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Sedimentary Petrology, Depositional Environment and Paleogeographic Significance of the Upper Eocene Hoko River Formation, Northern Olympic Peninsula, Washington

Jennifer H. (Jennifer Helen) De Chant
Western Washington University

SEDIMENTARY PETROLOGY, DEPOSITIONAL ENVIRONMENT AND PALEOGEOGRAPHIC SIGNIFICANCE OF THE UPPER EOCENE HOKO RIVER FORMATION, NORTHERN OLYMPIC PENINSULA, WASHINGTON

By

Jennifer H. De Chant

Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

Dean of the Graduate School

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MASTER'S THESIS

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SEDIMENTARY PETROLOGY, DEPOSITIONAL ENVIRONMENT AND PALEOGEOGRAPHIC SIGNIFICANCE OF THE UPPER EOCENE HOKO RIVER FORMATION, NORTHERN OLYMPIC PENINSULA, WASHINGTON

A Thesis Presented to the Faculty
of Western Washington University

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June 9, 1989

ABSTRACT

The upper Eocene Hoko River Formation is the oldest formation of the Twin River Group. Exposures dipping to the northeast and north run across the northern Olympic Peninsula. The Hoko River Formation is composed of siltstone, turbidites, channel conglomerates and debris flows. The sandstones are lithic-arenites and -graywackes and are composed of fine to very coarse, moderately well sorted to poorly sorted sand. The dominant cement is calcite with minor polycrystalline quartz and zeolite cements. The average composition of the sandstones is quartz (Q) = 29%±14, feldspar (F) = 15%±9, and lithics (L) = 55%±12. Comparison of these data to the tectonic provenance fields of ternary diagrams indicates a mixed tectonic source.

The lithic population of the sandstones contains 21%±15 polycrystalline quartz (Qp), 43%±20 volcanic and metavolcanic lithics (Lvm) and 36%±14 sedimentary and metasedimentary lithics (Lsm). These lithics occur in decreasing order of abundance: metasediments, basalt, chert, polycrystalline quartz, felsic and intermediate plutonics, volcanic glass, felsic and intermediate volcanics, metavolcanics and gabbro and diabase. A slight increase in chert and polycrystalline quartz was found in the Elwah River and Morse Creek sections. The Morse Creek section also showed an enrichment of volcanic glass fragments.

Of the possible source areas for the Hoko River Formation, southern and central Vancouver Island are favored because all of the lithic types found in the Hoko River Formation are present. The lack of high pressure, low temperature metamorphic mineral assemblages typical of the San Juan Islands and the northwest Cascade mountains is the primary basis for excluding these areas as sediment sources of the Hoko River Formation. Sediment shed from the Coast Plutonic Complex would have contained much

more potassium feldspar than the minor amounts found in the Hoko River Formation (0.5 % ± 1). The Olympic Core and Ozette terranes contain sufficient metasediment, basalt and polycrystalline quartz, but lack the other components. In addition, paleocurrent data suggest flow from the west and north to the east.

The Hoko River Formation was deposited in a submarine fan complex in middle-fan channel, outer middle-fan, and middle-fan depositional lobe environments, except at the most western section, Neah Bay, where a transgression of middle-fan channel deposits over inner-fan channel deposits occurs. Subsidence of that portion of the depositional basin is indicated.

The Hoko River Formation was deposited in the Juan de Fuca basin, separate from the basin in which the Chuckanut Formation and its distal equivalents were deposited. A comparison of petrologic data from the Chuckanut and Hoko River Formations shows they are clearly unrelated. Nor is the Hoko River Formation the distal equivalent of the Puget Sequence or the upper Eocene rocks of the Olympic Core. Based on similar depositional environments, Escalante Formation of the Caramanah Group may be a proximal equivalent of the Hoko River Formation.

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I have a long list of people who have, in their own ways, made this thesis possible. I apologize to anyone who is inadvertantly excluded.

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This thesis is dedicated to my brother,

Raoul Thomas De Chant,

who was not able to see me complete this project.

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INTRODUCTION

The purpose of this project was to determine the depositional environment and probable source areas for the Hoko River Formation. Tectonic implications for the northern Olympic Peninsula result from these conclusions. This study was part of an ongoing effort at Western Washington University to determine the geologic and tectonic history of the northern Olympic Peninsula.

Geologic Setting

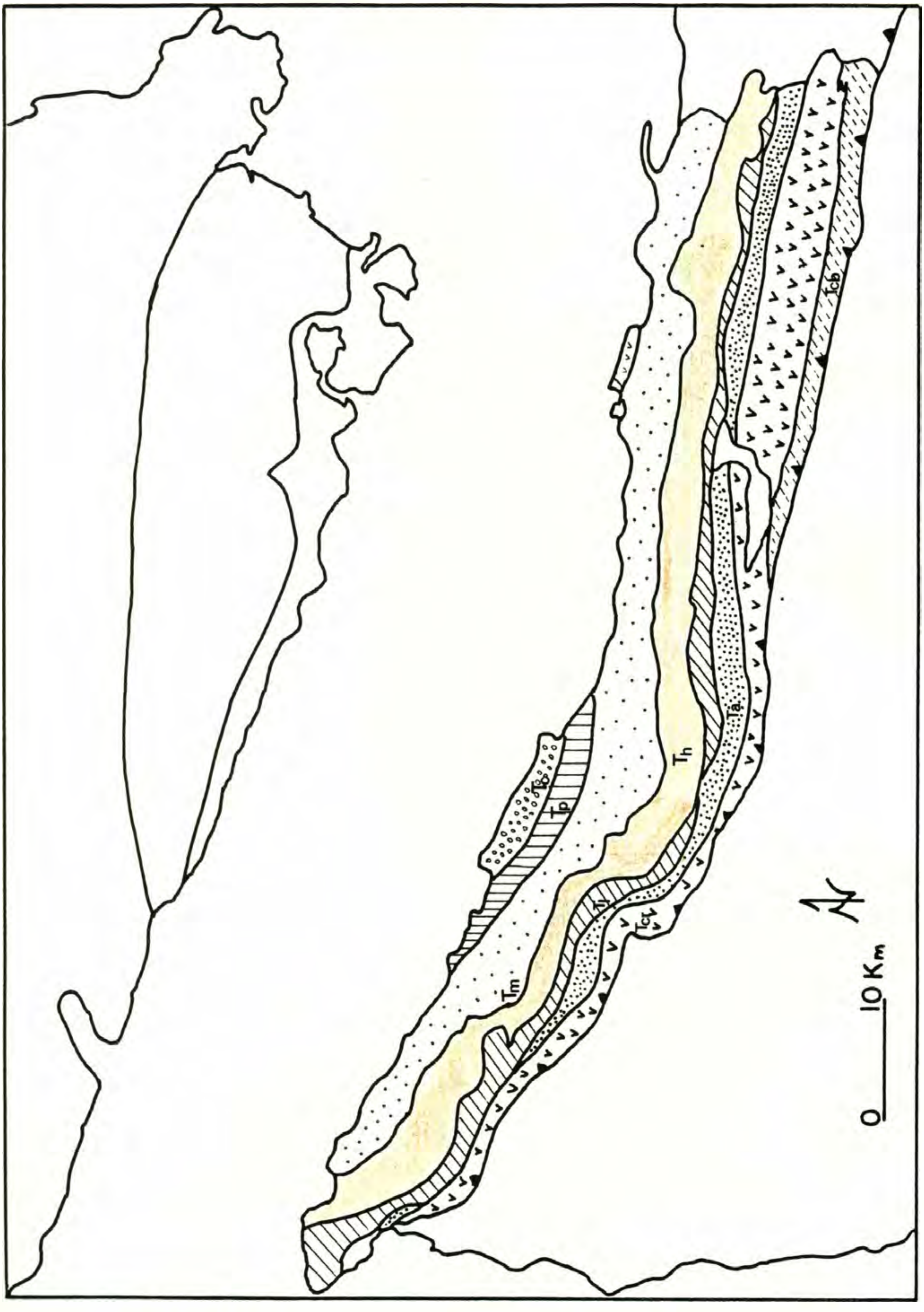
The upper Eocene Hoko River Formation is located along the northern edge of the Olympic Peninsula (Figure 1). It is the oldest formation of the Twin River Group, a thick package of marine sedimentary rocks. The Olympic Peninsula has been divided into the Ozette, Olympic Core, and Crescent terranes by Silberling and Jones (1984) (Figure 2).

The Crescent terrane is the least deformed of the three terranes. It is composed of continentally-derived sandstone and conglomerate, overlain by a thick sequence of basalt pillows, flows, breccias, and basaltic sediments, that are succeeded by a thick stack of marine sedimentary rocks ranging in age from early Eocene to Miocene (Figure 3). This terrane was previously referred to as the peripheral rocks (Tabor and Cady, 1978). The basaltic pillows, flows and breccias of the Crescent Formation were deposited on the basal Blue Mountain unit, continentally-derived submarine fan deposits (Einarsen, 1987)(Figures 1 and 3). The Blue Mountain unit-Crescent Formation contact is controversial and has been described as both a faulted contact (Einarsen, 1987) and a depositional contact (Tabor and Cady 1978; Einarsen, 1987).

The Crescent Formation is overlain by the Aldwell Formation, which is composed of outer fan deposits of siltstone, sandstone, and minor

Figure 1. Generalized geologic map of the northern Olympic Peninsula. After Snavely and others (1983) and Moyer (1985).

Tcb Blue Mountain unit	Tl Lyre Formation	Tp Pysht Formation
Tcr Crescent Formation	Th Hoko River Formation	Tc Clallam Formation
Ta Aldwell Formation	Tm Makah Formation	


Tm
Tp
Th
Ta
Tcb
0
10 Km

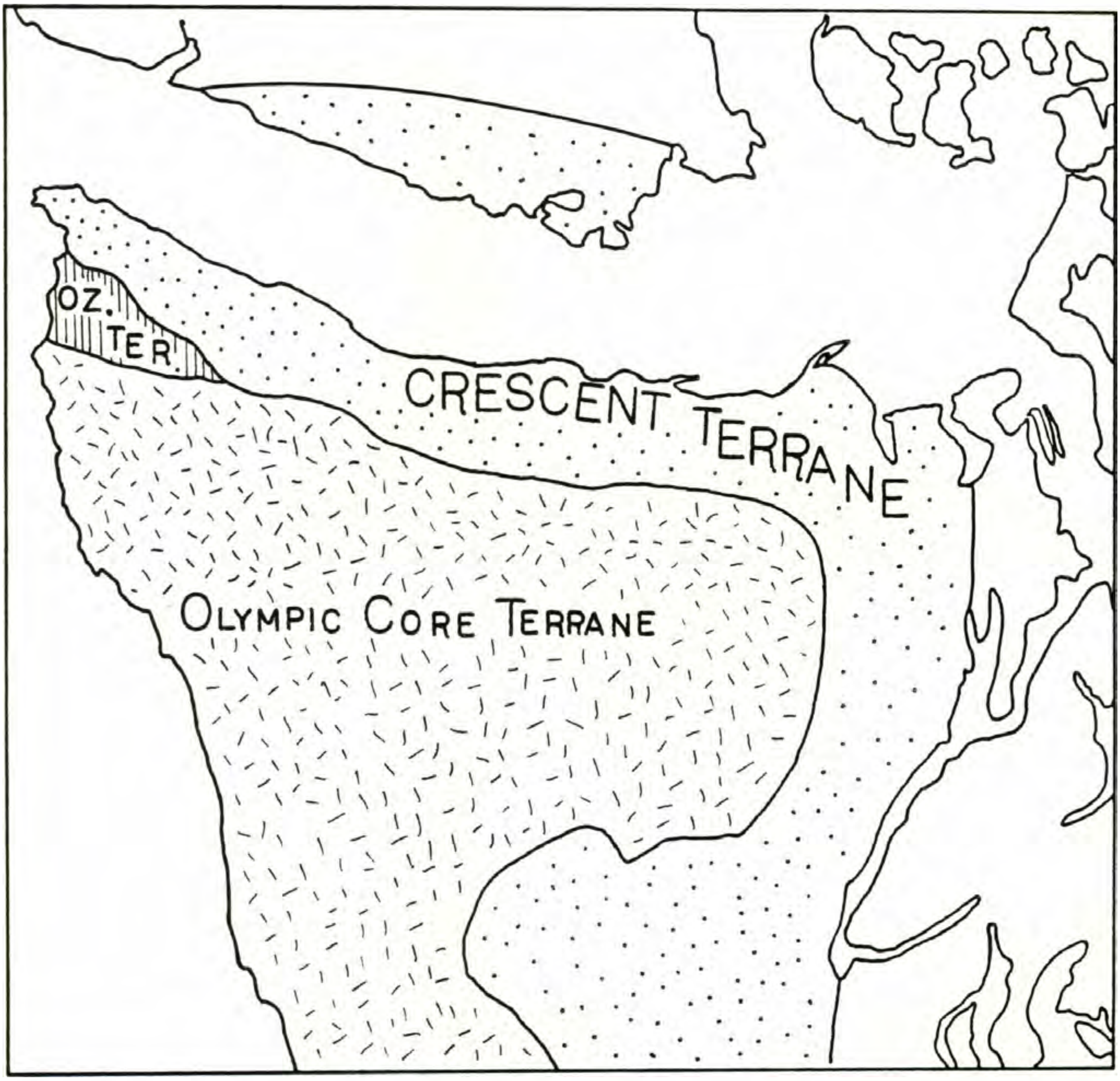


Figure 2. Generalized map of the Olympic Peninsula depicting the three terranes of Silberling and Jones (1984).

Crescent terrane

Olympic Core terrane

Ozette terrane

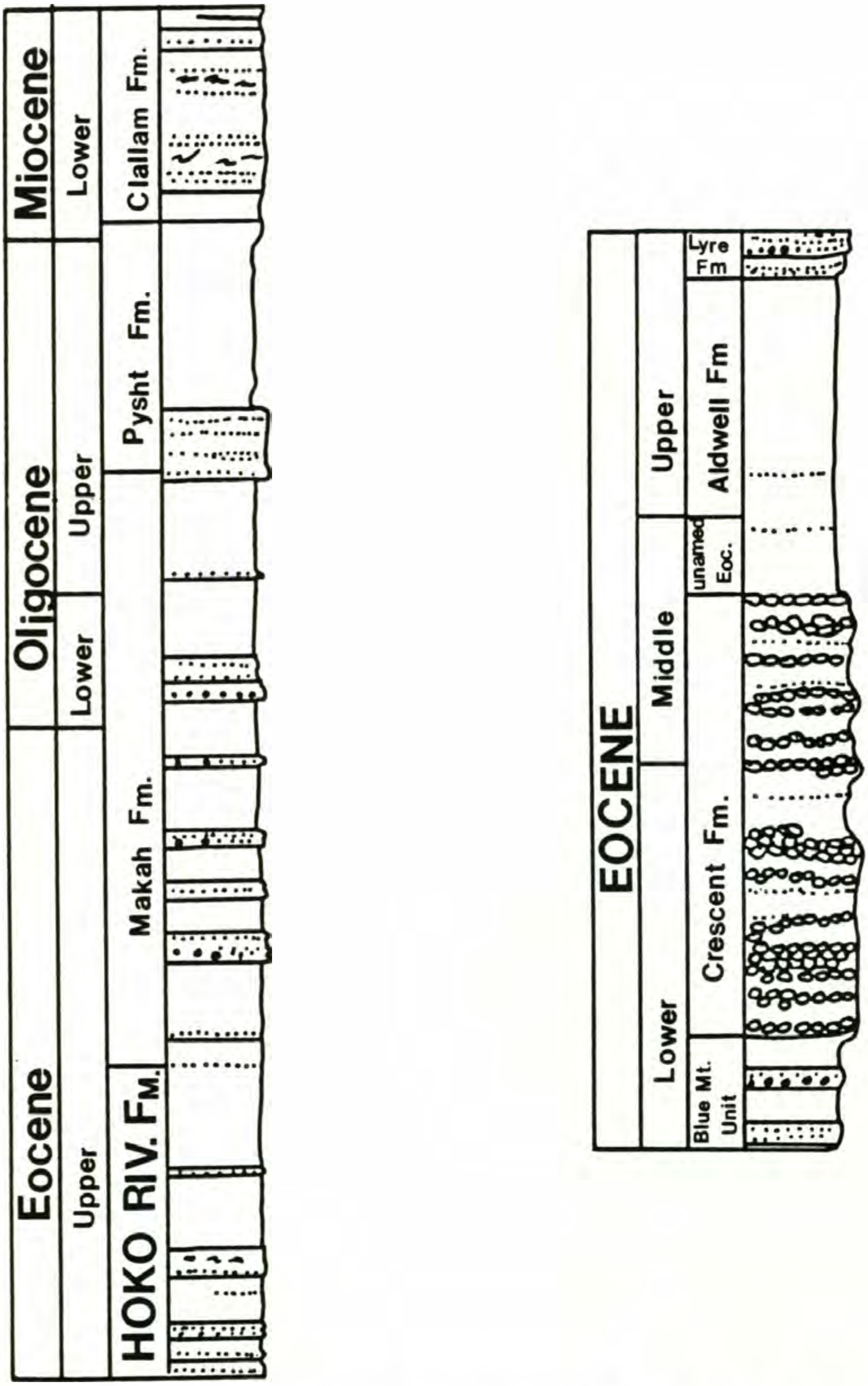


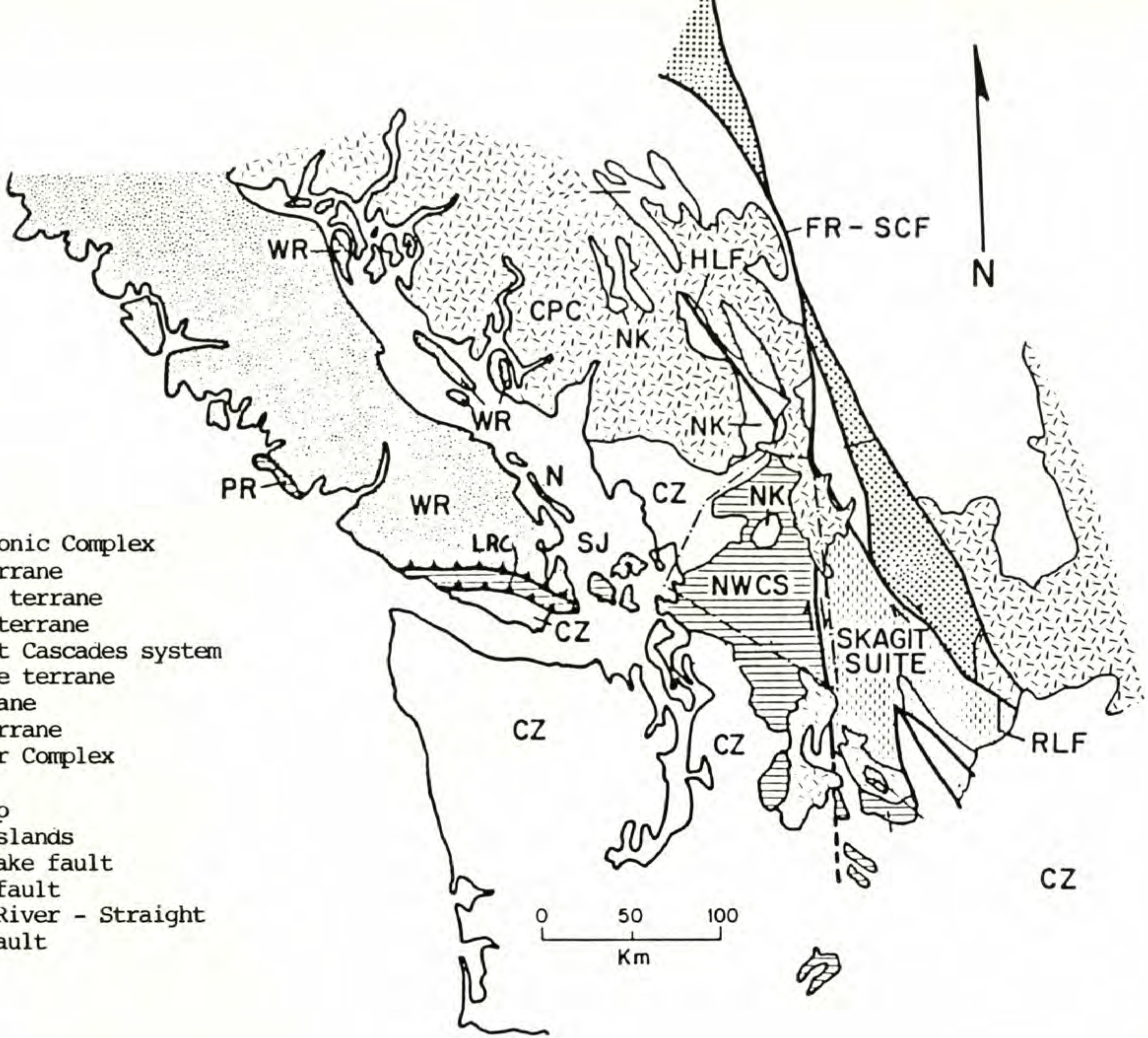
Figure 3. Composite stratigraphic section of Tertiary rocks exposed on the northern Olympic Peninsula, Washington after Snavely and others (1983) and Tabor and Cady (1978).

conglomerate (Marcott, 1984) (Figure 3). Depositionally above this lie the sandstone and conglomerate of the Lyre Formation, which represent portions of cone-fan systems (Ansfield, 1972) (Figure 3). Above this lie the deep to shallow marine siltstone, sandstone and conglomerate of the Twin River Group, comprising the Hoko River, Makah, and Pysht Formations (Snavely and others, 1978) (Figure 3). Lastly, the sequence is topped by the shallow marine sandstone with minor siltstone of the Clallam Formation (Anderson, 1985) (Figure 3).

The structures that affect the Hoko River Formation are a regional tilt down to the north and superimposed folds (Figure 1). A number of folds parallel the strike of the beds, especially in the eastern half of the study area where the major folds are the Clallam syncline and Morse Creek synclines. In the western half of the study area, another set of folds has axes trending northeast-southwest and plunging to the northeast.

The northern Olympic Peninsula lies amidst a region of suspect terranes. Virtually every neighboring region is composed of numerous units, fault-bounded and with a geologic history different than that of the adjacent unit (Figure 4). The exotic terranes surrounding the northern Olympic Peninsula are depicted in Figure 4. Wrangellia, the Northwest Cascades System, and the Coast Plutonic complex were tied together by the Late Cretaceous Nanaimo Group, an overlap assemblage (Pacht, 1984). Paleomagnetic evidence from the Mount Stewart Batholith ties these terranes to local North America at this time (Beck, 1985).

Southern and central Vancouver Island includes the following suspect terranes: northern extension of the Crescent terrane (Metchosin Formation), Wrangellia (Hillhouse, 1977; Yole and Irving, 1980), Leech River Complex (Fairchild and Cowan, 1982), Pacific Rim Complex (Brandon, 1985) and Pandora Peak unit (Rusmore and Cowan, 1985), (Figure 4). The



CPC = Coast Plutonic Complex
NK = Nooksack terrane
PR = Pacific Rim terrane
WR = Wrangellia terrane
NWCS = North West Cascades system
OC = Olympic Core terrane
OZ = Ozette terrane
CT = Crescent terrane
LRC = Leech River Complex
CZ = Cenozoic
N = Nanaimo Group
SJI = San Juan Islands
HLF = Harrison Lake fault
RLF = Ross Lake fault
FR-SCF = Fraser River - Straight Creek fault

Figure 4. Generalized regional geology of the Pacific Northwest from Brown (1987).

Crescent terrane is separated from the rest of Vancouver Island by the Leech River fault, a thrust fault that dips northeast under Leech River Complex and the Wrangellia terrane (Clowes and others, 1987). The timing of movement on this fault has been constrained to after 39-41 Ma (Fairchild and Cowan, 1982) and before the deposition of the upper Oligocene Hesquiat Formation (Cameron, personal communication, 1987).

To the northeast lie the terranes of the San Juan Islands: the Turtleback, Deadman Bay, Garrison, Decateur and Haro terranes and their associated units, the Constitution Formation and the Lopez Complex (Brandon and others, 1988) (Figure 4). The Northwest Cascade system of Brown (1987) comprises the Northwest Cascade Mountains, the San Juan Islands terranes, the Leech River Complex, Pacific Rim terrane, and the Pandora Peak unit (Figure 4). Last, the Coast Plutonic Complex (Figure 4) has been described by Roddick and others (1979) and Roddick (1983) as a intrusive complex of granodiorite and quartz-diorite. Its allocthonous nature was recognized by Irving and others (1985).

The timing of accretion of these terranes is complex and most of the events occurred before the deposition of the Hoko River Formation (Misch, 1966; Fairchild and Cowan, 1982; Pacht, 1984; Irving and others, 1985; Brown, 1987; Brandon and others, 1988). An in-depth review and summary of these events can be found in Einarsen (1987, Appendix 3: Terranes Peripheral to Siletzia).

Purpose

The depositional history, sedimentary petrology and provenance of the northern Olympic Peninsula have recently come under scrutiny. This study was needed to pin down sedimentation patterns during the late Eocene within the Crescent terrane.

The docking of the Crescent terrane along the Leech River fault occurred during or just after the late Eocene. Timing of movement on the Leech River fault is an important question. By studying sediments shed from southern Vancouver Island, ages of movement may be determined.

Questions this thesis attempts to resolve are the following:

What lithic and monocrystalline components comprise the Hoko River Formation? What is the average composition and are there variations within the study area ?

What was the depositional environment of the Hoko River Formation?

