, which is referred to as the tectonic facies; and 2) a southern part consisting primarily of claystone and siltstone, referred to as the lacustrine facies. The uppermost unit, III, consists of water-lain siltstone, volcanic lith-arenite, vitric (volcanic) lith-arenite, and minor pumicite and accretionary lapilli tuff.

The light mineral assemblage (sp gr 2.96) in the Selah member consists of altered vitric (devitrified ash) rock fragments (up to 99.8 percent by volume), sanidine feldspar, glass, plagioclase feldspar, and quartz, and indicates abundant primary volcanic air-fall sources. The heavy mineral assemblage (sp gr 2.96) consists of opaques, hypersthene, hornblende, basaltic hornblende, clinozoisite, epidote, topaz, and zircon, and also indicates a primary volcanic source. Plutonic/metamorphic minerals comprise less than 5 percent of the heavy mineral assemblage, and commonly less than 0.5 percent of the total mineral volume.

Explosive volcanic activity during Selah time, probably in the Cascade Range to the west, was a major source of the tephra that were deposited in streams and shallow lakes within the Roosevelt-Arlington basin. Penecontemporaneous deformation during Selah-time, probably associated with the major structural features bounding the Roosevelt-Arlington basin, is suggested by the presence of basaltic conglomerates, and an erosional unconformity at the base of unit II-tectonic facies. The absence of the ancient Columbia River in the Roosevelt-Arlington basin during deposition of the Selah Member is indicated by the structural and/or topographic isolation of the Roosevelt-Arlington basin, the lack of quartzitic gravels, and the low volume of plutonic/metamorphic sediments. It is suggested that the Columbia River occupied a northerly course during deposition of the Selah Member.

STRATIGRAPHY AND PETROGRAPHY OF THE SELAH MEMBER OF THE ELLENSBURG FORMATION IN SOUTH-CENTRAL WASHINGTON AND NORTH-CENTRAL OREGON

by

MAVIS HENSLEY KENT

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University
1978

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of Mavis Hensley Kent presented May 19, 1978.

[redacted]

Paul E. Hammond, Chairman

[redacted]

Robert O. VanAtta

[redacted]

Marvin H. Beeson

APPROVED:

[redacted]

Marvin H. Beeson, Head, Department of Earth Sciences

[redacted]

Stanley E. Rauch, Dean of Graduate Studies and Research

ACKNOWLEDGEMENTS

The writer's thesis advisors, Dr. Paul E. Hammond and Dr. Robert O. VanAtta, are thanked for their constant guidance and encouragement. Portland General Electric Company provided permission to sample Pebble Springs Nuclear Project borehole cores. Mr. and Mrs. Buzz Seely, of Roosevelt, Washington, generously granted access to outcrops located on their private property. The author also appreciated time spent with Mr. Saleem Farooqui, Shannon & Wilson, Inc., in discussing local and regional stratigraphy and structure.

Thanks go to Chris Lewis and Chris Nastrom, Shannon & Wilson, Inc., for laboratory assistance; Terri Jorgensen for field sampling assistance; Dr. David Bostwick of Oregon State University, Mrs. Irene Gregory, Prineville, Oregon, and Mr. Bruce Welton, Los Angeles County Museum, for some paleontological identifications; and Tom Amundson, Portland State University, for paleontological nomenclature assistance.

The greatest appreciation goes to the writer's family, without whose unwavering confidence and support, completion of this study may not have been realized. Special thanks go to Mr. Robert Hensley and Marna Jorgensen for untold hours of childcare, Mrs. Doris Hensley for typing of the thesis, to Richard for manuscript review, and to Christopher for his patience and good nature.

TABLE OF CONTENTS

ILLUSTRATIONS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

INTRODUCTION

PURPOSE

The Ellensburg Formation of south-central Washington and north-central Oregon has been described by many workers from the time of the original description by Russell (1893) to recent work by Schmincke (1964). However, detailed information concerning the stratigraphy and petrography of the Ellensburg Formation in south-central Washington and north-central Oregon is not available. This study is among the first detailed studies made of a member of the Ellensburg Formation; it provides a specific comparison and correlation of the Washington/Oregon occurrence with the type Ellensburg of central Washington.

The Selah Member is selected for study because of its stratigraphic and geographic importance in understanding the Ellensburg Formation in south-central Washington and north-central Oregon. It is represented by thick and fairly complete outcrop stratigraphic sections. In this report stratigraphy and petrography of the Selah Member is described and compared to field descriptions of Waters' (1955) and Mackin's (1961) type sections of the Selah Member in central Washington.

The field and petrographic data presented in this thesis are the basis for lithologic subdivision of the Selah Member. The lithologies described will be a means of comparison of Selah-equivalent sediments throughout the Columbia Plateau in terms of composition, depositional environment, and sedimentary and/or volcanic origin.

DESCRIPTION OF THE STUDY AREA

General Location

The study area is located near Roosevelt, Washington, and Arlington, Oregon (Fig. 1), where outcrops of Selah are found in steep slopes, stream drainages, and roadcuts. Natural slopes composed of the Selah Member are characteristically prone to landsliding and burial by thick layers of colluvium. Access to the study area is by state highway and unimproved roads.

Physiography

Moderate topographic relief is represented by surface elevations ranging from about 80 m at the Columbia River, to elevations of 300 to 433 m in the hills surrounding Arlington, Oregon. Higher topographic relief across the Columbia River near Roosevelt, Washington, has escarpment elevations up to 566 m. Differential erosion has produced very steep slopes and bluffs capped by resistant basalt flows, and more gentle slopes underlain by the less resistant interbedded sedimentary units. Landsliding in the sedimentary interbeds has resulted in hummocky topography and well-defined earth and debris flow features.

The Columbia River bisects the study area and is now

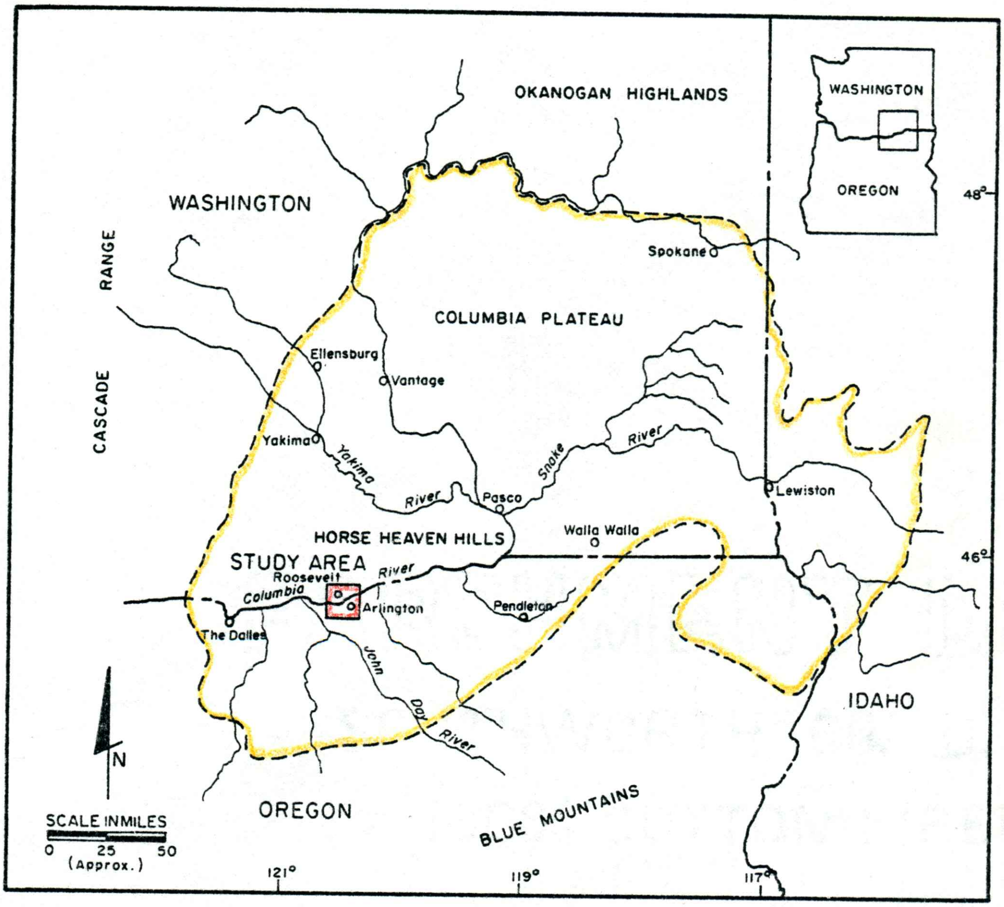


Figure 1. Location of study area. Map modified after McKee (1972).

locally cutting in the Priest Rapids Member of the Wanapum Basalt (new name proposed by Swanson and others, 1977) near Roosevelt, Washington. Numerous large tributary stream valleys with dendritic patterns drain into the Columbia at generally oblique confluences. Intermittent stream drainages are represented by numerous deep gullies and water ponding throughout the area. In contrast, some intermittent streams typically flow in trellis-like patterns, perpendicular to the strike of the side-slopes, and have moderate to steep gradients. The less resistant sedimentary interbeds, such as the Selah, are rapidly eroded as shown by deeper valleys and higher sediment loads of the streams.

According to national weather bureau statistics, mean annual rainfall in the study area is less than 25 cm per year, occurring primarily during the late winter and early spring months, while mean annual snowfall is about 27 cm. The low annual precipitation supports only sparse vegetation consisting of prairie grasses, low flowering plants, sagebrush, and occasional juniper trees. Phreatophytes, including some deciduous trees, many of which were brought in by early settlers, are found along stream valleys, near springs, and other areas of higher groundwater tables.

METHODS OF INVESTIGATION

General Field Studies

Outcrops of the Selah Member are described, sampled, and shown in eleven stratigraphic sections (Plates 2 and

3). Selah samples were also obtained from drilling cores that penetrated the entire thickness of the Selah Member near Arlington, Oregon. Permission for use of the Selah cores was provided by Portland General Electric Company, Portland, Oregon.

The locations of the eleven measured sections are shown on Plate 1. Detailed descriptions of the sections, which range from about 8 to 92 m in thickness, are included in Appendix A. Six sections are located in Washington, near Roosevelt (Plate 2), and five sections are located in Oregon, in the vicinity of Arlington (Plate 3). Included in the five Oregon sections are the three sections measured from drilling cores (Shannon & Wilson, Inc., 1975).

Outcrop and Core Sampling

Samples of 100 gram minimum each were obtained from the measured outcrops and cores. All units in the outcrops were sampled, tentatively described in the field, and bedding orientation measurements were recorded. Core was available for sampling in a limited volume through the courtesy of Portland General Electric Company. Therefore, a sampling method was devised to represent the significant Selah units from available core. One 100 gram sample was taken from the upper and lower halves of all sandstone units less than 5 m thick. If the sandstone unit exceeded 5 m, one 100 gram sample was taken from the upper, middle, and lower sections of the unit. One 100 gram sample was taken from all units other than sandstone, up to a maximum interval of 16 m.

Laboratory Preparation

Standard laboratory gradation procedures were followed for sample preparation. Laboratory methods included grain size sieve and pipette gradation of all samples. Detailed grain size analyses were then conducted on selected samples of sandy siltstone and sandstone using a set of standard U. S. mesh sieves in $\frac{1}{4}$ Ø intervals. A pipette analysis was conducted on all minus 62.5 μ size material in order to establish the silt to clay ratio within each sample. The minus 2 μ size clay fraction from selected samples was utilized for x-ray diffraction.

The light and heavy minerals were separated by centrifuge utilizing tetrobromoethane (sp gr 2.96) as the separation medium. The separated light and heavy fractions were then oven-dried and weighed. Mechanically-split portions of each light and heavy fraction were then mounted with epoxy (I. R. 1.54) on standard glass petrographic slides.

Petrographic Analysis

Minerals were identified from light and heavy mineral grain-mounted slides. Component percentages were calculated by the standard means of line counting. Line counts consisted of an arbitrary grid size of equally spaced lines. Up to 700 grains were counted for each slide except for certain heavy mineral fractions where less than about 200 grains were present.

X-ray diffraction on selected samples was used to definitively identify the clay minerals. A standard x-ray diffraction technique using CuKα radiation was used.

GEOLOGIC SETTING

PREVIOUS INVESTIGATIONS

The first description of the widespread sedimentary deposits in central Washington was by I. C. Russell (1893) who named them the John Day System (Fig. 2). Russell further determined an age of Miocene for the deposits, based upon paleontologic and physical similarities to the John Day Formation of central Oregon. Russell suggested that both were deposited in ancient Lake John Day. In his description of the John Day System, Russell recognized that the lowermost units were interstratified with the uppermost flows of what he described as the Columbia Lava in central Washington.

Smith (1901) renamed the John Day System of Washington the Ellensburg Formation (Fig. 2). Exposures of the Ellensburg near the mouth of the Naches River, and near the Normal School in the town of Ellensburg, were regarded by Smith as typical.

Buwalda and Moore (1930) and Culver (1937) later refined the age of the Ellensburg Formation as upper Miocene to lower Pliocene, and assigned an age of Pleistocene to the sedimentary beds of the White Bluffs on the basis of paleontology and stratigraphic relationships. The sediments at White Bluffs, in central Washington, were separated from the Ellensburg Formation as the Ringold Formation.

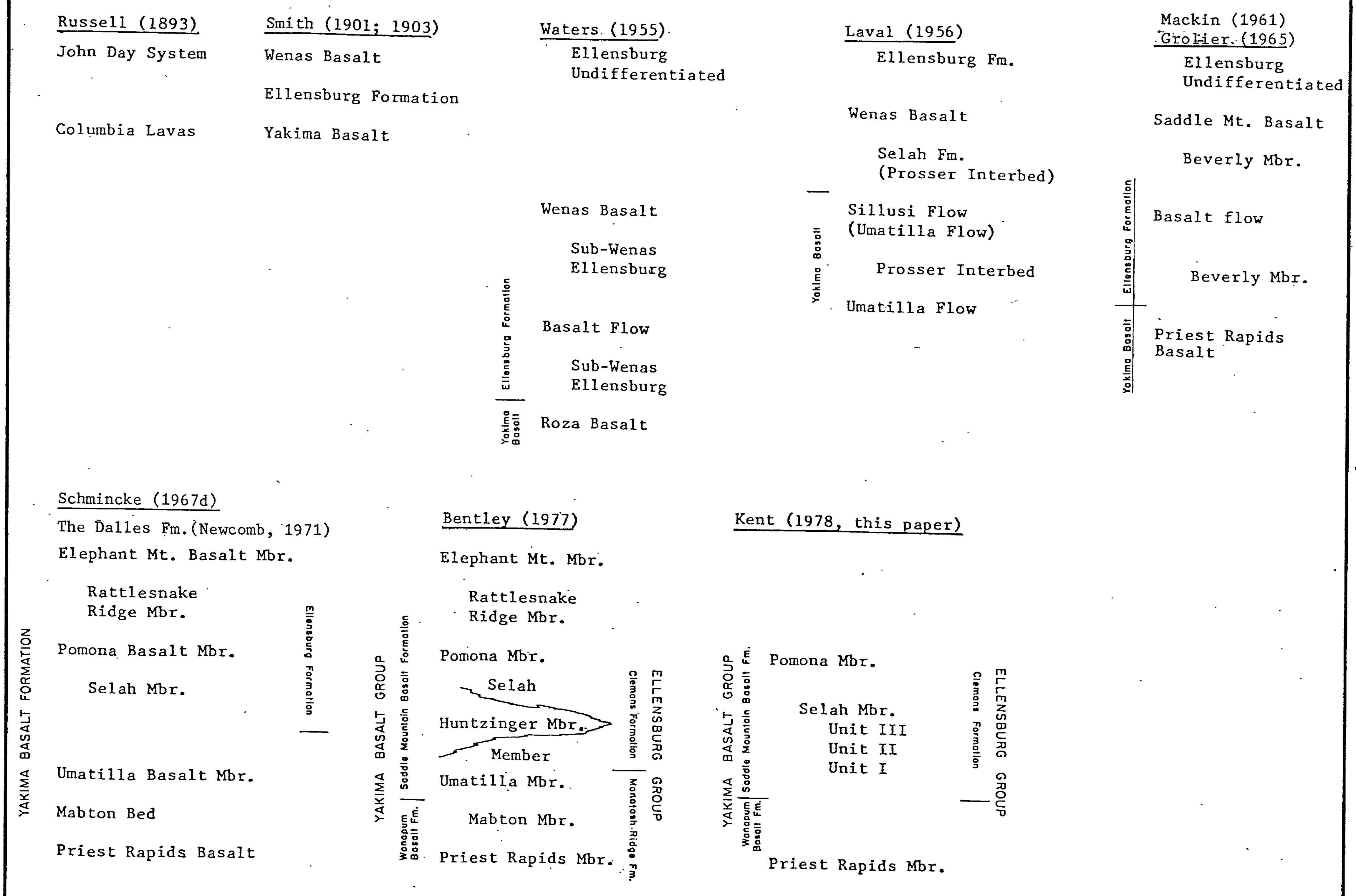


Figure 2. Development of nomenclature for Selah Member, Clemans Formation, and associated lithostratigraphic units.

Coombs (1941) described the heavy mineral assemblage in Smith's (1903) exposures along the Naches River, and in exposures of the Ellensburg Formation near the towns of Yakima and Ellensburg. Coombs concluded that the heavy minerals are composed exclusively of hornblende and magnetite while glass and plagioclase feldspar are typical light mineral components. He also noted that these minerals are persistent throughout the Ellensburg Formation, and that more extensive petrography would be an important aid in correlation.

Waters (1955) recognized the correlation problem created by defining a contact between the Ellensburg Formation and the underlying Yakima Basalt. He stated that Smith, in his mapping of the Ellensburg quadrangle, tended to place the basal contact of the Ellensburg Formation above stratigraphically higher flows in working from the northwest to southeast.

Waters preferred the concept of slow basin development associated with folding, as opposed to Russell's fault-block ridges. He attributed the basaltic conglomerates, associated with minor 10 degree unconformities in the upper Ellensburg Formation, to uplifting of the Yakima Basalt ridges that was contemporaneous with filling of the adjacent synclinal basins. Waters further concluded that the sub-Wenas Ellensburg sediments (Fig. 2) underwent a slower accumulation than did the upper Ellensburg Formation.

Laval (1956; Fig. 2) was the first to use the name

Selah Formation which referred to sediments below the Wenas basalt, and above the Priest Rapids basalt. Laval did not describe the Selah petrography in detail since his chief purpose was to delineate the regional stratigraphic relationships of the sediments and basalt units. The Ellensburg Formation, as described by Laval, includes clasts of andesite and pumice, glass (pumice, shards), plagioclase feldspar of Ab_{66-78} composition (10-90%), hornblende (<10%), magnetite (<5%), hypersthene (to 4% locally, and trace amounts of biotite, zircon, muscovite, and β-quartz.

According to Laval, deposition of the Selah occurred in downwarping structures, with andesitic clastics supplied from the west and north, and quartzitic debris only from the north. In a Selah section measured on the east side of Sentinal Gap, he noted an unconformity between the upper Ellensburg and the overlying Ringold Formation, thereby suggesting that the Ringold represents reworked portions of the Ellensburg Formation.

Mackin (1961) further defined the rather confusing nomenclature of Columbia Plateau stratigraphy (Fig. 2). Mackin recognized that the flows and sediments in the Beverly Section (measured at Sentinal Gap by Mackin), and in Waters' (1955) Roza Gap Section were similar. However, Mackin assigned different stratigraphic names to his Beverly Section and Waters' Roza Gap Section because of the difficulty in regional correlation of the two sections. Mackin proposed that Waters' (1955) sub-Wenas Ellensburg sediments required a separate name because the sediments occur in areas where the Wenas basalt is not present. Consequently, he referred to these sediments as the Selah Member of the Ellensburg Formation with the Roza Gap Section as the type locality.

Mackin (1961) pointed out that two types of deformation occurred in the Columbia Plateau; 1) a general Plateau subsidence evidenced by a basinward tilting and offlapping within the older group of Yakima Basalt flows (pre-Roza), and 2) a later folding, with formation of northwest trending ridges as evidenced by the continuity in thickness and/or occurrence of basalt flows and sediments across the axes of the folds.

Grolier (1965), in his mapping of the Big Bend area in central Washington, utilized Mackin's term of Beverly Member to include those sediments above the Priest Rapids basalt, underlying the Saddle Mountains basalt, and, in contrast to Mackin (1961; Fig. 2), directly overlying the Saddle Mountains basalt. Grolier's lithologic description of the Beverly Member includes; 1) conglomerate (quartzite, felsic porphyry, basalt, granitic and metamorphic pebbles and cobbles), 2) pumicite (glass shards with basal accretionary lapilli), and 3) interbedded tuffaceous sand, silt, and clay layers. Grolier (1965) also pointed out that both quartzitic conglomerate and brown tuffaceous sand are common to both the Beverly Member and the Ringold Formation, and suggested that the two designated formations may be the same. This appears to conflict with other workers who assigned an age of Pleistocene to the Ringold Formation (Buwalda and Moore, 1930; Culver, 1937), and recognized a basal unconformity (Mason, 1953; Laval, 1956).

Schmincke (1964, 1967d; Fig. 2) continued to work toward a clarification of the stratigraphy of the Ellensburg Formation and interbedded basalt flows assigned to the Yakima Basalt throughout central Washington. A definition of the Selah Member, as suggested by Schmincke, includes those sediments which lie below the Pomona basalt and above the next lowest Yakima Basalt flow, and which contains no interbedded basalt flows. Although Schmincke refers to these sediments as the Selah Member, he feels that Mackin's (1961) term Beverly Member may be legitimate where the Pomona basalt is not present.