What was the source area for the Hoko River Formation?

What constraints may be placed on the movement of the Leech River fault by investigating the depositional environment and source area of the Hoko River Formation ? Does the Hoko River Formation, in any way, document movement along this fault ?

Is the Hoko River Formation the marine equivalent of the large fluvial systems that existed during the late Eocene in the Pacific Northwest, such as the Chuckanut Formation or the Puget Group ?

What was the paleogeography of the region including and surrounding the Hoko River Formation during the late Eocene ?

Previous Work

The previous work on the Hoko River Formation can be divided into four major portions. The earliest work was general mapping of the Olympic Peninsula by a number of workers at the turn of the century. The work was taken over by USGS personnel in the 1950s and continued until the 1980s. From 1950 to 1975, the University of Washington sent a number of Master's students to the northern Olympic Peninsula to interpret the biostratigraphy of the peripheral rocks. Most recently, Western Washington University has made a concerted effort to determine the tectonic origin of the northern Olympic Peninsula. A dozen Masters students have gone to the field to determine the depositional environment, provenance, tectonic setting and paleomagnetic character of formations of the north, east and southeast sides of the Olympic Peninsula. This study concentrates on the depositional environment, provenance and tectonic origin of the Hoko River Formation.

Arnold (1906) was one of the first workers to attempt to unravel the geology of the Olympic Peninsula by studying the coastal exposures (Figure 5a). He divided the stratigraphy into the Eocene basalt flows and tuffs, named the Crescent Formation, which was unconformably overlain by Oligocene-Miocene sedimentary rocks named the Clallam Formation. The term Oligocene-Miocene series resulted.

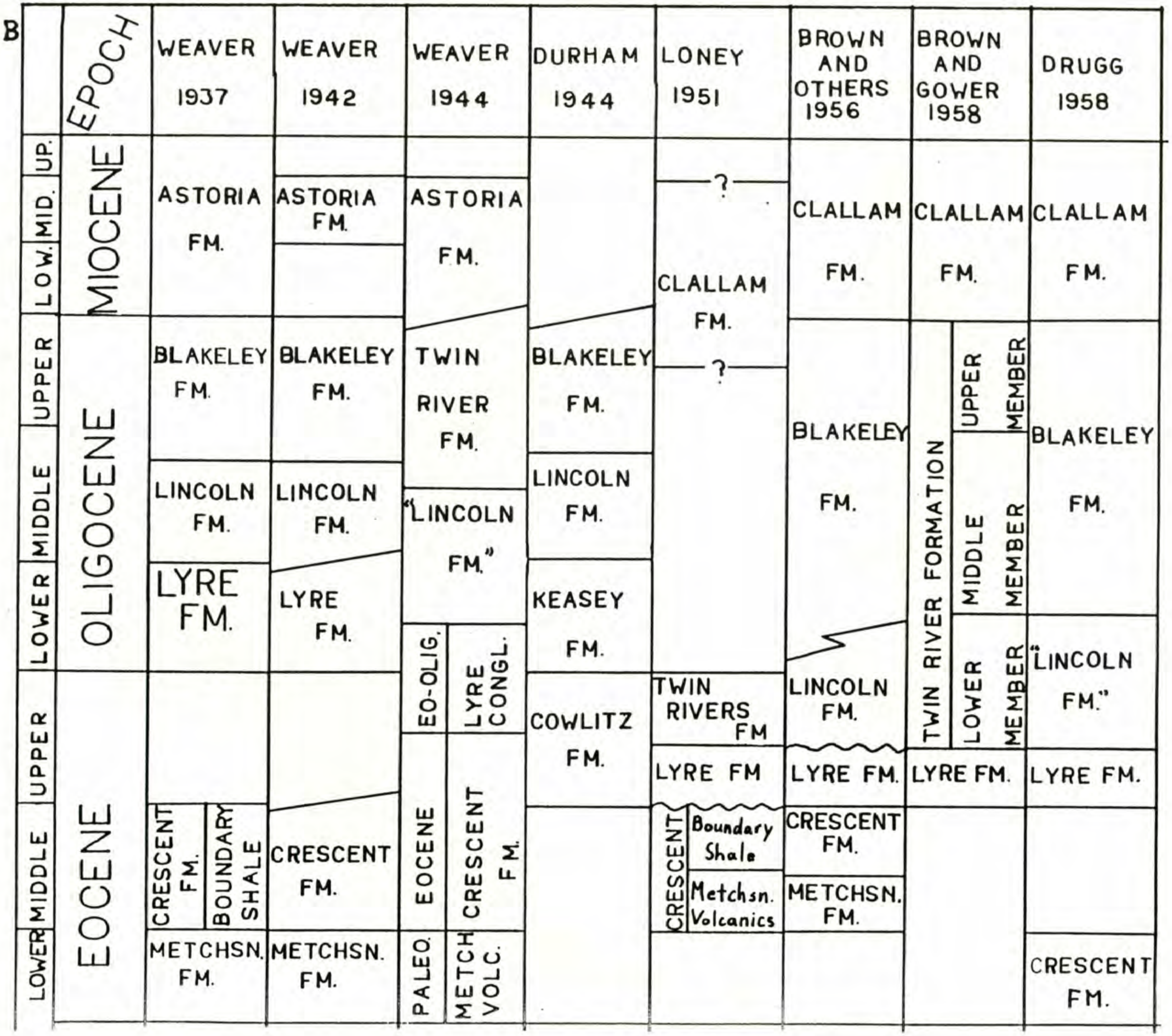
In 1909, Reagan published an account of his reconnaissance geology completed during the summers of 1905 to 1909 (Figure 5a). Besides including colorful historical notes and a summary of the previous work, he published the first systematic faunal description of the coastal exposures of the Olympic Peninsula. He followed the stratigraphic nomenclature of Arnold (1906).

Weaver (1912) designated sedimentary rocks immediately north of Lake

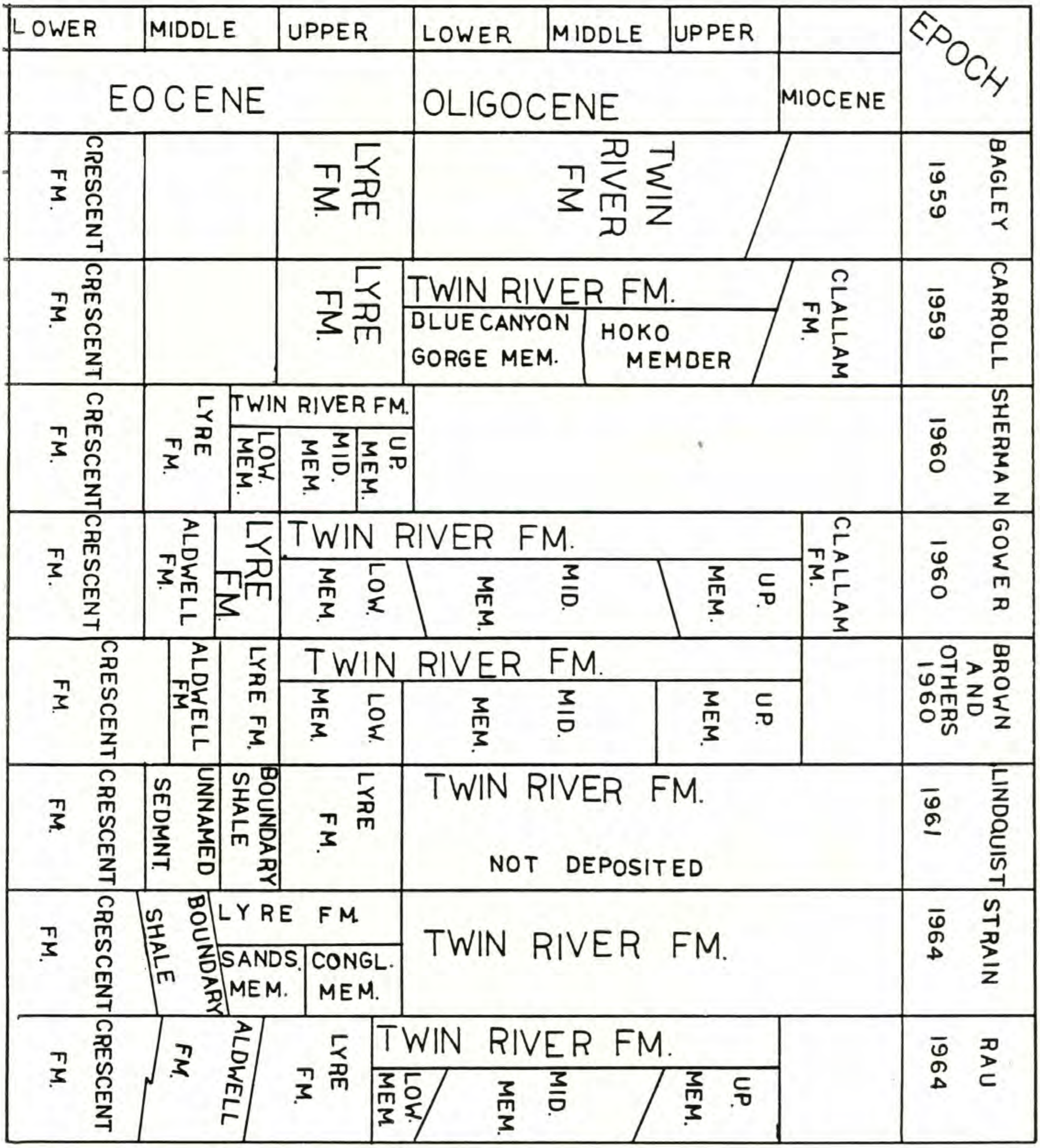
Figure 5a to 5d. Correlation chart of changes of nomenclature of the sedimentary and volcanic rocks of the northern Olympic Peninsula. See text for explanation of abbreviations.

EPOCH	EOCENE (LOWER / MIDDLE / UPPER)	OLIGOCENE	MIOCENE (LOW. / MID. / UP.)
ARNOLD 1906	CRESCENT FORMATION	CLALLAM FORMATION	
REAGAN 1909	CRESCENT FORMATION	CLALLAM FORMATION	
ARNOLD AND HANNIBAL 1913	SOOKE FORMATION	ASTORIA SERIES: SAN LORENZO FM. / SEATTLE FM. / TWIN RIVER FM.	MONTEREY (CLALLAM) FM.
WEAVER 1912	EOCENE BASALT	LINCOLN FORMATION	BLAKELY FM. / Wahkiakum F. / Montesano Fm.
WEAVER 1916 A	N.A.	CLALLAM FM.: MOLO. Lincolnensis / Turritella Porterensis / ACILA Gettysburgensis	WAHKIAKUM HORIZON
WEAVER 1916 B	TEJON GROUP	LINCOLN HORIZON / PORTER HORIZON / BLAKELEY HORIZON	Wahkiakum HORIZON / Montesano HORIZON
HERTLEIN AND CRICKMAY 1925	CRESCENT FORMATION	ASTORIA SERIES: SAN LORENZO FM. / SEATTLE FM. / TWIN RIVER FM.	CLALLAM FM.
PALMER 1927	AGGLOMERATE RIDGE	OLIGOCENE-MIOCENE SEDIMENTS	CLALLAM FM.

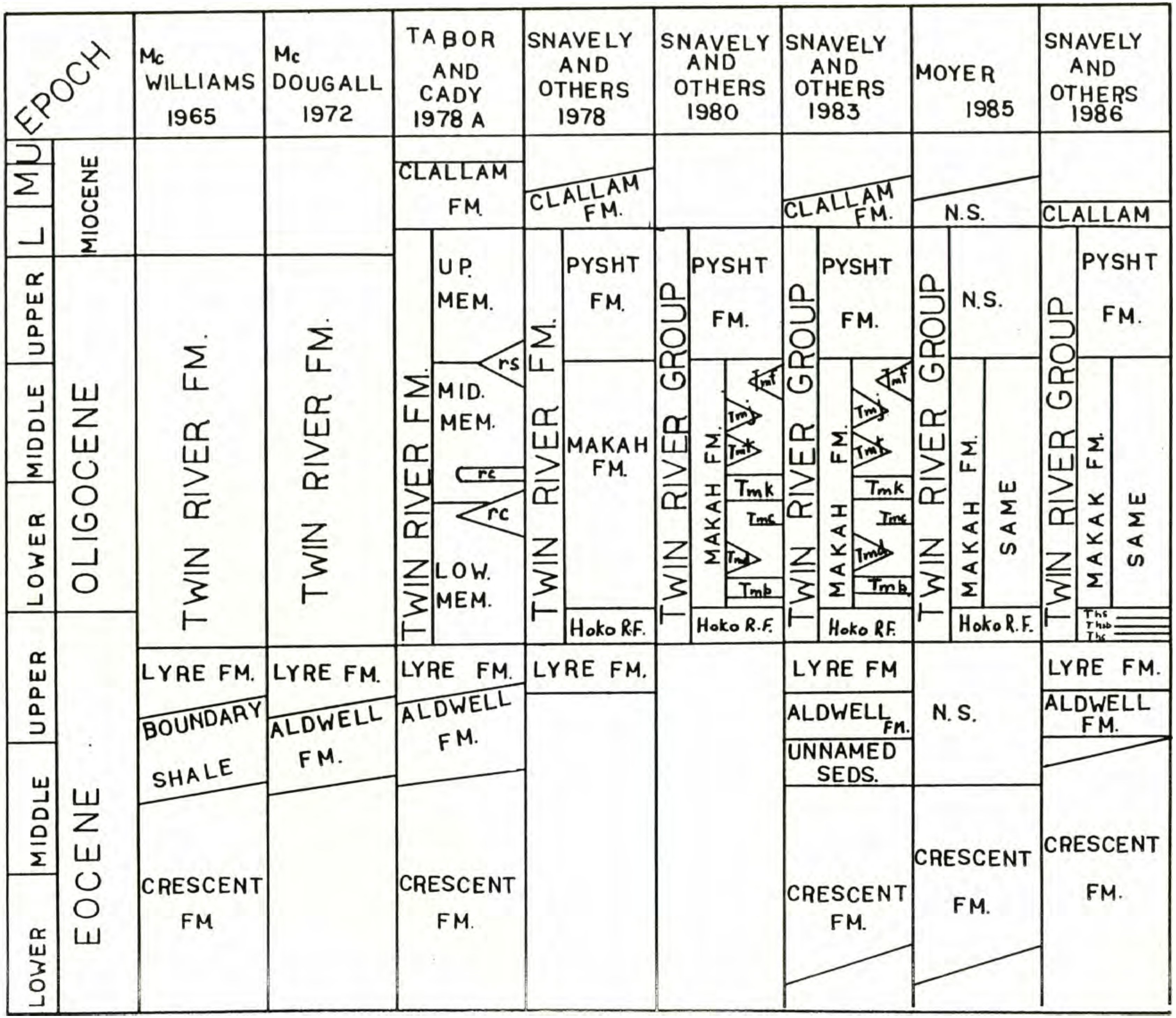
5B


EPOCH
WEAVER 1937
WEAVER 1942
WEAVER 1944
DURHAM 1944
LONEY 1951
BROWN AND OTHERS 1956
BROWN AND GOWER 1958
DRUGG 1958
UP.
MID.
LOW.
MIOCENE
UPPER
MIDDLE
LOWER
OLIGOCENE
UPPER
MIDDLE
LOWER
EOCENE
ASTORIA FM.
BLAKELEY FM.
LINCOLN FM.
LYRE FM.
CRESCENT FM.
BOUNDARY SHALE
METCHSN. FM.
ASTORIA FM.
BLAKELEY FM.
LINCOLN FM.
LYRE FM.
CRESCENT FM.
METCHSN. FM.
ASTORIA FM.
TWIN RIVER FM.
"LINCOLN FM."
EO-OLIG.
LYRE CONGL.
EOCENE
CRESCENT FM.
PALEO.
METCH VOLC.
BLAKELEY FM.
LINCOLN FM.
KEASEY FM.
COWLITZ FM.
?
CLALLAM FM.
?
TWIN RIVERS FM
LYRE FM
CRESCENT
Boundary Shale
Metchsn. Volcanics
CLALLAM FM.
BLAKELEY FM.
LINCOLN FM.
LYRE FM.
CRESCENT FM.
METCHSN. FM.
CLALLAM FM.
TWIN RIVER FORMATION
UPPER MEMBER
MIDDLE MEMBER
LOWER MEMBER
LYRE FM.
CLALLAM FM.
BLAKELEY FM.
"LINCOLN FM."
LYRE FM.
CRESCENT FM.

5c


EPOCH
LOWER
MIDDLE
UPPER
LOWER
MIDDLE
UPPER
EOCENE
OLIGOCENE
MIOCENE
BAGLEY 1959
CRESCENT FM.
LYRE FM.
TWIN RIVER FM
CARROLL 1959
CRESCENT FM.
LYRE FM.
TWIN RIVER FM.
BLUE CANYON GORGE MEM.
HOKO MEMBER
CLALLAM FM.
SHERMAN 1960
CRESCENT FM.
LYRE FM.
TWIN RIVER FM.
LOW. MEM.
MID. MEM.
UP. MEM.
GOWER 1960
CRESCENT FM.
ALDWELL FM.
LYRE FM.
TWIN RIVER FM.
LOW. MEM.
MID. MEM.
UP. MEM.
CLALLAM FM.
BROWN AND OTHERS 1960
CRESCENT FM.
ALDWELL FM
LYRE FM.
TWIN RIVER FM.
LOW. MEM.
MID. MEM.
UP. MEM.
LINDQUIST 1961
CRESCENT FM.
UNNAMED SEDMNT.
BOUNDARY SHALE
LYRE FM.
TWIN RIVER FM.
NOT DEPOSITED
STRAIN 1964
CRESCENT FM.
BOUNDARY SHALE
LYRE FM.
SANDS. MEM.
CONGL. MEM.
TWIN RIVER FM.
RAU 1964
CRESCENT FM.
ALDWELL FM.
LYRE FM.
TWIN RIVER FM.
LOW. MEM.
MID. MEM.
UP. MEM.

5D


EPOCH
Mc WILLIAMS 1965
Mc DOUGALL 1972
TABOR AND CADY 1978 A
SNAVELY AND OTHERS 1978
SNAVELY AND OTHERS 1980
SNAVELY AND OTHERS 1983
MOYER 1985
SNAVELY AND OTHERS 1986
L M U
MIOCENE
LOWER MIDDLE UPPER
OLIGOCENE
LOWER MIDDLE UPPER
EOCENE
TWIN RIVER FM.
LYRE FM.
BOUNDARY SHALE
CRESCENT FM
ALDWELL FM.
CLALLAM FM
UP. MEM.
MID. MEM.
LOW. MEM.
rs
rc
CLALLAM FM.
PYSHT FM.
MAKAH FM.
Hoko R.F.
TWIN RIVER GROUP
Tmk
Tmc
Tmb
UNNAMED SEDS.
N.S.
SAME
CLALLAM
MAKAK FM.
CRESCENT FM.

Crescent as the lower Miocene Blakeley Formation (Figure 5a); rocks from Lake Crescent to Cape Flattery were lumped into undifferentiated lower Miocene.

Arnold and Hannibal (1913) were the first to subdivide Arnold's (1906) Clallam Formation, which they broke into the San Lorenzo, Seattle, and Twin River Formations, the Astoria Series and Clallam Formation (Figure 5a). The San Lorenzo Formation corresponds to the present Lyre, Aldwell and Hoko River (part) Formations. The Seattle Formation corresponds to the Makah and the rest of the Hoko River Formations. Arnold and Hannibal's Twin River Formation is the present Pysht Formation, and their Monterey Formation is now the Clallam Formation.

Weaver (1916a) published a summary of the Tertiary faunal zones of western Washington (Figure 5a). The most notable change to the stratigraphy of the northern Olympic Peninsula was a recognized and defined Oligocene. No Eocene formations were mentioned or described. The Oligocene was subdivided into three zones: the Molopophorous lincolnensis Zone, the Turritella porterensis Zone and the Acila gettysburgensis Zone. The Clallam Formation was expanded to include all of the Oligocene sedimentary rocks. The Acila gettysburgensis Zone is equivalent to the present Cape Flattery conglomerate and the Hoko River, Makah and Pysht Formations.

Weaver (1916b) deleted names of the San Lorenzo, Seattle, Twin River, and Montesano Formations of Arnold and Hannibal (1913)(Figure 5a). He stated that faunal horizons would be more appropriate divisions than formational divisions. Also, the usage of the names San Lorenzo and Montesano imply correlations to formations in California that he did not feel were justified.

Hertlein and Crickmay (1925) attempted to sort out the previous stratigraphic nomenclature (Figure 5a). They adopted the Eocene Crescent Formation for the basalts in the Port Crescent area. They disagreed with Weaver's (1916a) faunal zones and reinstated Arnold and Hannibal's (1913) terminology. They also disagreed with Weaver's more extensive use of the Clallam Formation; they restricted its usage to the Miocene Monterey-age formation on the northern Olympic Peninsula.

The oil and gas potential of the Olympic Peninsula was discussed by Palmer (1927) (Figure 5a). He described the structure and stratigraphy in a general manner. A ridge of basaltic agglomerate located across the northern Olympic Peninsula from Cape Flattery to Port Angeles was named the Agglomerate Ridge, which corresponds to the earlier defined Crescent Formation. Palmer (1927) described it as an anticlinal structure. The overlying sediments, mostly shale with minor sandstone, were described as Oligocene and Miocene. The upper Miocene Clallam Formation is the only formal formation he recognized.

In 1937 Weaver wrote a summary report of the stratigraphy of western Washington and northwest Oregon (Figure 5b). In it, he completely revised the stratigraphic nomenclature on the northern Olympic Peninsula. In the Lake Crescent area, he named the Oligocene the Lincoln Formation. The sandstones of his Lyre and part of his overlying Lincoln Formations are equivalent to the present Hoko River Formation. Farther west, in the Pysht River - Clallam Bay area, his Oligocene Lincoln Formation corresponded closely to the present Hoko River Formation.

In 1942 Weaver compiled a comprehensive paleontology of the Tertiary of Oregon and Washington (Figure 5b). From voluminous paleontologic data, he derived the following stratigraphy for the northern Olympic Peninsula. The volcanic rocks were divided into two parts, the Metchosin volcanics and the Crescent Formation, overlain by the lower Oligocene Lyre Formation. The middle Oligocene Lincoln Formation unconformably overlay the Lyre Formation and was conformably overlain by the upper Oligocene Blakeley Formation. The column was topped by Astoria Formation, equivalent to the present Clallam Formation.

Weaver and others (1944) published a correlation chart of the Cenozoic formations along the west coast of North America (Figure 5b). The names on the northern Olympic peninsula changed again slightly. The Blakeley Formation was dropped and the Twin River Formation substituted.

Durham (1944) published a detailed study of the Oligocene of the Quimper Peninsula, the Twin Rivers area and the Blakeley Formation type section on the Kitsap Peninsula (Figure 5b). He divided the Oligocene into five faunal zones without changing the stratigrahic nomenclature of Weaver (1937). The six megafaunal zones are "Turicicula columbiana", Molopophorous stephensoni, Molopophorous gabbi, Turritella olymicensis, Turitella porterensis, Echinophoria rex, Echinophoria apta. The first zone was tentative and was the one to which the conglomerate of the Lyre Formation of Weaver (1942) belonged. The Twin River Formation of Weaver (1944) was the type section for the Echinophoria apta zone, which corresponds to the present day Pysht Formation.

Robert Loney (1951) was the first University of Washington student to work on the stratigraphy of the peripheral rocks (Figure 5b). His primary interest in renaming formations was to define mappable units rather than faunal zones. His study area was bounded on the north by the Straits of Juan de Fuca between Agate beach and Striped Peak and on the south by Lake Crescent. Within this area he found the middle Eocene Crescent Formation and the upper Eocene Lyre and Twin River Formations. His usage differs from that of Weaver (1942) in that Weaver's Lyre and Twin River Formations were Oligocene. The Lyre Formation was unconformably overlain by the Twin River Formation, which was unconformably overlain by the Clallam Formation. The age of the Clallam Formation was not determined in this study.

Brown and others (1956) redefined the Lyre Formation (Figure 5b). They limited it to the sandstones and conglomerates above the sediments associated with Crescent Formation. They found an unconformity at the top of the conglomerate beneath the sandstones and siltstones of Eocene and Oligocene age. This unconformity marked the top of the Lyre Formation (note: at least two previous studies (cited above) had an unconformity on top of the Lyre.) Their's was the first published data that extended the Eocene to Loney's (1951) Twin River Formation. Brown and others (1956) did not dispute and hence probably adhered to Weaver's (1937) nomenclature of the overlying strata, the Lincoln, Blakeley and Clallam Formations.

Brown and Gower (1958) redefined the Twin River Formation of Arnold and Hannibal (1913) to include a three-member mappable formation of late Eocene to early Miocene age (Figure 5b). Their lower member consisted mostly of interbedded siltstone and sandstone with some conglomerate near the base. The middle member contained more siltstone than the lower member and had many concretionary layers and lenses. Their upper member was mostly siltstone and mudstone with sparse very fine sandstone interbeds. Ages were defined for each member by molluscan and foraminiferal faunas. The lower member was upper Eocene, the middle member was upper Eocene to upper Oligocene, and the upper member was upper Oligocene or lower Miocene. The formation conformably overlies the Lyre Formation as defined by Brown and others (1956). A type locality, Deep Creek, and two reference sections, the Lyre River and the Straits of Juan de Fuca between the East Twin River and Murdock Creek, were defined. Brown and Gower's (1958) definition of the Twin River Formation set the precedent for all future workers. They either agree with, disagree with, or upgrade this work.

In 1958 Drugg completed a Master's thesis on the biostratigraphy of the Hoko River area (Figure 5b). He followed Weaver's (1937) usage of the Crescent, Lyre and Lincoln Formations. He named the Boundary Shale as a lower member of the Lyre Formation. His upper member of the Lyre Formation was the conglomerate member of Weaver (1937) and Loney (1951).

Bagley (1959) worked in the Seiku River Area and determined the paleontology and paleoecology of the Crescent, Lyre and Twin River Formations (Figure 5c). He followed Drugg's (1958) terminology and divisions for the Crescent and Lyre Formations. Bagley thought that the Twin River Formation was very similar to the Boundary Shale member of the Lyre Formation and that the two should be a single formation with three members.

Bagley's (1959) paleoecologic interpretation are quite specific and interesting (Figure 5c). The Boundary Shale member corresponded to the Nodosaria-Cibicides Zonule. It was thought to represent warm water and a neritic depth. The end of this zonule represented a slight cooling of the water and deepening of the basin. The Rhabdammina-Haplophrgoides Zonule, the later zonule of the Boundary Shale member, represented deposition in deep cold water with connection to the open ocean during the later stages. The Globobulimina-Cassidulina Zonule, in which the upper Lyre and lowest Twin River Formations fell, contained slightly more mixed genera. Deep, cold water was indicated by some faunas, while there was an absence of deep water Foraminifera. This lack reflected a cold, open ocean environment that was not as deep as before. The Rhabdammina-

Haplophragoides-Cyclamenina Faunule, which was present in the lower 1000 ft of the Twin River Formation, represented a deepening cold basin connected to the open ocean. He noted the similarity between the Zonule of the faunule of the Boundary Shale Formation and the Twin River Formation.

Carroll (1959) studied the Lyre Formation and the overlying Twin River Formation along the Hoko River (Figure 5c). He began where Drugg (1958) left off in the lower Twin River Formation. He presented a detailed paleontologic and stratigraphic study of the area. The Twin River Formation was divided into two members rather than the three members of Brown and Gower (1958) on the basis of "striking lithologic changes". The Blue Canyon Gorge member was about 6300 ft thick and consisted of "dark grey concretionary siltstone and fine grained sandstone" as typically exposed at the Blue Canyon Gorge of the Hoko River. His upper Hoko member was about 7,700 ft of interbeds of medium to dark gray siltstone and medium gray sandstone exposed from a point 2.2 miles south of the Route 101-112 intersection to Kydaka Point along the Hoko River. He determined the lower 960 ft of the Blue Canyon member to be upper Eocene, with the Narizian-Refugian boundary (upper Eocene to lower Oligocene) at 960 ft above the base of the Twin River Formation. The Hoko member was thought to be Oligocene or lower Miocene.

Carroll's (1959) paleoecologic data provide a number of interesting conclusions (Figure 5c). The fauna of the Blue Canyon Gorge member lived from medium to lower bathyal conditions 3000-6000 ft deep in cool water 40-60 degrees F except for the upper third of the Blue Canyon Gorge member, which corresponds to the top of the present Hoko River Formation, which may have existed in neritic to upper bathyal conditions of 0 to 3000 ft. The surface conditions of the lower 2000 ft were thought to represent tropical or subtropical environments. Above this the number of species dropped, indicating a cooler climate may have prevailed. A connection with the open ocean was postulated because of the presence of the genus Globigerina.

Sherman (1960) worked in the northeastern corner of the Olympic Peninsula (Figure 5c). He looked at the Crescent, Lyre, and Twin River Formations. In his study area, he divided the exposed 17,000 ft of Twin River Formation into three lithologic units. His lower unit was dominantly thin-bedded siltstone with regular very fine sandstone beds. His middle unit, about 1100 ft thick, contained mostly shales and mudstone with concretionary beds and occasional sandstone lenses. His upper unit was mostly a series of sandstone beds. His units differed from the three members of Brown and Gower (1958).

Gower (1960) published the first geologic map of the Pysht quadrangle at a scale of 1:62,500 (Figure 5c). His stratigraphic nomenclature was not changed from that of Brown and Gower (1958). He mapped three members in the Twin River Formation; the upper and lower contacts of the three members were gradational and "somewhat arbitrarily defined, (see description on reverse side of map, column 4)." The Twin River Formation was recognized as late Eocene to Oligocene.

Brown and others (1960) mapped the bedrock and Quaternary geology of the Lake Crescent-Port Angeles area at a scale of 1:62,500, including the Aldwell, Lyre and Twin River Formations (Figure 5c). Both the Lyre and Aldwell Formations underlie the Twin River Formation, due to discontinuous deposition of the Lyre Formation. The Clallam syncline, a broad east-west-trending fold with minor anticlines and synclines on its limbs, exposes their lower member of the Twin River Formation, which consisted of bedded sandstone and siltstone with lenticular conglomerate layers. Their middle member was mostly massive siltstone with minor thin sandstone beds and a 330m thick conglomerate unit at its base in the middle of the map area. Brown and others (1960) described the conglomerate as "lithologically similar to the Lyre Formation (see description on the reverse side of the map, column 8)." They suggested that it may represent a reworking of the Lyre Formation. Additionally, they note a sedimentary breccia at the base of mostly volcanic detritus thought to have come from the Crescent Formation. Their upper member was finer grained, composed chiefly of massive mudstone with minor thin sandstone beds. Their Twin River Formation ranged from upper Eocene to lower Miocene. The members are the following ages: the lower is late Eocene, the middle is late Eocene to late Oligocene and the upper is Oligocene or early Miocene.

Lindquist (1961) worked in the area south of Port Angeles and Sequim and also noted the absence of the upper Eocene Twin River Formation (Figure 5c).

The biostratigraphy of the Twin Rivers area was studied and interpreted by Strain (1964)(Figure 5c). He followed the stratigraphy of his peers at the University of Washington except for changes to the Boundary Shale, Lyre and Twin River Formations. He recognized a distinct Boundary Shale Formation above the upper Crescent member of the Crescent Formation and conformably underlying the Lyre Formation, which was composed of lower sandstone and upper conglomerate members. The upper conglomerate member of the Lyre Formation was overlain conformably by the Twin River Formation. The Twin River Formation was not divided into either the two members of Drugg (1958) and Carroll (1959) or the three members of Brown and Gower (1958). Strain did recognize lithologic changes, but he thought they were not definite enough to form members.

His Twin River Formation generally consisted of well indurated sandstone, thin to massively bedded, that graded into concretionary siltstone with minor sand lenses. Possible faulting along the Lyre-Twin River Formation contact was suggested as an explanation for the lack of the basal sandstone in some cases. His lower Twin River Formation is upper Eocene, upper Narizian of Mallory (1959). Strain (1964) determined that the upper Twin River Formation was lower Oligocene in age (Figure 5c). The paleoecology indicates that the water depth became shallower from the base of the Twin River Formation to the top, from bathyal to neritic depths. Open ocean conditions probably occurred as well. Temperatures cooled in the upper portion of the Twin River Formation with the exception of one anomalous fauna (Strain, 1964).

In 1964 Rau described the foraminifera on the northern Olympic Peninsula. He followed Brown and Gower's (1958) redefinition of the Twin River Formation and its three members (Figure 5c). He stated that the lower member, based on scarce forams, was upper Eocene, mostly the upper part of the Narizian stage of Mallory (1959). The upper portion of the lower member was early Oligocene and corresponded to the Refugian of Schenk and Kleinpell (1936). According to Rau (1964), the fauna of the Twin River Formation preferred deep, cold, open ocean water. The lower member included two types of fauna that together indicated water depths of 300 to 1000 ft: lower neritic to uppermost bathyal. The middle member was deposited in 1000-6000 ft of water. The upper member was upper neritic.

McWilliams (1965) presented a thesis on the biostratigraphy and geology of the Lake Crescent area. He studied the Crescent, Boundary Shale, Lyre and Twin River Formations (Figure 5d). He dropped the subdivisions within the Crescent Formation. He divided the Twin River

Formation into four different zonules with a fifth overlapping from the underlying Lyre Formation. His lowest portion of the Twin River Formation included the "impoverished" faunal indicating littoral to sublittoral depths. The next two zonules, the Haplophragmoides-Trochammina Zonule and the Eponides mansfield var. oregonsis Zonule, fell into the Narizian stage (late Eocene) and upper, then lower, bathyal depths. The Upper Bathsiphon Zonule restricted the Twin River Formation to upper bathyal depths and the beginning of the Refugian (early Oligocene). Last, the Globoberlimina pacifica Zonule represented lower bathyal depths during the Refugian and Zemorrian stages.

McDougall (1972) correlated all the previous biostratigraphic work of the University of Washington from the northern Olympic Peninsula in her Masters thesis, which dealt with the Narizian-Refugian boundary on the northern Olympic Peninsula (Figure 5d). She determined that the Narizian-Refugian boundary should fall in the upper Eocene, which is within the first 1000 ft to 3000 ft of the Twin River Formation depending on the exact section location. She determined that the Narizian-Refugian boundary should fall 700-725 ft above the Lyre-Twin River formation contact along the Hoko River. The Aldwell Formation was not recognized by McDougall. Along the Lyre River, correlative samples occurred in the upper Lyre Formation, due to the time-transgressive nature of the Lyre-Twin River Formation contact (McDougall, 1972). In general, she thought that the Narizian-Refugian boundary fell above the Twin River-Lyre Formation Boundary by amounts varying from 300 to 3500 feet, all within the Twin River Formation.

The first comprehensive geologic map of the Olympic Peninsula was published in 1978 by Tabor and Cady. The Twin River Formation was divided into the three mappable members of Brown and Gower's (1958) usage with the following additions (Figure 5d). A conglomerate lens (rc) was mapped within the lower and middle members, which were mostly thin-bedded sandstones with minor siltstone and pebbly sandstone at the base. The middle member contained more sandstone than the lower member. Their upper member was composed of massive to thin-bedded mudstone and siltstone except for the area between Kydaka and Seiku Points, which was sandstone and conglomerate (rs). The Twin River Formation overlay the older Lyre Formation unconformably in the east and conformably in the west. The middle Miocene Clallam Formation gradationally overlay the late Eocene Twin River Formation.

Tabor and Cady (1978) made several changes to the earlier stratigraphic nomenclature. They mapped and recognized the Aldwell Formation. They recognized an unconformity between the Aldwell and the Twin River Formation in places where the Lyre Formation had not been deposited. And, last, they recognized an intraformational unconformity between the lower and middle members of the Twin River Formation.

Snavely and others (1978) raised the Twin River Formation to group rank and named its three members: from oldest to youngest the Hoko River, Makah and Pysht Formations (Figure 5d). The Hoko River Formation was upper Eocene; the Makah Formation, upper Eocene to Oligocene and the Pysht Formation, Oligocene to lower Miocene. Type sections were described for each. The Hoko River type locality was designated along the Hoko River and an adjacent railroad grade and service roads, with reference sections at Deep Creek and the Straits of Juan de Fuca from Midway to Neah Bay.

Snavely and others (1978) described the Hoko River Formation as thin-bedded siltstone and quartz-rich, basaltic and phyllitic sandstones with smaller amounts of pebbly sandstone and conglomerate as lenses and channels. Concretions of calcite were noted throughout the formation. A few sandstone dikes cut through the strata. The Hoko River Formation was about 1600 m thick at the type section and 2300 m at the reference section along Deep Creek.

In 1980, Snavely and others published a professional paper on the Makah Formation (Figure 5d). This included the ages of the Hoko River and Makah Formations, and contact relationship between these two formations. The Hoko River Formation was described as a dark gray lithic sandstone, with phyllitic and basaltic fragments that are uncommon in the Makah Formation. The Hoko River Formation was described as hackly-fractured siltstone, distinct from the well-bedded siltstone and turbidites of the Makah Formation.

Snavely and others (1983) contributed descriptions and interpretations of the peripheral rocks of the Olympic Peninsula (Figure 5d). He included a composite stratigraphic column of these rocks on the northern Olympic Peninsula. His descriptions of the lithologies and contacts of the Hoko River Formation were similar to those in Snavely and others (1978). In a southwest to northeast cross-section from the Olympic Peninsula to southern Vancouver Island, he depicted a basin that thinned to the north with the youngest units reaching across the basin. A brief interpretation of the depositional environment of the the Lyre and Hoko River Formations stated that material was eroded from the fault scarps along the San Juan and Leech River Faults, to the north on Vancouver Island, into channels of a deep marginal basin known as the Tofino-Juan de Fuca basin. Subsequent uplift and erosion along these faults provided the sediment for the deposition of the Makah Formation.

Moyer and others (1985) completed a paleomagnetic study of the Tertiary rocks on the northern Olympic Peninsula (Figure 5d). Samples were taken from the Crescent, Hoko River and Makah Formations. Moyer (1985) discovered there were two structural regimes on the northern Olympic Peninsula, forming an eastern and a western domain. The rocks they studied have a complicated geologic history. The Crescent Formation was formed in a tectonic setting near its present location according to Beck and Engebretson (1982). Moyer and others (1985) stated that from Neah Bay to Port Townsend of the Crescent Formation and the older Tertiary sedimentary rocks were deflected 70 degrees counterclockwise. This was recorded as a primary direction of magnetization in several sites at one locality in the Hoko River Formation (Moyer and others, 1985; Moyer, 1985). Geologic, structural, and paleomagnetic evidence suggested to him that the two structural domains were separated after this initial event. The western domain, from Neah Bay to the Pysht River, was rotated 40 degrees clockwise. Evidence from one site indicated that the eastern portion was relatively unchanged during this second event.

In 1986, Snavely and others presented a geologic map of the northwest corner of the Olympic Peninsula (Figure 5d). In general, mapping was similar to that of Tabor and Cady (1978) but in more detail. The core rocks were divided into many different blocks or terranes. The Hoko River Formation was divided into four mappable units: "the Hoko River Formation [in general] (Th), a thick- to thin-bedded lithofeldspathic turbiditic sandstone unit (Ths), a thick- to thin-bedded carbonaceous, calcite-cemented, phyllitic and basaltic sandstone with minor siltstone interbeds (Thsb), and a unit of cobble and boulder channel deposits (Thc)" (Snavely and others, 1986, p.2). The Hoko River Formation (Th) contained the siltstone and sandstone previously described in Snavely and others (1978). Additionally, pebbly mudstone, mudflow breccia, sandstone dikes and thin ash beds were recognized. The turbiditic sandstones of the Ths unit were found in the eastern part of the map area from the Hoko to the Clallam Rivers. The phyllitic and basaltic sandstones of the Thsb unit were found in a belt in the western portion of the formation. Minor siltstone interbeds occurred within broad channels of this unit. The channel deposits of the Thc unit were found at the base of the section just west of Neah Bay. The compositions included basalt, phyllite, meta-plutonic rocks and conglomerate.

SEDIMENTARY PETROLOGY

The sandstones of the Hoko River Formation are lithic arenites and lithic graywackes (classification of Pettijohn and others, 1972). The grain size varies from fine to very coarse sand (0.125 to 2.0 mm). Grains are subrounded to angular with a mean of subangular. The sandstones are moderately well sorted to poorly sorted, the average sorting is moderate. The components comprising these sandstones form a distinctive assemblage that requires careful study to determine the nature of possible source areas. This section contains these petrologic details.

Methods

Modal analyses to determine the composition were performed on 50 thin sections of sandstones representing the range of fine to very coarse (0.125 to 2.00 mm), poorly to well sorted, and angular to subrounded. One half of each thin section was stained for potassium and plagioclase feldspar. Sodium cobaltinitrite produced a yellow stain on potassium feldspar, and amaranth produced a red stain on calcium-bearing plagioclase. Whole-rock counts of 300 points were made to determine proportions of the categories: quartz (Q), plagioclase (P), potassium feldspar (K), accessory (Acc), chlorite (Chl), amphibole + epidote + zoisite (Amp/Ep), carbonate cement (CC), matrix (M), total lithic (Lt), and other (O). The lithic components were further subdivided in a separate 200-point count into the following categories: mafic volcanic, intermediate volcanic, felsic volcanic, glassy volcanic, meta-volcanic, schist + phyllite, other meta-sediment, chert, polycrystalline quartz, sedimentary, fossils, amphibole + epidote, felsic plutonic, dioritic plutonic, gabbroic plutonic, and others. These categories were combined to form the following ternary plots: Q-F-L, Qm-F-Lt, Qp-Lvm-Lsm, Qm-P-K, Lm-Ls-Lv. See Tables 1 and 2 for explanation of symbols.

The Gazzi-Dickinson method of point counting as revised by Ingersoll and others (1984) was used to reduce discrepancies due to grain size in all cases except that of plutonic lithics. These were treated in the following manner: if the cross-hairs landed on the boundary between two crystals of a plutonic lithic, ie., between quartz and plagioclase in a felsic plutonic grain, that point was counted as a lithic.

Mineral Descriptions

Quartz (Qm) crystals greater in size than very fine sand were counted as monocrystalline quartz grains. Plutonic, metamorphic, and vein quartz are common. Plutonic or "common" quartz can be recognized by its somewhat undulose extinction and lack of vacuole trains. Plutonic quartz is also recognized by its association with amphibole, euhedral plagioclase and rare potassium feldspar. Metamorphic and vein quartz can sometimes be recognized by their crenulated crystal boundaries, highly undulose extinction, and lineated vacuole trains. Occasionally, recrystallized metamorphic quartz forms very fine sand-sized aggregates of equant crystals with interlocking to straight boundaries that are counted in the Qp category. Quartz crystals that occur as veins in lithic fragments are often large enough to be counted as single crystals.

Plagioclase (P) is most often found in volcanic lithic clasts with some isolated single-crystal occurences in fine to coarse sand. Crystals are concentrated in two sizes, fine and coarse sand, probably reflecting volcanic and plutonic sources, respectively. Both varieties are recognized by their lath shapes, by albite and carlsbad twins, and by

Table 1 ABBREVIATIONS USED DURING POINT COUNTS

Whole Rock Count - 300 points

Qm	Monocrystalline quartz
P	Plagioclase feldspar
K	Potassium feldspar
Acc	Accessory minerals - pumpellyite, muscovite, biotite, pyroxene, opaques, serpentine, talc, sulfides, hematite
Ch	Chlorite
Amp/Ep	Amphibole, epidote, and zoisite
CC	Carbonate cement
M	Matrix - pseudomatrix and protomatrix (detrital clays)
Other	Miscellaneous materials of note that were not included elsewhere, such as zeolite and silica cements and unidentified grains

Lithic Count - 200 points

Volcanic	
lvm	Mafic volcanics, basalt
lvi	Intermediate volcanics, dacite, andesite
lvf	Felsic volcanics, rhyolite
lvg	Volcanic glass

Metamorphic	
lmv	Meta-volcanics
lmsp	Schist and phyllite
lms	Meta-sediments

Sedimentary and Other	
cht	Chert and recrystallized chert
Qp	Polycrystalline quartz
ls	Sedimentary clasts, siltstone and very fine sandstone
fos	Fossils, clams, forams, and brachiopods
amp/ep	Amphibole- and epidote- or zoisite- rich schist and gneiss
other	Miscellaneous and unidentifiable lithics

Plutonic	
lpf	Felsic plutonics; granite, granodiorite
lpd	Diorite, quartz-diorite
lpg	Gabbro, diabase

Table 2 SUMMATION OF CATEGORIES FOR TERNARY DIAGRAMS

Q-F-L

Q = Qm + Qp + cht
F = K + P
L = Lt - (Qp + cht)

Qm-P-K

Qm = Qm
P = P
K = K

Lv-Ls-Lm

Lv = lvm + lvi + lvf + lvg
Ls = ls
Lm = lms + lmsp + lmv

Qm-F-Lt

Qm = Qm
F = K + P
Lt = Lt

Qp-Lvm-Lsm

Qp = Qp + cht
Lvm = lvm + lvi + lvf + lvg + lmv + %lmsp
Lsm = ls + %lmsp + lms

staining. Some crystals are zoned, and mainly zoned crystals are altered. Calcite replacement of plagioclase is common in the mafic volcanic lithics, especially in concretionary sandstone samples; in these, relict textures are used to identify the plagioclase. In plutonic lithic fragments, the plagioclase is commonly clouded by sericite alteration that picks up the yellow sodium-cobaltinitrite stain. Mafic volcanics show sericitization of feldspar also. Plagioclase compositions from samples throughout the field area are summarized in Table 3. The A-normal, combined twins, and Michel-Levy methods were used to determine the compositions. Both calcium- and sodium-rich varieties were found. The compositions range from An 10 to An 37 with the mode from An 20-30. The relatively sodic compositions are not easily explained but may be due to low temperature diagenesis of the sediments. Generally, the sodic varieties of plagioclase did not take either the sodium cobaltinitrite or amaranth stain.

Potassium feldspar (K) is rare in most of the Hoko River Formation. Microcline is recognized by cross-hatch twinning, cleavage angles, and yellow-brown stain along the cleavage planes. Other occurences of potassium feldspar are in micrographic intergrowths with quartz in plutonic rock fragments.

Accessory (Acc) minerals include, in decreasing order of abundance, biotite, muscovite, pyroxene, opaques, serpentine, and talc. Detrital biotite is present only in trace amounts but is common in some metamorphic lithic fragments. Muscovite is common in schists, phyllites, and polycrystalline quartz aggregates. In these forms it is usually too small to count as a discrete crystal, but it does occur as rare detrital grains and in some plutonic lithics. Clinopyroxene occurs as discrete detrital fragments and in plagioclase aggregates. Opaques are mostly sulfides

Table 3 PLAGIOCLASE COMPOSITIONS

This table represents the compositions of plagioclase crystals in lithic fragments across the study area. The horizontal axis denotes locations of samples by stratigraphic sections. On the left, Morse Creek (MC) is the most eastern section while Neah Bay (NB) is the western most section. Elwah River (ER), Crescent Beach (CB), West Agate Beach (WAB), West Twin River Road (WTR), Burnt Mountain Road (BMR), Hoko River (HR) comprise the abbreviations used.

Composition*	MC	ER	CB	WAB	WTR	BMR	HR	NB
Basalt	33c 15m	11-15m 20m 6-10m 8m 22m 21-25m 20-30m	32m	12m 15m	20-22m 22-27m 25m 16-18m	15m 10m 10m 17-20m	8m 22m 15-21m 21-25m 20-30m 6-10m	18m
Andesite/ Dacite	25a							
Granite/ Granodiorite			30m 27m 12a					40a 42a
Diorite/ Quartz-diorite				20-27m	0a			24c 30c
Gabbro/ Diabase			27m		12a			
Metased/ Metavolcanic		37a	23a				37a	
Amphibolite						17m		

*All numbers are given in percentage of anorthite present.
m = Michel-Levy method of plagioclase determination.
a = The A-normal method of plagioclase composition determination
c = Combined twins (carlsbad and albite twins) method of plagioclase compostion determination.

(pyrite and chalcopyrite) and hematite. Hematite occurs as a fringing cement, as stains on lithics, and as an alteration of the volcanic lithics. Garnet, serpentine, and talc occur in trace amounts. Uncommon pumpellyite has been identified in the metavolcanics and mafic volcanic lithics. Prehnite was identified in two metavolcanic lithic clasts.

Chlorite (Ch) is a common alteration product in these sediments. Chlorite occurs as detrital fragments; as an alteration product in volcanic, metamorphic, and plutonic lithics; and a replacement of amphibole, pyroxene, volcanic glass and groundmass in mafic volcanics. Fresh chlorite is light green pleochroic under plane light and anomalous blue, slate-gray, and bright green under crossed nicols. Chlorite forms fibrous bundles, radiating masses, and finely radiating, patchy crystals. Oxidation produces an orange color, especially around the edges of chlorite patches.

Amphiboles (Amp) are numerous in diorites, quartz diorites, and amphibole-plagioclase metamorphic lithics. Cummingtonite or grunerite is present in amphibole-quartz aggregates. The amphiboles are partially replaced by calcite and epidote.

Epidote (Ep) and zoisite (and clinozoisite ?) occur as discrete tabular crystals or disseminated patches. Epidote is a common alteration of the mafic components of many lithics, amphiboles, pyroxene, and mafic groundmass. Zoisite is relatively rare and usually forms discrete crystals.

Calcite cement (CC) is the dominant cement. No aragonite or dolomite was found. The calcite occurs as void filling, blocky spar, and pseudospar. At least two sizes of calcite crystals, very-fine (0.0625 mm) and medium (0.25 - 0.50 mm) are present. The murky calcite that often surrounds clasts is recrystallized micrite or primary marine cement. The next most common cement is fine-grained silica cement. Minor amounts of a calcium-rich zeolite form a late stage void-filling cement.

Matrix (M) is common as both a silt-sized fraction in sand-sized samples and detrital clays. Often crushed metasedimentary grains resemble matrix, but they were included with phyllite. Pseudomatrix, orthomatrix and protomatrix found in various samples and indicate differing diagenetic processes.

Lithic Descriptions

Mafic volcanic lithics (lvm) dominate the volcanic lithic group. These clasts are typically dark to opaque under crossed nicols, with plagioclase lathes, chlorite, epidote, calcite, or pumpellyite comprising most of the identifiable minerals (Figures 6 and 7). Microlitic plagioclase and its alteration products are typical. Although some plagioclase is partially replaced by calcite, twinning and original crystal outlines are usually preserved; thus a determination of mineralogy could be made. The plagioclase composition of the basalts range from An 6 to 42 with a mode of An 20-30. This is more sodic than found in unaltered basalt and may be explained by seawater metasomatism of basalt during the formation of spilite.