Schmincke (1964; Fig. 3) lists 6 major basins in which the Ellensburg Formation (including the Selah Member) was deposited, although not necessarily contemporaneously. The basins occur in synclinal lows bounded by growing anticlines in Yakima Basalt, where sedimentation was contemporaneous with uplift. According to Schmincke (1964, 1967c) sedimentation during Selah time occurred at a greater rate than basin subsidence, thereby burying some rising anticlines and allowing the Pomona Member to flow over nearly as great an area as earlier Yakima Basalt flows. The sediments accumulating in the basins originated from three principal source areas: 1) ancient Cascade

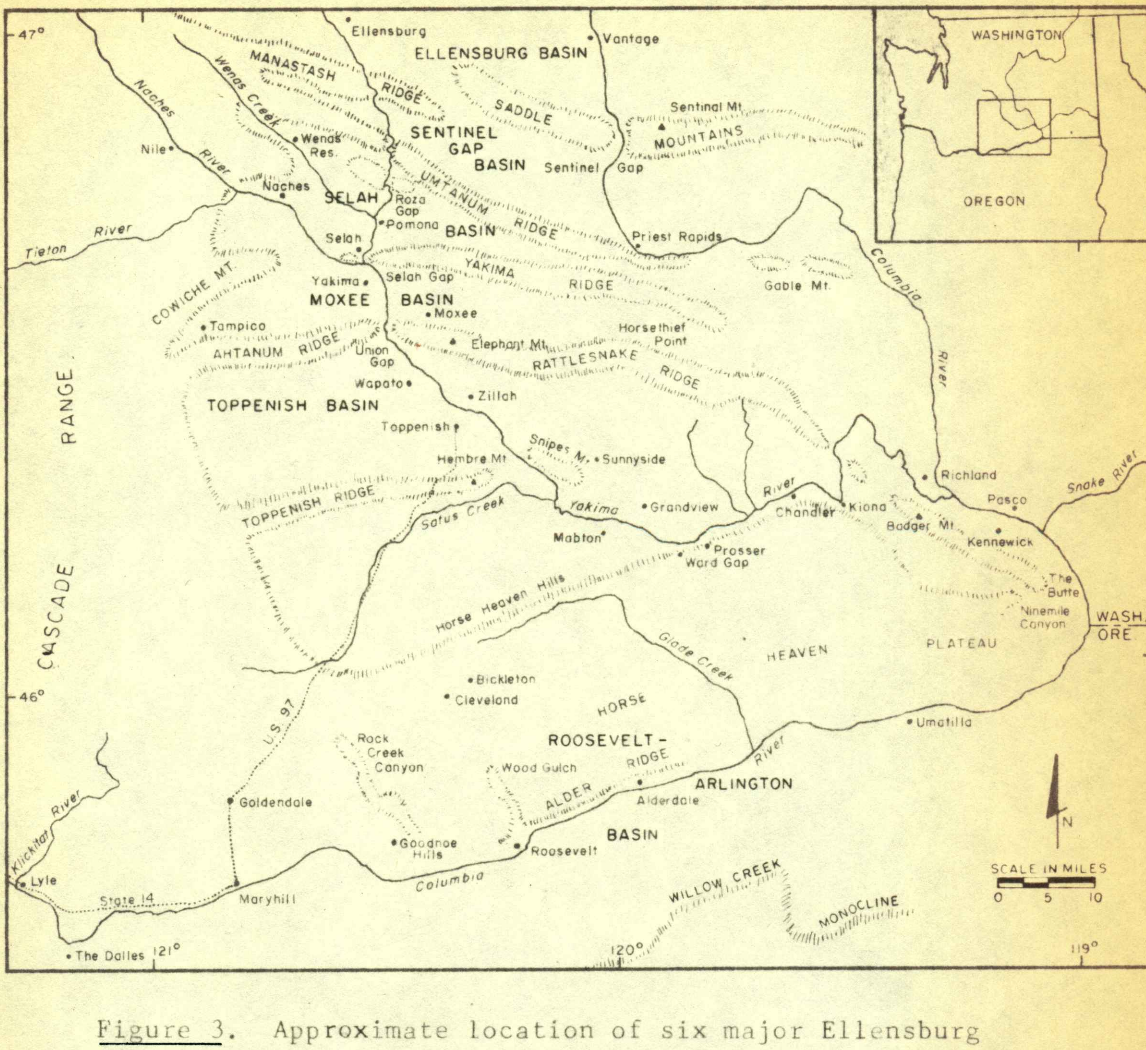


Figure 3. Approximate location of six major Ellensburg depositional basins in south central Washington and north central Oregon. Map modified after Schmincke (1967d).

volcanoes to the west, 2) metamorphic and plutonic highlands to the north, drained by an ancient Columbia River, and 3) rising anticlines in Yakima Basalt.

Schmincke (1964) concurred with earlier workers (Smith, 1903; Mason, 1953; Waters, 1955; Laval, 1956; and Mackin, 1961) that the majority of the Ellensburg Formation is composed of fluvial sandstones, with a local abundance of volcanic and nonvolcanic conglomerates, siltstones, diatomite, and laharic deposits. Waters (1955) and Mackin (1961) felt that a local abundance of basaltic conglomerate suggested an increase in the rate of folding of anticlines, possibly at a greater rate than deposition in adjacent synclines. The presence of nonvolcanic (quartzitic) conglomerates tends to confirm, according to Mackin (1961), the presence of a former channel of the ancient Columbia River or a tributary. In addition, Schmincke (1964, 1967d) states that occurrence within the Ellensburg Formation of lahars (unsorted or poorly sorted pyroclastic mudflow deposits) is restricted to an area north of Rattlesnake Ridge, near the towns of Yakima, Selah, and Naches.

Newcomb (1971) traced the Selah and Rattlesnake Ridge Members of the Ellensburg Formation, and the Priest Rapids, Pomona, and Elephant Mountain Members of the Yakima Basalt into north-central Oregon. The Pomona basalt extends southward into north-central Oregon for about 16 km, and overlies more than 90 m of Selah sediments. Where the Pomona Member pinches out, south of Arlington, Oregon, the Selah Member is overlain with erosional unconformity by the eastward extension of The Dalles Formation of Pliocene age (Newcomb, 1966).

Detailed geologic mapping in a portion of north-central Oregon and south-central Washington was performed by Shannon & Wilson, Inc., (1972, 1973, 1975) as a part of nuclear and coal-fired electric power plant siting. Results of their work include regional correlation of the Yakima Basalt flows exposed above the Priest Rapids Member, including the interbedded Ellensburg Formation, The Dalles Formation, and the overlying Pleistocene to Holocene sedimentary units. Shannon & Wilson, Inc., closely followed Schmincke's (1964, 1967d; Fig. 2) terminology in description of the Selah Member.

A recent revision of Columbia Plateau stratigraphic terminology is presented by Bentley (1977; Fig. 2). Bentley proposes the name Yakima Basalt Group for the basalt lava flows and Ellensburg Group for all sedimentary units interbedded with Yakima Basalt flows. The Selah Member is assigned to his Clemans Formation of the Ellensburg Group. Reference to the Selah Member in this study follows the proposed terminology of Bentley (1977).

GEOLOGY

Stratigraphy

The study area is underlain by sedimentary units belonging to the Ellensburg Group interbedded with basalt flows of the Yakima Basalt Group. Conglomerates and tuffs of The Dalles Formation overlie the Selah and Rattlesnake Members of the Clemans Formation (of Bentley, 1977) and the Pomona Member of the Saddle Mountains Basalt Formation with erosional unconformity (Newcomb, 1971; Farooqui, 1977, personal communication). The general stratigraphic section in the vicinity of the study area is shown in Figure 4, with a total section exposed of approximately 305 m (Newcomb, 1971). Recent K-Ar dating (McKee and Swanson, 1977) indicates the age of the Pomona Member as 12 million years before present.

As described above, the stratigraphic position of the Selah Member in the Roosevelt-Arlington basin is in accord with Schmincke's (1964) definition. It underlies the Pomona Member of the Saddle Mountains Basalt and overlies the Priest Rapids Member of the Wanapum Basalt. Laval (1956) and Schmincke (1964, 1967d) show the Selah Member also overlying either the Umatilla Member or Priest Rapids Member in south-central Washington. The Umatilla Member does not extend into the study area.

Mackin (1961) outlines a similar stratigraphic problem for north-central Washington near Sentinal Gap. The Beverly Member includes an unnamed basalt flow, apparently not recognized by Mackin, the Pomona Member. Near Sentinal Gap, where it occurs within Mackin's Beverly Member, it overlies Selah equivalent sediments using Schmincke's (1964) definition of Selah Member. Where the

Super group	Group	Formation	FORMATION	THICKNESS (meters) OREGON	THICKNESS (meters) WASHINGTON
			The Dalles Formation	0–21.2	
			unconformity		
COLUMBIA RIVER SUPER GROUP	ELLENSBURG GROUP	(Clemons Formation)	Rattlesnake Ridge Member	12.1–18.1	9.0
			Selah Member	49.4-90+	18.1 –90+
	YAKIMA BASALT GROUP	Saddle Mtn. Basalt Fm	Elephant Mountain Member	0–6.0	12.1
			Pomona Member	0–24.2	51.5
		Wanapum Basalt Formation	Priest Rapids Member		51.5
			Sedimentary Interbed	0-30cm.	

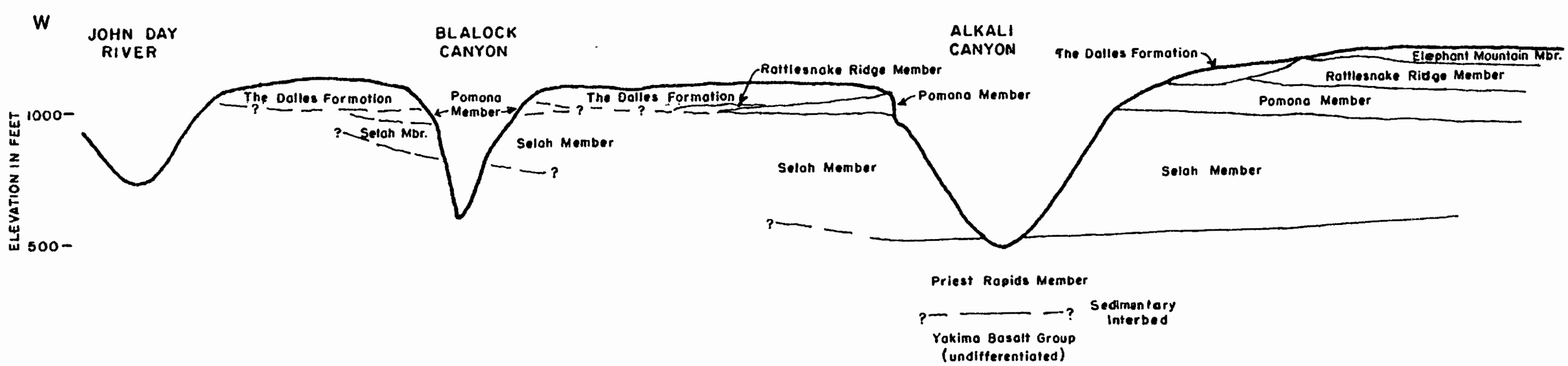


Figure 4. Diagrammatic west-east cross section near Arlington, Oregon, showing general stratigraphic relationships within the study area. Chart lists known thicknesses of associated lithostratigraphic units.

Pomona Member is not present, the Rattlesnake Ridge Member (uppermost part of Mackin's Beverly Member) unconformably overlies Selah-equivalent sediments. It is therefore concluded that Mackin's description of the Beverly Member for units below the basalt flow (Pomona) are equivalent to the Selah Member.

Lithology

Lithologic characteristics of the Selah Member of central Washington are: 1) the predominantly andesitic composition (Laval, 1956), 2) an overall paucity of basalt in the sandstones and conglomerates, 3) the occurrence of quartzitic conglomerates (denoting the presence of an ancient Columbia River or tributary), and 4) the presence of accretionary lapilli tuffs.

The Selah Member of the Clemans Formation (of Bentley, 1977; Fig. 2), as described by Waters (1955) in his type section measured at Roza Gap in central Washington, consists of interbedded volcaniclastic sandstone, siltstone, and andesitic conglomerates composed of pebbles and cobbles of andesite with minor plutonic rocks, quartzite and basalt. Laval (1956) measured several sections of the Selah Member in central Washington which also consisted of interbedded tuff, volcaniclastic siltstone, sandstone, and pebble to cobble conglomerate. In contrast to the section described by Waters at Roza Gap, Laval found layers of pumicite and massive claystone, commonly bentonitic, within the Selah Member. Schmincke (1964) further refined the lithology, in describing layers of accretionary lapilli tuff, typical of the basal portion of the Selah Member.

STRUCTURE

Columbia Plateau

The structure of the Columbia Plateau in Washington is characterized by east to southeast trending narrow anticlines separated by broad synclinal basins (Fig. 3). The folds are superimposed upon a large regional basin centered near Pasco, Washington (McKee, 1972).

Both Russell (1893) and Mackin (1961) recognized a basinward tilting of the Yakima Basalt flows. Mackin (1961) further recognized an offlapping of younger flows, and attributed the discordant relationship between the Frenchman Springs and Priest Rapids Members, and the overlying sediments, to a general plateau subsidence during mid-Yakima time. Russell (1901) had earlier suggested a genetic relationship between the basinward tilting of the basalts and the outpouring of an estimated 120,000 to 150,000 km^3 of basalt (Schmincke, 1964), later estimated at more than 200,000 km^3 (McKee and Swanson, 1977).

Columbia Plateau subsidence had substantially diminished by early Pliocene (Selah) when anticlinal folding of the Plateau began (Mackin, 1961). According to Waters (1955), the Ellensburg Formation was deposited in subsiding synclinal basins adjacent to rising anticlines. This was inferred from the presence of minor unconformities, particularly in the upper portion of the Ellensburg Formation, and the presence of basaltic conglomerates, typically overlying the unconformities and interfingering with the Ellensburg sediments.

The growth of the Washington Columbia Plateau fold structures during Selah time is discussed by Waters (1955) and Mackin (1961). Both authors felt that folding was in progress during early Ellensburg time, although not well developed and that sedimentation in synclinal basins kept pace with uplift of adjacent anticlines. The isopach map of the Selah Member (Fig. 5) does not reflect any prominent structures present within the Plateau during Selah time and further indicates that any relief due to penecontemporaneous deformation was not well developed. This conclusion is further supported by Kienle and others (1978) who dated the Yakima Ridge folding north of the Roosevelt-Arlington basin from 8 to 3.5 million years before present. The Selah Member is 13.5 to 12 million years of age (McKee, Swanson, and Wright, 1977), and therefore pre-dates the regional deformation in Washington recognized by Kienle, et al (1978).

Waters also noted paleontological evidence, contained in the post-Selah Ellensburg, of a climatic change between Selah and post-Selah Ellensburg, marking uplift of the Cascade Range to the west. Although uplift of the Cascade Range may have begun during mid-Ellensburg time, Mackin

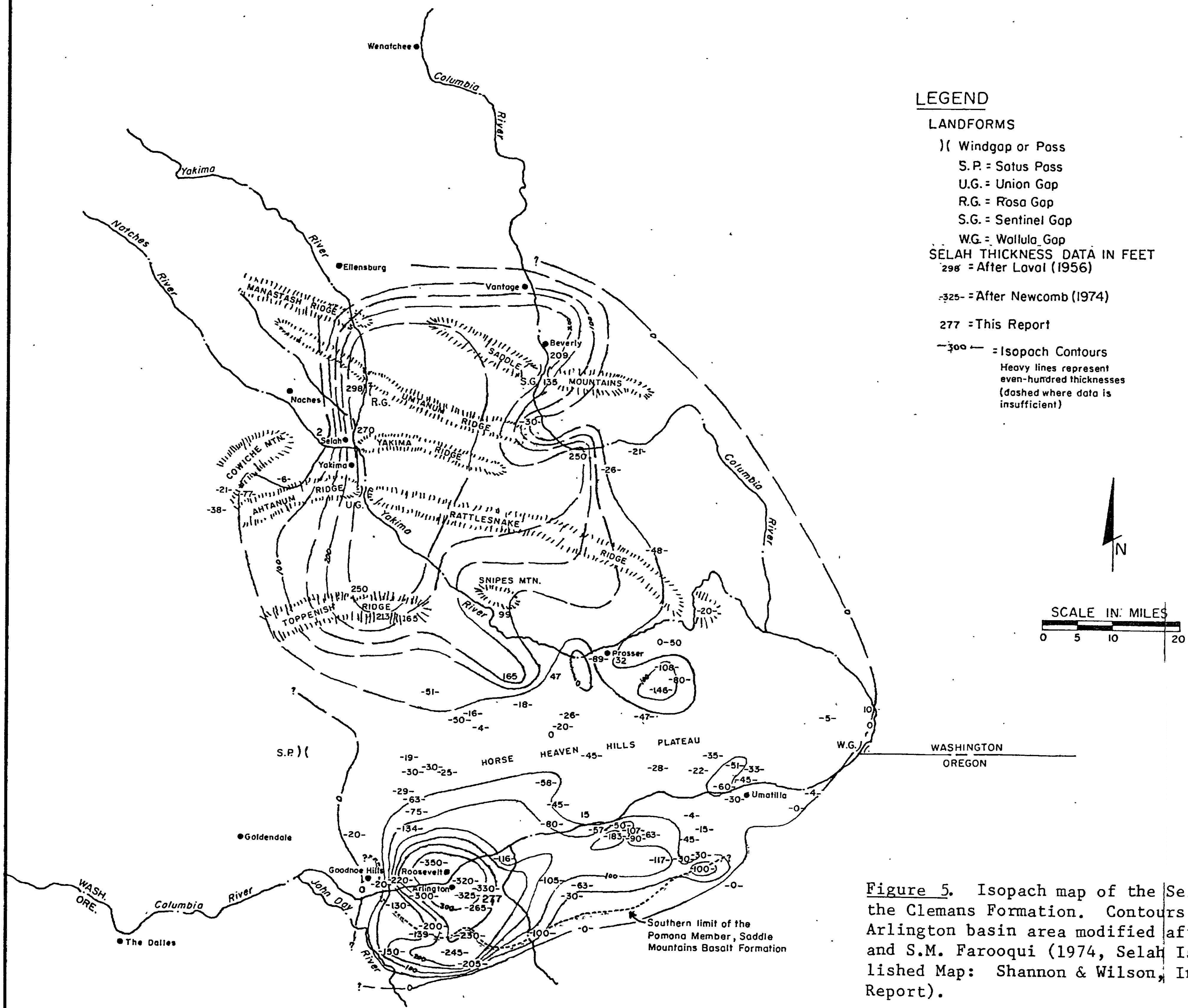


Figure 5. Isopach map of the Selah Member of the Clemans Formation. Contours in Roosevelt-Arlington basin area modified after R.C. Newcomb and S.M. Farooqui (1974, Selah Isopach Unpublished Map: Shannon & Wilson, Inc., Proprietory Report).

(1961) points to the difficulty in distinguishing the structural effects of Cascade uplift from Plateau subsidence.

Mackin (1961) concluded that some basins present during Ellensburg time (Fig. 3) may have been isolated from the great eastward spreading Beverly-Selah alluvial fans. Schmincke (1964) refers to the area of north-central Oregon and south-central Washington as the Roosevelt basin; referred to herein as the Roosevelt-Arlington basin (Farooqui, 1977, personal communication). Mackin's and Schmincke's observations concerning the presence of isolated basins of deposition during Ellensburg time brings into focus the existing problems in regional correlation of the Ellensburg Group sediments. Their observations also emphasize the importance of regional Yakima Basalt stratigraphy as a primary key in correlation of the Ellensburg Group sediments on a detailed lithologic and petrographic level.

Roosevelt-Arlington Basin

Structure As previously described, the structure of the study area is characterized by southeast and east trending folds and faults (Fig. 6). The Roosevelt-Arlington basin, part of the Dalles-Umatilla syncline, extends from Umatilla, Oregon, to a point east of Goodnoe Hills (Fig. 5). The basin is bounded primarily by the Willow Creek monocline to the south, the Horse Heaven Hills anticline to the north, and the Service Butte-Sillusi Butte

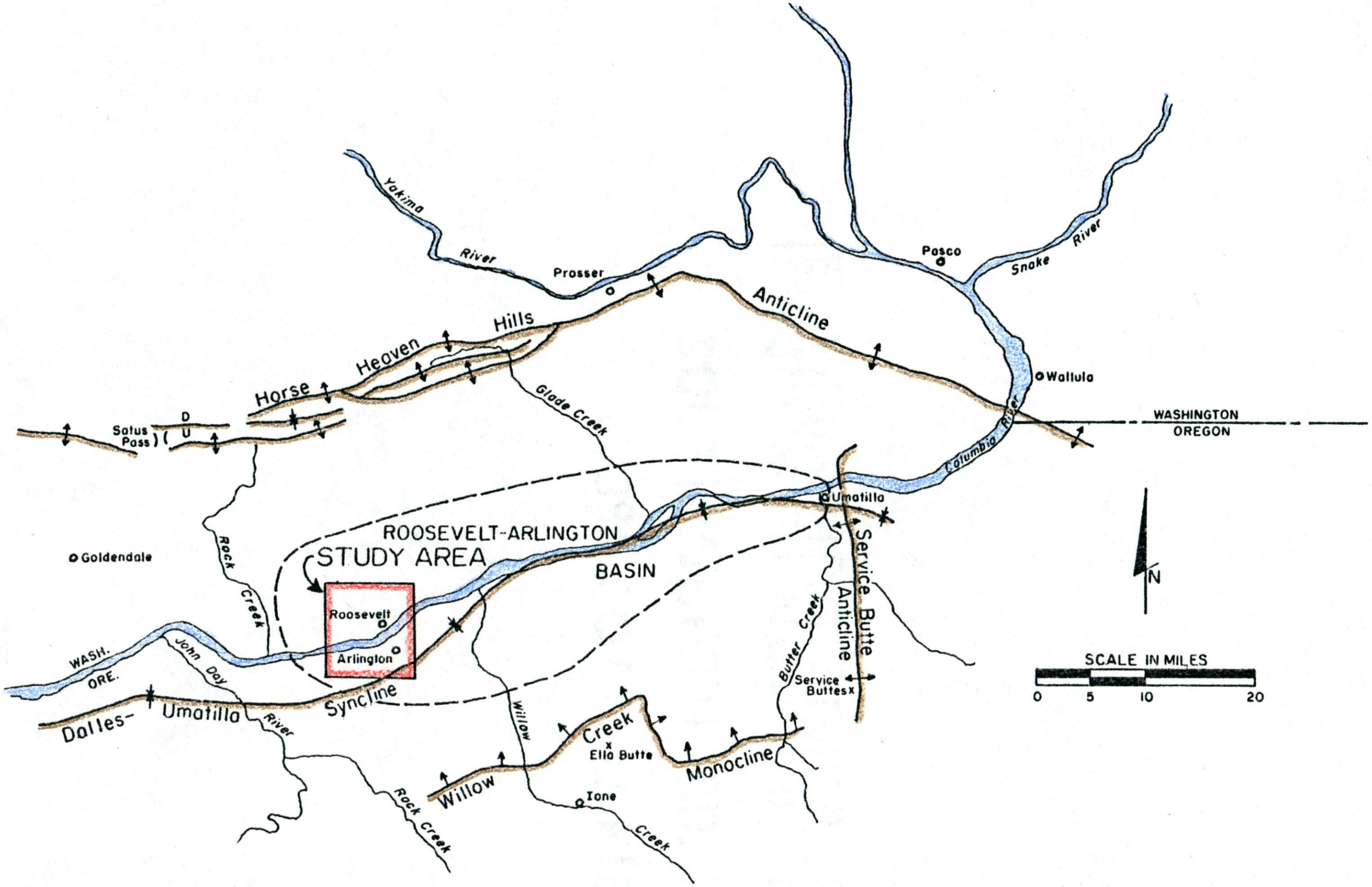


Figure 6. Generalized map showing major structural features defining Roosevelt-Arlington basin in north central Oregon and south central Washington. Structure after Newcomb (1969).

anticline to the east. Thickness contours of the Selah Member in the Roosevelt-Arlington basin (Fig. 5), along with the spatial arrangement of the bounding structures, illustrates the linear and trough-like configuration of the basin.

Age of Structures Much evidence exists for the presence of the bounding structures of the Roosevelt-Arlington basin prior to deposition of the Selah Member. Farooqui and Kienle (1976) have recognized three periods of deformation for the Roosevelt-Arlington basin area: 1) pre-Roza, 2) pre-Selah, and 3) post-Elephant Mountain. Two of the bounding structures of the Roosevelt-Arlington basin are associated with these periods of deformation.

The Willow Creek monocline, to the south, was a structural high formed during a pre-Roza stage of deformation (Farooqui and Kienle, 1976). This structure prevented the advancing Priest Rapids flows from spreading farther south than the north flank of the Willow Creek monocline.

The Horse Heaven Hills anticline, to the north, became a significant structural boundary for the Roosevelt-Arlington basin, probably in pre-Selah time, subsequent to the advance of the Priest Rapids basalt flows, which maintain their thicknesses across the anticline. The presence of the Horse Heaven Hills anticline in some relief prior to Selah deposition is shown by the thinning of the Selah Member (predominantly air-fall tuff) to less than 16 m over the crest of the anticline.

STRATIGRAPHY OF THE SELAH MEMBER

DEFINITION

Extent

The Selah Member occurs over an area of approximately 360,000 km^2; extending on the west from Cowiche Mountain east to Wallula Gap, and from northern Vantage, Washington, to about 9 km south of the Columbia River, in north-central Oregon (Fig. 5).

The Selah Member in the Roosevelt-Arlington basin occurs as a sedimentary interbed, overlain by the Pomona Member of the Saddle Mountain Basalt and underlain by the Priest Rapids Member of the Wanapum Basalt (Schmincke, 1964).