Intermediate volcanic lithics (lvi), andesites and dacites, and felsic volcanic lithics (lvf) are recognized by the lack of chlorite and the presence of lath-shaped plagioclase. Euhedral crystals of plagioclase, infrequently zoned, surrounded by microlitic plagioclase and a glassy groundmass are common. Blades of plagioclase and quartz in a glassy groundmass are counted as intermediate volcanics and felsic volcanics. These lithics appear to have undergone low grade metamorphism,

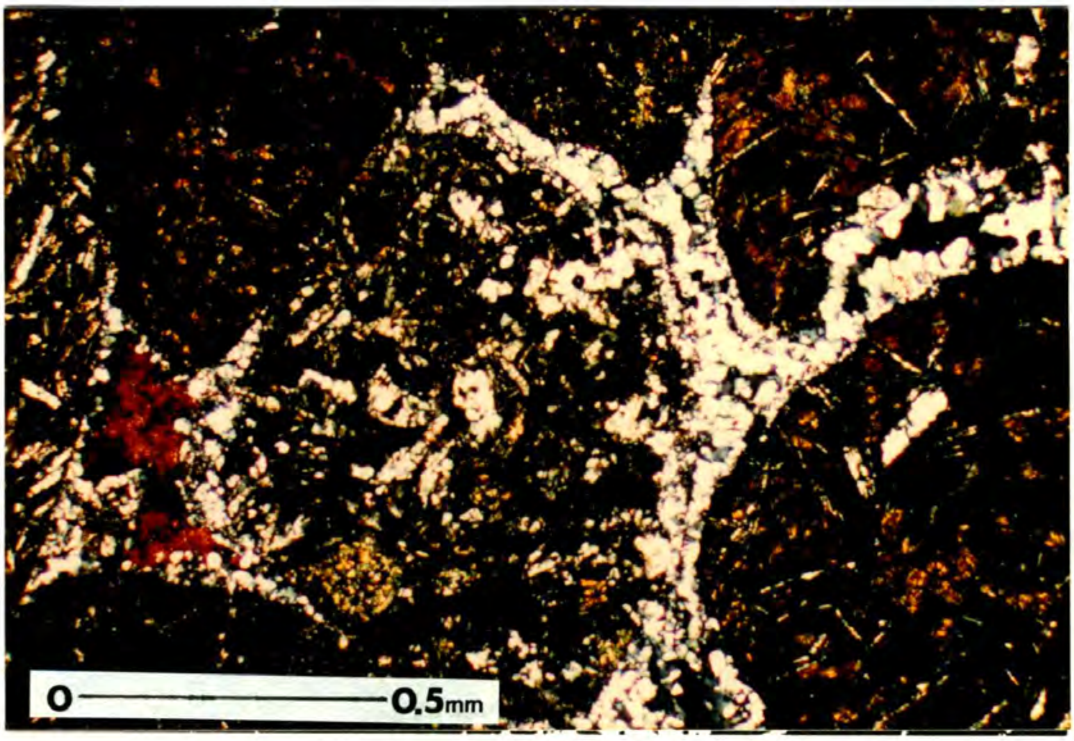


Figure 6. Photomicrograph of highly altered basalt in silica (primary) and zeolite (secondary) cements under crossed nicols. Sample WTR-39J.

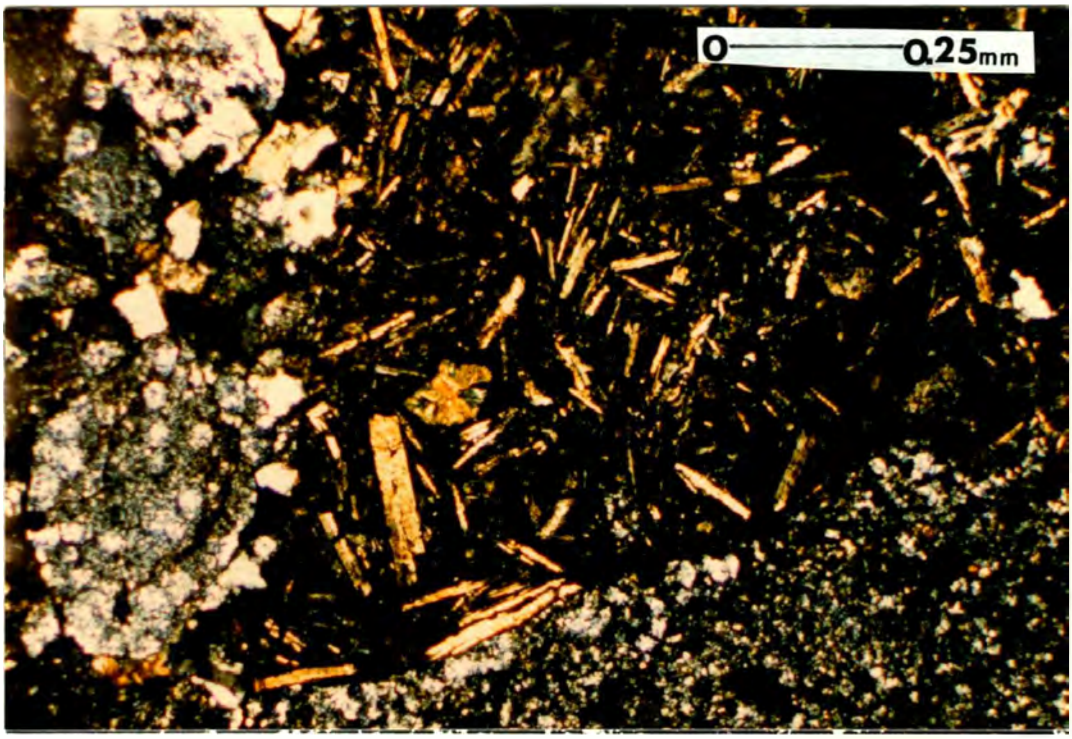


Figure 7. Photomicrograph of basalt and radiolarian chert under crossed nicols. Sample MC-41.

because of the intergrown texture of the crystals. This plagioclase did not stain red, indicating An less than 5%. The crystals are coarse to very-fine (0.50 to 0.125 mm) and bladed. One distinct felsic volcanic lithic type comprises fine-grained lithics that resemble chert but stain red and have sparse, fine plagioclase laths.

Volcanic glass lithics (lvg) have a distinctive color and texture and are isotropic or devitrified. They are yellow or green in plane light. Glass shards and vacuoles are common. Shard-like shapes help to distinguish devitrified glass from chlorite. Vacuoles are usually filled with one of the following: calcite, chlorite, or zeolites.

The metavolcanic lithic category (lmv) includes volcanics that have been highly altered and are of indeterminant composition. The dominant minerals are chlorite, plagioclase, and quartz. Minor components are pumpellyite and prehnite (two occurrences of this mineral). Some compositions indicate that these were originally felsic or intermediate volcanics: relict zoned plagioclase, euhedral and embayed quartz, and hexagonal mafic mineral. Broken and somewhat deformed plagioclase indicates deformation and metamorphism in lathwork metavolcanics of mafic origin. Sausseritized or sericitized plagioclase and chloritic patches are distinct alteration products. Plagioclase compositions are An 23-37 (Table 3).

Schist-phyllite (lmsp) fragments form a distinct petrologic group that was counted separately. They are foliated, low to medium grade metamorphic lithics, including the following assemblages: well-foliated graphitic schist and phyllite (Figure 8), chlorite + microcrystalline quartz + muscovite + biotite + opaques schist, graphite + quartz + muscovite/sericite schist (Figure 9), plagioclase + epidote + chlorite + opaque schist and quartz + plagioclase schist. Quartz and plagioclase

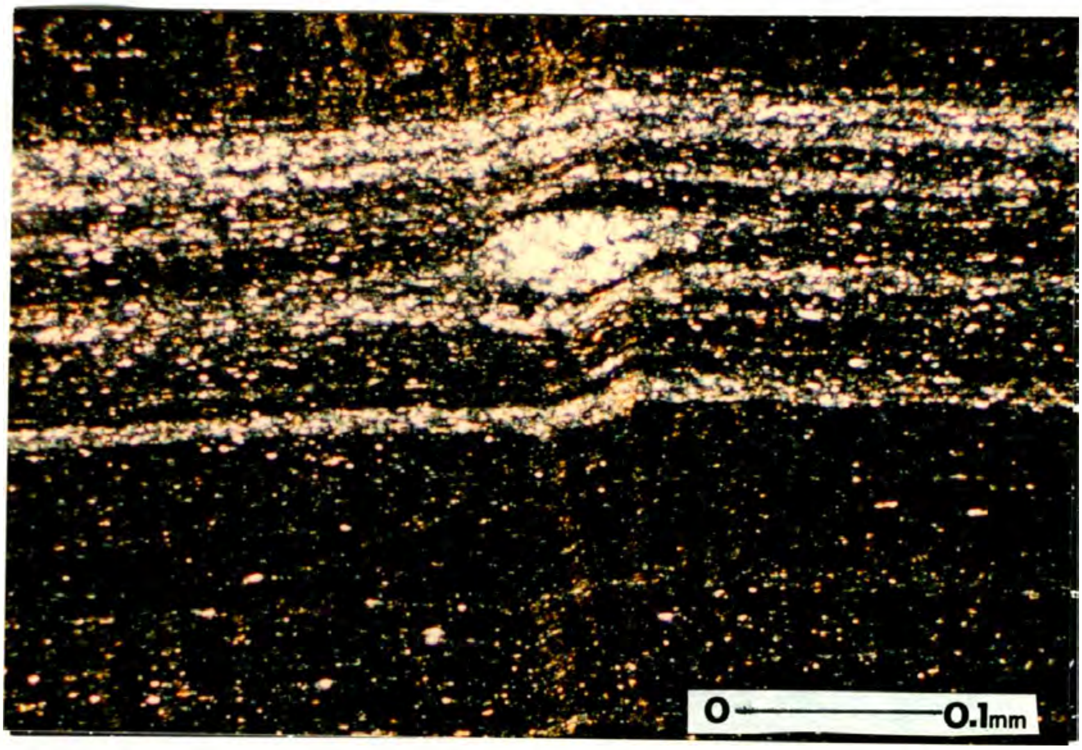


Figure 8. Photomicrograph of a clast of graphitic phyllite showing some of the detail of this lithic type under crossed nicols. Sample from the Neah Bay section.

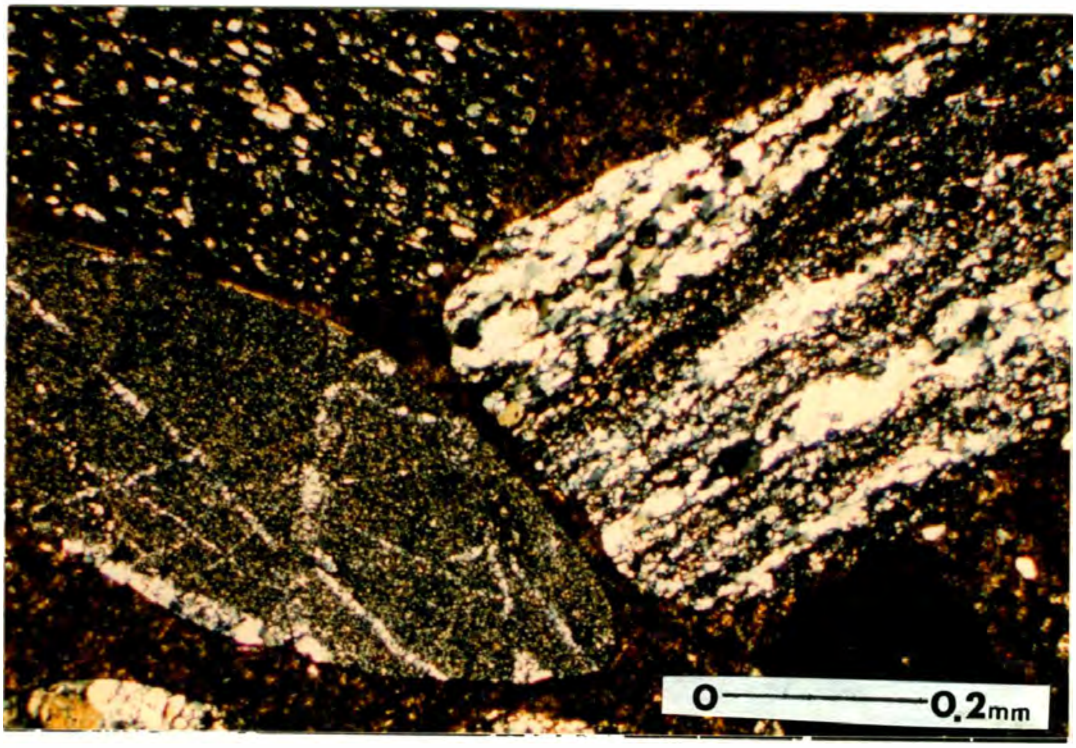


Figure 9. Photomicrograph of chert, graphitic phyllite (lmsp) and sheared metasediment (lms) counterclockwise from the bottom left under crossed nicols. Sample CB-11.

crystals have been broken, pulled apart, rolled around and squashed, and thus indicate extensive shearing and strain in the source units (Figure 8).

A subgroup of schist/phyllite (lmsp) is that of quartz-mica aggregates. Grains with greater than 5% mica that are lineated or foliated are part of the schist/phyllite (lmsp) group. Grains with greater than 5% mica, but lacking a distinct foliation were counted as meta-sedimentary lithics (lms). Fabric is the most important factor of this subgroup.

All other metasedimentary lithics (lms) that do not fit in above were put into this category (one example in Figure 9). They were counted separately to determine whether they were derived from a source different than that of the schists and phyllites (lmsp). Some of these lithics have undergone shearing that is evident from rotated and pulled-apart crystals in a matrix phyllosilicates. Polycrystalline quartz with greater than 5% mica or other debris and lacking foliation was included in this category. Chert with many inclusions of clay and organic debris, greater than 5%, also falls into this category.

The chert (cht) includes red, black, and clear chert varieties; some grains are recrystallized or heavily veined. The interlocking nature of the quartz crystals of both chert and recrystallized chert is diagnostic. Radiolarian ghosts are present in samples throughout the field area (Figures 7 and 9).

Aphanitic polycrystalline quartz (Qp) lithic fragments, except chert, are included in the polycrystalline quartz category. Foliated metamorphic and vein-filling quartz are the two most common varieties. If less than 5% mica or other inclusions are present, the lithic falls in this category.

Lithic siltstone and sandstone (ls) are counted in the sedimentary lithic category. Siltstone is the dominant lithology and is composed of quartz and feldspars in micrite, clays, and organic debris. Unmetamorphosed sandstones are usually counted as individual mineral components. However, if the crosshairs landed on the matrix within one of these lithics, it was counted as a sedimentary lithic. Lithics that comprise this category are unmetamorphosed, although they are compacted to varying degrees.

Fossils (fos) are rare. Of those found, foraminifera are the most common; bivalves are the next most common.

Amphibolites (amp) occur in foliated and non-foliated varieties. They are a distinctive lithology, composed of plagioclase (An 17), amphibole and lesser amounts of quartz (Table 3). The crystals vary in size from 2.0 mm to 0.625 mm. Only finer polycrystalline grains were included here. Coarse crystals were counted as amphibole, plagioclase, or quartz.

Felsic plutonic lithics (lpf) include lithic fragments of siliceous and calc-alkaline plutonic rocks, ie., granites, and granodiorites. Aggregates of quartz + epidote replacing amphibole, quartz + amphibole, quartz + plagoiclase + potassium feldspar + (epidote) + (amphibole) comprise this group. Large blocky crystals with straight boundaries form the aggregates. Micrographic texture is found in one clast. Epidote is both a replacement and primary vein mineral.

Diorite and quartz diorite (lpd) include plutonic lithics with plagioclase + (quartz) + (epidote or zoisite) + (amphibole). Amphibole is replaced by epidote, zoisite or chlorite. Blocky crystals dominate rather than lath-shaped crystals. The plagioclase composition varies from An 0-

30 with the mode between An 20-30 (Table 3). The plagioclase is more sodic than would be expected for a diorite or quartz diorite (An 35-60, according to MacKenzie and others, 1982), probably due to diagenesis or low grade metamorphism.

The gabbroic plutonic lithic category (lpg) includes gabbroic lithics and diabase. Plagioclase + (epidote) + (amphibole) + altered groundmass is the most common assemblage. Plagioclase varies in composition from An 12 to 27. Generally, gabbros have a plagioclase composition of labradorite (An 50) or greater according to MacKenzie and others (1982). The less calcic varieties present have probably been metasomatised or have become enriched in sodium during diagenesis or metamorphism.

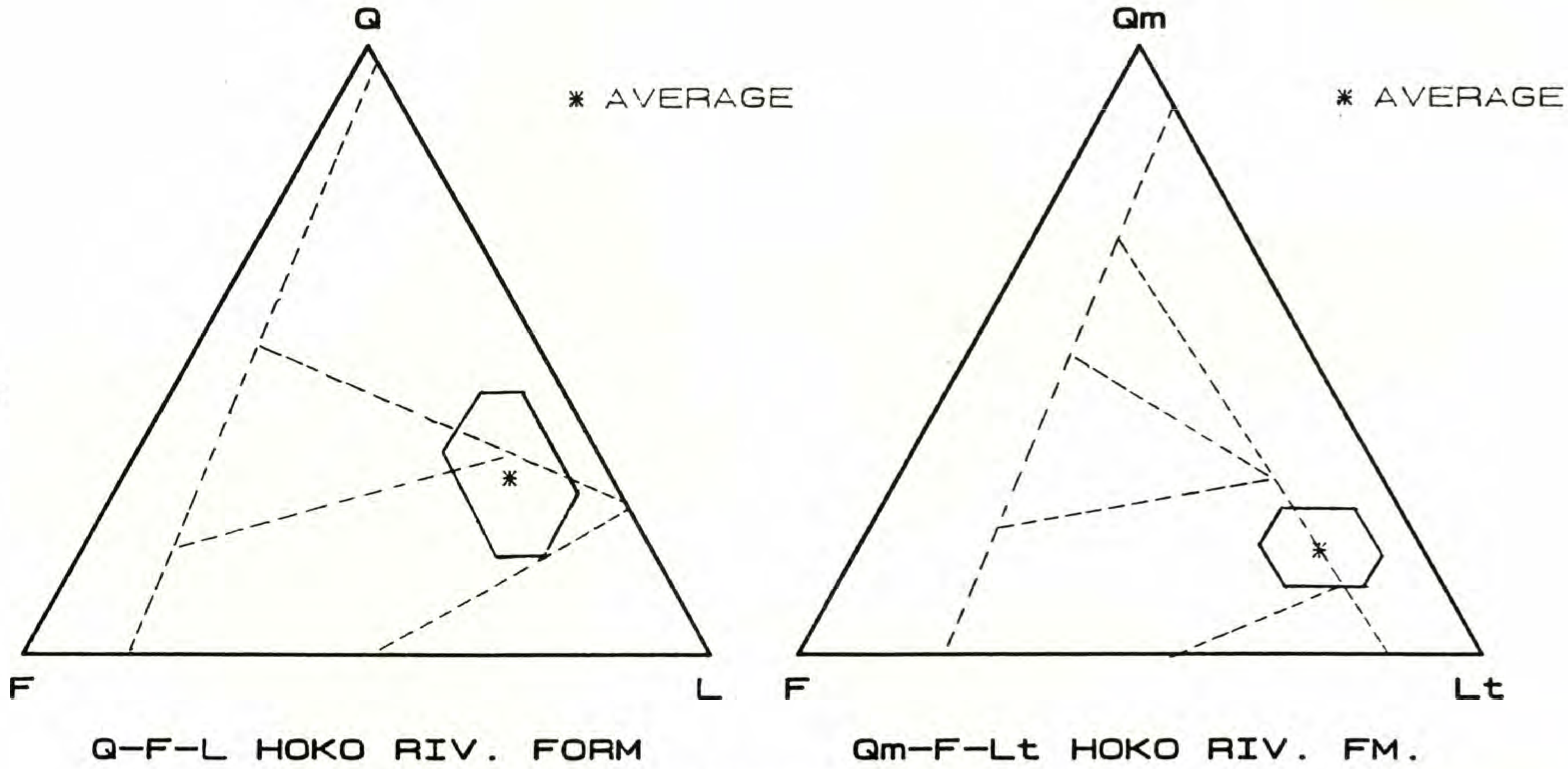
PROVENANCE

Determining the tectonic provenance of the Hoko River Formation is one of the goals of this study. The composition of a source area is reflected in the sediments derived from it. By looking at the petrology of the Hoko River Formation in detail, dominant lithologies comprising the source area should be apparent. Three methods of analyzing the petrographic data are presented, followed by results and interpretations.

Ternary Diagrams

The data from 50 point counts from nine stratigraphic sections in the field area were plotted on five ternary diagrams in an attempt to delineate lithofacies (Figure 10 to 17). The samples were taken from nine stratigraphic transects, from east to west: Morse Creek, Crescent Beach, west Agate Beach, Field Creek, Elwah River, West Twin River Road, Burnt Mountain Road, Hoko River, and Neah Bay (Figure 18). The locations contained the following number of samples: Morse Creek-6, Elwah River-6, Crescent Beach-4, west Agate Beach-3, Field Creek-5, West Twin River Road-5, Burnt Mountain Road-5, Hoko River-5, Neah Bay-11. Table 4 compiles the grain sizes of all of the samples used in point counts. The ternary diagrams plotted are Q-F-L, Qm-F-Lt, Qm-P-K, Qp-Lvm-Lsm, Lm-Lv-Ls (Figures 10 to 17). Figures 10 to 12 contain the formation mean and standard deviation, while figures 13 to 17 present the mean and standard deviation for each section location, as well as the formation mean and standard deviation.

Q-F-L and Qm-F-Lt diagrams were compared to those of Dickinson and others (1983). A trend of increasing maturity from Dickinson and Suczek (1979) was plotted on the Qm-P-K diagram. The Qp-Lvm-Lsm and Lm-Lv-Ls



Figures 10a and 10b. Q-F-L and Qm-F-Lt ternary diagrams of the average composition of the Hoko River Formation and one standard deviation with the provenance fields of Dickinson and others (1983). See Table 5 for summary of abbreviations.

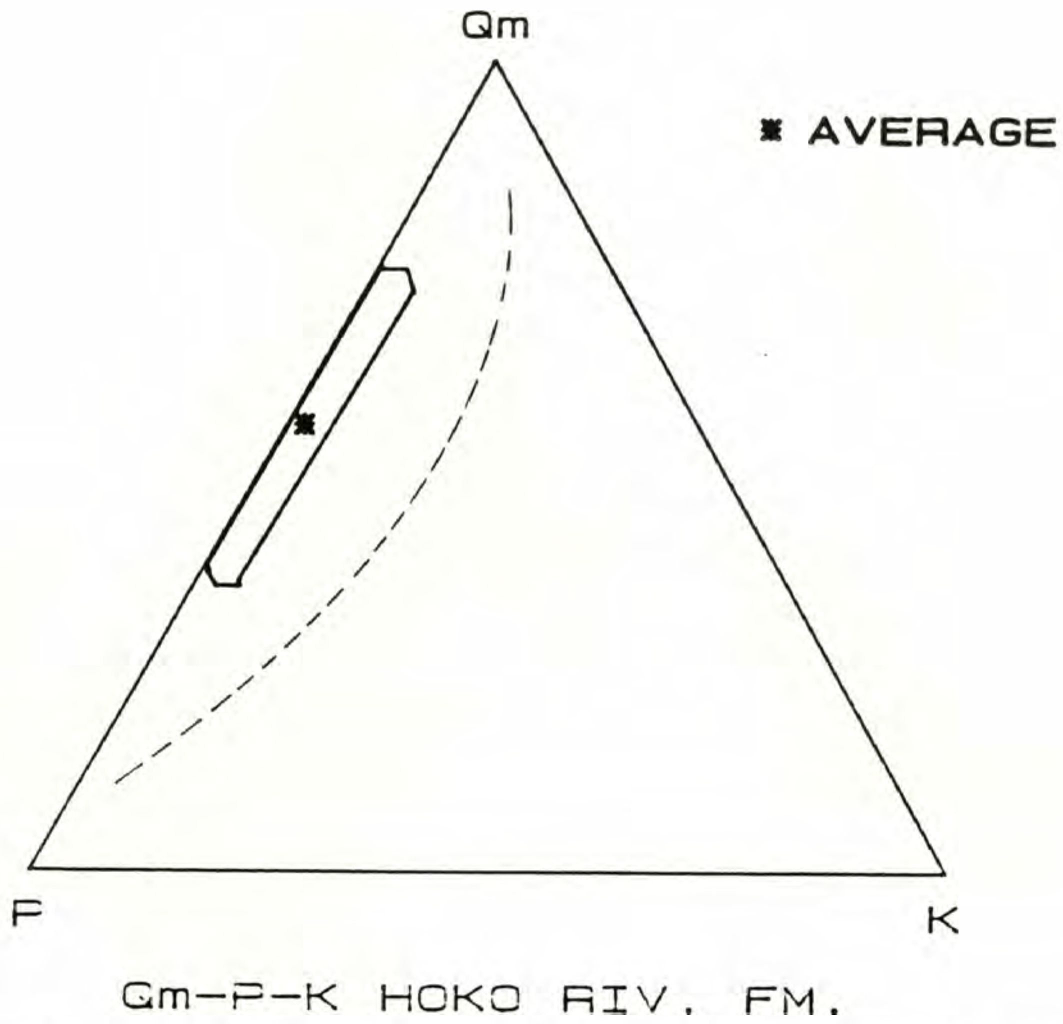


Figure 11. Qm-P-K ternary diagram of the Hoko River Formation average and one standard deviation with the trends of increasing maturity and increasing ratio of plutonic/ volcanic components from Dickinson and Suczek (1979).

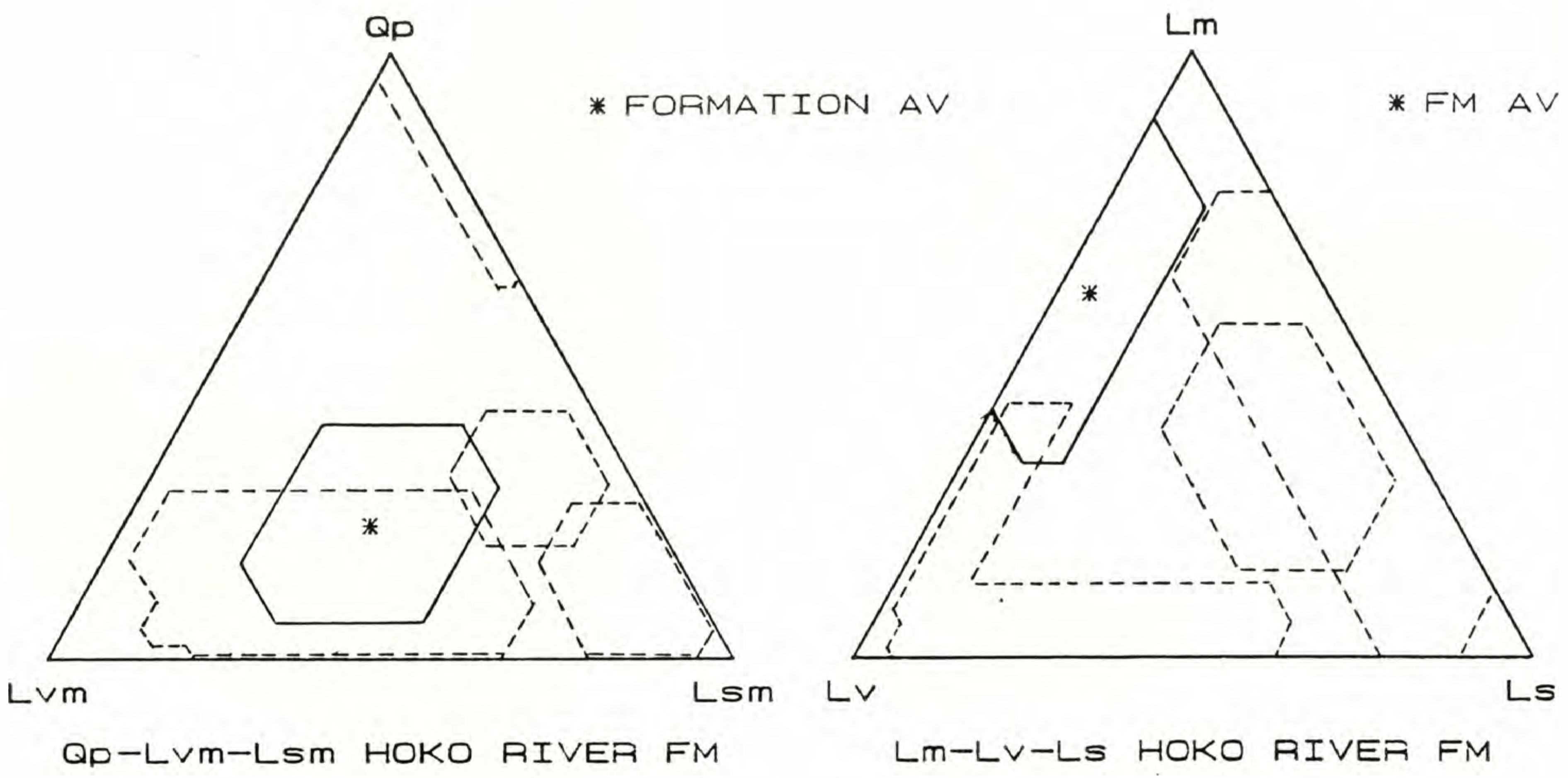


Figure 12a and 12b. Qp-Lvm-Lsm and Lm-Lv-Ls ternary diagrams of the Hoko River Formation average and one standard deviation with the provenance fields of Suczek and Ingersoll (1985). See Table 5 for summary of abbreviations.

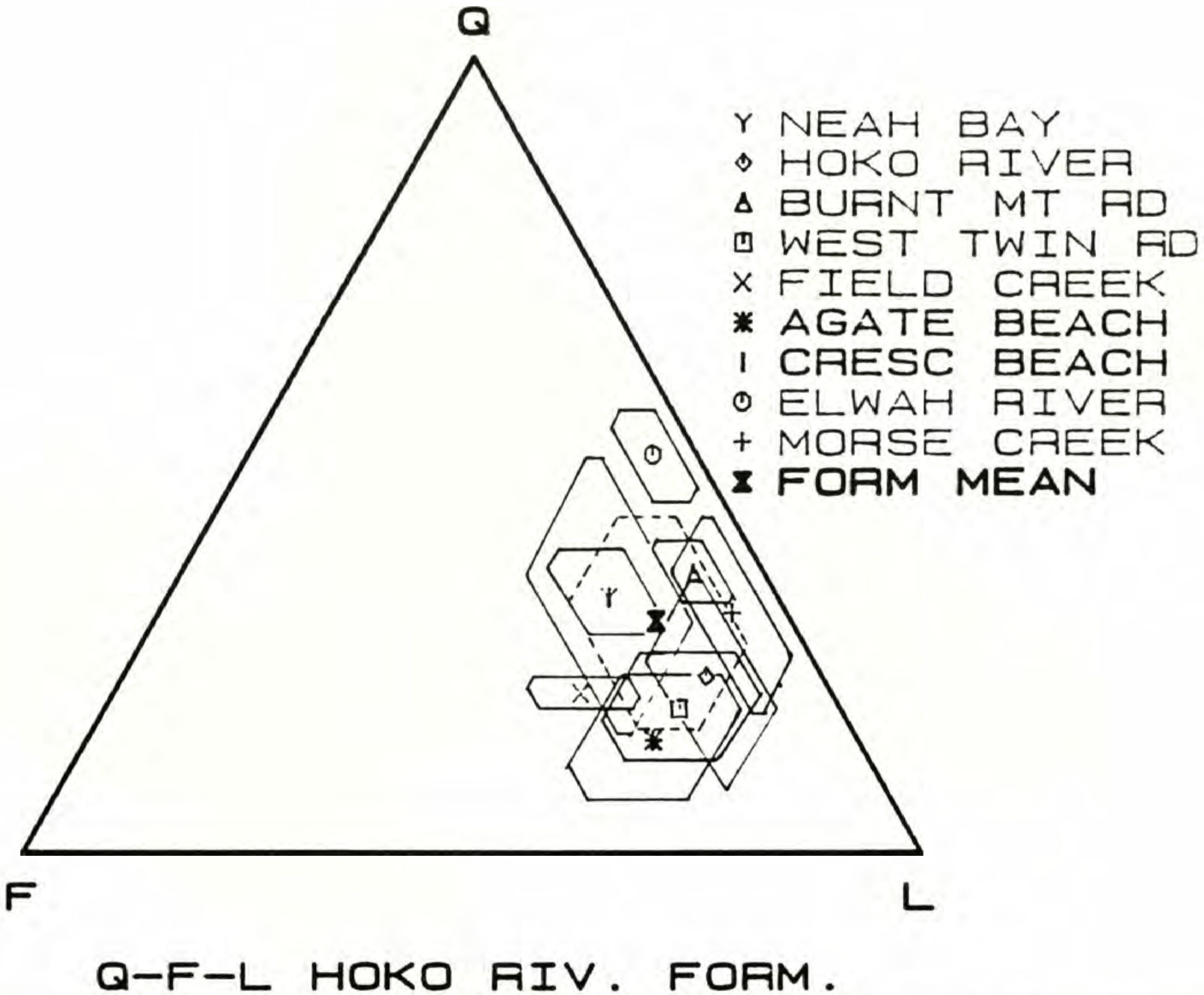


Figure 13. Q-F-L diagram of petrologic data from the different locations in the Hoko River Formation and the formation average with standard deviations.

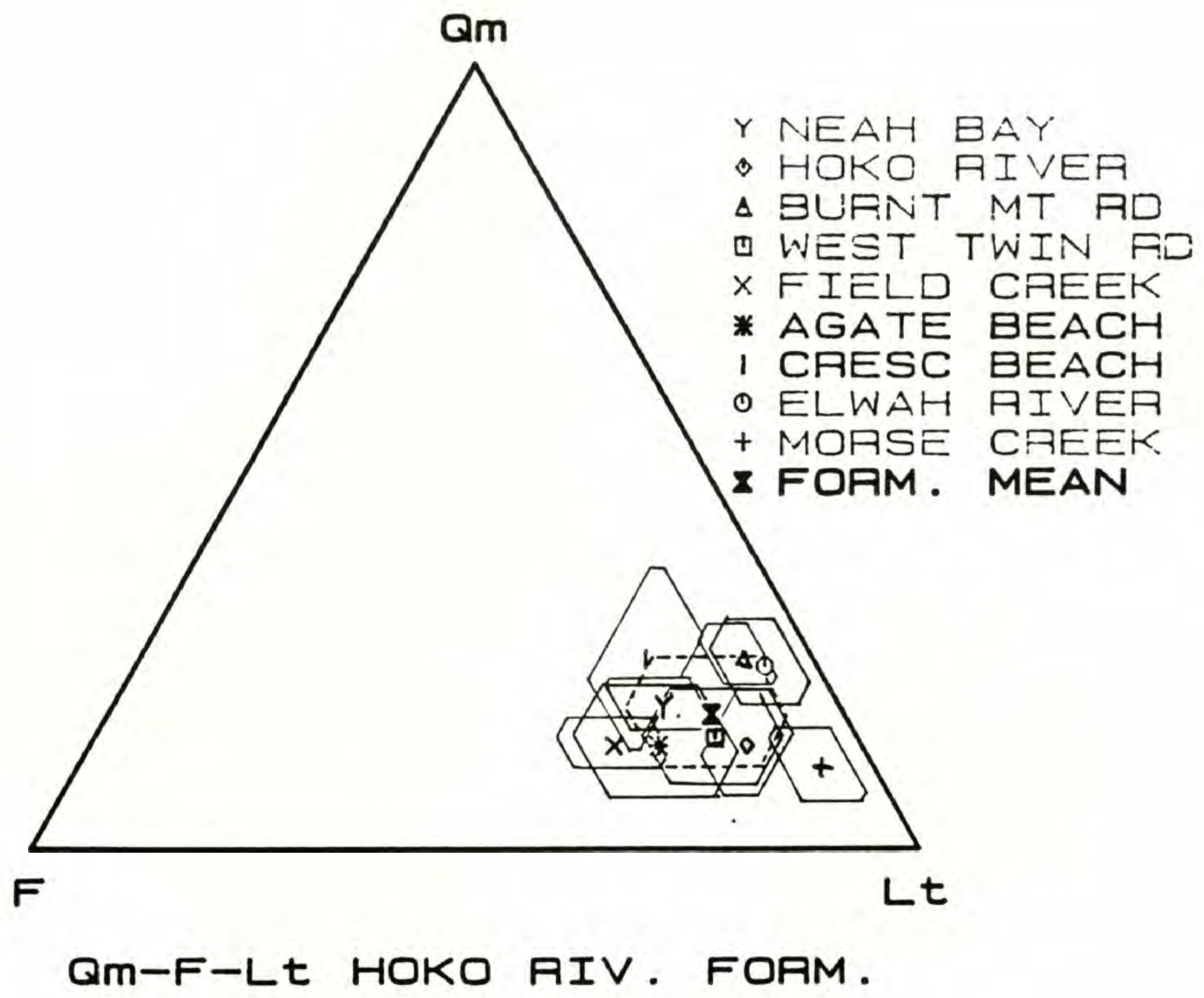


Figure 14. Qm-F-Lt diagram of petrologic data from the different locations in the Hoko River Formation and the formation average with standard deviations.

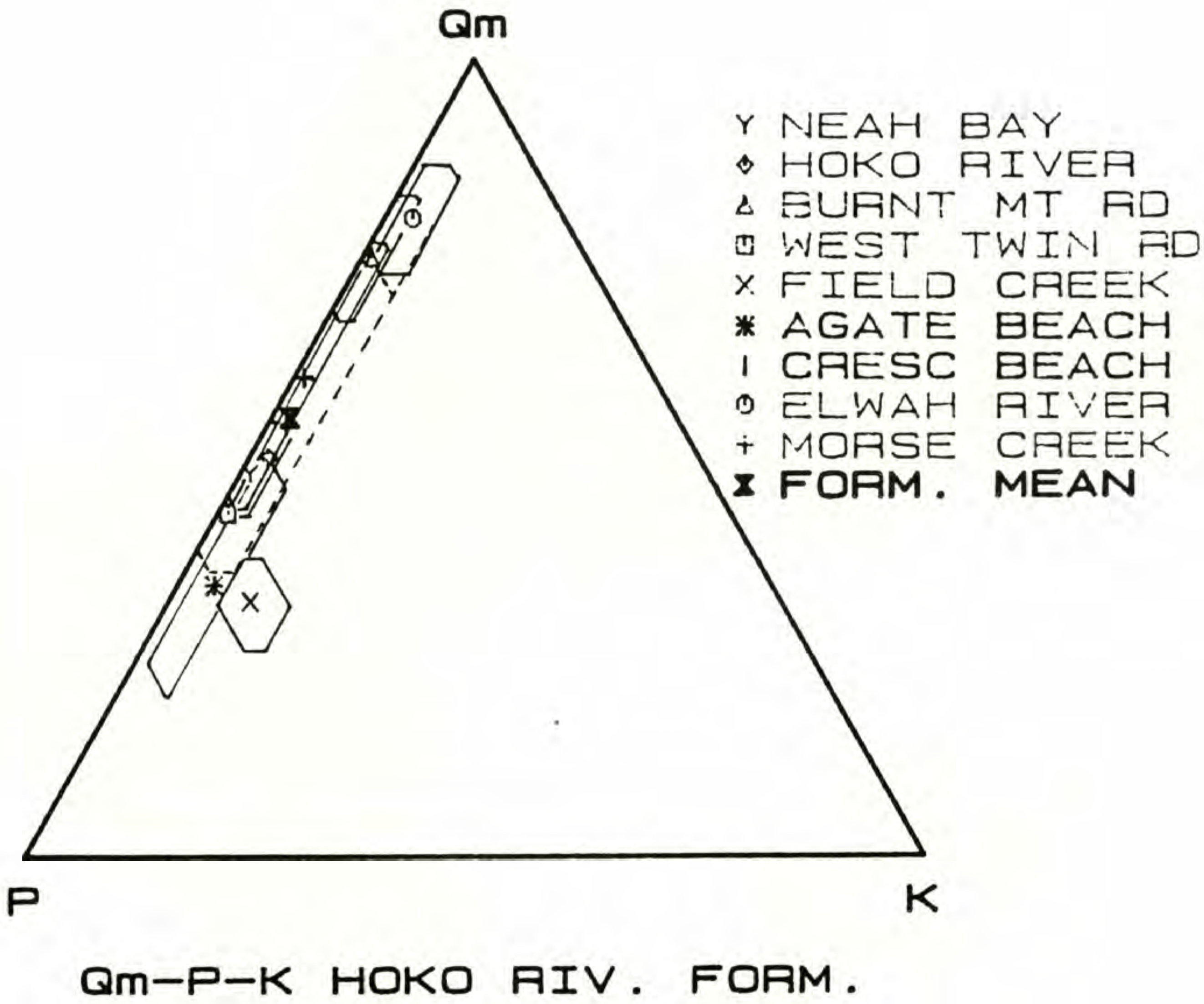


Figure 15. Qm-P-K diagram of petrologic data from the different sampling locations in the Hoko River Formation and the formation average with standard deviations, where applicable.

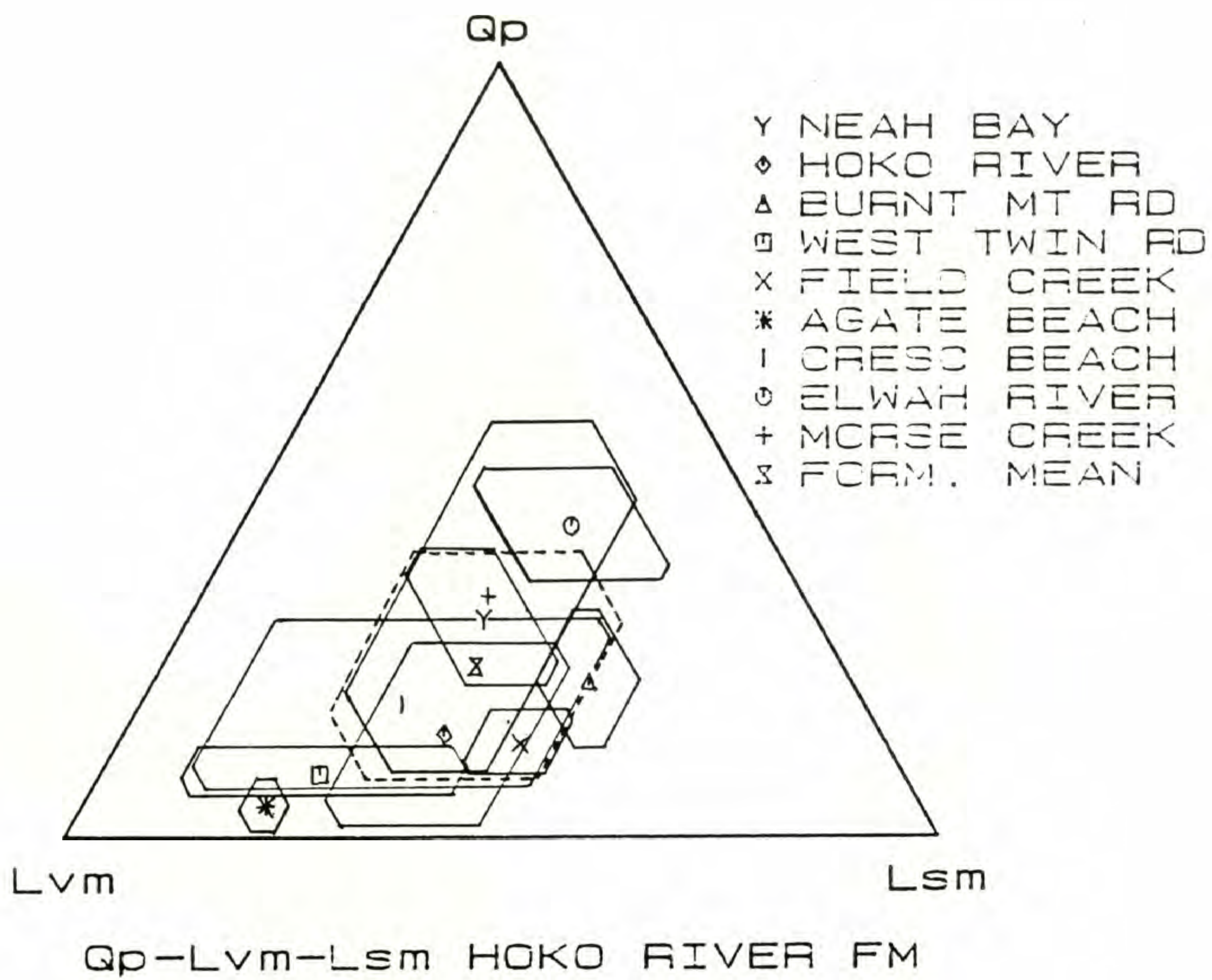


Figure 16. Qp-Lvm-Lsm diagram of petrologic data from the different locations in the Hoko River Formation and the formation average with standard deviations.

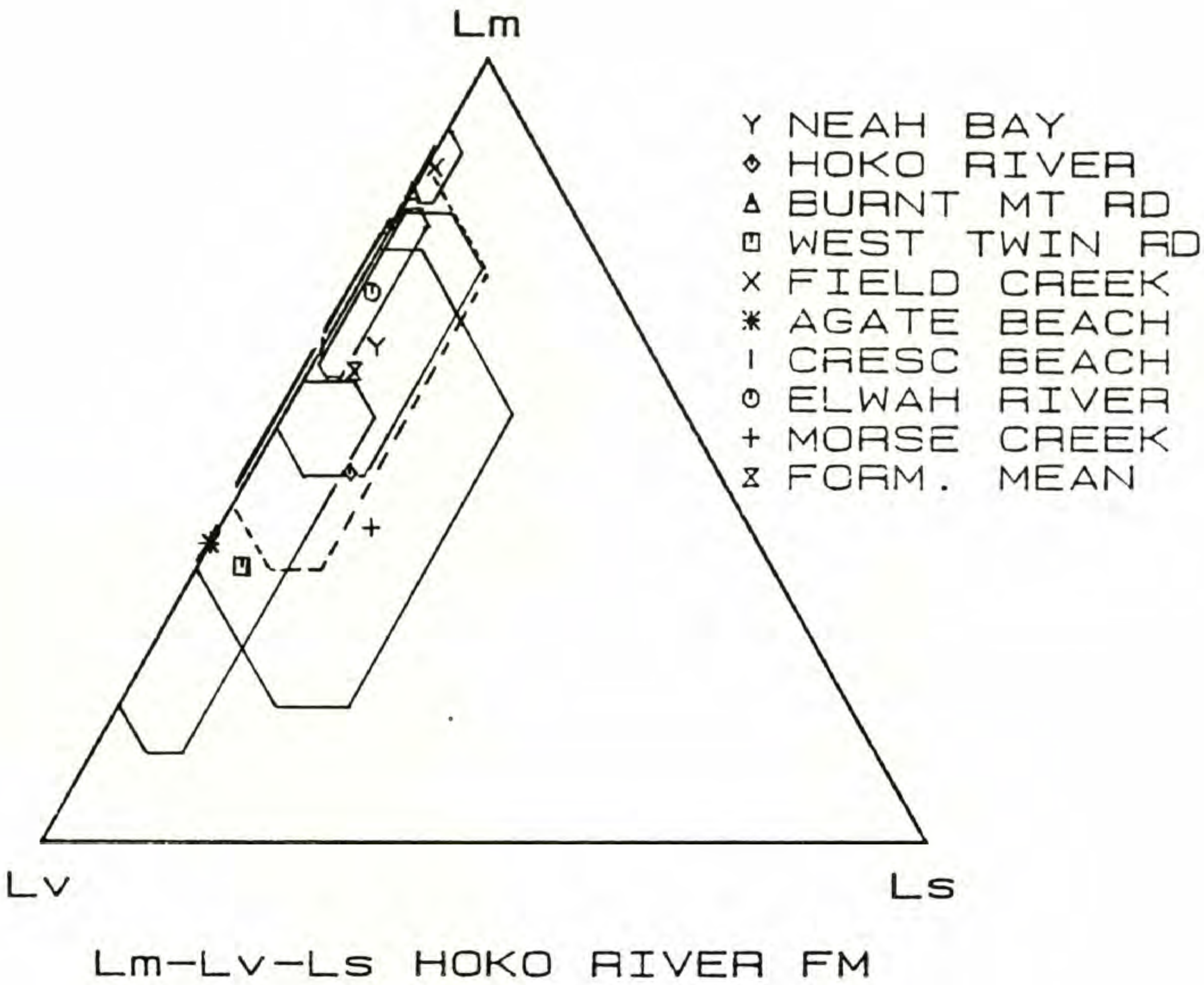


Figure 17. Lm-Lv-Ls ternary diagram of petrologic data from the different locations in the Hoko River Formation and the formation average with standard deviations.