Gross Lithology and Thickness

Within the Roosevelt-Arlington basin the typical lithology of the Selah Member consists of tuff, volcaniclastic siltstone and sandstone, claystone, and basaltic conglomerate. It reaches a maximum thickness of 115 m, near Roosevelt, Washington, in the west-central portion of the basin. The Selah pinches out to the west in the area of Goodnoe Hills (Fig. 5), and to the south along the northern flanks of the Willow Creek monocline. To the east the Selah Member thins gradually and eventually pinches out east of Umatilla, Oregon (Fig. 5). It thins to less than 16 m as it passes north over the Horse Heaven Hills Plateau into central Washington (Fig. 5).

UNIT DIVISION

Definition of Units

Lithologic characteristics and stratigraphic position allow the Selah Member in the Roosevelt-Arlington basin to be divided in this study into three units (Plates 2 and 3).

The lowermost unit I consists principally of sediments of air-fall origin. The middle unit II is subdivided into two time-equivalent interfingering facies. The first, occurring north of the Columbia River, is characterized by truncated trough-set cross-bedded basaltic conglomerate and sandstone overlying an erosional unconformity and is referred to in this study as the tectonic facies. The second, occurring south of the Columbia River, is characterized by uniform fine-grained, thin-bedded sediments and is referred to in this study as the lacustrine facies. An overall change in lithology defines the uppermost unit III. The lithology of unit III is characterized by complex sequences of interbedded fluvial and lacustrine sediments with minor air-fall tuffs.

Contact Relationships

Contact relationships between the three units of the Selah Member are described on Table I, Summary of Bedding Characteristics.

Unit I The base of unit I, and of the Selah Member,

TABLE I

SUMMARY OF BEDDING CHARACTERISTICS

UNIT	THICKNESS(M)	CONTACT RELATIONSHIPS	PRIMARY STRUCTURES
III	41-55	Upper: Sharp, baked (up to 30 cm fused tuff), conformable w/overlying Pomona Member	Parallel bedding w/minor trough-set cross bedding
		Lower: Gradational, change in lithology	
II-tectonic facies	12.1-21.5	Lower: Erosional unconformity w/underlying unit I	Truncated trough-set cross bedding in basal portion grading upward to parallel bedding
II-lacustrine facies	12.4-30.6	Lower: Well-defined change in lithology	Parallel bedding w/minor trough-set cross bedding in some volcanic lith-arenite strata
I	15-23.6	Basal: Sharp, conformable, on underlying relatively fresh Priest Rapids Member	Parallel bedding, w/minor trough-set cross bedding

rests conformably upon a relatively fresh surface of the Priest Rapids Member of the Wanapum Basalt. The top of the basalt, in Section H, is a buckled pahoehoe surface.

The upper contact of unit I with the overlying tectonic facies of unit II is an erosional unconformity. Cut and fill structures are present with irregular channels and pockets gouged into the underlying tuff of unit I and filled with fine- to coarse-grained pebbly volcanic lith-arenite (Fig. 7). Rounded basalt and pumice pebbles occur randomly and in lenses within the volcanic lith-arenite. In some outcrops slight imbrication of the pebbles was observed. Clasts of siltstone and tuff, on the order of 2 to 3 cm in size, and probably derived from the underlying unit I, are incorporated into the volcanic lith-arenite. An iron oxide staining permeates the lower meter of the volcanic lith-arenite along bedding planes and pebble lenses. Nontronite was observed in the basal iron-stained portion of the volcanic lith-arenite, and also detected in the microscopic analysis of samples 81 and 82 (Appendix B).

The contact between unit I and the overlying lacustrine facies of unit II is marked by a change in lithology, from tuff, pumicite and volcaniclastic siltstone upwards into massive and laminated claystone and coal (Plates 2 and 3).

Unit II The tectonic and lacustrine facies of unit II are considered to be interfingering facies. Although

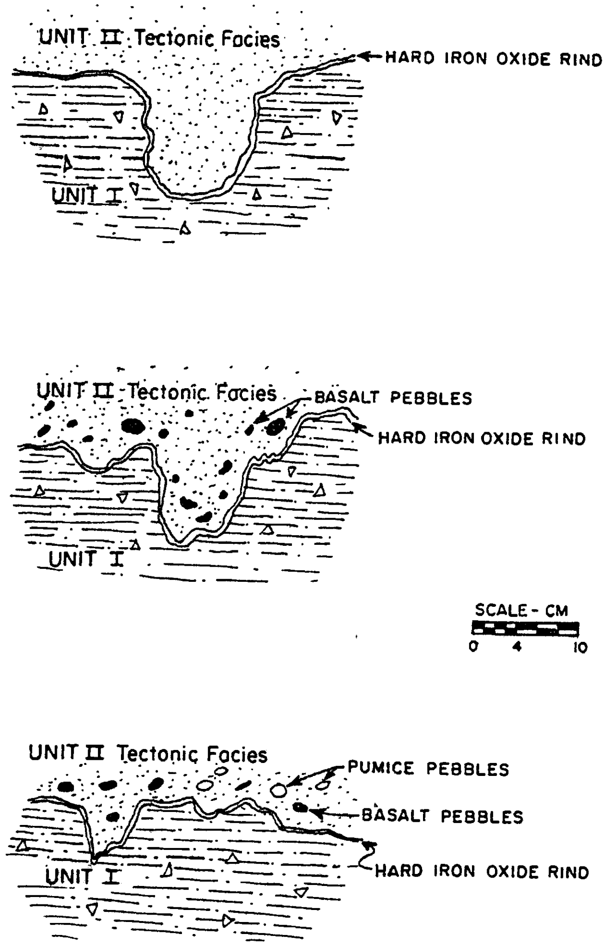


Figure 7. Cut and fill structures common to unit II-tectonic facies/unit I contact, particularly in Section H (NW ¼ sec. 3, T3N, R21E, Wood Gulch, Ore-Wash, 7.5' quadrangle; Appendix A).

this stratigraphic relationship between the tectonic and lacustrine facies has not been observed, it probably lies in an east-west direction within the present course of the Columbia River, now incising the Priest Rapids Member. The location of the facies interfingering is suggested by two field observations. First, the greatest thickness of the Selah Member is centered along the present course of the Columbia River, which also corresponds to the location of the Dalles-Umatilla syncline in the center of the Roosevelt-Arlington basin. Second, the tectonic facies is restricted to the northern portion of the Roosevelt-Arlington basin and exposed along the north bank of the Columbia River, while the lacustrine facies is restricted to the southern portion of the basin and exposed along the south bank of the river.

Unit III The contact between unit III and the underlying unit II is marked by a gradational change in lithology.

The upper contact of unit III with the overlying Pomona Member of the Saddle Mountains Basalt is characterized by a baked zone, ranging in thickness from a few centimeters to nearly a meter. Where volcanic lith-arenite is present below the Pomona Member, individual sand grains are coated with dark blue clay. In Section G, the Selah tuff has been fused to a blue-black obsidian-like rock with a perlitic texture, similar to the contact described by Schmincke (1967a). The thickness of the fused tuff in the

Arlington area ranges from a few to nearly 30 cm. According to Schmincke, the Pomona flow advanced over unconsolidated, low density sediments, forming a fused tuff. The formation of fused tuff, rather than pillow-palagonite complexes as exposed at the base of other Yakima Basalt flows, was probably a result of a general drying-out of Selah sediments and the disappearance of lakes prior to the out-pouring of the Pomona Basalt.

LITHOLOGY AND SEDIMENTARY STRUCTURES

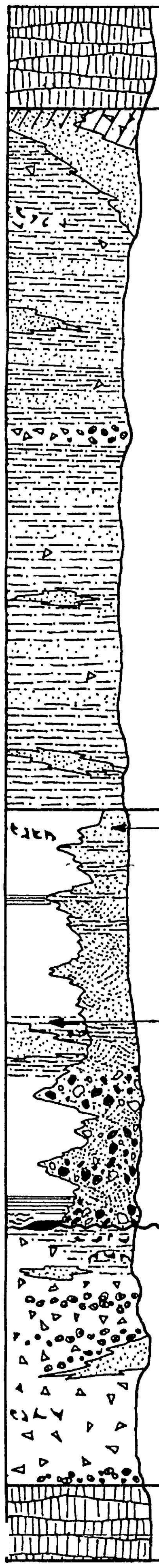
Lithology

The lithology of the three units of the Selah Member is summarized in the composite stratigraphic section, Figure 8. Detailed lithology of each measured section is shown in Plates 2 and 3, and described in Appendix A.

Unit I Unit I ranges in thickness from 15 to 23.6 m (Table I); thinning slightly to the south. A basal air-fall tuff sequence, thickest in the northern portion of the Roosevelt-Arlington basin, consists of dark green lapilli and accretionary lapilli tuff. A layer of white to light gray, thin-bedded, fissile pumicite within this basal sequence is described in Section H (Appendix A).

The basal air-fall tuff sequence is overlain by a laterally persistant layer of volcanic lith-arenite, it is brown to gray in color and tends to be slightly to moderately well cemented. In outcrop, it forms prominant cliffs which are steeper where the degree of cementation

COMPOSITE STRATIGRAPHIC SECTION
SELAH MEMBER



POMONA MEMBER of the
SADDLE MOUNTAIN BASALT
Age = 12 million years (McKee, Swanson, and Wright, 1977)

UNIT III: 41-55 m thick; consists of parallel interlayered beds of light gray to brown and pale yellow siltstone and volcanic lith-arenite, with lenses of tuff and accretionary lapilli tuff in central portion, thin-bedded white pumicite in upper portion, layers of fine- to medium-grained volcanic lith-arenite throughout and at top of unit; has gradational lower contact defined by overall change in lithology, upper contact baked up to 1 m thick with formation of fused tuff north of Columbia River.

UNIT II-Tectonic Facies: 12.1-21.5 m thick; north of Columbia River, basal sequence consists of truncated trough-set cross bedded beds of gray go brown basaltic conglomerate and volcanic lith-arenite grading to upper sequence of parallel bedded gray to brown vitric and feldspathic volcanic lith-arenite and sandy siltstone; interfingers to south with time-equivalent lacustrine facies; upper contact defined by overall change in lithology.

UNIT II-Lacustrine Facies: 12.4-30.6 m thick; south of Columbia River; consists primarily of massive and laminated dark green to brown and gray claystone, a basal 0.3 m lens silicified coal, and lenses of brown and gray vitric (volcanic) lith-arenite, siltstone and tuff in central portion, and light gray thin-bedded pumicite in upper portion; interfingers with time-equivalent tectonic facies; upper contact defined by overall change in lithology.

UNCF

UNIT I: 15-23.6 m thick; consists primarily of dark green tuff, lapilli tuff, and interbedded lenses of accretionary lapilli tuff, with lenses white-light gray thin-bedded pumicite in upper and lower portions, brown to gray volcanic lith-arenite in middle and upper portions, and pale gray to green siltstone in upper portion; basal contact sharp, upper contact defined by erosional unconformity.

PRIEST RAPIDS MEMBER of the WANAPUM BASALT
~~Age = 13.5 million years (Mckee, Swanson, and Wright, 1977)~~

EXPLANATION

Conglomerate (Basalt = ●; Pumice = ○)	Coal	Laminations
Sandstone	Tuff	Convolute Laminations
Siltstone	Accretionary Lapilli Tuff	Volcaniclastic
Claystone	Pumicite	Baked Zone

Figure 8. Composite stratigraphic section of the Selah Member, Ellensburg Formation. For detailed descriptions of sections see Appendix A, and Plates 2 & 3.

is greatest.

Above the volcanic lith-arenite, the upper portion of unit I consists of dark green interbedded lapilli and accretionary lapilli tuff grading upwards to pale gray and green siltstone and white thin-bedded pumicite in the western and northern portion of the Roosevelt-Arlington basin.

In outcrop, unit I is more resistant than the overlying units II and III, and tends to form slightly steeper slopes.

Unit II The tectonic facies of unit II ranges from 12.1 to 21.5 m in thickness, and consists of a basal sequence of gray to brown interbedded basaltic conglomerate and sandstone, grading upwards to interbedded gray to brown sandstone and siltstone. In general, the tectonic facies is not cemented, and tends to form moderately steep slopes.

The lacustrine facies of unit II ranges from 12.4 to 30.6 m in thickness (Table I), and thins slightly to the south. An 0.3 m thick layer of silicified coal marks the base of the lacustrine facies, and grades to brown and green laminated and convolute-laminated claystone to the south. The coal is overlain, in ascending order, by a basal thick layer of dark green massive claystone; an interbedded sequence of brown and gray claystone, siltstone, vitric (volcanic) lith-arenite, and tuff; and a dark green to gray massive claystone grading laterally toward the Columbia River (north) to light gray thin-bedded pumicite.

In general, the lacustrine facies has a low resistance to erosion and, in outcrop, tends to form very gentle slopes.

Unit III The thickness of unit III ranges from 41 to 55 m (Table I), and is thickest southeast of Arlington, Oregon (Section C, Appendix A).

Unit III consists primarily of interbedded thin-bedded volcaniclastic siltstone and volcanic lith-arenite. Massive layers of fine- to medium-grained volcanic lith-arenite occur both at the base and top of unit III. A thin lens of accretionary lapilli tuff grading southward to tuff occurs at about 25 m from the top of unit III. The color of unit III (shades of light gray, brown, and pale yellow) is in marked contrast to the darker browns and greens of unit II. This is a valuable aid in field identification of unit III.

Unit III forms very gentle slopes, reflecting the low resistance of the thin-bedded sediments.

Primary Structures

Unit I Parallel bedding of massive tuff beds is the primary structure within unit I (Table I). Accretionary lapilli tuff layers are commonly discontinuous laterally over short distances, with an apparent random size distribution of accretionary lapilli. The majority of the lapilli are nearly spherical in shape, and only a small percentage slightly flattened parallel to bedding.

Volcanic lith-arenites are typically massive and thin out laterally over short distances. The cliff-forming and laterally persistant volcanic lith-arenite exhibits truncated trough-set cross bedding only in Section D (Appendix A). Siltstones (Sections A, D, E, and I) are thin-bedded, with bedding planes marked occasionally by thin layers of fissile pumicite (Section E, Appendix A).

Unit II The primary structure in the lower portion of the tectonic facies is characterized by truncated trough-set cross bedding of the conglomerates and sandstones, which overlie an erosional unconformity. This suggests a high sediment-load environment of deposition such as steep gradient, braided streams in an area of tectonic uplift.

The subrounded to rounded pebbles which occur in the volcanic lith-arenite are commonly imbricated. Five bedding orientation measurements made of both the trough-set cross bedding and pebble imbrication (Sections D and H, Appendix A) suggest a dispersal direction towards the ESE and SE.

In the upper portion of unit II-tectonic facies, the primary structure is conformable parallel bedding of the vitric and feldspathic volcanic lith-arenite and sandy siltstone. Each parallel bedding set consists of fine-grained silty vitric or feldspathic volcanic lith-arenite (1.5 to 3.5 m thick) grading upwards to sandy siltstone (30 to 60 cm thick). Within the fine-grained silty vitric or feldspathic volcanic lith-arenite are massive to graded bedded strata ranging in thickness from about 4 to 6 cm. The vague parallel bedding within the sandy siltstone is marked by lighter colored volcaniclastic siltstone layers.

Within the unit II-tectonic facies the change in primary structures, from truncated trough-set cross bedding at the base to conformable parallel bedding in the upper portion, suggests that the energy of the depositional environment decreased upwards. This may be a result, in part, of an early period of accelerated uplift of the Horse Heaven Plateau area to the north, possibly coupled with minor subsidence of the Dalles-Umatilla syncline in the Roosevelt-Arlington basin. This period of tectonic activity appears to have been short lived, based upon: 1) the upwards decrease in depositional environment energy within the tectonic facies, and 2) the occurrence of the basaltic conglomerates, along with their thinness relative to the total thickness of the Selah Member.

The primary structure of unit II-lacustrine facies is typified by parallel bedding, as interpreted from drilling cores. Volcanic lith-arenite and sandy siltstone within the upper 20 m of the lacustrine facies exhibit primarily parallel bedding with minor trough-set cross bedding.

Unit III The primary structure within unit III is parallel bedding of conformable beds of vitric (volcanic) lith-arenite and volcanic lith-arenite, siltstone, and tuff. Within individual volcanic lith-arenite strata, both parallel bedding, including massive and graded textures, and minor trough-set cross bedding occur. Parallel bedding sets, which occur at 30 to 60 cm intervals, consist of fine-grained silty vitric (volcanic) lith-arenite and volcanic lith-arenite layers (2 to 3 cm thick) grading upwards to siltstone. In unit III tuff beds are typically massive in structure, while the pumicite (Section G, Appendix A) is thin-bedded and fissile.

Secondary Structures

Secondary structures were noted in portions of the Selah Member, particularly within the lacustrine facies of unit II, and in portions of unit III.

A pencil-type fracturing is common to the thickest claystone layer in the lower portion of the lacustrine facies (Plate 3). The pencil-fracturing, observed in fresh drilling cores, is essentially vertical (perpendicular to the plane of bedding) and very closely spaced.

Concretions occur in the lacustrine facies and in unit III. Commonly the concretions contain cores of pyrite and/or chalcopyrite, or fish vertebrae with pyrite encrustations.

Columnar jointing, with columns measuring up to 1 or 2 cm in diameter, occur within the fused tuffs at the contact between unit III and the Pomona Member. Development of columnar jointing was caused by baking of the unit III tuff by the overlying Pomona flow.

Grain Size Characteristics

Sand:silt:clay ratios for 39 samples of the Selah Member are plotted on a triangular diagram (Fig. 9). In general, the 39 samples fall into Folk's (1974) classification of sandy siltstone, silty sandstone, or sandstone. Individually, each unit occupies a distinctive, although overlapping, field on the diagram. The lacustrine facies-unit II and unit III are of similar configuration in a narrow zone ranging from sandy siltstone to silty sandstone. Plots of unit II-tectonic facies form a relatively broad zone with a more restricted range from silty sandstone to sandstone. Unit I also forms a relatively broad field, with a smaller range from sandy siltstone to silty sandstone.

In addition to the grain size parameters listed on Table II, Summary of Grain Size Characteristics, the size distribution for each of the units of the Selah Member are illustrated by the cumulative grain size curves of Figures 10 through 13. As can be seen from these data, sorting (σ_I) in the three units of the Selah Member ranges from poor to extremely poor. Units I and III tend to be very poorly to extremely poorly sorted, while the tectonic facies of unit II is very poorly sorted. Sorting in unit II-lacustrine facies varies from poor to extremely poor. Skewness (SK_I) values in units I and II range from fine- to strongly fine-skewed, while unit III is strongly fine-skewed.

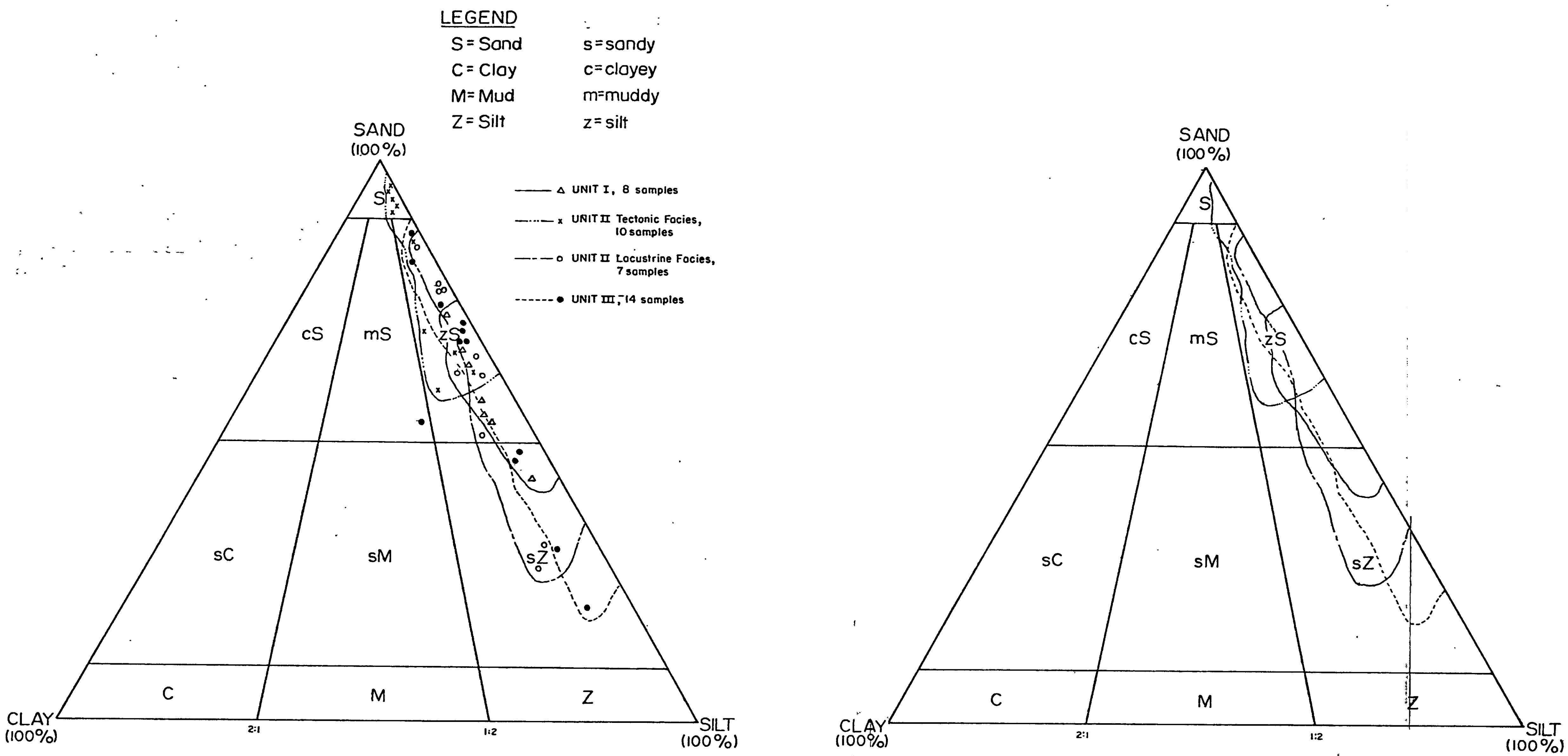


Figure 9. Sand:silt:clay ratio diagram for 38 samples from Selah Member. The triangular diagram, at right, shows the respective fields occupied by each of the units of the Selah Member. The data points within each field are shown on a similar diagram, at left.

TABLE II

SUMMARY OF GRAIN SIZE CHARACTERISTICS

Unit	Sample No.	$M_z(\emptyset)$*	$\sigma_I(\emptyset)$*	SK_I*
Unit III	10	3.65	2.42	+.50
	11	2.64	1.19	+.54
	14	4.68	3.12	+.54
	28	4.64	-	-
	31	4.96	3.89	+.74
	35	7.06	4.22	+.51
	50	4.75	4.80	+.78
	52	2.86	4.06	+.56
	55	4.62	2.81	+.63
	57	7.37	3.99	+.57
	58	4.63	2.5	+.53
	59	4.62	2.64	+.66
	60	4.14	2.3	+.72
	61	7.68	3.85	+.23
Unit II - Tectonic Facies	81	1.0	3.3	+.7
	82	1.63	3.6	+.2
	83	2.3	2.7	+.6
	84	2.7	2.4	+.6
	88	0.1	1.3	+.4
	105	3.6	1.85	+.62
	106	1.8	1.24	+.4
	109a	3.9	1.59	+.7
Unit II - Lacustrine Facies	6	2.38	1.43	+.57
	19	3.77	2.26	+.74
	20	3.6	2.3	+.69
	21	5.2	2.77	+.43
	38	7.23	4.43	+.07
	39	4.8	3.07	+.73
	40	6.27	3.31	+.15
Unit I	24	5.9	3.9	+.47
	42	4.4	4.5	+.33
	44	4.4	4.2	+.51
	45	3.6	4.1	+.73
	66	3.5	3.9	+.57
	67	3.1	4.1	+.46
	86	-0.4	2.3	+.4
	90	0.6	2.2	+.46
	91	3.62	2.1	+.16

*Note: Graphic mean (M_z), inclusive graphic standard deviation (σ_I), and inclusive graphic skewness (SK_I) after Folk (1974).