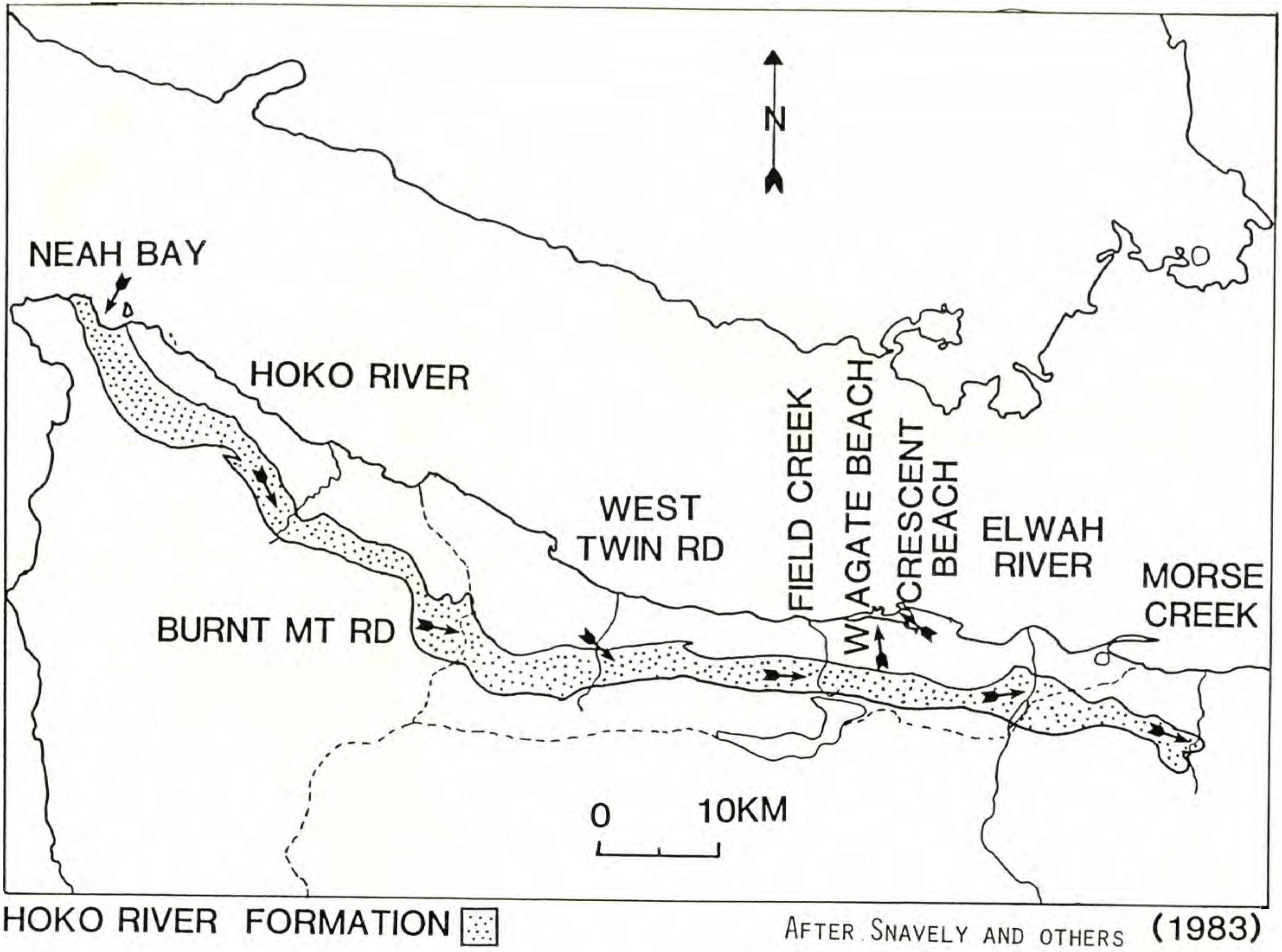


Figure 18. General location map of sample locations and stratigraphic sections on the northern Olympic Peninsula.

Table 4 Grain sizes of the samples used in these analyses.

Sample Number	Grain Size	Sample Number	Grain Size
MC-06	VC	TR-01	VC
MC-16	MED-C	WTR-39J	VC
MC-18	MED-C	WTR-43J	VC
MC-36	C-VC	WTR-44J	FINE-MED
MC-41	VC	WTR-47J	FINE/VF AND C
MC-42	VFINE-MED		
		BMR-52	C-VC-GRAN
ER-07	C-VC	BMR-53	VF-C
ER-08	VC-C	BMR-54	MED-VC
ER-20	C-VC	BMR-55	GRAN
ER-25	C	BMR-58	VC
ER-26	C-VC		
ER-27	C	HR-08	VC-GRAN
		HR-10	FINE-VC
CB-07	VC	HRR-02	MED-VC
CB-08	VC	HRR-10	FINE-VC
CB-11	C-VC	HR-45B	VFINE-FINE
CB-12	VC		
		FSB-04	MED-C
WAB-01	C-VC	FSB-11	C
WAB-04	C-VC	FSB-16	C-GRAN
WAB-05	MED-C	CF-01	GRAN
		CFT-01	VC
FC-13	FINE-MED	CFT-09	VC
FC-19	FINE-MED	CFT-11B	C
FC-20	FINE-MED	CFT-32	FINE-C
FC-22	FINE-MED	CFT-57	VC
FC-27	FINE-MED	CFT-61	C-VC
		CFT-62	C

The abbreviations in the table stand for the following:
FINE = fine sand
MED = medium sand
C = coarse sand
GRAN = granule
V = very

The division between fine and medium sand is 0.25 mm, between medium and coarse sand is 0.50 mm, between coarse sand and very coarse sand is 1.00 mm, and between very coarse sand and granule is 2.00 mm (Folk, 1974).

Table 5 Summation of categories for ternary diagrams

Q-F-L	Qm-P-K	Lv-Ls-Lm
Q = Qm + Qp + cht	Qm = Qm	Lv = lvm + lvi + lvf +lvg
F = K + P	P = P	Ls = ls
L = Lt - (Qp + cht)	K = K	Lm = lms + lmsp + lmv

Qm-F-Lt	Qp-Lvm-Lsm
Qm = Qm	Qp = Qp + cht
F = K + P	Lvm = lvm + lvi + lvf + lvg + lmv + %lmsp
Lt = Lt	Lsm = lsm + %lmsp + lms

The summation of categories for ternary diagrams. See the appendices for further explanation.

diagrams were compared to Suczek and Ingersoll (1985) to determine whether a specific tectonic provenance is indicated.

Results

The sandstones of the Hoko River Formation are lithic arenites, and they plot toward the lithic end of the Q-F-L ternary diagram Q=29 ± 14, F=15 ± 9, L=55 ± 12 (Figure 10a). The Elwah River section contains the most Q; the Field Creek section, the most F; and both the Hoko River and West Twin River Road sections have similar high L values (Figure 13). Because of the overlapping error polygons, in general, the variations among the sections are not considered significant (Figure 13). The formation-mean plots in the transitional-arc field, while the standard deviation overlaps into recycled orogenic, dissected arc, transitional arc, and undissected arc provenances of Dickinson and others (1983) on the Q-F-L plot (Figure 10a).

On the Qm-F-Lt diagram (Figure 10b) the data plot even closer to the lithic pole at Qm=17 ± 7, F=15 ± 9, Lt=68 ± 10, because of the significant amounts of chert and polycrystalline quartz in the samples, which are included in Lt on this diagram. Morse Creek has the largest amount of Lt, while Field Creek has the highest percentage of F. The Burnt Mountain Road, Elwah River, and Field Creek sections have slightly more Qm than the rest. The overlapping polygons of one standard deviation suggest similar compositions between the sections (Figure 14). The formation-mean plots between the transitional arc and lithic recycled area of the recycled orogen provenance of Dickinson and others (1983)(Figure 10b). Some locations extend into the undissected arc and transitional recycled fields.

The Qm-P-K diagram (Figure 11) shows low amounts of potassium feldspar are present in all of the Hoko River Formation sediments (Qm=54 ± 20, P=43 ± 20, K=2 ± 3). The Elwah River section is the most Qm-rich, and the west Agate Beach section is the most P-rich. The Field Creek section has a high P value and the highest K value (Figure 15). The shift to the P and K ends of the diagram for the Field Creek section may be due to the fine-sand size of the samples. The fine-sand size fraction may have a greater percent feldspar than coarser sizes because feldspar tends to cleave and form smaller particles, while quartz has to be abraded or fractured and, thus, it forms slightly larger particles. A coarser fraction that might have been more comparable to the rest of the samples was not available.

The Qp-Lvm-Lsm diagram (Figure 12a) shows samples clustering away from the polycrystalline quartz (Qp) pole, abit closer to the volcanic-metavocanic (Lvm) pole than sedimenatary-metasedimentary (Lsm) pole at Qp=22 ± 15, Lvm=42 ± 20, Lsm=36 ± 14. The Elwah River section contains the most Qp, the west Agate Beach section, the greatest amount of Lvm, and the Burnt Mountain Road section, the most Lsm (Figure 16). The Hoko River Formation sediments are metasedimentary-, metavolcanic-, and volcanic-rich sediments. The formation mean falls into the mixed magmatic arc-rifted continental margin region of the Qp-Lvm-Lsm diagram of Suczek and Ingersoll (1985) with a minor amount of overlap into their subduction complex region (Figure 12a).

On the Lm-Lv-Ls diagram (Figure 12b), the data lie in the region indicating small values for Ls; Lm=60 ± 26, Lv=35 ± 22, Ls=5 ± 9. Field Creek contains the highest Lm value, Morse Creek is the most Ls-rich, and the West Twin River Road and west Agate Beach sections have similar amounts of Lv (Figure 17). The data suggest that the source area was slightly more metamorphic- than volcanic-rich and that it was depleted in sedimentary lithologies. The mean falls outside of most defined areas of Suczek and Ingersoll (1985)(Figure 12b). A few individual sections have standard deviations that overlap the magmatic arc region.

Discussion

An explanation for the inconsistencies in the location of the data within the provenance fields of the ternary plots can be found by considering the tectonic setting of the Hoko River Formation. The northern Olympic Peninsula is surrounded by amalgamated terranes that contain complex mixtures of very different lithologies. The diverse lithologies of the source area are reflected in the sediments of the Hoko River Formation. The interpretations of Dickinson and Suczek (1979), Dickinson and others (1983), and Suczek and Ingersoll (1985) are best applied to classic tectonic settings, not the regional setting of the Hoko River Formation.

The problem of data for a formation falling into a number of fields has been addressed by Suczek (1987). When the formation lies in two or more fields on the same diagram, a mixed tectonic provenance is indicated. If the formation plots in different provenances on different diagrams, as in the case of the Hoko River Formation, another interpretation is needed; the sand may have been derived, at least in part, from a source area not defined on the diagrams. One example of this is the deviation of fields in the Q-F-L and Qm-F-Lt diagrams (Figures 10a and 10b). The formation average covers three fields and touches a fourth (transitional, dissected, and undissected arcs and recycled orogen) on the former diagram, while on the latter diagram, the formation average lies in two regions and touches a third (transitional and undissected arc and recycled orogen provenances), missing the dissected arc provenance entirely.

A second example is found in the Qp-Lvm-Lsm and Lm-Lv-Ls diagrams (Figures 12a and 12b). In the former diagram, the formation average lies in the magmatic arc and mixed magmatic arc-subduction complex regions, while in the latter diagram, the average lies primarily in an undefined zone and extends into the magmatic arc region, missing the mixed magmatic arc and subduction complex region. Ternary diagrams are useful when applied to classic tectonic settings, but are not helpful when applied to the Hoko River Formation, which is surrounded by exotic terranes.

One reason to use these ternary diagrams in spite of difficulties is that they are good discriminatory plots that should show major compositional trends within the formation. Also, data from key units in the region, the Aldwell, Lyre, Clallam, and Chuckanut Formations and the Nanaimo and Puget Groups, has been plotted on these diagrams and comparisons between these units and the Hoko River Formation are facilitated by using this method of presenting data. Comparisons between the Hoko River Formation and other formations and contemporary sedimentary units in the region are found in the Tectonic section of this thesis.

Geographic Variability of Lithics

Lithofacies variability with location has been documented in the underlying Aldwell Formation (Marcott, 1984). He demonstrated that, in the Aldwell Formation, there is a chert-rich lithofacies in the west and a basalt-rich lithofacies in the east. Because similar trends were not immediately apparent in the Hoko River Formation, two other methods were employed.

Location versus Percentage

An alternative method of analyzing the data is to plot the average percent of the total grains of various lithic types by location (Figures 19 to 28). These plots are used to evaluate the geographic variabilty of the lithofacies. The lithic types considered are some of those discussed in the Sedimentary Petrology section and they include: basalt, metasediment, chert, volcanic glass, polycrystalline quartz, felsic and intermediate plutonics, felsic and intermediate volanics, metavolcanics, gabbro and diabase, and amphibole- and epidote-rich schists. Within each section the samples were normalized (Appendix 4) and a mean and standard deviation calculated (Table 6). One standard deviation is represented by the vertical error bars (Figures 19 to 28).

Basalt lithics comprise 8% $\pm$ 7 of the total grains (Figure 19). The Crescent Beach section has one very basalt-rich sample, Crescent Beach-12, that produced a large standard deviation. This sample was probably derived from the underlying basalt. The section average and standard deviation are still within the average for the formation. The geographic variability of basalt lithics is random.

The metasedimentary lithics have an average of 22% $\pm$ 12 (Figure 20). Random variation with location was found, along with some large standard deviations. The Hoko River samples have a large standard deviation because they represent two different environments of deposition. The Hoko River samples of low value are located within a channelized area of the stratigraphic section, while the rest of the samples are from isolated sand beds above and below the channelized portion. While there is a large range of values for the section means and standard deviations, they overlap.

The percentages of chert lithics among the total number of grains show a pattern of enrichment in the eastern-most sections, Morse Creek and Elwah River (Figure 21). The Hoko River Formation, as a whole, contains

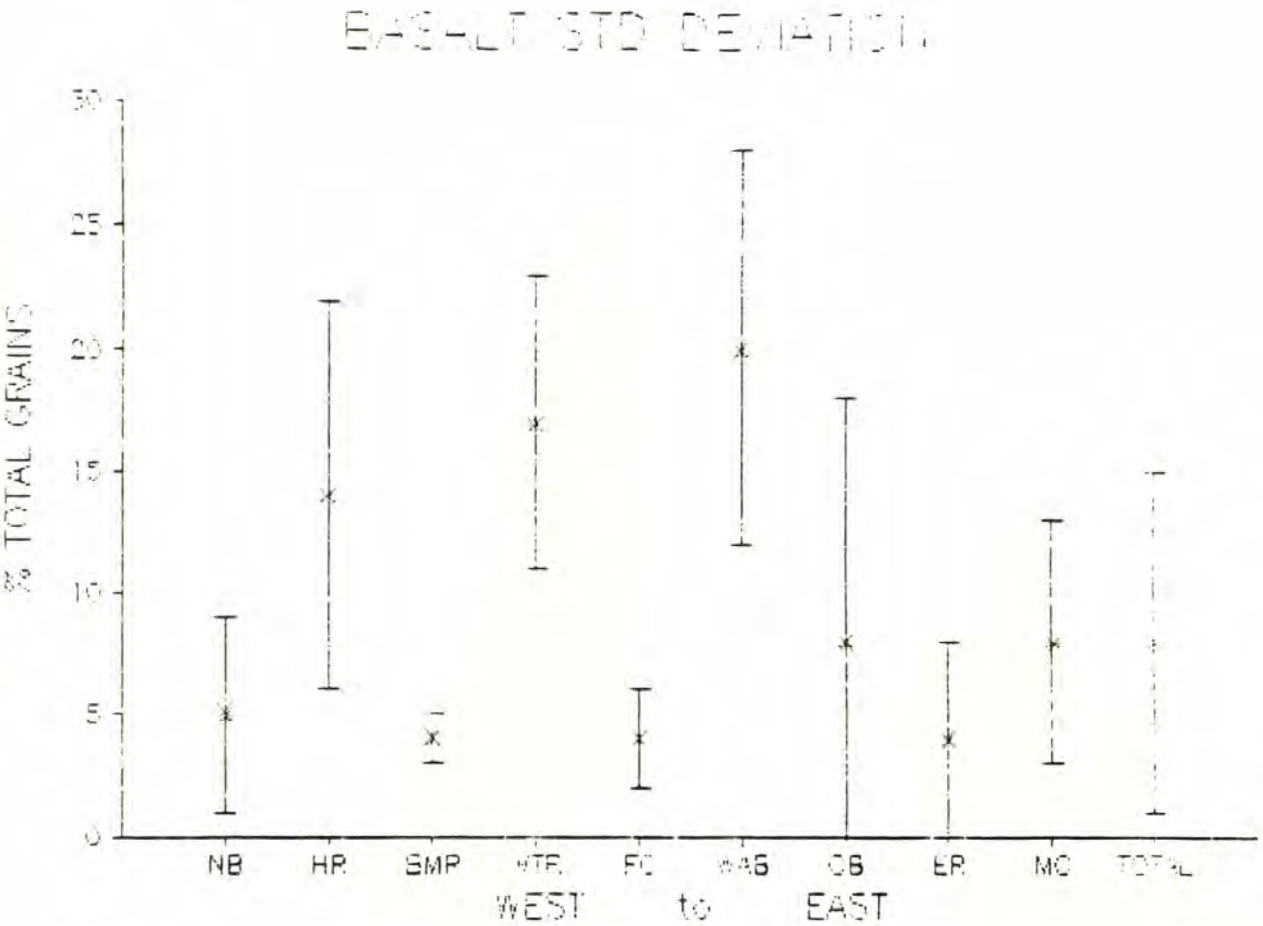


Figure 19. Variations of percent of basalt from the most western to most eastern sample locations of the Hoko River Formation.

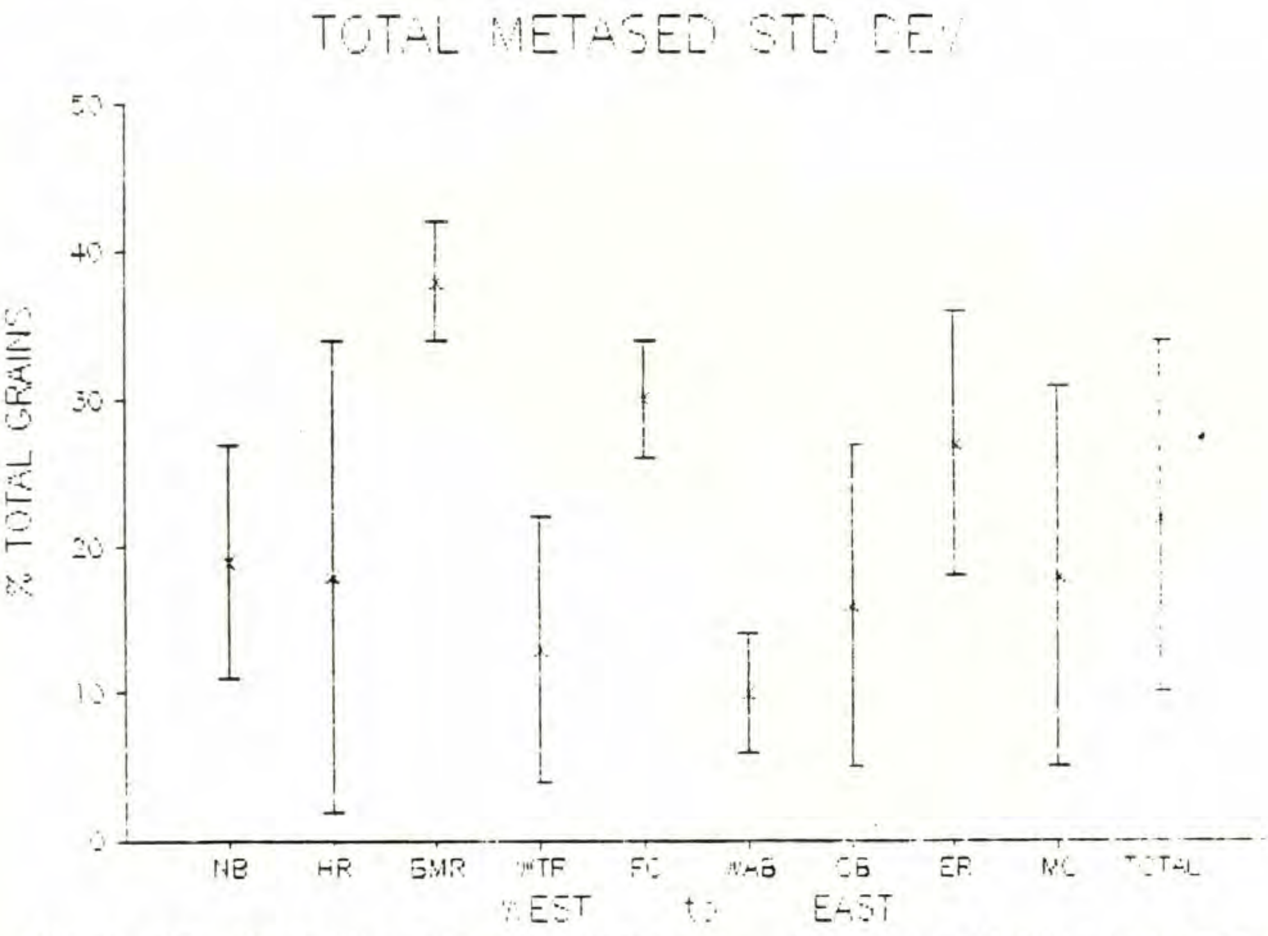


Figure 20. Variations of percent of metasedimentary lithics from the most western to most eastern sample locations of the Hoko River Formation.

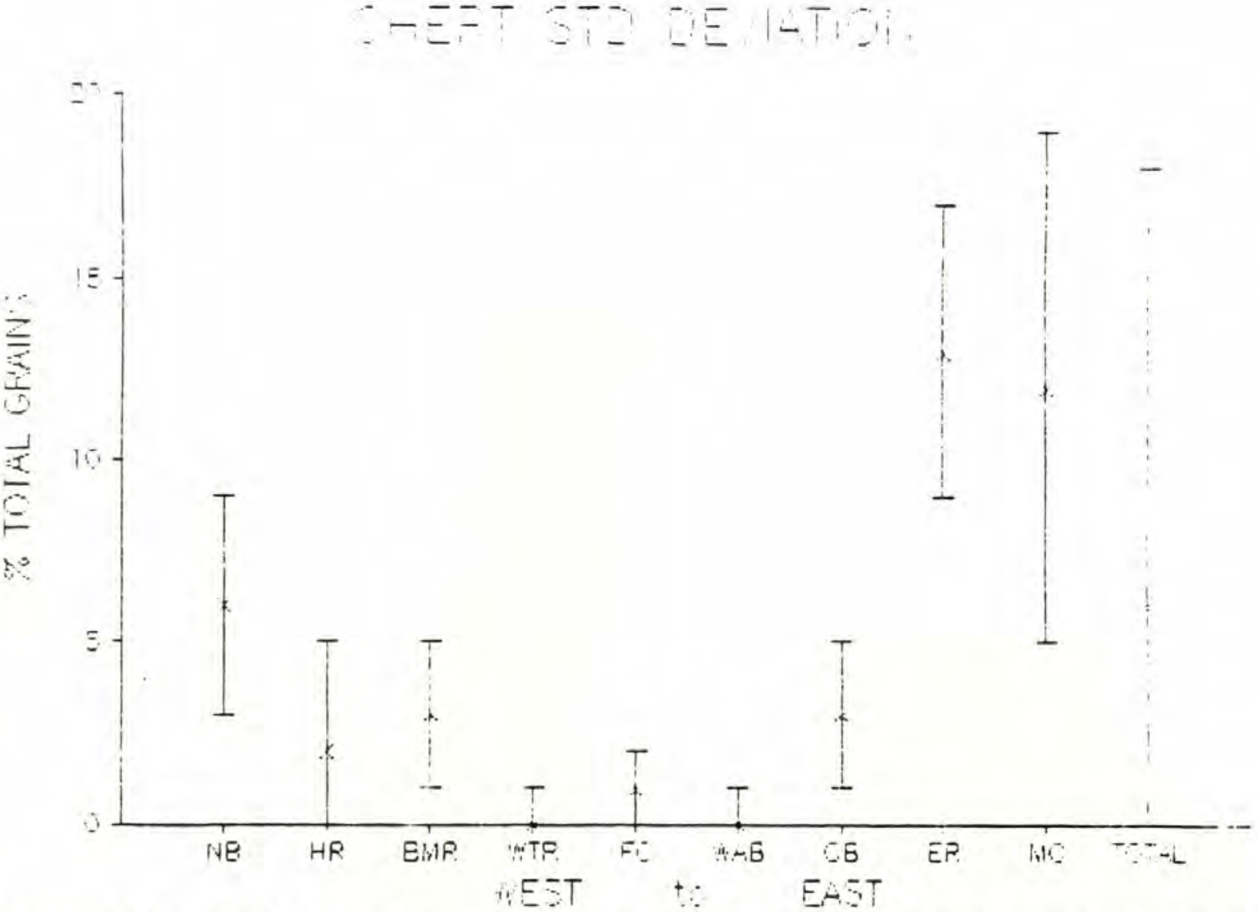


Figure 21. Variations of percent of chert from the most western to most eastern sample locations of the Hoko River Formation.