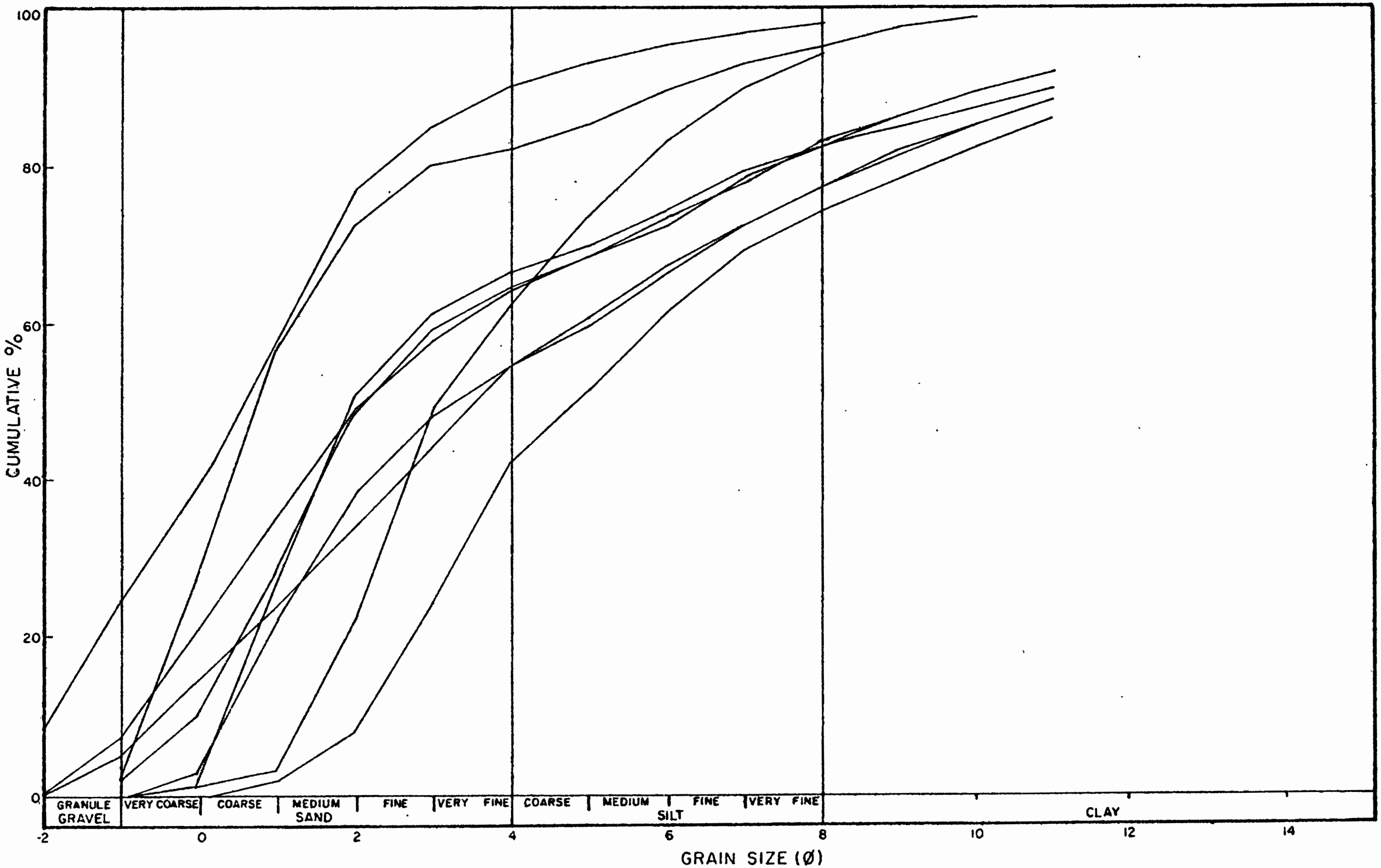


Figure 10. Cumulative curves showing size distribution for 9 samples from unit I of the Selah Member.

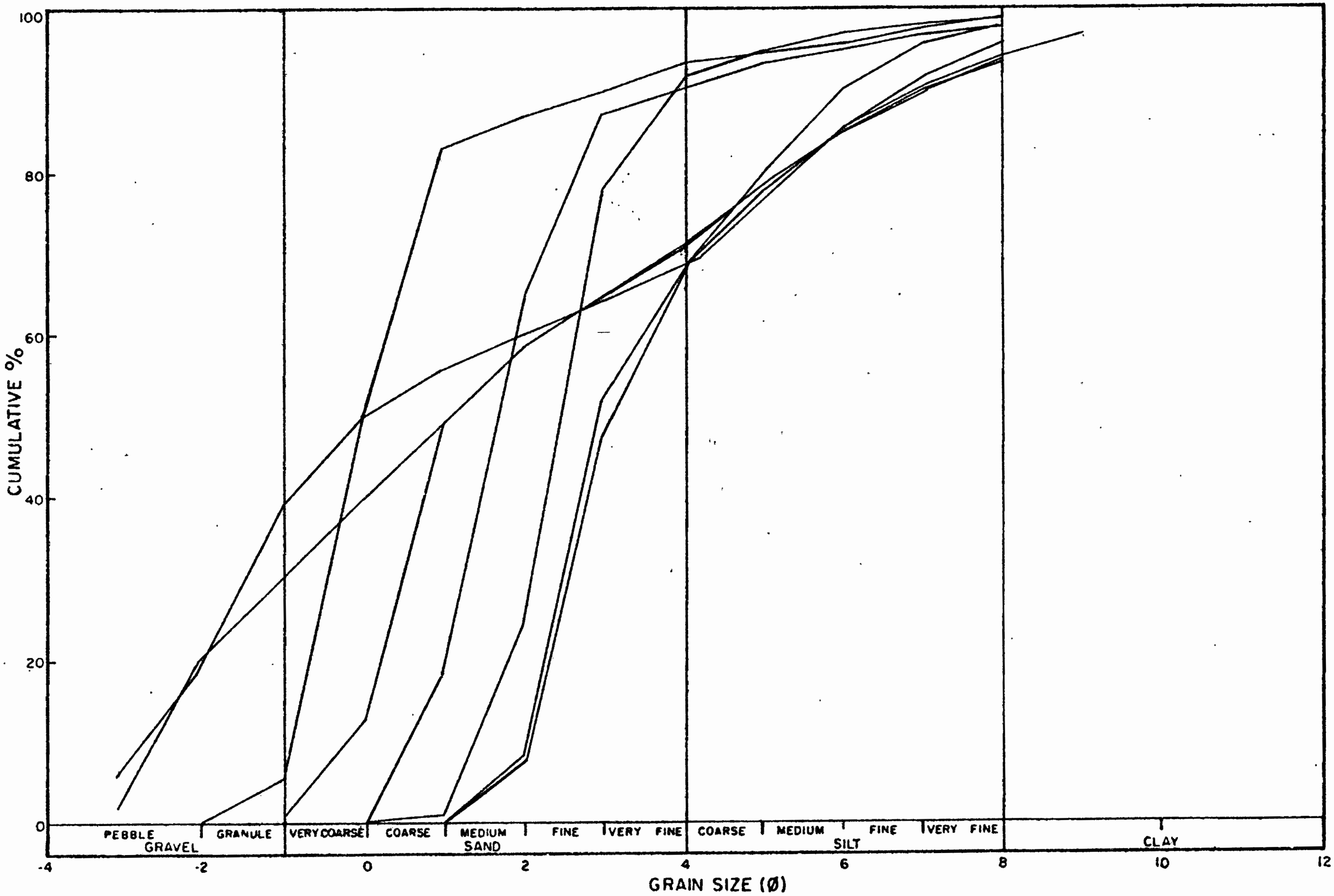


Figure 11. Cumulative curves showing size distribution for 8 samples from unit II-tectonic facies of the Selah Member.

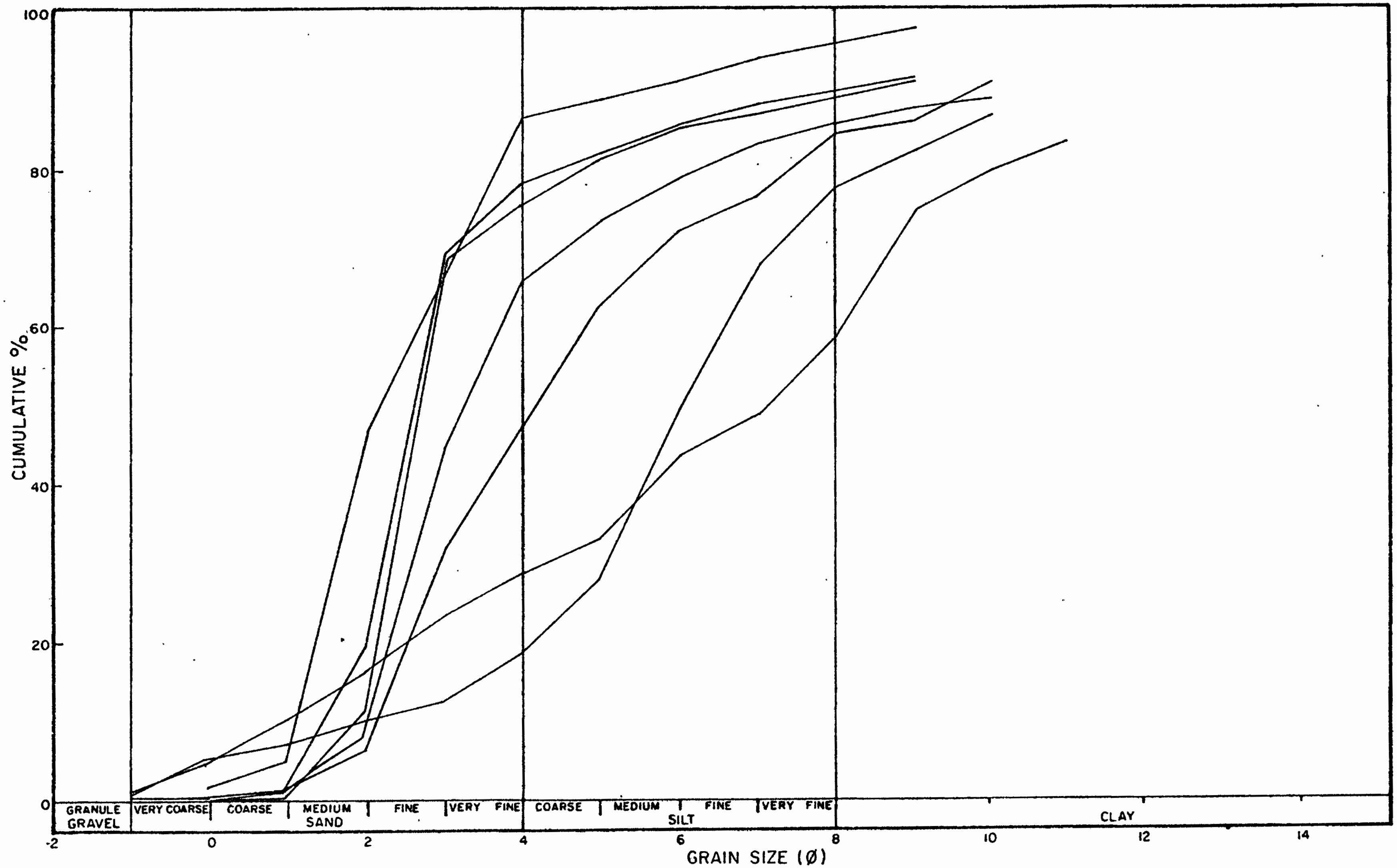


Figure 12. Cumulative curves showing size distribution for 7 samples from unit II-lacustrine facies of the Selah Member.

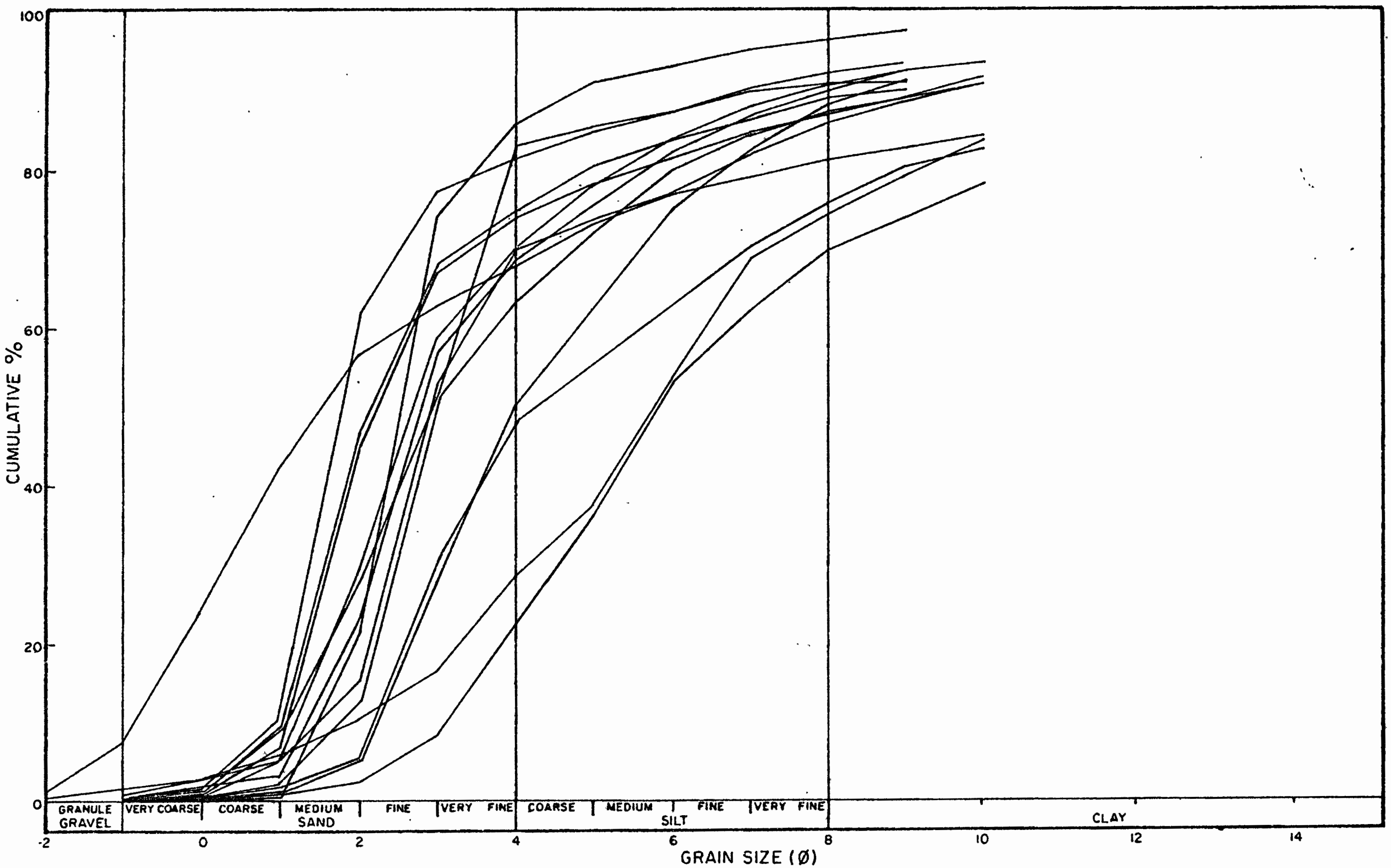


Figure 13. Cumulative curves showing size distribution for 14 samples from unit III of the Selah Member.

A plot of graphic mean (M_z) versus sorting (σ_I) for 36 samples from the three units of the Selah Member is shown in Figure 14. The 36 samples are representative of vertical and lateral extent of each unit within the study area. A vertical trend between these two grain size parameters in each of the units (except the tectonic facies-unit II) is evident. Unit I (air-fall; open squares), unit II-lacustrine facies (crosses), and unit III (open circles) show a vertical increase in median diameter coupled with a higher degree of sorting. While this is consistent with Inman's (1949) discussion on the increase in the degree of sorting for grain sizes increasing to 0.18 mm in diameter, the trend is upward within each unit (except the tectonic facies-unit II), and not laterally (i.e. progressive or downstream increase in sorting). As discussed in the following paragraph, the trend for the tectonic facies shows lateral, or direction changes. The vertical trend of unit I, III, and lacustrine facies-unit II may, then, be more representative of a lacustrine, or settling, environment of deposition, rather than a fluvial environment. It may also be indicative of a low velocity fluvial environment. The high volume of air-fall sediments in the three units, regardless of the depositional environment, and the consistently low degree of sorting suggests that the volume of sediments introduced persistently exceeded the sorting ability of the depositional environment, resulting in a high sediment volume/sorting ability ratio. This high

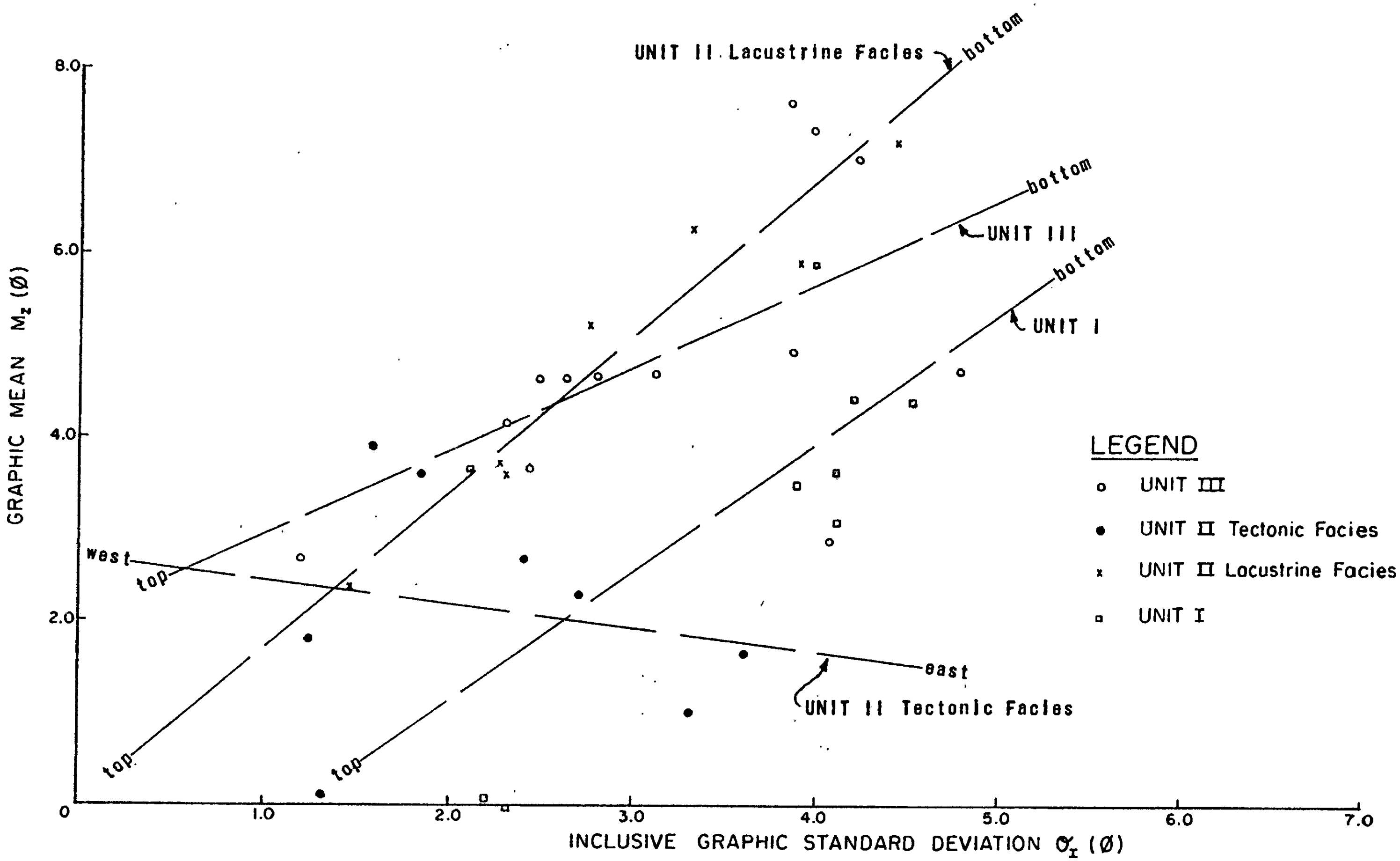


Figure 14. Plot of graphic mean (M_z) versus inclusive graphic standard deviation (σ_I) (i.e., sorting) for units I, II, and III of the Selah Member. Plot of Unit II-tectonic facies suggests aggradational environment such as alluvial fan, while unit I, unit II-lacustrine facies, and unit III suggests sustained air-fall deposition into relatively static fluvial/lacustrine system. Grain size parameters after Folk (1974). Best fit curve according to statistical method of linear regression using $y=a_1x+a_0$ ($M_z=a_1\sigma_I+a_0$).

ratio of sediments supplied versus sorting ability is interpreted to be a result of sustained air-fall deposition into a relatively static fluvial/lacustrine system.

The unit II-tectonic facies (closed circles) graphic mean/sorting plot (Fig. 14) indicates that the degree of sorting increases to the west along with a decrease in mean size. This westerly increase in sorting coupled with a decrease in mean size suggests an aggradational environment, such as an alluvial fan, centered in the eastern portion of the study area, where the flow gradient is steep and the distance of transport is short.

Cementation

Cementation within the Selah Member is restricted to portions of the lacustrine facies of unit II and unit I. Petrographic analysis (see Petrography) identifies siderite as a cementing agent. Traces of siderite were found in samples 38, 39, and 40 (Table IV, Appendix B), from unit II-lacustrine facies. An abundance of siderite, up to 82.1 percent by volume of the total heavy mineral fraction, was found in samples 45, 66, and 67, all from the cliff-forming volcanic lith-arenite bed of unit I.

According to Jackson (1970), siderite may develop from ferrous iron in a reducing environment, below the water/sediment contact, where there is a low supply of sulfur and abundant carbon dioxide given off by the decay of organic debris. The formation of siderite is restricted in environment, inasmuch as it is precipitated only from sediment pore water. The formation and occurrence of siderite is discussed in further detail under Authigenic Minerals (see Petrography).

General Discussion

A lithologic comparison between the Selah Member in the Roosevelt-Arlington basin, and the Selah Member/Ellensburg Group of central and south-central Washington, reveals some significant similarities and differences.

A thick unit of lapilli tuff, with interbedded layers of accretionary lapilli, is present at the base of the Selah Member in the Roosevelt-Arlington basin. Schmincke (1964) noted a similar basal tuff containing accretionary lapilli, persisting throughout central Washington and across the Horse Heaven Hills.

Thin-bedded and fissile pumicite occurs throughout the Selah Member of the Roosevelt-Arlington basin, and are similar in composition to those exposures of the Selah Member in Mackin's (1961) Beverly Section and at Selah Butte Ridge in central Washington. Although the number of pumicite layers and their thicknesses vary, they do consistently occur in the Selah Member in unit I (at the top and toward the base), at the top of unit II-lacustrine facies, and at the top of unit III.

Up to 30 cm of the top of the Selah Member within the Roosevelt-Arlington basin has been baked by the overriding

Pomona Member; a columnar jointed or obsidian-like fused tuff is commonly present. Similar baked zones at the Pomona-Selah contact in central and south-central Washington are reported by Laval (1956) and Schmincke (1964; 1967a).

Lahars, as described by Schmincke (1964; 1967a), are not present in the Selah Member of the Roosevelt-Arlington basin. By contrast, lahars are common to the Ellensburg Group of central Washington, particularly in the western portion of the Columbia Plateau, adjacent to the eastern flanks of the Cascade Range. Lahars and pyroclastic flows typically advance along natural topographic lows, such as stream valleys. The lack of lahars within the Selah Member of the Roosevelt-Arlington basin suggests that: 1) laharic episodes did not occur in the southern Washington Cascades during Selah-time, or 2) if they did occur, their volume was not sufficient to reach the Roosevelt-Arlington basin, or 3) there was no direct access to the Roosevelt-Arlington basin via stream valleys. If the latter is valid, it further suggests that the Roosevelt-Arlington basin may have been structurally and/or topographically isolated from the Cascade Range in terms of long distance fluvial transportation of volcanic and clastic detritus, and that introduction of Cascade volcanic debris was primarily by means of air-fall deposition.

Quartzitic conglomerates were not observed within the Selah Member of the Roosevelt-Arlington basin during the course of this study. Most workers concur that the presence of quartzitic conglomerates denotes a former channel of the Columbia River, or a tributary. Quartzitic conglomerates have been described within the Selah Member of central Washington by Waters (1955), Laval (1956), Mackin (1961), Schmincke (1964), and Grolier (1965). Two interpretations may be drawn by the lack of quartzitic conglomerates in the Selah Member in the Roosevelt-Arlington basin. First, and most importantly, the lack of quartzitic conglomerates suggests that the ancient Columbia River was not in its present position during deposition of the Selah Member in the Roosevelt-Arlington basin. Rather, the presence of quartzitic conglomerates in Ellensburg sediments exposed stratigraphically above Wanapum Basalt, and below the post-Pomona Simcoe Basalt (0.9 to 4.5 my, Kienle and Newcomb, 1973), between Goldendale, and Satus Pass, Washington, indicates that the Columbia River lay to the west. The time-stratigraphic span between the Wanapum Basalt and the Simcoe Basalt (13.5 to 4.5 my) encompasses the period of deposition of the Selah Member (13.5 to 12 my). Second, if the ancient Columbia River was not in its present position during deposition of the Selah Member in the Roosevelt-Arlington basin, then the basin was perhaps isolated structurally, or topographically, from the plutonic and metamorphic provenances to the north and west.

PETROGRAPHY

DISCUSSION OF TERMS

Thirty-three samples were selected from the Selah Member for petrographic analysis. The stratigraphic locations of the samples are summarized on Plates 2 and 3, along with percentages of some minerals shown to the right of the stratigraphic sections.

Light Minerals

A tabulation of percentages for the light minerals present in the Selah Member are presented on Table III, entitled Summary of Petrographic Data, Light Minerals (Appendix B). Also summarized on Table III is the rock name classification system used in this study.

The rock classification system used in this study is modified after Folk's (1974) classification of sandstones, and is shown on the diagram of Figure 15. According to Folk (1974), arenite (sandstones) which are composed of more than 50 percent rock (lithic) fragments may be called lith-arenite, and those rocks which contain 25 to 50 percent feldspar are called feldspathic lith-arenite. All of the rock samples from this study fall into Folk's categories of feldspathic lith-arenite and lith-arenite (Fig. 15).

According to Folk, if the origin of the lithic

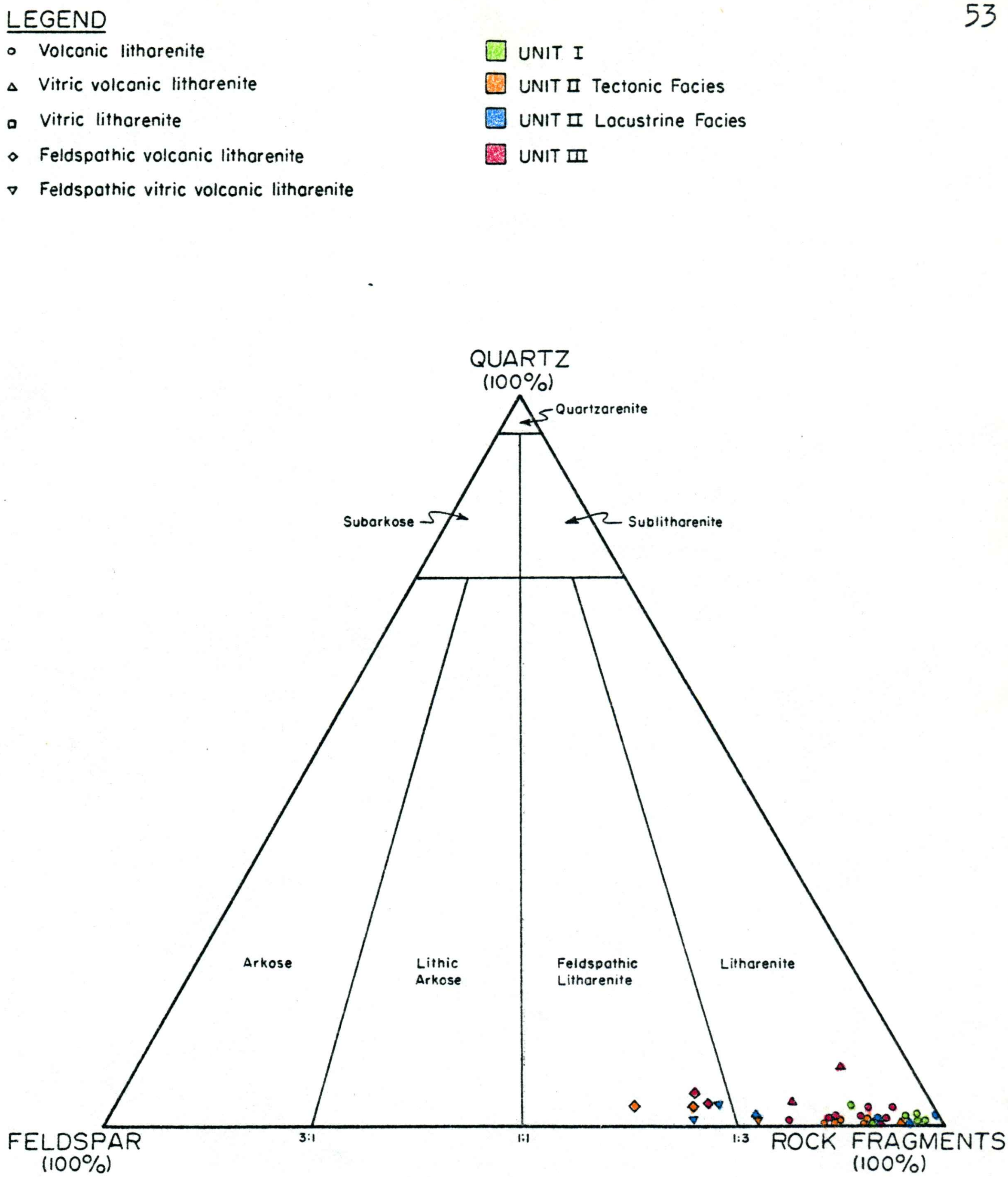


Figure 15. Rock classification distribution diagram for units I, II, and III of the Selah Member. Triangular diagram and classification modified after Folk (1974). See text for definition of rock types listed above.

fragments can be determined, then a primary modifier may be used with the term lith-arenite. The lithic fragments in this study are volcanic; therefore, the term volcanic lith-arenite is used. Folk further suggests that a secondary modifier may be used if rock type distinctions can be made within the predominant lithic fragment group. The volcanic rock fragments in this study are divided into; 1) altered vitric (devitrified volcanic ash), 2) fresh volcanic glass, and 3) volcanic (extrusive lava). All three types of volcanic rock fragments are included in the total percentage of rock fragments.

The modification of Folk's sandstone classification system used in this study is intended to emphasize the presence of fresh volcanic glass, without altering the defining compositional percentages as described by Folk (1974). The rock names used in this study are defined in Table III, and consist of utilizing the term vitric (fresh volcanic glass) as a secondary modifier when 10 to 50 percent of the rock fragments consist of fresh volcanic glass. Vitric is used as a primary modifier following Folk's (1974) usage, when more than 50 percent of the rock fragments consist of fresh volcanic glass.

Heavy Minerals

A tabulation of percentages for the heavy minerals

TABLE III

SELAH MEMBER ROCK CLASSIFICATION SYSTEM

Rock Name	Lithic Fragments		Feldspar***
	Volcanic*	Vitric**	
Volcanic lith-arenite	75%	10%	25%
Vitric (volcanic) lith-arenite	75%	10-50%	25%
Vitric lith-arenite	75%	50%	25%
Feldspathic volcanic lith-arenite	50-75%	10%	25-50%
Feldspathic vitric (volcanic) lith-arenite	50-75%	10-50%	25-50%

*Lithic fragment percentage of total light mineral fraction.

**Fresh volcanic glass percentage of total volcanic rock fragment fraction.

***Feldspar percentage of total light mineral fraction.

present in the Selah Member are presented on Table IV, entitled Summary of Petrographic Data, Heavy Minerals (Appendix B). For ease of discussion, the heavy minerals have been grouped under the subheadings, following Folk (1974), of opaque minerals, ultrastable minerals (those minerals which survive prolonged abrasion or multiple reworking), metastable minerals (those minerals less resistant to abrasion), and authigenic minerals.

LIGHT MINERALS

The total light mineral fraction in unit I, unit II-lacustrine facies, and unit III ranges from 92.3 to 99.8 percent by weight, and in unit II-tectonic facies, from 79.5 to 98.9 percent by weight. The light mineral assemblage consists of rock fragments, plagioclase and potassium feldspar, glass, and quartz.

Rock Fragments

As can be seen on Table III, rock fragments comprise from 30.7 to 96.9 percent, by volume, of the total light mineral fraction. Three types of rock fragments include altered vitric, volcanic, and metamorphic/plutonic.

Altered vitric fragments, interpreted to be volcanic ash in moderate to extreme stages of devitrification, are the most abundant type of rock fragment in the majority of the samples analyzed. The altered vitric fragments are typically rounded to subrounded. Polarized light is transmitted variably in the vitric fragments, giving rise to a "patchy" extinction. Color under plane polarized light ranges from yellow and yellow green, to light yellow browns, with first order colors of yellow to orange common under crossed nicols. The index of refraction is close to, and commonly slightly above 1.54. Grain structure varies from homogeneous to a relict vesicular structure with internal radial structure. Relict crystals are common in the altered vitric grains, with occasional relict feldspar laths, β-quartz pseudomorphs, and diatom inclusions (see Paleontology).

Alteration products of the vitric fragments include chlorite (sample 7), nontronite (sample 59), and sericite. Zeolites occur commonly as a void or vesicle filling, along with calcite (present at some grain boundaries, possibly as an overgrowth or cement).

Volcanic rock fragments typically comprise less than 5 percent by volume of all rock fragments. Although highly altered, the volcanic rock fragments are probably of andesitic to basaltic composition. The volcanic rock fragments are subangular to rounded, and consist of randomly oriented to subparallel feldspar laths, commonly less than .05 mm in length, set in a brown to black highly altered matrix.

Results of a pebble count, made on three samples from unit II-tectonic facies, are shown diagrammatically on the histogram of Figure 16. One hundred randomly chosen pebbles were examined from each sample, with both the composition and roundness noted. The volcanic rock fragment portion of samples 93 and 110, which consist of 99 and 98 percent by volume basalt, respectively, tends to be of greater roundness than the rock fragment portion of sample 105, which consists of 95 percent by volume andesite, fused crystal tuff, and pumice. An incongruity is evident, in that pebble constituents of greater hardness and resistance exhibit a higher degree of roundness. This would suggest that either the more resistant constituents have been transported for a greater distance, or perhaps that eruptive volcanic material greater than lapilli size (4 to 32 mm) was being introduced into the Roosevelt-Arlington basin as air-fall with subsequent reworking.

Metamorphic/plutonic rock fragments are identified as meta-quartzarenite, and may be distinguished from chert by their coarse-grained texture. The metamorphic/plutonic rock fragments are subangular to rounded with sutured grain boundaries and undulose extinction. They were probably derived from a metamorphic/plutonic province outside of the Roosevelt-Arlington basin, and carried in by means of a through-flowing stream such as the Snake or Umatilla Rivers. The first occurrence of the metamorphic/plutonic rock fragments is in the tectonic facies-unit II (samples 81 and 82), and also in the overlying unit III.

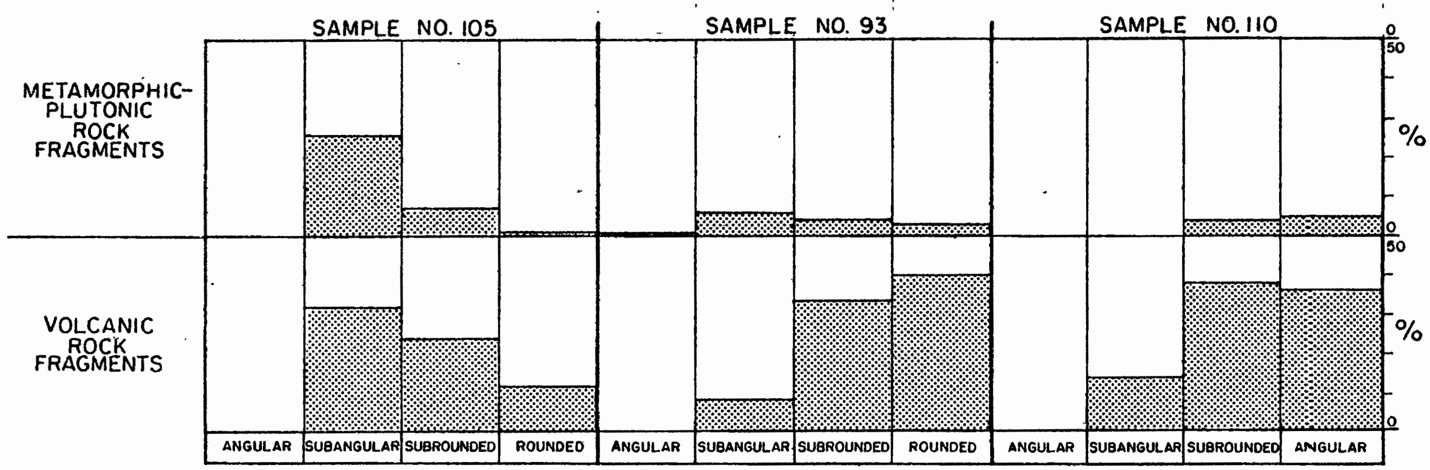


Figure 16. Histogram of pebble count for three samples from unit II-tectonic facies. Metamorphic-plutonic fraction consists of metaquartz-arenite and granitic rocks; volcanic fraction consists principally of basalt, volcanic glass, andesite, crystal tuff, and pumice. The volcanic fraction of sample 105 consists of 5% rounded basalt; in samples 93 and 110 the volcanic fraction consists of 99% and 98%, respectively, of rounded basalt. Roundness after Pettijohn (1957). See Plate 2 for sample locations.

Feldspar

Both plagioclase and potassium feldspar are present throughout the Selah Member, with plagioclase typically more abundant (Table III, Appendix A). In most cases, the two feldspars were differentiated on the basis of optical properties, twinning, cleavage, and grain shape. However, where differentiation was difficult, staining characteristics aided in identification.

In general, the plagioclase feldspars are unaltered and contained no inclusions. A few grains, however, contain highly birefringent inclusions. Alteration where noted, consists of fine-grained sericite occurring in thin wedges along composition planes, as well as at grain boundaries and in randomly oriented zones.

Of the plagioclase feldspar grains examined in the Selah, nearly all are subhedral to euhedral, with grain boundaries formed by (010) and/or (001) planes. Most grains are bounded by at least one fractured side. Plagioclase feldspars with no well-defined twinning contained internal cleavage traces. All twinned individuals were examined in terms of proper orientation for the purpose of composition determinations. The majority of the grains exhibit twinning, with albite the most common form, and Carlsbad and combined albite-Carlsbad occurring occasionally. Nine composition determinations were made on combined albite-Carlsbad twinned grains. Composition values of Ab_{48-56}, typical to unit I, fall within the range of andesine to labradorite. Composition values of Ab_{20-40}, typical of units II and III, fall within the range of oligoclase to andesine. The predominance of albite and Carlsbad twinning, in conjunction with the sparsity of zoned individuals throughout the Selah, would suggest that source rocks may have been high temperature extrusive rocks, as opposed to plutonic or intrusive. An occasional zoned feldspar was noted; although poorly oriented, highly eroded and fragmented. Occasional Baveno twinning was also observed in poorly oriented and highly fractured grains.

Sanidine is the most common potassium feldspar, followed in abundance by orthoclase. Sanidine occurs in clear unaltered euhedral crystals, coated in varying degrees with fresh to slightly devitrified glass. Some sanidine crystals are interpreted to be epiclastic constituents, probably of primary volcanic origin, introduced by air-fall with subsequent reworking.

Orthoclase feldspar occurs as anhedral, subangular to subrounded grains, with occasional Carlsbad twinning. Some grains were slightly corroded, or contained inclusions. Fine-grained sericite is a common alteration product at the center of some grains. A trace of perthitic microcline was also noted (Table IV, Appendix B).

Glass

Glass types include shards and pumice, clear glass with opaque inclusions, and palagonite. Shards and pumice are the most abundant forms of glass. These are typically unaltered and angular. The shards vary in color from clear to shades of light brown or gray brown, while the pumice is typically clear. The index of refraction of the glass is, by comparison, equal to, or slightly less than 1.54. Vesicles in the glass are commonly lined or filled with devitrified glass or clay. While glass shards and pumice are interspersed throughout the Selah, thicker accumulations occur as thin-bedded and fissile layers of pumicite. One such layer sampled (sample 107, Section G, Appendix A), contains approximately 95 percent by volume of clear glass shards, with 5 percent by volume sanidine, amphibole, and pyroxene crystals. This pumicite layer is similar in composition to Selah pumicites in Mackin's (1961) Beverly Section, and in a Selah Butte Ridge outcrop in central Washington (off of I-82, near Burbank Creek). In both of these exposures, clear glass shards composed about 95 to 97 percent of the total samples, with feldspar, amphibole and pyroxene crystals comprising the remaining 3 to 5 percent.

Schmincke (1964) felt that an analysis of the index of refraction and composition of the glass constituent of the Selah Member would not be a diagnostic characteristic, since his studies revealed that the index of refraction of glass from throughout the Ellensburg Group consistently fell into the range of 1.502 to 1.506, with no discernable distinction between any two members.

Clear glass with euhedral opaque inclusions is second in abundance to shards and pumice. This "dusty" glass is typically subrounded to rounded, and commonly slightly to moderately devitrified or altered to sericite, feldspar, and silica. Although clearly of volcanic origin, a small percentage of the "dusty" glass may be reworked from older volcanic units, based upon its greater roundness and recrystallized state.

Palagonite is the least common type of glass, and is yellow to yellow brown under plane polarized light. Relict vesicular structure is common, with radial structure within the relict vesicles often accompanied by a weak birefringence. Alteration products include chlorite and nontronite (Table III, Appendix B). Field observations, in conjunction with petrographic data, suggest that extensive development of nontronite has occurred at the base of the tectonic facies of unit II. Locally this may form a weak cement.

Quartz

The most common forms of quartz present are euhedral β-quartz pseudomorphs, anhedral clastic quartz, and anhedral chalcedony. The β-quartz pseudomorphs, exhibiting β-quartz morphology but probably of α-quartz structure, are considered to be an epiclastic constituent of primary volcanic origin with post-depositional reworking.

Chalcedony may represent secondary deposition in vesicles or cavities of volcanic units present either within or outside of the Roosevelt-Arlington basin. Quartz over-growths partially encase some grains of chalcedony. However, if the chalcedony grains represent vesicle fillings, then the occurrance of overgrowths may be a misinterpretation.

Trace amounts of composite quartz were identified, particularly in unit III and unit II-tectonic facies. These grains are described as meta-quartzarenite.

Mica

Biotite, muscovite, chlorite and sericite are present throughout the Selah Member, in amounts ranging from a trace to 2.8 percent by volume of the light mineral fraction.

Brown biotite, the most common mica, is typically anhedral. The biotite and muscovite may be either epiclastic constituents of primary volcanic origin, or derived from metamorphic and plutonic source rocks. Trace amounts of both chlorite and sericite probably represent alteration of volcanic ash, feldspar, and glass, as well as some of the mafic constituents. The free occurring chlorite grains may also be derived from pre-existing volcanic rocks.

Miscellaneous

Zeolite is present in radial fibrous and fibrous masses that are typically subrounded to rounded. According to Schmincke (1964) the presence of zeolites may indicate the beginning stages of cementation development, although the zeolites may also occur as a weathered-out vesicle filling.

According to Schmincke (1964), in his study of the Ellensburg Group, the development of cementation progresses from the formation of zeolites, to opal and clays, and finally to calcite. Although a trace of zeolites and calcite occur throughout most of the Selah Member, along with some clays, no other evidence was observed to substantiate such a progression in formation of cement.

HEAVY MINERALS

Heavy minerals compose up to 20.5 percent by weight of the total mineral sample, with an average of less than 10 percent (Table IV, Appendix B). The heavy mineral assemblage consists of opaque minerals, hornblende, hypersthene, epidote, clinozoisite, zircon, rutile, and topaz, with accessory tourmaline, corundum, garnet, apatite, staurolite, sphene, riebeckite, augite, and spinel.

Opaque Minerals

The two most common opaque minerals are euhedral magnetite and ilmenite, and occur with equal abundance. Although both minerals, particularly magnitite, may be formed in a variety of conditions, their typical euhedral form would suggest a predominantly primary volcanic origin.

In portions of unit III ilmenite is occasionally altered to leucoxene (Table IV, Appendix B).

Pyrite and some chalcopyrite are common, although of lesser abundance than magnetite or ilmenite. Pyrite and chalcopyrite both occur as euhedral crystals. Pyrite also occurs as subhedral crystals, in rod-like grains, and in framboidal masses. A variety of origins are ascribed to pyrite, however, the majority of the pyrite within the Selah Member is probably of secondary origin, formed as a result of the decay of organic materials in a reducing environment. A few euhedral crystals identified as chalcopyrite were observed at the base of unit III, and in Unit II-lacustrine facies. Chalcopyrite may also be of secondary origin. Trace amounts of hematite occur in nearly all of the samples analyzed, and may either be an alteration product or a secondary mineral.

Ultrastable Minerals

The ultrastable mineral group includes topaz, zircon, tourmaline, rutile, and corundum. Topaz is common to units II and III, and occurs with the least abundance in unit I. Topaz is typically rounded, in euhedral crystals and occasionally in granular masses. Nearly all of the topaz, especially the rounded euhedral crystals, are interpreted to be of acid igneous origin, possibly from a source area outside of the Roosevelt-Arlington basin, and may represent more than one cycle of erosion.

Zircon, the second-most abundant ultrastable mineral, is present in amounts up to 3.6 percent by volume, with the highest and most consistant amounts in unit III (Table IV, Appendix B). Color under plane polarized light varies from clear or pale gray, to light brown and light green. Virtually all of the zircon occurred in doubly terminated euhedral crystals. A small number of the zircon crystals contained inclusions. Both sharp-faced and slightly rounded crystals occur with equal abundance. Folk (1974) reports that euhedral zircon is an indicator of a volcanic source. Furthermore, the greater the rounding of euhedral zircon, the higher the probability that the grains have undergone prolonged reworking. In this light, the zircon crystals which occur in the Selah Member are probably all of primary volcanic origin, with a large portion reworked from older volcanic units. The zircon of unit II-tectonic facies, however, tends to be more angular, which suggests a first, or early cycle of erosion.