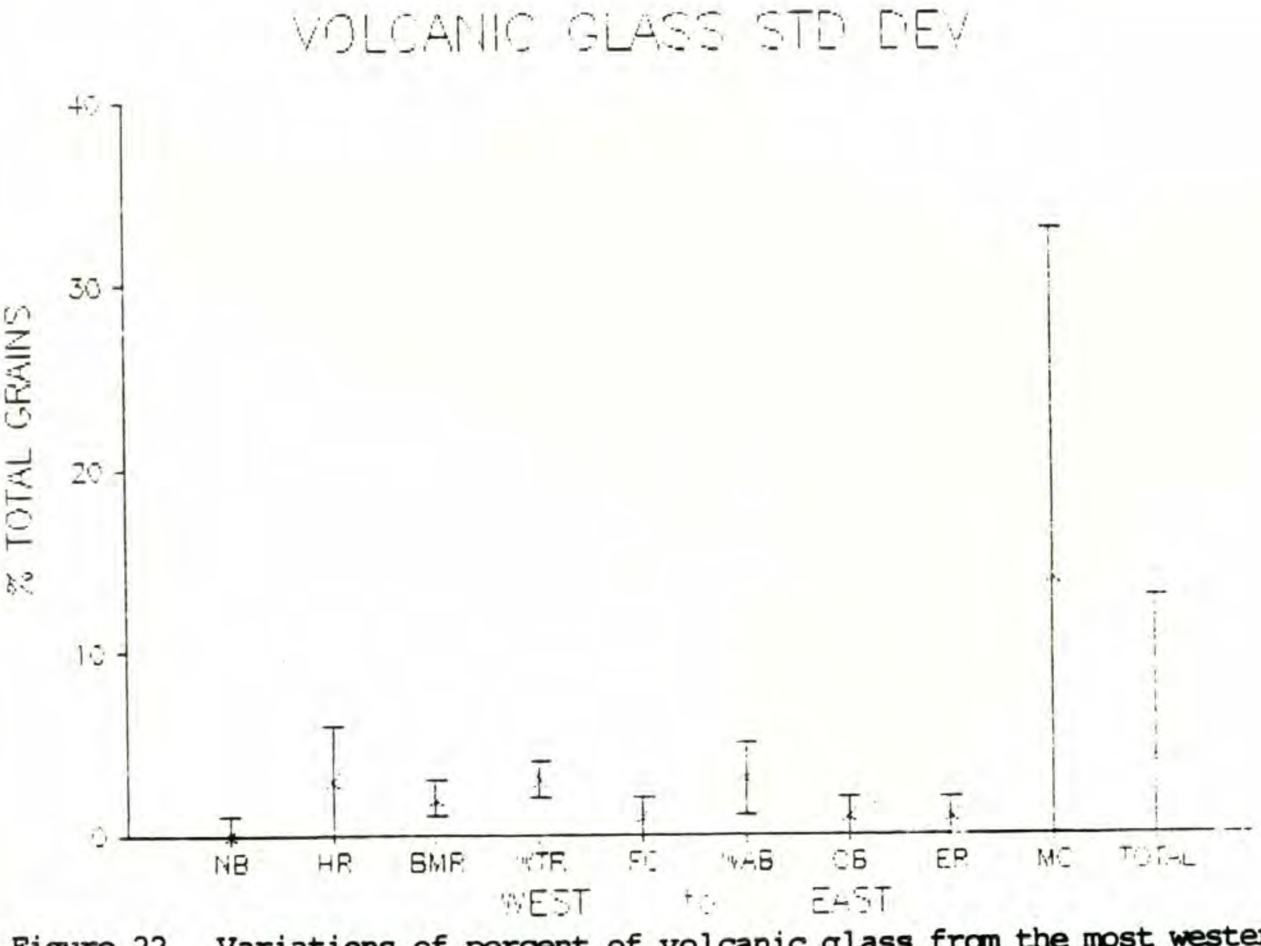


Figure 22. Variations of percent of volcanic glass from the most western to most eastern sample locations of the Hoko River Formation.

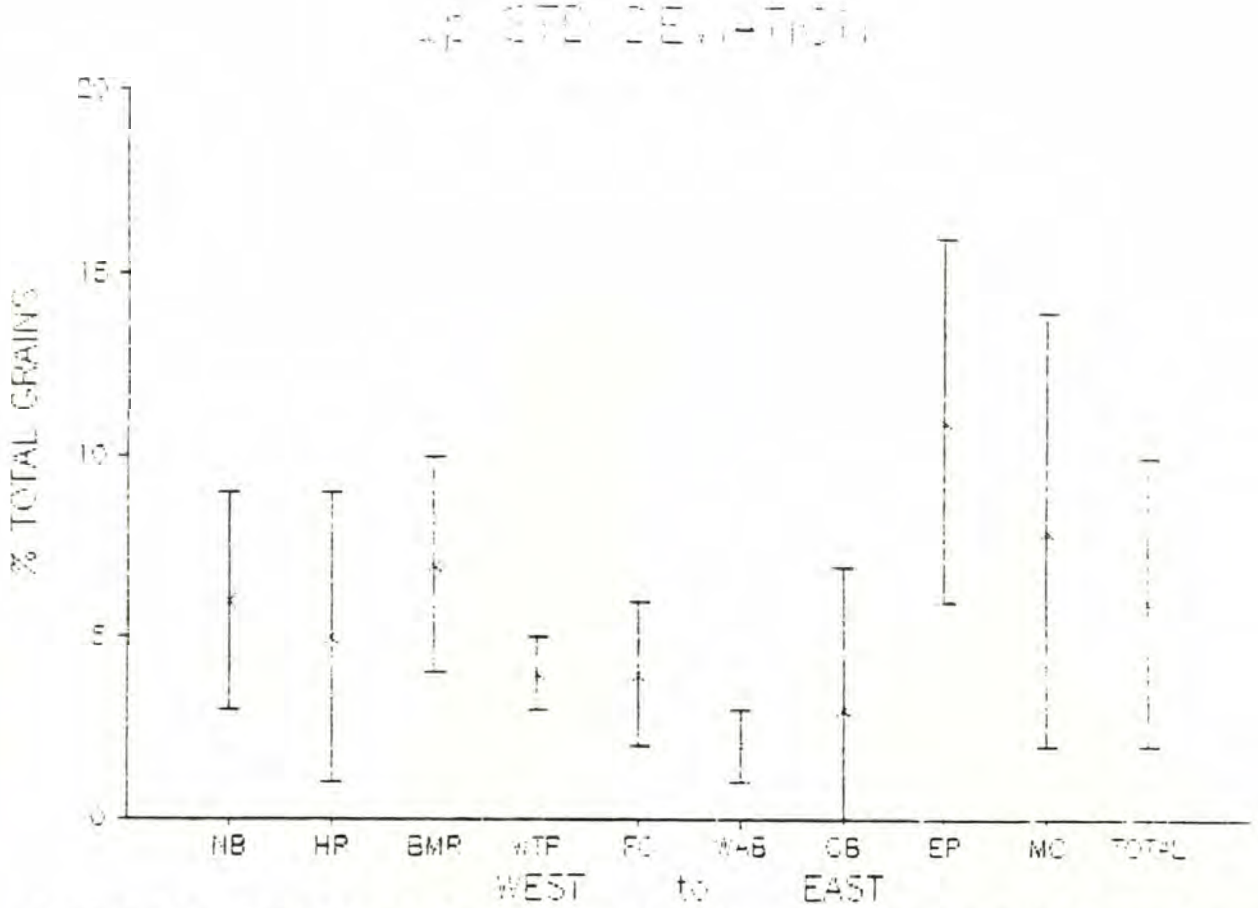


Figure 23. Variations of percent of polycrystalline quartz from the most western to most eastern sample locations of the Hoko River Formation.

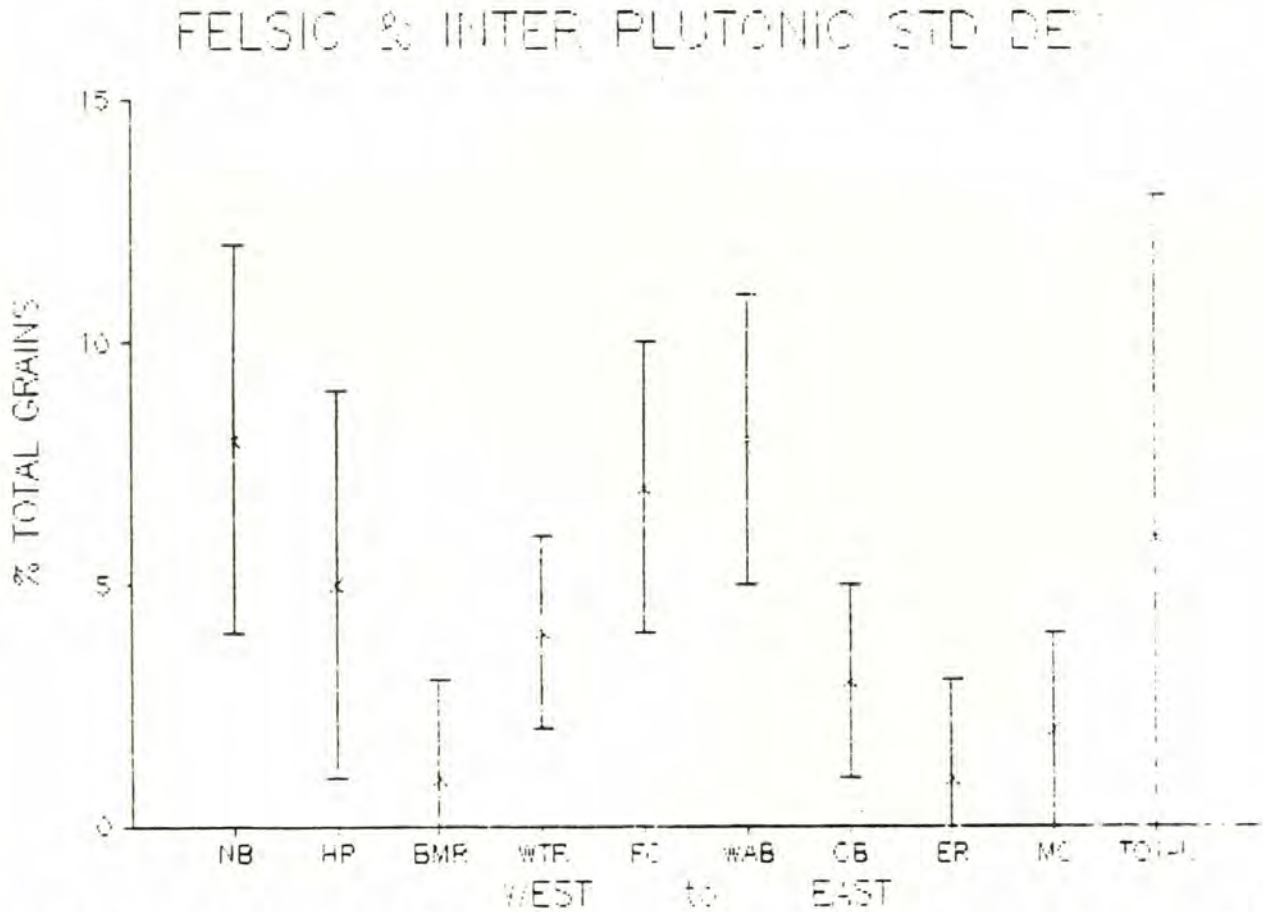


Figure 24. Variations of percent of felsic and intermediate plutonics from the most western to most eastern sample locations of the Hoko River Formation.

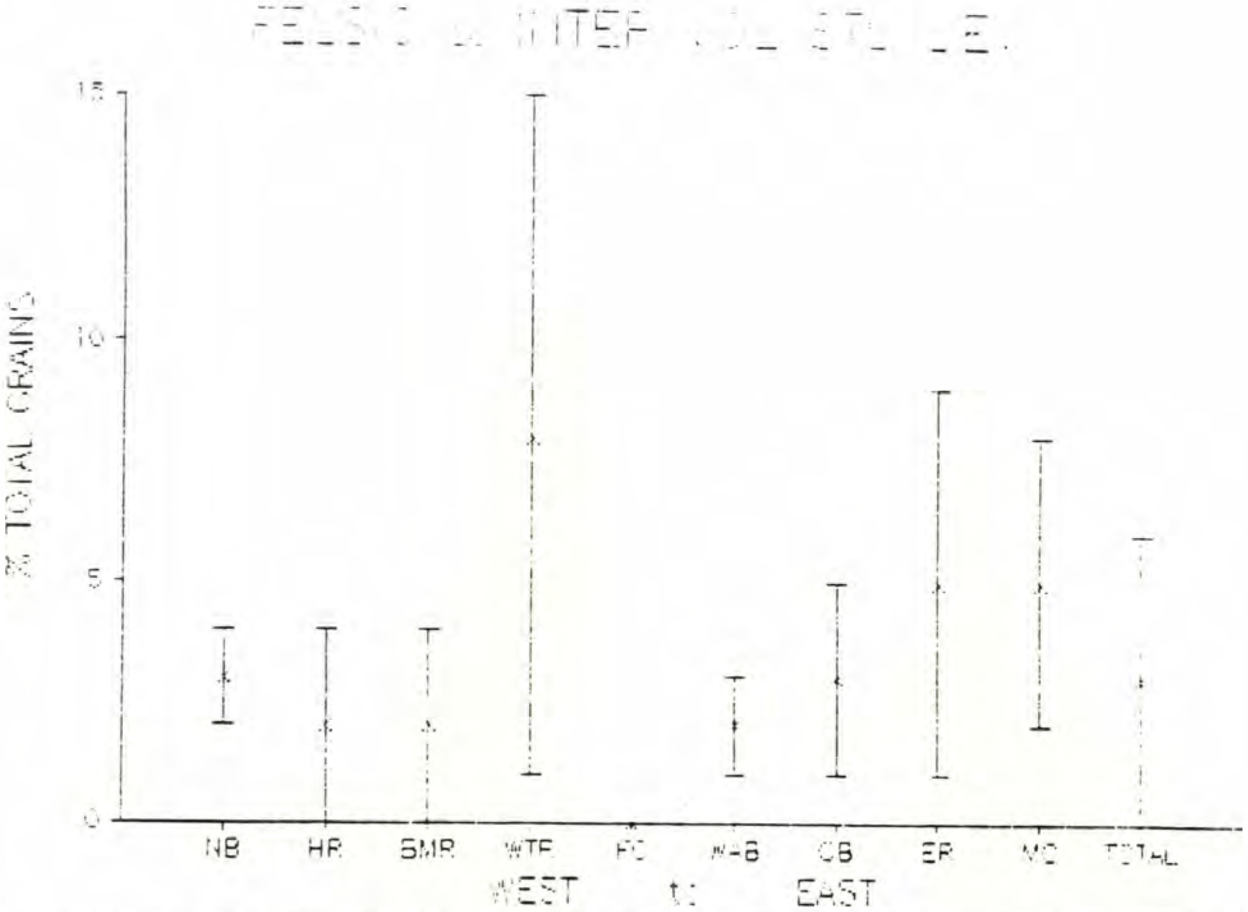


Figure 25. Variations of percent of felsic and intermediate volcanic glass from the most western to most eastern sample locations of the Hoko River Formation.

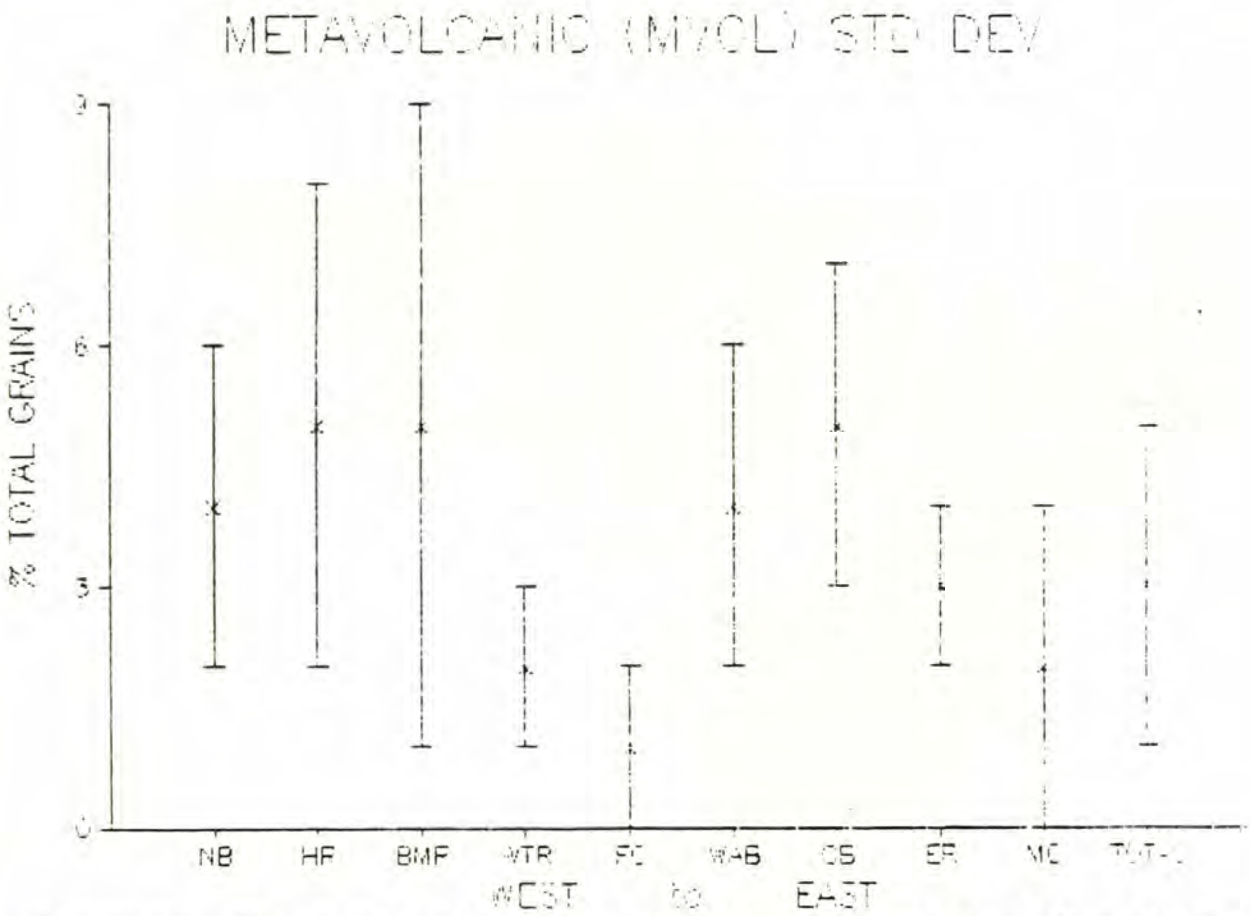


Figure 26. Variations of percent of metavolcanic lithics from the most western to most eastern sample locations of the Hoko River Formation.

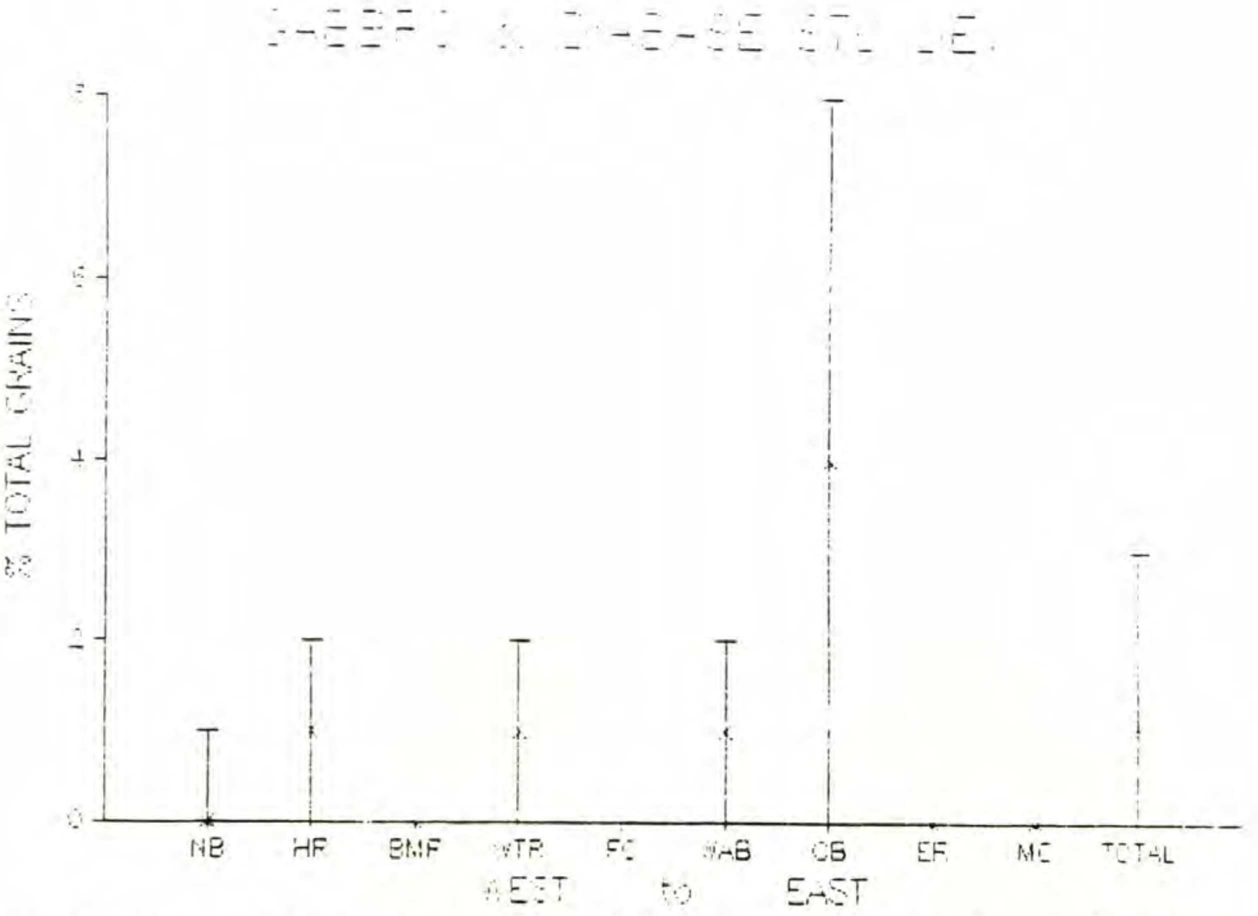


Figure 27. Variations of percent of gabbro and diabase from the most western to most eastern sample locations of the Hoko River Formation.

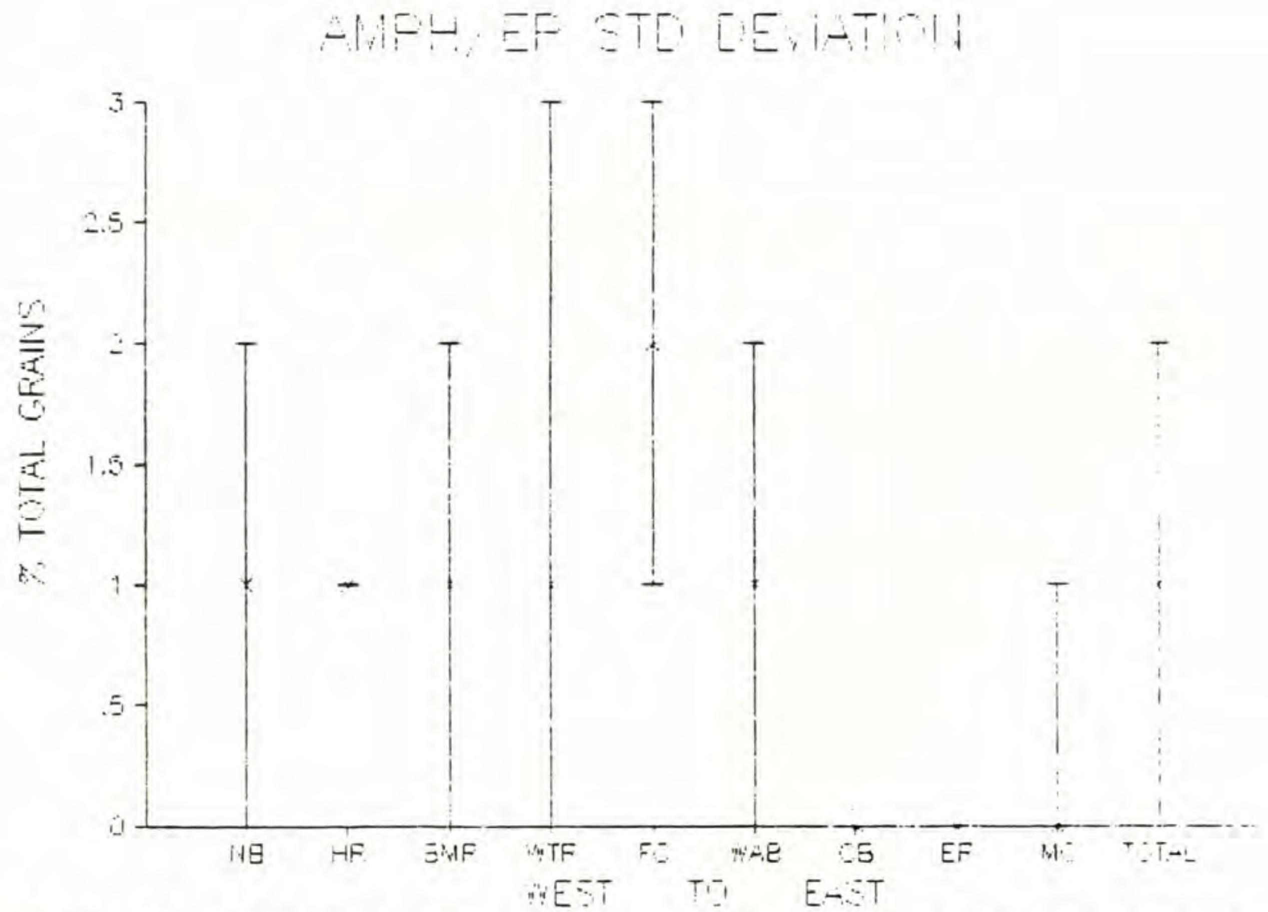


Figure 28. Variations of percent of amphibole- and epidote-rich lithics from the most western to most eastern sample locations of the Hoko River Formation.