Rutile occurs throughout the Selah Member, in trace amounts and up to 5.0 percent by volume, and with greatest abundance in the lacustrine facies-unit II and in unit III. Rutile grains are typically subhedral to euhedral, and vary from angular to subangular in unit I, to subrounded to rounded in the remainder of the Selah Member. Corundum occurs as subhedral to euhedral subrounded to rounded crystals, and as angular cleavage flakes. Tourmaline, rutile, and corundum appear to be reworked, probably from metamorphic or plutonic sources, and may represent the constituents of the Selah Member which have traveled the farthest.

Metastable Minerals

The metastable mineral group is represented by hornblende, hypersthene, epidote, and clinozoisite, with accessory garnet, staurolite, apatite, augite, sphene, spinel, and riebeckite.

Hornblende typically occurs in subhedral to euhedral prismatic crystals with an overall slight to moderate etching at crystal terminations. Hornblende is generally more abundant than hypersthene. Basaltic hornblende occurs in trace amounts in unit II-lacustrine facies and unit III, and comprises up to 50 percent by volume of the total hornblende in unit I and unit II-tectonic facies. Etching of the basaltic hornblende was not evident.

Subhedral to euhedral prismatic hypersthene occurs throughout the Selah Member, and is more abundant than hornblende in unit II. Perhaps this shift in the hornblende:hypersthene ratio reflects a shift to a more local source area, possibly within the Roosevelt-Arlington basin, during deposition of unit II. In other words, deposition of unit II may have been a result, in part, of erosion of pre-existing Selah sediments and other exposed volcanic rocks.

Some hypersthene grains in units I and III are slightly etched, while the majority of the grains in unit II are moderately to extremely etched with "hacksaw"-shaped grain terminations (Fig. 17). Although the degree of etching of the hypersthene is greater within unit II, and appears to increase as the enclosing sediments become generally more coarse, Schmincke (1964) found no evidence to support a mechanism of selective intrastratal solution as related to increased permeability.

Epidote and clinozoisite are present throughout the Selah Member, with epidote typically more abundant than clinozoisite. Epidote commonly occurs in anhedral grains or aggregates, and occasionally as euhedral crystals. In sample 38, some grains appear to be partly enclosed in over-growths of quartz. Clinozoisite occurs in subhedral to anhedral grains, and occasionally as euhedral crystals. A parallelism in occurrence of epidote and clinozoisite is evident. That is, where an increase in abundance of epidote is observed, a similar increase in abundance of clinozoisite also occurs. This is interpreted as suggesting a common source for both minerals, with fluctuations in transport conditions seen as changes in abundance.

Other metastable minerals, occurring in trace amounts and up to 0.7 percent by volume, include pale brown and pink garnet, apatite, staurolite, augite, riebeckite, and spinel. All occur in subhedral to euhedral crystals which are subrounded to rounded. Of these minerals, apatite, augite, and riebeckite are known to occur in volcanic rocks,

Figure 17. Photomicrograph of etched hypersthene grain from sample 89. Note "hacksaw"-shaped grain terminations (plane polarized light, 28.5X).

while garnet, staurolite and spinel are more typical of metamorphic provenances.

Authigenic Minerals

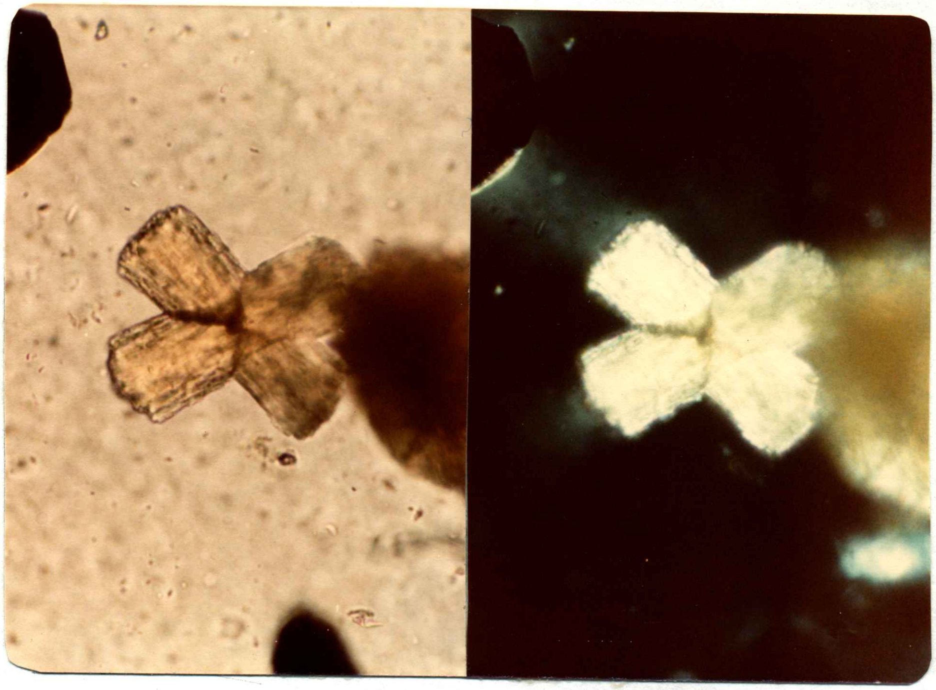
Siderite is present throughout the Selah Member in amounts up to 2.2 percent by volume, but occurs with particular abundance in the cliff-forming volcanic lith-arenite of unit I (Plates 2 and 3). Siderite occurs primarily in radial to fibrous sheaf-like crystals, some of which contain opaque cores of pyrite (Fig. 18).

The occurrence of authigenic siderite as a cementing mineral is considered to be of notable importance in the post-depositional history of unit I. An explanation for the formation of siderite might be the result of epidiagenesis, a diagentic process which occurs in shallowly buried or tectonically uplifted sediments that are exposed to weathering and geochemical change with percolation of groundwater. This assumption is based upon several factors.

First, the basic requirements for an epigenetic environment are evident in unit I. The erosional unconformity found at the contact of unit I and the overlying unit II-tectonic facies, indicates that the sediments of unit I were not only exposed at the surface for some period of time before burial by unit II, but also probably elevated from a previously lower position.

Second, the predominance of air-fall tuffs within unit I would suggest a relatively rapid burial of the now

(a)



(b) (c)

<u>Figure 18.</u> Photomicrograph of euhedral authigenic siderite from sample 24 (Section A, Plate 3). Euhedral grain with opaque core shown under plane polarized light (a), note radial sheaf-like structure. Twinned grain shown under plane polarized light (b), and under crossed nicols (c) (magnification 28.5X).

siderite-cemented cliff-forming volcanic lith-arenite. The unit I tuffs are, for the most part, subaerial, with no appreciable evidence of diagenetic changes such as would be expected in a subaqueous deposit. This would suggest that the diagenetic changes in the volcanic lith-arenite of unit I are probably a result of groundwater percolation, as opposed to a saturated deep-burial condition.

Third, according to Jackson (1970) siderite may occur in a reducing environment where ferrous iron reacts with available carbon dioxide, given off by decaying organic material. The formation of siderite, instead of sulfide minerals, is due to a general lack of available sulfur. Since epidiagenesis occurs in the zone of leaching and weathering, it is assumed that the majority of the necessary iron was derived through leaching of the surrounding tuffs by groundwater. While assuming that some amount of organic material was trapped during deposition of the volcanic lith-arenite, another source of carbon may be necessary for the formation of considerable amounts of siderite, especially if the sediments are sealed off by overlying sediments with no additional carbon sources being deposited. It is here that the data falls short in the identification of a second or additional source of carbon for the formation of siderite. It is probable, however, that percolating groundwater may have carried an appreciable supply of carbon dioxide.

CLAY MINERALS

An x-ray diffraction study of eleven samples, summarized in Table V, was made in order to obtain a general overview of the clay mineralogy throughout the Selah Member. The minus 2 μ size fraction from each sample was mounted on porous ceramic tiles and examined by x-ray diffraction in: 1) an untreated state, 2) after calcium (Ca++) saturation, and 3) after Dimethyl Sulfoxide (DMSO) saturation (this was not a standard method, and was intended to simulate ethylene glycol saturation).

As can be seen from the data, a smectite peak of 14.72 Å was common in most of the Ca++ saturated samples. In the majority of the samples the Ca++ peaks increase from a range of 13.8 Å to 14.72 Å, to a range of 18.87 Å to 20.53 Å after DMSO saturation. This peak may represent the clay mineral nontronite (Brown, 1961). In sample 27, the Ca++ peak increased from 20.06 Å to 21.53 Å after DMSO saturation, perhaps indicative of interlayered montmorillonite and chlorite, or possibly kaolinite.

A 7.13 Å peak is common in many of the samples. This may denote the presence of kaolinite, however, this was not confirmed by heating to 550° C.

In general, the x-ray diffraction data tends to corroborate field and petrographic data, suggesting that a variety of secondary minerals has been produced primarily through devitrification and alteration of volcanic ash.

These secondary minerals include montmorillonite, chlorite, and nontronite, although this x-ray diffraction study is not conclusive. While clay minerals are persistent throughout the Selah Member, their relative abundance is low, as shown in the sand:silt:clay ratio diagram (Fig. 9).

GENERAL DISCUSSION

The petrography of the Selah Member is relatively consistent; 92.3 to 99.8 percent by weight of samples from units I, II-lacustrine facies, and III, and 79.5 to 99.9 percent from unit II-tectonic facies, consist of light minerals. The light:heavy mineral ratio is high.

The light mineral assemblage typical to the three units of the Selah Member, listed in order of abundance, includes rock fragments, plagioclase feldspar, potassium feldspar, volcanic glass, and quartz, with accessory mica, clay, and zeolites. With the exception of units II and the lower portion of unit III, the rock fragments consist almost entirely of devitrified volcanic ash, a constituent with low resistance to weathering and abrasion. The introduction of the volcanic ash into the Roosevelt-Arlington basin is seen as both primary and epiclastic in origin. The final deposition of the volcanic material is as epiclastic detritus, with the exception of unit I, which remains principally of primary volcanic origin. In units II and III, volcanic rocks comprise up to 85.3 percent of the rock fragments, by volume, with trace amounts of metamorphic rocks. Roughly 85 to 90 percent of the light mineral assemblage is of primary volcanic origin, which would include altered vitric (devitrified ash) and volcanic rock fragments, a portion of the plagioclase feldspar, sanidine, volcanic glass, and β-quartz pseudomorphs.

The heavy mineral fraction consists of opaque, metastable, ultrastable, and authigenic minerals. Essentially all of the metastable minerals may be of primary volcanic origin. Apatite and zircon, which compose up to 95 percent of the ultrastable minerals, are also of primary volcanic origin. The remainder of the ultrastable minerals, along with clastic quartz, orthoclase feldspar, and metamorphic rock fragments, represents that portion of the Selah sediments which were derived from plutonic or metamorphic provinces outside of the Roosevelt-Arlington basin. This percentage of plutonic/metamorphic constituents amounts to about 10 to 15 percent by volume of the light mineral fraction, and less than about 5 percent by volume of the heavy mineral fraction.

Previous petrographic studies of the Ellensburg Group include those of Coombs (1941), Laval (1956), and Schmincke (1964). Coombs (1941) reports a light mineral assemblage consisting of feldspar and glass, and a heavy mineral assemblage exclusively of hornblende and magnetite. Coombs' total mineral assemblage is of much smaller scope than that presented herein. However, the section analysed by Coombs may include more of the Ellensburg Group than just the Selah Member. Laval (1956) described light and heavy mineral assemblages of the Ellensburg Group, in central and south-central Washington, similar to those presented in this paper, with the exception of lower reported percentages of hornblende and hypersthene, and a more calcic range in feldspar composition. Petrographic data pertaining specifically to the Selah Member is included in Schmincke's (1964) petrography of the Ellensburg Group. Schmincke's data on the Selah Member is similar to that of this report, although a much higher percentage of altered devitrified ash is present within the Roosevelt-Arlington basin. The higher and more variable percentage of hypersthene in the Selah Member, as compared to the whole of the Ellensburg Group, is interpreted by Schmincke as evidence for a different or unique source for the Selah Member. The distribution of hypersthene may enable correlation of the Selah Member throughout the extent of the Ellensburg Group, in view of the relatively higher percentage of hypersthene noted in the Selah Member of the Roosevelt-Arlington basin (this report) as compared to the composite Ellensburg Group petrographic data presented by Coombs (1941), and Laval (1956). However, a compilation of detailed petrographic data is lacking for individual members of the Ellensburg Group.

PALEONTOLOGY

INTRODUCTION

A variety of fossil materials were encountered during the course of the field and petrographic portions of this study. A preliminary identification was made of certain taxa which included four genera of diatoms, one genus of megaspores, and well preserved fish vertebrae. A 30 cm thick layer of silicified coal was also encountered.

DIATOMS

All of the diatoms examined belong to the Order Bacilariales. The two Suborders identified are Discineae and Biraphidineae. The samples in which the following tentatively identified diatoms occur are summarized on Table VI.

Suborder Discineae

One genera of diatom tentatively assigned to the Subfamily Melosiroideae, occurs throughout the Selah Member, and is typically described as cylindrical cup-shaped segments. In most occurrences at least two segments are present, with trails of minute pores around the circumference of each segment, and either parallel to the length of the segment or in a radial arrangement giving a slight spiral-effect around the segment. Typical segment lengths range from 0.25 to 0.75 mm, with diameter:length ratios of

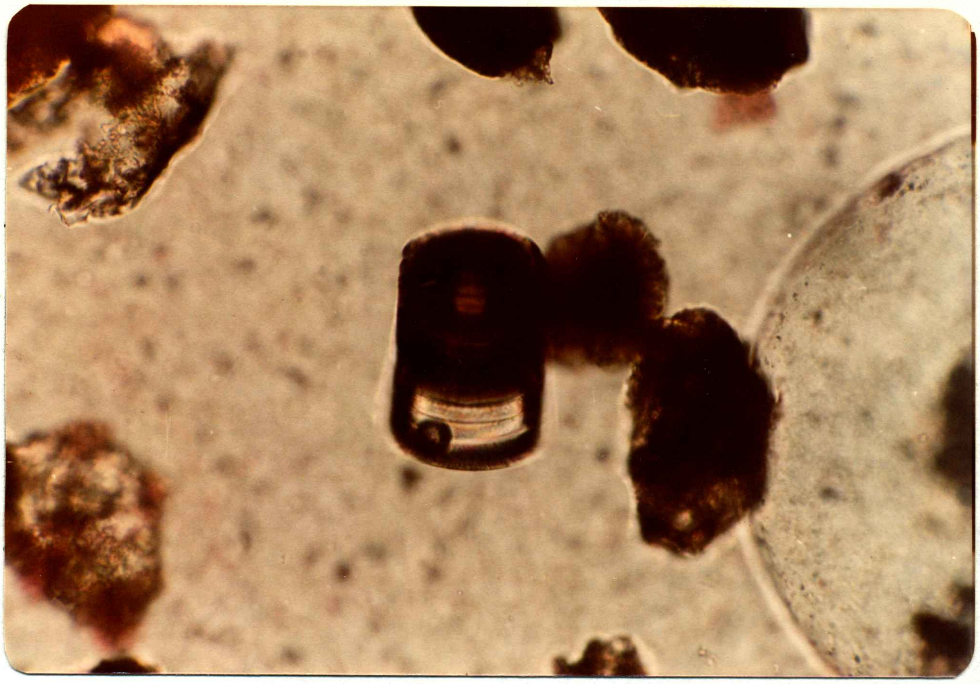
1:1 to 1:2 or less. The cup-shaped diatons may be Melosira, (Fig. 19), although a detailed identification was not possible due to their fragmented state. According to VanLandingham (1964), Melosira is a very common diatom in Miocene fresh-water and non-marine deposits on a world-wide basis, with a known extent of Paleocene to Recent. Van-Landingham also stated (1964; p. 10) that, "Melosira may have been the first genus to invade the fresh-waters".

One genera of diatom, typically thin and platelette-shaped, is 0.1 to 0.2 mm in diameter and tentatively assigned to the Subfamily Coscinodiscoideae, similar to Coscinodiscus (VanLandingham, 1964). VanLandingham (1964) found these diatoms to occur with moderate frequency in fresh-water deposits.

Suborder Biraphidineae

Two genera are tentatively assigned to the Suborder Biraphidineae, Genus Caloneis schmuanniana var. c. biconstricta and Genus Pinnularia.

Although somewhat uncommon in non-marine sediments, the probable extent of Caloneis schumanniana var. c. biconstricta, as stated by VanLandingham (1967), ranges from upper Miocene or lower Pliocene to Recent. This identification is based upon VanLandingham's (1967) report of Miocene diatomites in the Otis Basin, Oregon.



(a)

(b)

<u>Figure 19.</u> Photomicrograph of some diatoms common to Selah Member. Shown under plane polarized light are (a) <u>Melosira</u>, from sample 7 (Section J, Plate 3), and (b) <u>Pinnularia</u>, from sample 5 (Section J, Plate 3) (magnification 28.5X).

TABLE VII

DIATOM FOSSIL OCCURRENCES

Sample Number	Suborder Discineae Melosira	Coscinodiscus	Suborder Biraphidineae Caloneis	Pinnularia
Unit III				
7	X	X		X
14	X	X		
31	X	X		X
35	X			
Unit II				
5	X		X	X
19	X			
38	X	X		X
39	X			
40	X	X		
Unit I				
24	X			

Pinnularia has an approximate extent of Oligocene or Miocene to Recent. Although Pinnularia (Fig. 19) was identified throughout the Selah Member in the Roosevelt-Arlington basin, it is not a common genus, and its tentative identification herein is based upon VanLandingham's (1964) report on the Miocene non-marine diatoms in south-central Washington.

Summary

VanLandingham (1967) felt that detailed taxonomic studies on non-marine diatoms may provide paleoecological data useful for statigraphic correlation purposes. Before such stratigraphic correlation is possible, a substantial diatom biochronology and zonation must be established. In his study of the Otis Basin (1967), VanLandingham identifies four fossil diatoms of limited stratigraphic value:

Tetracyclus celatom; *Stylobiblium* (*Tetracyclus*) *japonicum*; *Stauroneis hercynia*; and *Navicula Pantocsekiana*. In his study of Miocene diatomites of central Washington, VanLandingham (1964) lists two fossil diatoms of limited value: *Gomphonema cholnokyites*; and *Coscinodiscus miocaenicus*. The purpose of diatom identification in this study was to determine if indicator fossil diatoms occur in the Selah Member and if they could be used for correlation. Although none of VanLandingham's indicator fossil diatoms were noted in samples examined in this study, detailed taxonomic studies of the Selah Member of the Roosevelt-Arlington basin, as well as the whole of the Ellensburg Group, may prove the presence of a diatom zonation scheme useful for biostratigraphic correlation. The presence of diatoms throughout the Selah Member, in addition to lithologic and petrographic data, would further suggest that lakes were present during the depositional history of the Selah Member in the Roosevelt-Arlington basin.

MEGASPORES

A variety of megaspore is present in samples 15, 52, and 57 from unit III; sample 21 from unit II; and in samples 24, 42, 44, 45, and 67 from unit I. The variety of megaspore has been tentatively identified as belonging to the Subfamily Isoetes (Quillwort Family) (Dr. David Bostwick, 1976, personal communication). The megaspores are typically 100 to 200 µ in diameter, and have an equatorial ridge, with three ridges extending from the equatorial ridge to the summit of the upper hemisphere. The surface of the megaspores can be described as pebbled. Although a precise identification of the megaspores was not attempted, a comparison with published literature (Fernald, 1950) suggests that the megaspores may belong to Genus Melanopoda. Isoetes, as noted by Fernald (1950), is an aquatic to terrestrial herb inhabiting shallow water, near to lakes or streams, and in low-lying meadows and woods.

COAL

A 30 cm thick layer of silicified coal was encountered in sample 23 (Section A, Plate 2). Thin section examination indicates that at least a portion of the coal may be identified as Family Fagaceae (Irene B. Gregory, 1976, personal communication). Although the identification of the type of oak was not possible, due to poor preservation of the more delicate cellular structure, the well-defined seasonal growth rings would indicate that a temperate climate with distinct seasonal changes existed at that time. Mackin (1961) pointed out that the Ellensburg Group contains flora ranging from a humid climate in the lower portion of the Ellensburg, to a continental climate in the upper portion of the Ellensburg. This climatic change is interpreted by Mackin as one historical evidence for the time and extent of the growth of the Cascade Range, where sufficient elevations were achieved to cause climatological changes in central Washington.

FISH VERTEBRAE

Fish vertebrae occur in unit III and unit II-lacustrine facies (Plates 2 and 3). One such vertebrae from the lacustrine facies was tentatively identified as a minnow, belonging to Family Cyprinidae (Mr. Bruce Welton, 1977, personal communication). In addition to minnows, the Family Cyprinidae also includes white fish and carp, all of which are widespread and common fish.

ORIGIN AND DEPOSITION OF THE SELAH MEMBER

ORIGIN

The age of the Selah Member lies between 13.5 and 12 my, the ages of the latest Wanapum Basalt flow and the Pomona Member of the Saddle Mountains Basalt, respectively (McKee, Swanson, and Wright, 1977). Three sources are interpreted for the Selah Member of the Roosevelt-Arlington basin: 1) explosive volcanism in the Cascade Range to the west, 2) interbasin erosion, and 3) plutonic/metamorphic regions outside the Roosevelt-Arlington basin.

The largest volume of the Selah sediments were introduced to the Roosevelt-Arlington basin as air-fall tephra from explosive volcanism in the Cascade Range. The pyroclastic materials include altered vitric rock fragments (devitrified ash), pumice, relatively fresh volcanic glass, euhedral glass-encased sanidine crystals, β-quartz pseudomorphs, idiomorphic zircon, hypersthene and hornblende. Cascade volcanism appears to have been active throughout Selah-time.

Erosion within the Roosevelt-Arlington basin is apparently an additional source of sediments, particularly during deposition of units II and III. An influx of volcanic rock fragments in units II and III, along with basaltic conglomerates and an erosional unconformity at the base of unit II-tectonic facies, suggests an increase in the rate of erosion. These volcanic rock fragments were derived, in part, from the northern or northwestern margin of the Roosevelt-Arlington basin, as shown by SE and ESE dispersal directions in the tectonic facies. Perhaps Selah sediments were absent at some point along the perimeter of the basin, exposing pre-Selah Yakima Basalt flows to erosion. Primary volcanic sediments, introduced by air-fall, were reworked before being deposited as the epiclastic sediments of units II and III, as shown by fluvial and lacustrine bedding structures.

The volumetrically smallest, but possibly most significant portion of the Selah Member are the sediments derived from plutonic/metamorphic regions outside of the Roosevelt-Arlington basin. The volume of material attributed to plutonic/metamorphic source(s) is on the order of 10 to 15 percent of the light mineral fraction, and less than about 5 percent of the heavy mineral fraction. Introduction of plutonic/metamorphic derived sediments into the basin was by a west-flowing stream originating outside of the basin. The headwater area and flow direction of the stream is significant to the evolution of the basin. It is concluded that the ancient Columbia River was probably not present in the Roosevelt-Arlington basin during deposition of the Selah Member, and that the source of the plutonic/metamorphic sediments were not from the same northern source areas as the Ellensburg Group of central and south-central Washington. Perhaps another stream system, such as the ancestral Snake or Umatilla Rivers, carried the plutonic/metamorphic sediments from the east or southeast.

DEPOSITION

Explosive volcanic activity and accumulation of air-fall tuffs marked the beginning of deposition of the Selah Member. The tuffs of unit I, predominantly lapilli tuff with lenses of accretionary lapilli tuff, were laid down on a relatively unweathered surface of Priest Rapids Basalt. Based upon the lack of bedding and fluvial sediments within individual tuff strata, the tuffs of unit I are an indication of fairly rapid accumulation. Small lakes may have formed as streams were disrupted, as shown by layers of thin-bedded and fissile pumicite. The laterally persistent diatom-bearing volcanic lith-arenite of unit I marks a period when existing streams became stabilized, supporting vegetation along their margins. The increase in thickness of the tuffs underlying the volcanic lith-arenite suggests that the deepest portion of the basin during deposition of unit I was located near the southern flank of the Horse Heaven Hills anticline, in the area of Roosevelt, Washington.

The intensity and/or abundance of explosive volcanic activity appears to have diminished toward the close of deposition of unit I. In the upper portion of unit I tuffs have been reworked and incorporated into bedded siltstone and volcanic arenite. Bedding characteristics of the volcanic lith-arenites and the upper portion of unit I further strongly suggests the presence of a stream flowing through the Roosevelt-Arlington basin in early Selah-time.

An erosional unconformity indicative of minor tectonic activity, marks the beginning of deposition of the tectonic facies of unit II. The surface of unit I has been scoured, as evidenced by cut and fill structures along the contact. The unconformity is interpreted as the result of minor uplifting along the Horse Heaven Hills anticline accompanied by downwarping of the Dalles-Umatilla syncline. Minor tectonic activity involving the Horse Heaven Hills had two effects on the Roosevelt-Arlington basin. First, erosion along portions of the Horse Heaven Hills anticline was accelerated, and, second, the lowest surface of accumulation in the basin was shifted slightly to the south.

The conglomerate and volcanic lith-arenite of the tectonic facies are part of a localized interbasin alluvial fan growing outward from the south flank of the Horse Heaven Hills anticline in a SE to ESE direction. The tectonic facies sediments were probably derived chiefly from within or near the margin of the Roosevelt-Arlington basin, by erosion of pre-existing and/or contemporaneous tuffs, and older Yakima Basalt flows. The westward increase in sorting versus decrease in grain size suggests that the tectonic facies alluvial fan may have been largely restricted to the north-central portion of the Roosevelt-Arlington basin. A small percentage of the tectonic facies sediments are plutonic/metamorphic in origin, apparently introduced into the basin by a stream draining a plutonic/metamorphic province outside of the basin.

Lakes, in which claystone and siltstone of the lacustrine facies of unit II accumulated, occupied the south-central portion of the Roosevelt-Arlington basin, along the northern flank of the Willow Creek monocline. At least two successive lakes occupied the basin, and were of sufficient depth to accumulate massive claystones up to 14 m thick. It seems probable that progressive downwarping occurred in the Roosevelt-Arlington basin during unit II time, with deposition of lacustrine facies sediments filling the southern portion of the basin, and partially burying the tectonic facies alluvial fan, and reducing the topographic relief across the basin.

Tectonic activity within the Roosevelt-Arlington basin was greatly diminished at the beginning of unit III deposition. A high percentage of the lacustrine facies sediments are of primary volcanic origin, although reworked and deposited into an extensive shallow lake, in contrast to the deeper and laterally restricted lakes of unit II time. Sporadic explosive volcanic activity is recorded as thin lenses of accretionary lapilli tuff and thin-bedded fissile pumicite. Although only occasional lenses of primary air-fall deposits occur within unit III, petrographic analysis of the unit suggests that volcanic activity contributed a large quantity of air-fall ash to the basin, which was nearly totally reworked and deposited as epiclastic detritus.

Sedimentation had essentially filled the Roosevelt-Arlington basin toward the close of deposition of unit III. Low topography within the basin, as well as in other Selah basins of deposition throughout central Washington, enabled the Pomona Member of the Saddle Mountains Basalt Formation to advance as a thin sheet over a large area.

GEOLOGIC HISTORY OF THE SELAH MEMBER

The Columbia Plateau encompasses nearly 15,000 km^2 in southeastern Washington, north-central Oregon, and a portion of western Idaho. The Plateau is underlain by a thick sequence of Miocene tholeiitic flood basalts emitted from large fissures represented, in part, by the Grande Ronde and Cornucopia dike swarms of northeastern Oregon (Schmincke, 1964). Along the western edge of the Plateau lies the Cascade Range, a chain of late Tertiary to Recent volcanoes overlying early to mid-Tertiary sedimentary, volcanic, and intrusive rocks. To the north and east lie the Okanogan Highlands, and the Idaho batholith metamorphic and plutonic rocks of Mesozoic age. The Blue Mountains border the Plateau to the south and consist of a variety of sedimentary, volcanic, and plutonic rocks ranging in age from early Triassic through Pliocene (McKee, 1972).

The great outpourings of basalt, characteristic of the Columbia Plateau, became less frequent toward the end of Miocene time. Each new surface of portions of the plateau was covered by intermittent showers of pyroclastic debris and large eastward spreading alluvial fans extending from the growing Cascade Range to the west. Large volumes of sediments containing metamorphic and plutonic clasts were supplied from the north and east by the ancestral Columbia River (Laval, 1956; Schmincke, 1964).

The thick sequence of flood basalts, known as the Yakima Basalt, are interbedded with volcaniclastic sediments, known as the Ellensburg Formation. The Selah Member of the Ellensburg Formation was deposited across the plateau into many basins in a period between the outpouring of the Priest Rapids Member (13.5 my) and the Pomona Member (12 my). Structural highs which defined the boundaries of the Roosevelt-Arlington basin prior to deposition of the Selah Member are: the Horse Heaven Hills anticline to the north; the Willow Creek monocline to the south; and the Service Butte-Sillusi Butte anticline to the east. Minor tectonic activity associated with the basin-defining structures occurred during deposition of the Selah Member.

The air-fall tuffs of the lowermost unit I, deposited with rapid succession upon a relatively fresh surface of Priest Rapids Basalt, were derived from explosive volcanic activity in the Cascade Range to the west. Minor tectonic activity, which began at the close of unit I deposition, accelerated interbasin erosion and resulted in deposition of the basaltic conglomerates and sandstones of the tectonic facies of unit II. The tectonic facies was deposited unconformably upon the underlying unit I as an aggrading alluvial fan growing southward from the Horse Heaven Hills anticline. Interfingering between the tectonic facies and the lacustrine facies of unit II occurred in the area of the present course of the Columbia River. Subsequent erosion by the river has removed nearly all the transitional facies zone and encised the underlying Priest Rapids Basalt.

The claystones and siltstones of the lacustrine facies-unit II were deposited into at least two successive lakes which occupied the southern portion of the Roosevelt-Arlington basin. These deep lakes represent the lowest point of accumulation within the basin, which had shifted south from an earlier position (during unit I time) along the southern flank of the Horse Heaven Hills anticline. A variety of flora and fauna were associated with the lakes, including fish, diatoms, and aquatic herbs and trees growing along the perimeter of the lakes.

Tectonic activity and the resulting interbasin erosion diminished toward the close of unit II deposition. The deep lakes that occupied the southern portion of the Roosevelt-Arlington basin during deposition of unit II filled with sediments and were succeeded by a shallow and more extensive lake into which the volcaniclastic sediments of unit III were deposited. Intermittent explosive volcanic activity occurred throughout deposition of unit III as shown by lenses of tuff and layers of thin-bedded pumicite.

By the time the basaltic flood lava flows of the Pomona Member covered the area, the Roosevelt-Arlington basin had filled with sediments and the once extensive shallow lake had disappeared. The Pomona Member advanced over a relatively flat topography within the Roosevelt-Arlington basin, baking the unconsolidated sediments of the underlying unit III.

During Selah deposition the eastern-lying Roosevelt-Arlington basin was structurally and/or topographically isolated from the growing Cascade Range, and beyond the fluvial transport of Cascade sediments. The basin was also bounded on the north by the Horse Heaven Hills anticline, across which the Selah Member thins to less than 16 m. The structural and/or topographic isolation of the Roosevelt-Arlington basin to the west and north, along with the sparseness of metamorphic/plutonic sediments in the Selah Member, indicates that the Columbia River was not in its present position within the Roosevelt-Arlington basin during Selah-time. The Columbia River appears to have occupied a more northerly or northwesterly course during deposition of the Selah Member.

SUMMARY

The following conclusions can be made from this detailed stratigraphic and petrographic study of the Selah Member of the Ellensburg Formation:

1) The Selah Member of the Ellensburg Formation was deposited into a large basin, referred to as the Roosevelt-Arlington basin, underlain by Columbia River Basalt. The basin formed along part of the Dalles-Umatilla syncline in south-central Washington and north-central Oregon.

2) The Selah Member of the Roosevelt-Arlington basin is stratigraphically defined, as in other areas of the Columbia Plateau, by the overlying Pomona Member of the Saddle Mountains Basalt and the underlying Priest Rapids Member of the Wanapum Basalt.

3) The Selah Member may be divided into three lithologic and petrographic units, referred to in this study as units I, II, and III.

4) The middle unit II is subdivided into two time-equivalent interfingering facies: trough-set cross bedded sandstone and basaltic conglomerate referred to in this study as the tectonic facies, and claystone and siltstone referred to as the lacustrine facies.

5) An erosional unconformity separates the lowermost air-fall unit I from the overlying fluvial and lacustrine unit II.

6) The light mineral assemblage of the Selah Member

consists of up to 99.8 percent by volume primary volcanic minerals, and shows a predominant volcanic source.

7) The heavy mineral assemblage consists of up to 95 percent by volume primary volcanic minerals, also showing a volcanic source, with less than 5 percent by volume metamorphic/plutonic minerals.

8) Three source areas are interpreted for the Selah Member of the Roosevelt-Arlington basin: a) explosive volcanic activity in the Cascade Range to the west, b) erosion within the Roosevelt-Arlington basin resulting from tectonic activity in the Horse Heaven Hills anticline to the north, and c) plutonic/metamorphic provenances outside of the Roosevelt-Arlington basin. The largest volume of sediments was derived from source area a), with minor volumes derived from b) and c).

9) A stratigraphic/lithologic comparison between the Selah Member of the Roosevelt-Arlington basin and the type Selah of central Washington has similarities: a) a basal air-fall tuff layer, b) occurrence of thin-bedded fissile pumicite throughout the three units, similar in composition to the pumicites in the type Selah of central Washington, and c) a fused tuff formed at the contact between the Selah Member and the overlying Pomona Member.

10) The absence of lahars and quartzitic conglomerates in the Roosevelt-Arlington basin suggests a structural and/or topographic isolation of the basin from the Cascade Range to the west and plutonic/metamorphic provenances to

the north during deposition of the Selah Member.

11) The structural and/or topographic isolation of the Roosevelt-Arlington basin during deposition of the Selah Member suggests an air-fall deposition of the primary volcanic sediments with the minor amounts of plutonic/metamorphic sediments coming from the east or southeast.

12) The lack of quartzitic conglomerates in the Selah Member of the Roosevelt-Arlington basin indicates that the Columbia River was not in its present position in the basin during deposition of the Selah Member.

13) The course of the Columbia River during deposition of the Selah Member was farther west and north, where quartzitic conglomerates are present in a Selah-equivalent stratigraphic sequence.

REFERENCES

Bentley, R. D., 1977, Stratigraphy of the Yakima Basalts and Structural evolution of the Yakima ridges in the western Columbia Plateau (Field Trip no. 12) p. 339-389, in Brown, E. H., and Ellis, R. C., eds., Geological Excursions in the Pacific Northwest: Western Washington University, Bellingham, Washington, 414 p.

Bingham, J. W., and Grolier, M. J., 1966, The Yakima Basalt and Ellensburg Formation of south-central Washington: U. S. Geol. Survey Bull. 1224-G, 15 p.

Blatt, H., Middleton, G., and Murray, R., 1972, Origin of sedimentary rocks: Englewood Cliffs, Prentice-Hall Inc., 634 p.

Bloss, F. D., 1961, An introduction to the methods of optical crystallography: New York, Holt, Rinehart and Winstone, 294 p.

Brown, G., 1961, The x-ray identification and crystal structures of clay minerals: London, Mineralogical Society, 544 p.

Coombs, H. A. 1941, Hornblende and magnetite heavies in the Ellensburg of central Washington: Jour. Sed. Petrol., v. 11, no. 3, p. 142-144.

Deer, W. A., Howie, R. A., and Zussman, J., 1966, An introduction to the rock forming minerals: New York, John Wiley and Sons Inc., 528 p.

Farooqui, S. M., and Kienle, C. F., 1976, Structural implications of the Yakima Basalt in north-central Oregon and south-central Washington: Geol. Society of Amer., Cordilleran Section Mtg. (abs.), Pullman, Washington, in Abstracts with Program, v. 8, no. 3, p. 372.

Fernald, 1950, Gray's manual of botany: New York, American Book Co., 1,632 p.

Grolier, M. J. 1965, Geology of part of the Big Bend Area, in the Columbia Plateau, Washington: The Johns Hopkins Univ., Ph.D. thesis, 267 p., unpub.

Hay, R. L. 1959, Origin and weathering of late Pleistocene ash deposits on St. Vincent, B. W. I.: Jour. Geol., v. 67, no. 1.

Hitchcock, Cronquist, Ownby, and Thompson, 1969, Vascular plants of the Pacific Northwest: Univ. of Washington Press, Part I, p. 30-37.

Inman, D. L., 1949, Sorting of sediments in the light of fluid mechanics: Jour. Sed. Petrol., v. 19, no. 2., p. 51-70.

Jackson, K. C., 1970, Textbook of lithology: New York, McGraw-Hill Book Co., 552 p.

Kerr, F., 1959, Optical mineralogy: New York, McGraw-Hill Book Co., 442 p.

Kienle, C. F., Bentley, R. D. Farooqui, S. M., Anderson, J. L., and Thoms, R. E., 1978, The Yakima Ridges - an indicator of an anomalous Plio-Pleistocene stress field: Geol. Society of Amer., Cordilleran Section Mtg. (abs.), tempe, Arizona, in Abstracts with Program, v. 10, no. 3, p. 111.

Kienle, C. F., Jr., and Newcomb, R. C., 1973, Geologic studies of Columbia River Basalt structures and age of deformation, Shannon & Wilson, Inc., Portland, Oreg., 55 p.

Laval, W. N., 1948, An investigation of the Ellensburg Formation: Washington Univ., M.S. thesis, 58 p., unpub.

__________, 1956, Stratigraphy and structural geology of portions of south-central Washington: Washington Univ. (Seattle) Ph.D. thesis, 208 p.

Mason, G. W., 1953, Interbasalt sediments of south central Washington: State College of Washington, M.S. thesis, 58 p., unpub.

Mackin, J. H., 1961, A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south central Washington: Washington Div. Mines and Geol. Rept. Inv. 19, 45 p.

McKee, B., 1972, Cascadia, the geologic evolution of the Pacific Northwest: New York, McGraw-Hill Book Co., 394 p.

McKee, E. H., Swanson, D. A., and Wright, T. L., 1977, Duration and volume of Columbia River Basalt volcanism, Washington, Oregon and Idaho: Geol. Soc. Amer. Abs. with Programs, v. 9, no. 4, p. 463-464.

Moore, J. G., and Peck, D. L., 1962, Accretionary lapilli in volcanic rocks of the western continental United States: Jour. Geol., v. 70, p. 182-194.

Newcomb, R. C., 1966, Lithology and eastward extension of The Dalles Formation, Oregon and Washington: U. S. Geol. Survey Prof. Paper 550D, p. D59-D63.

______________, 1969, Effect of tectonic structure on the occurrance of groundwater in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U. S. Geol. Survey Prof. Paper 383-C, 33 p.

______________, 1971, Relation of the Ellensburg Formation to extensions of The Dalles Formation in the area of Arlington and Shutler Flat, north-central Oregon: The Ore Bin, v. 33, no. 7, p. 133-142.

Nolan, T. B., 1958, Suggestions to authors of the reports of the United States Geological Survey: U. S. Government Printing Office, 255 p.

Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G., and Dole, H. M., 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U. S. Geol. Survey Prof. Paper 449, 56 p.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper & Row, 718 p.

Robinson, C. F., 1966, Stratigraphy and structural geology of Ahtanum Ridge, Yakima, Washington: Univ. of Washington, M.S. thesis, 34 p. unpub.

Russell, I. C., 1893, Geological Reconnaissance in central Washington: U. S. Geol. Survey, 108 p.

______________, 1901, Geology and water resources of Nez Perce County, Idaho: U. S. Geol. Survey Water-Supply Paper 53, p. 54, footnote.

Schmincke, H. U., 1964, Petrology, paleocurrents, and stratigraphy of the Ellensburg Formation and inter-bedded Yakima Basalt flows, south-central Washington: unpub., Ph.D. thesis, The Johns Hopkins Univ., Baltimore, Md., 426 p.

______________, 1967a, Fused tuff and peperities in south-central Washington: Geol. Soc. Amer. Bull., v. 78, p. 319-330.

__________, 1967b, Graded lahars in the type sections of the Ellensburg Formation, south-central Washington: Jour. Sed. Petrol., v. 37, no. 2, p. 438-448.

__________, 1967c, Flow directions in Columbia River Basalt flows and paleocurrents of interbedded sedimentary rocks, south-central Washington: Sonderdruck aus der Geologischen Rundschau Band 56, p. 992-1,020.

__________, 1967d, Stratigraphy and petrography of four Upper Yakima Basalt flows in south-central Washington: Geol. Soc. Amer. Bull., v. 78, p. 1385-1422.

Shannon & Wilson, Inc., 1972, Geologic and subsurface investigation, proposed mid-Columbia thermal power plant sites, Morrow, Gilliam, and Umatilla Counties, Oregon: Private Report to Portland General Electric Company, Portland, Oregon.

__________, 1973, Geotechnical investigation for central plant facilities, Carty West Site, Boardman Nuclear Project, Morrow County, Oregon: Private Report to Portland General Electric Company, Portland, Oregon.

__________, 1975, Geotechnical investigation for central plant facilities, Pebble Springs Site, Boardman Nuclear Project, Gilliam County, Oregon: Private Report to Portland General Electric Company, Portland, Oregon.

Smith, G. O., 1901, Geology and water resources of a portion of Yakima County, Washington: U. S. Geol. Survey Water-Supply Paper 55, 67 p.

__________, 1903, Description of the Ellensburg Quadrangle, Washington: U. S. Geol. Survey Geol. Atlas, Folio 86, 7 p.

VanLandingham, S. L., 1964, Miocene non-marine diatoms from the Yakima region in south-central Washington: Beihefte Zur Nova Hedwigia, Heft 14, 78 p.

__________, 1967, Paleoecology and microfloristics of Miocene diatomites, from the Otis Basin-Juntura Region of Harney and Malheur Counties, Oregon: Beihefte Zur Nova Hedwigia, Heft 26, 77 p.

Waters, A. C., 1955, Geomorphology of south-central Washington, illustrated by the Yakima East Quadrangle: Geol. Soc. Amer. Bull., v. 66, no. 6, p. 663-684.

_____________, 1961, Stratigraphic and lithologic variations in the Columbia River Basalt: Am. Jour. Sci., v. 259, p. 583-611.

Williams, H., Turner, F. J., and Gilbert, C. M., 1954, Petrography: San Francisco, W. H. Freeman and Co., 406 p.

APPENDIX A

Section A

Section measured from boring B-9 (Shannon & Wilson, Inc., 1975), Oregon State system north zone plan grid coordinates N736,017, E2,095,133, in north ½ sec. 6, T2N, R22E, Horn Butte, Oregon, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
POMONA MEMBER (Saddle Mt. Basalt Formation)		
Contact - Sharp, baked		
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit III		
Sandstone - gray, fine- to medium-grained, volcanic lith-arenite. Cross-bedded at 0°-35°, slightly cemented subrounded basalt pebbles to 2.5 cm at base, upper 10-20 cm baked.	1.8	6
Siltstone - light gray to pale yellow, volcaniclastic, scattered pumice fragments and lenses of fine sand.	21.4	70.5
Tuff - yellow green, accretionary lapilli.	0.3	1
Siltstone - pale yellow, volcaniclastic, scattered lapilli to 6 mm.	14.4	47.5
Sandstone - pale yellow, fine- to medium-grained, silty, volcaniclastic, volcanic lith-arenite.	0.4	1.5
Siltstone - pale yellow to green, 30 mm thick layer pumice fragments in upper 2.1 m, 2.5 cm spacing, inclined 0°-10°.	5.0	16.5
Unit II - Lacustrine Facies		
Claystone - green gray, silty, volcaniclastic, massive.	6.1	20
Claystone - dark brown, massive, scattered carbonaceous imprints.	2.0	6.5
Claystone - green gray, silty, volcaniclastic, massive.	1.8	6
Tuff - gray brown, scattered carbonaceous imprints, pumice fragments.	2.0	6.5
Sandstone - dark green, fine- to medium-grained, silty, vitric (volcanic) lith-arenite. Noncemented, parallel bedding inclined 0°-10°.	2.3	7.5
Siltstone - dark green, fine-grained feldspathic vitric (volcanic) lith-arenite interbeds 2.5-15 cm thick at 8-60 cm spacing, inclined 0°-5°.	2.7	9

Claystone - dark green, silty, vertical pencil-fracturing in upper 9 m, massive, bedding in lower 3.6 m inclined 10° -15°.	13.5	44.5
Coal - brown to black, silicified.	0.3	1
<u>Unit I</u>		
Siltstone - dark green, volcaniclastic, micaceous, irregular lenses of fine- to medium-grained sandstone.	4.8	16
Tuff - dark green, lapilli, rubbly.	4.4	14.5
Tuff - dark green, accretionary lapilli.	0.9	3
Tuff - dark green, lapilli, rubbly.	4.8	16
Tuff - dark green, accretionary lapilli.	0.2	0.5
Tuff - dark green, lapilli, rubbly.	1.4	4.5
Sandstone - brown, fine- to coarse-grained, volcanic lith-arenite. Grains rounded, porosity 0-10%, weakly cemented.	0.4	1.5
Tuff - dark green, lapilli slightly vesicular rounded to 2 cm.	1.5	5
Total Selah Penetrated	92.4	305.0

Contact - Sharp, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section B

Section measured from boring B-14 (Shannon & Wilson, Inc., 1975), Oregon State system north zone plane grid coordinates N735,901, E2,095,242, in north ½ sec. 6, T N, R22E, Horn Butte, Oregon 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	THICKNESS (Feet)
POMONA MEMBER (Saddle Mt. Basalt Formation)		
Contact - Sharp, baked		
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
<u>Unit III</u>		
Sandstone - gray, fine- to medium-grained, volcanic lith-arenite. Slightly cemented, upper 30 cm baked.	2.1	7
Siltstone - pale gray brown, clayey, lenses fine-grained sandstone, 60 cm thick ash zone with blocky structure 20 m from top of unit, lapilli to 2.5 cm	29.1	96
Sandstone -. pale yellow, fine-grained, volcaniclastic, micaceous, vitric (volcanic) lith-arenite.	0.3	1

Siltstone - pale yellow, clayey, volcaniclastic in bottom 1.8 m.	5.5	18
Sandstone - dark green, silty, fine-grained, volcaniclastic, volcanic lith-arenite.	3.6	12
Sandstone - dark green, silty, fine-grained volcaniclastic, micaceous, volcanic lith-arenite.	0.3	1
<u>Unit II - Lacustrine Facies</u>		
Claystone - dark green, silty, scattered shear planes inclined 40° -50° .	6.7	22
Claystone - black and dark green, silty, laminated, carbonaceous imprints.	1.5	5
Claystone - dark green, silty, scattered leaf and carbonaceous imprints.	2.1	7
Claystone - brown, silty, carbonaceous imprints.	0.6	2
Claystone - dark green, silty, scattered leaf and carbonaceous imprints.	1.8	6
Sandstone - dark green, fine- to medium-grained, silty, volcaniclastic, volcanic lith-arenite. Noncemented, carbonaceous imprints.	1.8	6
Claystone - dark green, volcaniclastic, silty, 2.5-15 cm thick lenses fine- to medium-grained sandstone at 10-15 cm spacing, carbonaceous imprints, sulfide crystals.	2.1	7
Claystone - dark green, silty, vertical pencil-fracturing in upper 3 m, sulfide crystals.	10.0	33
Claystone - light and dark green, silty, laminae <1.5 mm thick.	3.6	12
<u>Unit I</u>		
Tuff - dark green, lapilli, porosity 10% locally.	3.1	10
Sandstone - dark green, fine-to coarse-grained, silty, feldspathic volcanic lith-arenite. Irregularly bedded, noncemented.	0.6	2
Tuff - dark green, lapilli to 6 mm, porosity 10% locally, scattered shear planes inclined 40° -50° .	4.0	13
Tuff - dark green, accretionary lapilli, moderately indurated.	3.1	10
Tuff - dark green, lapilli to 6 cm, porosity 10% locally.	2.1	7
Sandstone - dark green, fine- to coarse-grained, silty, volcaniclastic volcanic lith-arenite. Grains rounded to 2.5 mm, noncemented.	1.5	5

Tuff - dark green, rounded lapilli to 2.5 cm, scattered shear planes inclined 40°-50°.	3.8	12.5
Claystone - dark green, volcaniclastic, hard, fractured.	0.4	1.5
Total Selah Penetrated	89.7	296.0

Contact - Sharp, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section C

Section measured from boring B-15 (Shannon & Wilson, Inc., 1975), Oregon State system north zone plane grid coordinates N733,357, E2,096,654, in T2N, R22E, Horn Butte, Oregon 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
POMONA MEMBER (Saddle Mt. Basalt Formation)		
Contact - Sharp, baked		
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit III		
Siltstone - brown, volcaniclastic, grades to fine- to medium-grained sandstone, upper 90 cm baked, grains coated with dark blue clay.	1.8	6
Siltstone - light gray, clayey, volcaniclastic.	11.8	39
Sandstone - dark gray, fine- to coarse-grained, silty, volcanic lith-arenite.	0.3	1
Siltstone - pale yellow to green, silty, volcaniclastic, scattered lenses fine-grained sandstone, 2.1 m thick blocky fractured ash layer 11.5 m from top of unit, 15 cm thick pumice layer 3.9 m from base of unit.	31.5	104
Siltstone - green, volcaniclastic, irregular layers of fine- to medium-grained volcanic lith-arenite.	3.1	10
Siltstone - dark green, volcaniclastic.	2.1	7
Sandstone - dark green, fine- to coarse-grained, silty, volcaniclastic, volcanic lith-arenite. Slightly cemented, graded parallel bedding inclined 5°-10°.	0.9	3

Siltstone - dark green, clayey, irregularly interbedded fine-grained sandstone layers inclined 0°-15°.	3.7	12
Unit II - Lacustrine Facies		
Claystone - dark green, silty, vertical pencil-fracturing in upper 3 m, scattered leaf imprints, fish vertebrae, sulfide crystals.	7.3	24
Tuff - dark green, lapilli.	0.3	24
Siltstone - pale gray brown, laminae <1.5 mm thick.	3.3	11
Siltstone - dark brown, clayey, carbonaceous, convoluted laminae.	1.5	5
Unit I		
Tuff - dark green, lapilli to 2.5 cm.	4.0	13
Tuff - dark green, accretionary lapilli.	0.3	1
Tuff - dark green, lapilli to 2.5 cm.	1.5	5
Tuff - dark green, accretionary lapilli.	0.6	2
Tuff - dark green, lapilli.	1.5	5
Tuff - dark green, accretionary lapilli.	0.8	2.5
Sandstone - light brown, fine- to coarse-grained, silty, volcanic lith-arenite. Grains rounded, weakly cemented.	2.1	7
Tuff - dark green, accretionary lapilli, lapilli estimated to be 30-40% of rock volume.	4.2	14
Total Selah Penetrated	82.6	272.5

Contact - Sharp, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section D

Section measured on Seely property, SE¼, SE¼, sec. 12, T3N, R20E, Wood Gulch, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit II - Tectonic Facies		
Top of Selah not exposed (covered section)		
Sandstone - gray, fine-grained, silty, feldspathic volcanic lith-arenite. Horizontal bedding 2.5 to 5 cm thick, interbedded with 30 to 60 cm layers of pale brown siltstone at 1.5-3 m spacing.	11.8	39

Sandstone - light gray, fine- to medium-grained.	1.8	6
Conglomerate - yellow brown, silty, sandy volcaniclastic, rounded to elongate pebbles of basalt and pumice, and siltstone clasts to 5 cm.	1.8	6
Sandstone - gray, fine- to medium-grained, silty, volcanic lith-arenite. Rounded basalt pebbles to 2.5 cm, siltstone clasts to 30 cm. Truncated trough-set cross bedding.	3.0	10
Conglomerate - yellow brown, rounded pebbles basalt and pumice, and siltstone clasts to 2.5 cm, SE bedding direction, truncates underlying layers.	0.6	2
Sandstone - gray, fine- to medium-grained, silty, feldspathic volcanic lith-arenite. Thin-bedded.	1.8	6
Conglomerate - yellow brown, silty, rounded basalt pebbles to 5 cm, moderately well indurated.	0.6	2
Unconformity - Erosional		
Unit I		
Siltstone - light gray to white, volcaniclastic, poorly exposed.	4.3	14
Sandstone - gray, fine- to coarse-grained, volcanic lith-arenite. Truncated trough-set cross bedding. Grains rounded, weakly to moderately cemented, marker bed.	1.5	5
Tuff - pale brown, lapilli, massive with some vague horizontal bedding, bottom 10.6 m poorly exposed.	16.7	55
Total Selah Exposed	43.9	145.0

Contact - Sharp, conformable, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section E

Section measured on Seely property, SE¼, SE¼, sec. 12, T3N, R20E, Wood Gulch, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		

Unit II - Tectonic Facies		
Top of Selah not exposed (covered section)		
Sandstone - gray, fine- to medium-grained, volcaniclastic, feldspathic volcanic lith-arenite. Bedding 1.5-3 mm thick.	12.7	42
Conglomerate - yellow brown, silty, rounded basalt pebbles and siltstone clasts to 5 cm.	0.3	1
Sandstone - gray, fine- to medium-grained, silty, feldspathic vitric (volcanic) lith-arenite. Parallel bedding, poorly indurated.	2.7	9
Unconformity - Erosional		
Unit I		
Siltstone - pale brown, slightly sandy, volcaniclastic, blocky fracturing, 2.5-5 cm thick white pumicite interbeds at 30-90 cm spacing.	4.6	15
Tuff - yellow gray to yellow brown, rounded lapilli to 2.5 cm, poorly to moderately well indurated.	19.1	63
Total Selah Exposed	39.4	130.0

Contact - Sharp, conformable, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section F

Section measured on Seely property SW¼, SW¼, sec. 7, T3N, R21E, Wood Gulch, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit II - Tectonic Facies		
Top of Selah not exposed (covered section)		
Sandstone - gray, fine- to medium-grained feldspathic volcanic lith-arenite. Massive.	3.0	10
Sandstone - gray, fine- to medium-grained feldspathic volcanic lith-arenite. Massive siltstone interbeds 8-10 cm thick at 15-90 cm spacing, leaf imprints in siltstone.	5.5	18
Covered Section.	5.1	17
Siltstone - pale brown, volcaniclastic.	6.1	20

Sandstone - gray, medium-grained, volcanic lith-arenite. Rounded pumice to 5 cm, graded bedding.	1.5	5

Unconformity - Erosional

Unit I		
Tuff - lapilli, poorly exposed.	4.2	14
Sandstone - gray, fine- to coarse-grained, volcanic lith-arenite. Massive, grains rounded to 1.2 mm, moderately well sorted, moderately well cemented, marker bed.	1.8	6
Tuff - pale brown, lapilli to 2.5 cm, poorly exposed toward base.	14.6	48
Total Selah Exposed	41.8	138.0

Contact - Sharp, conformable, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

Section G

Section measured on Seely property, SW¼, NW¼, sec. 7, T3N, R21E, Wood Gulch, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
POMONA MEMBER (Saddle Mt. Basalt Formation)		
Contact - Sharp, baked, fused, tuff present		
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit III		
Tuff - brown, fused.	0.3	1
Tuff - brown, lapilli.	1.5	5
Sandstone - pale brown, silty, volcaniclastic, volcanic lith-arenite. Massive, pumice to 3 mm.	8.5	28
Conglomerate - brown, subrounded to rounded siltstone clasts and pumice and volcanic pebbles to 5 cm, poorly sorted, moderately well cemented with black oxides (MnO?).	0.9	3
Siltstone - pale yellow green, vague parallel bedding.	2.4	8
Pumicite - white, thin-bedded, fissile.	0.3	1

Siltstone - pale yellow green, volcaniclastic, scattered limonite nodules to 3 mm.	5.8	19
Base of Selah not exposed (covered section)		
Total Selah Exposed	19.7	65.0

Section H

Section measured near viewpoint northeast of Roosevelt, Washington NW¼ sec. 3, T3N, R21E, Wood Gulch, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit III		
Top of Selah not exposed (covered section)		
Siltstone - pale brown, volcaniclastic, low density, well indurated, massive, blocky fracturing, leaf imprints, fish vertebrae.	6.1	20
Unit II - Tectonic Facies		
Sandstone - brown to gray green, feldspathic volcanic lith-arenite to volcanic lith-arenite. Thin lenses basalt and pumice pebbles to 2.5 cm, trough-set cross bedding imbricated to ESE & SE, massive in portions, friable, cut and fill structures at basal contact (see Fig. 7).	12.1	40
Unconformity - Erosional		
Unit I		
Tuff - pale gray green, slightly sandy, lapilli to 5 cm, massive.	13.9	46
Pumicite - light gray, thin-bedded, fissile.	0.9	3
Tuff - pale gray green, lapilli to 5 cm, fused accretionary lapilli tuff layers 15 cm thick in basal 3 m.	9.1	30
Total Selah Exposed	42.1	139.0
Contact - Sharp, conformable, relatively unweathered		
PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)		

Section I

Section measured northwest of Roosevelt, Washington, SW¼, SE¼ sec. 14, T3N, R20E, Sundale, Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit II - Tectonic Facies		
Top of Selah not exposed (covered section)		
Sandstone - gray, medium- to coarse-grained silty, vitric lith-arenite. Subrounded basalt and volcanic pebbles to 18 mm, subrounded pumice pebbles to 12.5 cm, truncated trough-set cross bedding, very poorly indurated, grains clay-coated, cut and fill structure at base.	1.8	6
Sandstone - gray, medium- to coarse-grained, silty, vitric (volcanic) lith-arenite. Truncated trough-set cross bedding, very poorly indurated.	4.3	14
Unconformity - Erosional		
Unit I		
Siltstone - pale gray green, volcaniclastic.	12.4	41
Base of Selah not exposed (covered section)		
Total Selah Exposed	18.5	61.0

Section J

Section measured east of Arlington, Oregon, on I-80, NE¼ NE¼ sec. 15, T3N, R21E, Arlington, Oregon-Washington, 7.5' quadrangle.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit III		
Top of Selah not exposed (covered section)		
Siltstone - pale yellow to pale brown, volcaniclastic, massive.	6.1	20
Covered Section.	9.1	30
Siltstone - pale yellow, volcaniclastic.	1.5	5
Sandstone - pale brown, medium-grained, silty, volcanic lith-arenite. Poorly indurated.	0.9	3

Siltstone - pale yellow, volcaniclastic, clayey.	0.9	3
Unit II - Lacustrine Facies		
Claystone - dark gray brown, carbonaceous imprints, poorly indurated.	1.5	5
Pumicite - light gray, diatomaceous, thin-bedded, slightly fissible.	3.3	11
Base of Selah not exposed (covered section)		
Total Selah Exposed	67.2	222.0

Section K

Section measured east of Arlington, Oregon, along I-80, NE¼, SE¼ and SE¼, NE¼ sec. 21, T3N, R21E, Arlington, Oregon-Washington, 7.5' quadrangle. Composite section of closely spaced exposures.

STRATIGRAPHIC UNIT	THICKNESS Meters	(Feet)
SELAH MEMBER (Clemans Formation of Bentley, 1977)		
Unit I		
Top of Selah not exposed (covered section)		
Tuff - dark green, lapilli, accretionary lapilli.	0.5	1.5
Sandstone - brown, fine- to coarse-grained, slightly silty, volcanic lith-arenite. Grains rounded, moderately well cemented.	1.7	5.5
Tuff - dark green, lapilli, layers of accretionary lapilli.	5.4	18.0
Total Selah Exposed	7.6	25.0

Contact - Sharp, conformable, relatively unweathered

PRIEST RAPIDS MEMBER (Wanapum Basalt Formation)

APPENDIX B

TABLE IV

SUMMARY OF PETROGRAPHIC DATA

LIGHT MINERALS

LIGHT MINERAL ASSEMBLAGE

UNIT I

SAMPLE NO	24	42	44	45	66	67	86	90	91
Rock Fragments									
Vitric	60 5	65.1	86.4	91.4	87.2	96.9	79.8	83.5	94.5
Volcanic	Tr							0.8	
Metamorphic									
P-Spar	17 7	10.1	5.9	3.4	3.5	2.2	6.8_{11}	9.2_5	4.3_5
K-Spar	10.2_5	16.8	1.8	0.2	0.8_5	0.2	1.3	2.2	0.4
Glass	6 2	3.0	0.4	3.2	0.8	0.6	11.5	3.6	0.7
Quartz	3.2	3.4	1.5	0.2	Tr	Tr		0.3	Tr
Mica	1.7	0.7	2.7	1.2				0.3	
Fossil	0.5		0.2	Tr	Tr	Tr			
Clay									
Zeolite			Tr						
Calcite			Tr		Tr				
Unknown		0 9	Tr	0.2	7.7	0.1	0.6		
Rock Name	D	D	A	A	A	A	B	A	A

UNIT II - TECTONIC FACIES

SAMPLE NO	81	82	83	84	85	88	89	106	109_a
Rock Fragments									
Vitric	76.9	85.8_6	84.0	64.7	81.1	78.2	Tr	63.3	40.0
Volcanic						Tr	30.7		3.0
Metamorphic	Tr	Tr							
P-Spar	12.1	6.1	11.9	31.1	8.8	5.0	10 0	21.2	30.0
K-Spar	2.8	2.8_5	1.1_5	0.3_7	0 3	0.7	2.5_5	0.9_5	3.0
Glass	7.3_4	3.0_4	2.5	2.8	9.8	16.1	55.0	12.6	10.0
Quartz		0.5	0.2	1.2	Tr	Tr		0.6	3.0_8
Mica		Tr					Tr	1.3	
Fossil	Tr	0.9	Tr						2.0
Clay									
Zeolite							Tr		
Calcite	Tr							Tr	
Unknown		0 7	0.4				1.2		
Rock Name	A	A	A	D	A	B	C	E	D

UNIT II - LACUSTRINE FACIES

SAMPLE NO	5	19	20	38	39	40
Rock Fragments						
Vitric	83.9_9	48.6	38.7	78.6	59.1	Tr
Volcanic	0.6				5.2	85.3
Metamorphic						
P-Spar	0.8	22.8	23.5	1.2	14.8	4.7
K-Spar		2.3	3.9	2.0	4.0_7	1.6
Glass	7.8	14.9	24.4_4	12.2	12.6_2	4.0
Quartz	0.3	5.0		0 3	2.2	1.4
Mica		2.0	Tr	1.7	2.2	0 5
Fossil	6.5	0.7		4.0	Tr	0.6
Clay			0.4_{10}			
Zeolite				Tr	Tr	Tr
Calcite			Tr			Tr
Unknown			3.7			1.8
Rock Name	A	E	E	B	B	A

UNIT III

SAMPLE NO	7	14	31	35	52	57	58	59	61
Rock Fragments									
Vitric	72.2_2	35.4	63.0	83.8	84.5	82.9	81.8	70.2_4	87.4
Volcanic	11.6	13.4							
Metamorphic					Tr_3				
P-Spar	Tr	3.5	8.2	7.7	4.[illegible]	7.8	13.0	15.8	7.7
K-Spar	4.5	5.3	7.4	1.3	1.7_5	4.7		3.0_5	0.9_5
Glass		34.0	12.4	3.2	4.9	2.6	2.8	9.6	2.7
Quartz	1.9	6.2	2.6	0 6	0.4	0 2	1.6	0.8	Tr
Mica	2.8_1	1.2_1	2.5		1.5		0.6		0.5
Fossil	0.3	0.9	2.5	2.9		0.3	Tr	0 2	0 3
Clay									
Zeolite									
Calcite								Tr	
Unknown	6.7		1.3	0.5	2 3	1 5	0 3	0 3	0.3
Rock Name	A	B	B	A	A	A	A	A	A

EXPLANATION

Rock Classification (modified after Folk, 1974; see Table III)

A = Volcanic lith-arenite

B = Vitric volcanic lith-arenite

C = Vitric arenite

D = Feldspathic volcanic lith-arenite

E = Feldspathic vitric volcanic lith-arenite

Notes.

1) Biotite
2) Chlorite alteration
3) Meta-quartzarenite
4) Patches of nontronite
5) Sanidine grains with clinging devitrified glass
6) Calcite overgrowths
7) Trace of microcline
8) Grains with clinging devitrified glass
9) Diatom inclusions
10) Nontronite
11) Zoned plagioclase
12) Data shown in percent by volume

TABLE V

SUMMARY OF PETROGRAPHIC DATA

HEAVY MINERALS

HEAVY MINERAL ASSEMBLAGE	UNIT I									UNIT II - TECTONIC FACIES									
SAMPLE NO.	24	42	44	45	66	67	86	90	91	81	82	83	84	85	88	89	105	106	$109a_{11}$
Opaque	52.0	94.1	80.5	80.8	16.1	26.6	76.5	73.1	17.6	81.5	82.0	81.3	83.1	62.0	90.7	51.9	10.6	61.8	
Hornblende	0.5	0.9_3	3.1_2	Tr_2	0.3_2	0.5	5.4_8	12.7_9	58.8_9	4.1_9	7.5_8	7.4	1.3_2	5.6_9	2.1_8	1.4_9	40.2	9.0_2	3.0
Hypersthene	0.2	0.6_2	2.3	1.9	0.5_2	0.2_2	5.4_2	Tr	5.9_2	10.0_4	5.0_2	8.4_4	12.2_4	24.8_4	3.3_4	44.4_4	8.6_4	24.7_4	
Clinozoisite	Tr	1.2	3.1	1.9	0.5	1.5	1.8	2.2	5.9	0.4	0.4	0.6			0.6	0.1	3.7		
Epidote	2.2	1.5	4.7	1.9	0.1	0.2	4.8	5.9	5.9	1.5	2.2	2.3	1.8	3.6	0.6	0.5	12.1	1.1	
Topaz			0.8				3.6	Tr		1.5	0.4	Tr	0.2	3.2	1.2	0.8	3.8		2.0
Zircon	1.2	0.6	1.6	0.9	0.3		Tr	3.0	Tr	0.7	0.7	Tr	0.8	Tr	0.6		3.2	2.2	2.0
Rutile	Tr	0.3	0.8		0.1		0.6	Tr			0.4	Tr	0.2	Tr	0.6		3.8		
Apatite	Tr	Tr					Tr		5.9		0.7					0.5	3.8		
Garnet	Tr	Tr	0.8	Tr			1.2	0.7		Tr	0.7			0.8	0.3		2.9	1.1	
Siderite	40.8	Tr		12.5	82.1	72.4									0.1				
Sphene																	3.8		
Corundum	Tr	Tr			0.1														
Tourmaline																			Tr
Staurolite		0.3		Tr													3.8		Tr
Augite																			1.0
Spinel																			
Alunite																			
Cummingtonite																			
Other	Tr_1		0.7_5	Tr_6		0.1_1	0.6_7	Tr_1		0.7_{10}			0.2_{10}			0.1_{10}		Tr_{10}	

HEAVY MINERAL ASSEMBLAGE	UNIT II - LACUSTRINE FACIES						UNIT III								
SAMPLE NO.	5	9	20	38	39	40	7	14	31	35	52	57	58	59	61
Opaque	56.4	7[illegible].9	65.5	93.0	70.9	82.1	14.4	62.6	28.2	79.6	92.3	87.1	84.5	80.9	77.9
Hornblende	7.3	$[illegible].0_9$	5.3_9	0.4_2	4.4_9	2.9_9	2.4_9	16.6	52.6_9	0.6_9	1.9_3	0.1	1.0_3	3.5_9	6.4_9
Hypersthene		$1[illegible].9_4$	24.0_4	3.0_2	17.8_2	5.9_2	2.4	3.9	7.6_2	0.6_2	1.1	1.1_3	0.3_3	9.8_2	4.0_2
Clinozoisite			Tr		1.1	1.5		Tr	3.3	5.1	0.3	3.3	3.2	1.0	2.0
Epidote	9.0	[illegible].3	2.9	0.9	1.1	1.5	6.0	10.9	2.4	7.0	0.4	5.5	7.1	1.8	5.2
Topaz	12.7	[illegible].8	2.3	0.2	1.1	2.2	62.6	1.1		1.7	1.6	1.1	1.6	1.0	1.6
Zircon	1.8	[illegible].8	0.6	0.9	1.1_{12}	1.5	3.6	1.7_{12}	2.4	0.6	0.3	1.1	0.6	1.3	0.8
Rutile	5.0	[illegible].1	Tr				1.1	1.0			0.8		0.3	0.2	
Apatite			Tr		0.5		3.1	Tr	1.2	1.7	0.2	0.1	0.6	0.2	0.2
Garnet	6.0	[illegible].2		0.3	0.6		1.1	1.0	0.5	1.3	0.3	0.1	0.3		
Siderite				0.9	0.4	2.2			0.5		0.3	0.1			0.4
Sphene															
Corundum				0.3	0.5	Tr		0.7				0.1			0.2
Tourmaline														0.2	
Staurolite		[illegible].1					3.1	0.7		1.7		0.1			
Augite								Tr	1.2						
Spinel					0.5								0.6		
Alunite	1.0														
Cummingtonite	0.7														
Other							Tr_7	Tr_1			0.1_6	0.1_7		$0.2_{1,7}$	$0.1_{1,7}$

NOTES:

1) Biotite
2) Slightly etched
3) Moderately etched
4) Extremely etched
5) Amphibole
6) Calcite
7) Riebeckite
8) Basaltic hornblende in samples: 86 = 45%, 82 = 30%, 83 = 50% 88 = 35%
9) Trace basaltic hornblende
10) Unknown
11) Percentages of total sample
12) Trace zircon overgrowths
13) Data shown in percent by volume

TABLE VI

SUMMARY OF X-RAY DIFFRACTION DATA

	SAMPLE NUMBER	Na+ SATURATED	PEAK*	Ca++ SATURATED	PEAK	DMSO SATURATED	PEAK
WEATHERED SELAH	2	13.18	b;d	14.72	s	19.62	s
		7.13	d	7.13	d	9.50	b;d
						7.49	b;d
	3	12.80	d	14.72	s	18.78	s
		7.13	d	7.13	s	9.50	d
						7.31	d
UNIT III	7			14.24	s		
	10	12.27	s	14.72	s		
UNIT II Lacustrine Facies	81	13.80	b	14.72	s	18.87	s
	82	14.48	b;d	14.72	b;d	20.53	d
		7.37	vd				
UNIT II Tectonic Facies	5	12.99	b;d	14.72	s	19.19	s
		8.84	s	7.13	s	9.03	b;d
		7.13	b;d			7.13	b;d
	6	14.24	b	14.72	s	11.62	b;d
UNIT I	27			20.06	d	21.53	b
				15.23	b;d		
	45	12.10	b;d	14.02	b	19.62	s
		7.13	s	7.13	s	9.60	b;d
						7.07	b;d
						19.19	s
	67	11.94	b;d	13.18	b;d	9.71	b;d
		7.25	s	7.25	s	7.19	s

*Ncte: b=broad, d=diffuse, s=sharp, vd=very diffuse