TABLE 6 PERCENT OF TOTAL GRAINS OF LITHIC CATEGORIES

Location	Lvm	Lmst	Chert	Lvgl	Qp	Lpfi	Lvfi	Lmv	Lpg
MC	8	18	12	14	8	2	5	2	0
±	5	13	7	19	6	2	3	2	0
ER	4	27	13	1	11	1	5	3	0
±	4	9	4	1	5	2	4	1	0
CB	8	16	3	1	3	3	3	5	4
±	10	11	2	1	4	1	2	2	4
WAB	20	11	0	3	2	8	2	4	1
±	8	4	1	2	1	3	1	2	1
FC	4	30	1	1	4	7	0	1	0
±	2	4	1	1	2	3	0	1	0
WTR	17	13	0	3	4	4	8	2	1
±	6	6	1	1	1	2	7	1	1
BMR	4	38	3	2	7	1	2	5	0
±	1	4	2	1	3	2	2	4	0
HR	14	18	2	3	5	5	2	5	1
±	8	16	3	3	4	4	2	3	1
NB	5	18	6	0	6	8	3	4	0
±	4	8	3	1	3	4	1	2	1
TOTAL	8	22	7	3	6	5	3	3	1
±	7	12	12	8	4	4	3	2	2

An average of the percent of total grains of the major lithic types and standard deviation from each section is presented. Formation averages and standard deviations for each lithic type are shown under Total. The abbreviations for these percentages are the following:

Lvm basalt	Lvgl volcanic glass
Qp polycrystalline quartz	Lpfi felsic and inter. plutonics
Lmv metavocanics	Lpg gabbro and diabase
Lmst total metasediments	Chert
Lvfi felsic and intermediate volcanics	

7% ± 12 chert, the Elwah River section has 13% ± 4, and the Morse Creek section comprises 12% ± 7 chert. The average of the Hoko River Formation, minus these two sections, is 2% ± 2, which is significantly different from the averages of the Morse Creek and Elwah River sections. A more chert-rich source is evident in the eastern-most source areas (Figure 21).

Volcanic glass lithics average 2% ± 1, except for the Morse Creek section, which contains 14% ± 19 (Figure 22). The Morse Creek section contains a tuff bed that was kaolinized in outcrop. Samples above the tuff layer show an enrichment of volcanic glass, up to 49% in one sample. Samples lower and much higher in the stratigraphic section have low levels of volcanic glass, similar to the formation average. A local volcanic event in the source area or in the depositional basin of Morse Creek section is implied by the isolated increase of volcanic glass.

Random geographic variability between the sections is found for the following lithic types: polycrystalline quartz, felsic and intermediate plutonic and volcanics, metavolcanics, gabbro and diabase, and amphibole- and epidote-rich schists. Polycrystalline quartz lithics compose 6% ± 4 of the formation total (Table 6, Figure 23).

The felsic and intermediate plutonic fragments of granite, granodiorite, quartz-diorite, and diorite comprise less than five percent each at any sample location (Table 6, Figure 24). Exceptions are the granodiorite to diorite lithics at Neah Bay, which average 8% ± 4, and the lithics at west Agate Beach, which average 8% ± 2. These averages are within the limits of the overall formation average of 5%± 6, but may indicate slight enrichment.

The felsic and intermediate volcanics, rhyolite, dacite, and andesite, comprise 3% ± 3 (Table 6)(Figure 25). The large standard deviation in the West Twin River Road section (8% ± 7) results from one sample with 19% felsic and intermediate volcanic lithics. Metavolcanic lithics form 3% ± 2 of the lithic population of the formation (Table 6, Figure 26). Mafic plutonics, gabbro and diabase, (Figure 27) have an overall average of 1% ± 2 with Crescent Beach containing the most (4% ± 4, Table 6).

<u>Summary</u> The percentages of chert and volcanic glass lithics increase in the eastern-most sections (Elwah River and Morse Creek). The rest of the lithics, including basalt, metasediments, polycrystalline quartz, felsic and intermediate plutonics and volcanics, metavolcanics, mafic plutonics, and amphibole- and epidote-rich schists, show random geographic variability. More statistical work could be done to determine whether the latter groups are truly random. Distinctive lithic signatures for each section might be defined and compared to each other using multivariant analysis, an area of future research.

Grain-size variation was not a factor controlling the size of the standard deviations. The standard deviations of the Field Creek section (medium sand-size grains) (Table 4) are similar to those of the other sections (coarse to very coarse sand). Samples from all locations are well distributed vertically within their sections, suggesting that the standard deviation is not controlled by stratigraphic position. Depositional processes do appear to control the standard deviations within some sections. A further investigation of changes in lithic populations in adjacent depositional environments would be helpful.

Multivariant Analysis

The simultaneous variation of two or more clast populations was investigated by plotting the percentage of certain lithic components against location on the same diagrams (Figure 29 to 31). These diagrams document the increase or decrease of two or three lithic components from one section to another. Error bars of one standard deviation are omitted to keep the diagrams simple. The data are the same as those used in the previous section (Table 6).

The metamorphic lithics were subdivided into three subpopulations by petrographic characteristics (see Sedimentary Petrology for detailed descriptions). The groups are metavolcanics (Mvol = Lmv), graphitic phyllite and graphitic schist (Phyll = Lmsp), and other metasediments (Msedl = Lms)(Figure 29). The metavolcanics include schists with mafic assemblages and lithics with relict volcanic textures. The graphitic schists and graphitic phyllites form a distinctive lithology, recognized by the presence of graphite. The third subgroup, other metasediments, contains metamorphic lithics that are not included elsewhere and are comprised mainly of argillite, mylonitic lithics, and clay-rich. Clay-rich cherts are dramatically high in the Elwah River and Morse Creek Sections. These will be referred to as nonspecific metasediments.

Graphitic phyllite and schist and nonspecific metasediment show similar variance from the Burnt Mountain Road to the West Agate Beach sections (3 to 6). At the Hoko River (2), Crescent Beach (7), and Elwah River (8) sections, the inflection points for these lithic types are dissimilar. At the Neah Bay (1) and Morse Creek (9) sections the inflection points are ambiguous because they are end points. The inflection points of the nonspecific metasediments at Crescent Beach (7), Elwah River (8), and Morse Creek (9) are similar to the inflection points

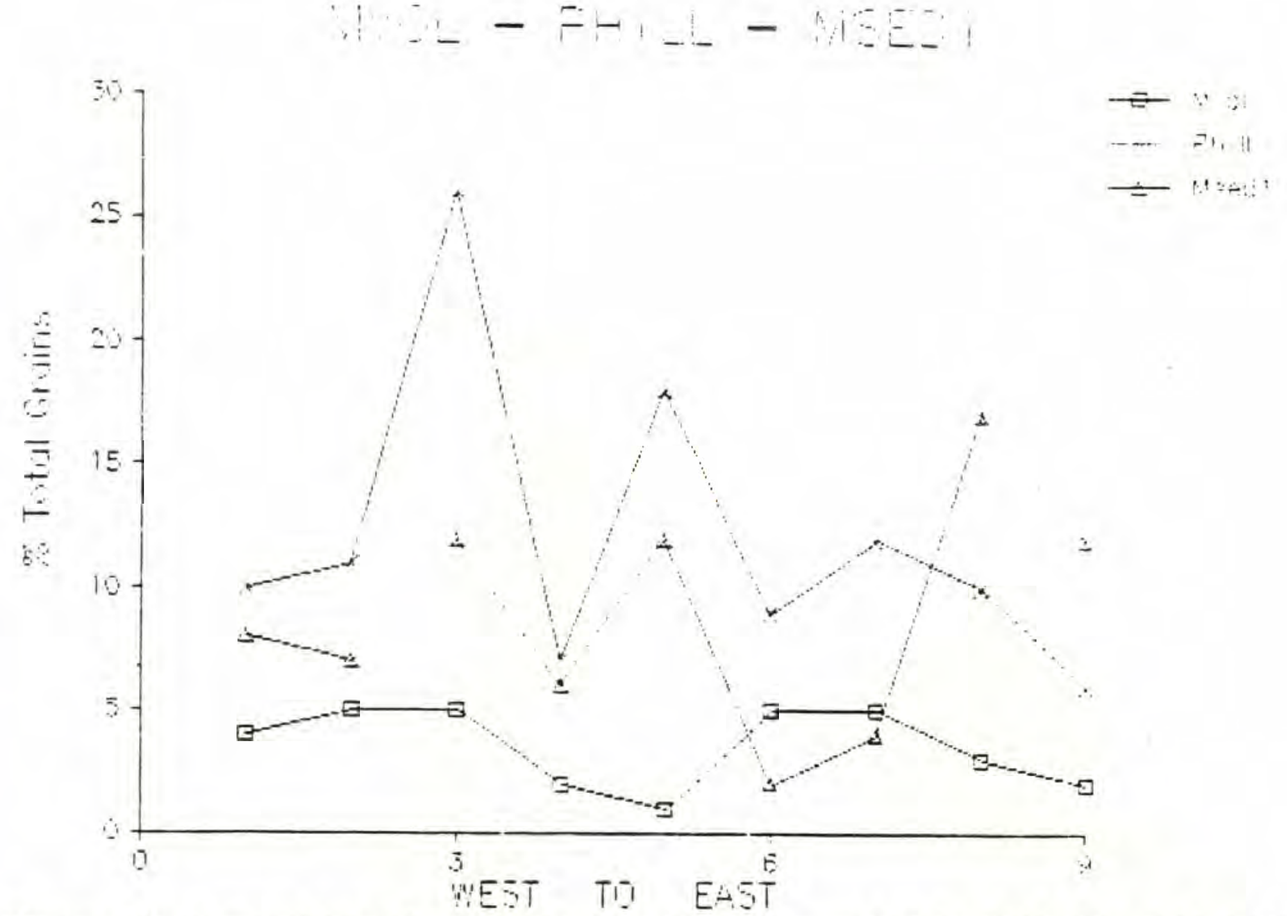


Figure 29. Comparison of metavolcanic (Mvol), graphitic phyllite and schist (Phyll), and metasedimentary (Msed1) lithic averages from the most western to the most eastern sections in the Hoko River Formation.

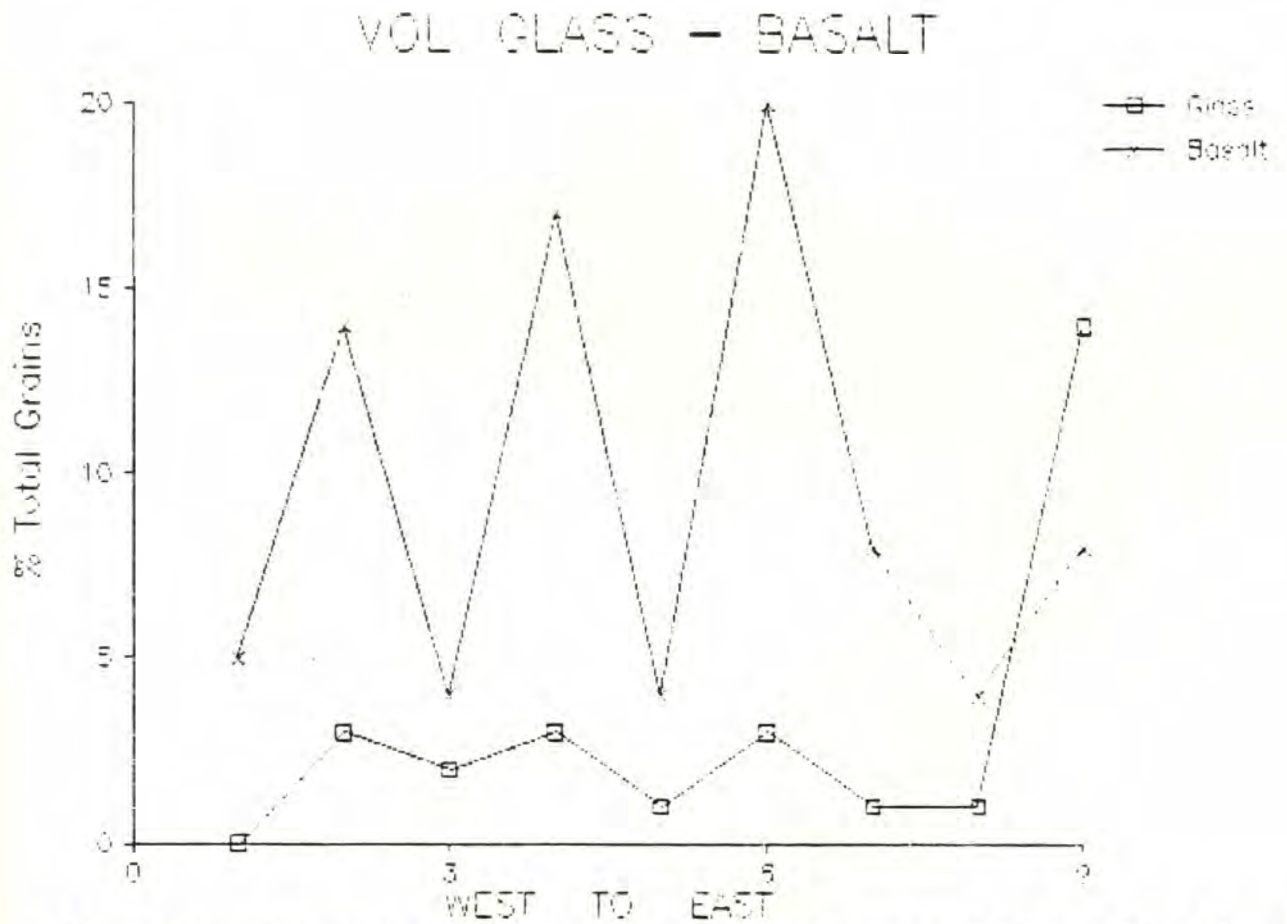


Figure 30. Comparison of volcanic glass and basalt lithics from the most western to most eastern sections in the Hoko River Formation.

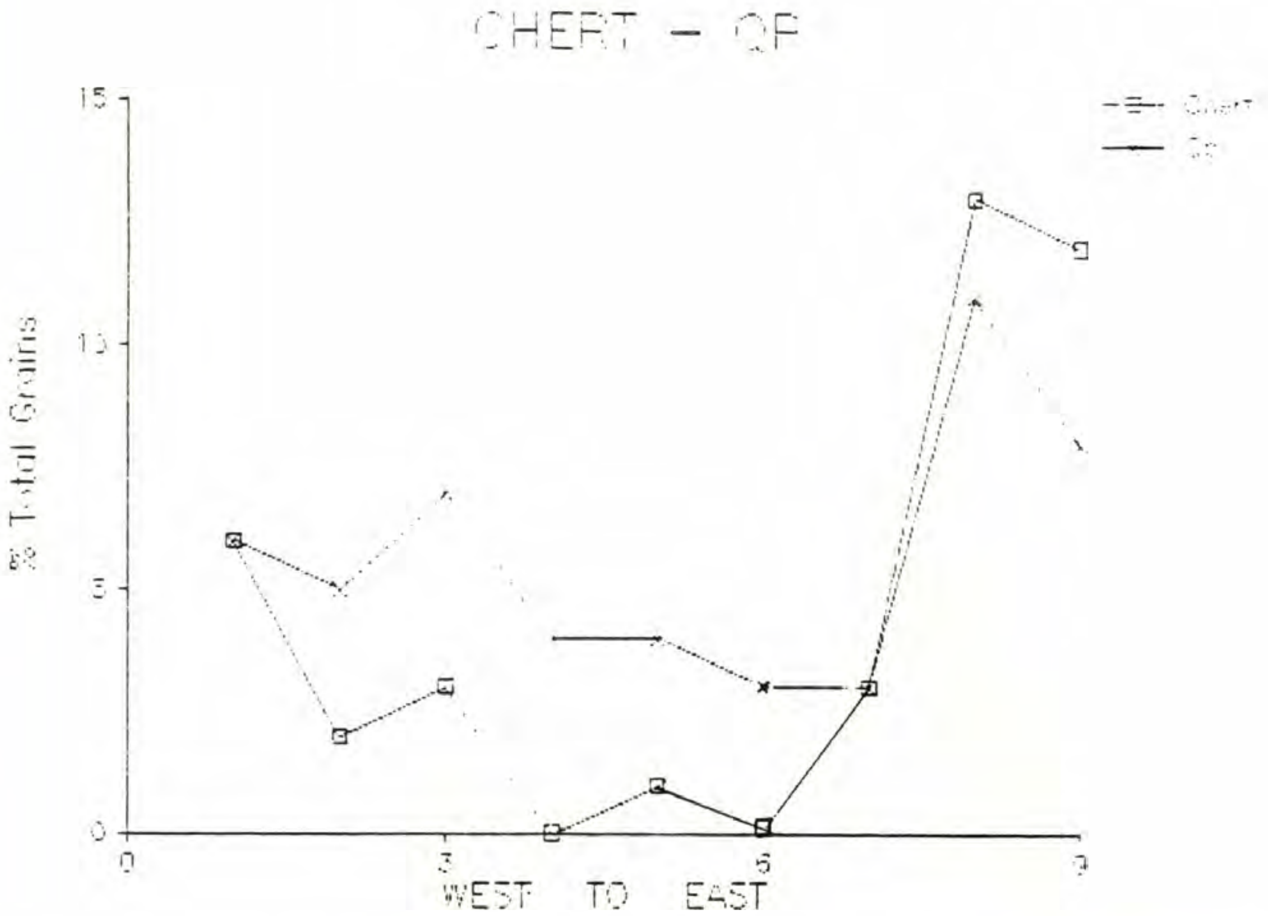


Figure 31. Comparison of chert and polycrystalline quartz lithics from the most western to most eastern sections in the Hoko River Formation.

of these sites for Chert and polycrystalline quartz (Qp)(Figure 31). An increase in the number of clay-rich chert grains was noticed at the Elwah River (8) and Morse Creek (9) sections. The presence of much clay-rich chert at these locations is the probable cause of the infection points of nonspecific metasediments resembling those of the Chert and Qp data rather than the graphitic phyllite and schist data. The increase in the nonspecific metasediments at these sections is probably a real effect, rather than an artifact of this graphing technique.

Metavolcanic data is only weakly covariant with graphitic phyllite and schist data at the Neah Bay (1), Hoko River (2), Crescent Beach (7), Elwah River (8), and Morse Creek (9) sections. There is not enough data to make an accurate interpretation. The inflection points of metavolcanic data not follow those of the nonspecific metasedimenta data, suggesting that different sources were involved.

Volcanic glass and basalt were plotted against one another (Figure 30). The two lithic grain types show similar inflection points at all locations except for the Crescent Beach (7) and Elwah River (8) sites. The amount of basalt found at Crescent Beach is greater, probably due to the erosion of an underlying basalt at Crescent Beach. The anomalous concentrations of volcanic glass at the Morse Creek sections is apparent in the increase in the percentage of grains composed of volcanic glass.

Chert and polycrystalline quartz vary similarly (Figure 31) in all sections given the precision of the data. This relationship suggests that chert and polycrystalline quartz were derived from the same source areas. The Elwah River and Morse Creek sections reflect an increase in chert in the source area. Polycrystalline quartz also increases at these sites; however, not as distinctly.

Summary The metavolcanic lithics show only a weak similarity to the variation exhibited by the other metamorphic lithic types. The source for these lithics may not be the same as for the other metamorphic lithic types. Variation between the graphitic phyllites and schists and the other metasedimentary lithics is similar suggesting a source area containing both lithic groups. The Elwah River and Morse Creek sections are exceptions, inwhich an increase in clay-rich cherts in the source area may be the controlling factor. Alternately, two separate depositional systems may have been responisible for this variation in lithic composition, one transporting and depositing sediment to the Morse Creek and Elwah River section and the other depositing sediment everywhere else.

Volcanic glass and basalt were probably derived from the same source area, except at the Morse Creek section, where there was a local influx of volcanic glass. The data suggests that chert and polycrystalline quartz from the Neah Bay to Crescent Beach sections were derived from one source, different from the source for the Elwah River and Morse Creek sections.

SOURCE AREAS FOR THE HOKO RIVER FORMATION

A detailed study of the lithic types and the surrounding regions was undertaken to ascertain what the source areas for the Hoko River Formation were. Five possible source areas for the sediments are the core terranes of the Olympic Peninsula, the Coast Plutonic Complex, the San Juan Islands, the North Cascades and terranes of southern and central Vancouver Island (Figure 32). The lithic types common in the Hoko River Formation have been thoroughly described in the section on Sedimentary Petrology and are listed in Table 7. This is followed by a list of the lithologies found in each possible source area (Table 8). Each area is examined for its merits as a source.

The core terranes of the Olympic Peninsula

The Olympic Core and Ozette terranes of Silberling and Jones (1984) comprise the major units found in the core rocks of the Olympic Peninsula (Figure 33). The ages of the rocks of the Olympic Core and Ozette terranes vary from Eocene to Oligocene with small Jurassic and Cretaceous inliers (Table 8). The Olympic Core terrane has been subdivided by Tabor and Cady (1978) into a number of lithic assemblages (Figure 33). The compositions include metasedimentary rocks (argillite, slate, semi-schists, and minor meta-conglomerate), meta-basalt, meta-diorite, melange and associated conglomerate (Table 9). The Olympic Core and Ozette terranes are not probable candidates for source areas to the Hoko River Formation because of the lack of significant quantities of basalt, chert, polycrystalline quartz, and felsic and intermediate plutonics and volcanics.

Figure 32. Generalized map of the areas surrounding the Olympic Peninsula that could have provided sediment to the Hoko River Formation.

Olympic Peninsula	fault
Coast Plutonic Complex	thrust fault
San Juan Islands	SJF San Juan fault
North Cascades	LRF Leech River fault
Northwest Cascades	SMF Survey Mountain fault
Southern and central Vancouver Island	

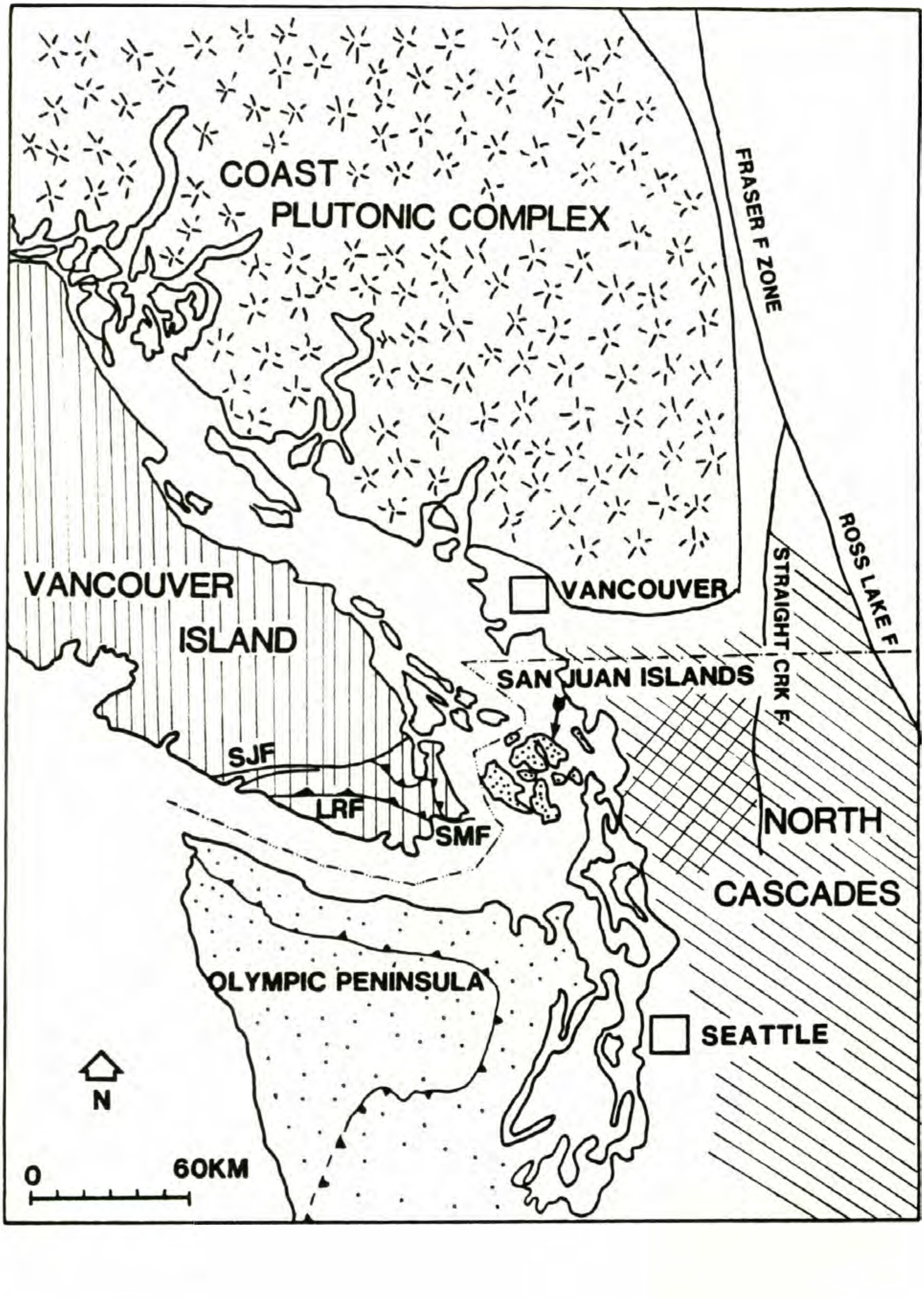

COAST
PLUTONIC COMPLEX
FRASER F ZONE
ROSS LAKE F
STRAIGHT CRK F.
VANCOUVER
VANCOUVER
ISLAND
SAN JUAN ISLANDS
SJF
LRF
SMF
NORTH
CASCADES
OLYMPIC PENINSULA
SEATTLE
N
0
60KM

Table 7 Lithic types and mineralogies in the Hoko River Formation. The formation means for lithic types were calculated from raw point count data. See Appendix 3 - Lithic count: Raw Data for these data.

The data for the formation means for whole rock and monocrystalline components are found in Appendix 2 - Whole rock data: percentages. These data are percents of total points counted for each sample averaged.

Average Composition of Lithic Types

Metasediment, phyllite/schist	24 %
Basalt	14 %
Chert	8 %
Glass	4 %
Polycrystalline quartz	9 %
Felsic and intermediate plutonics	9 %
Felsic and intermediate volcanics	5 %
Metavolcanics	14 %
Gabbroic plutonics and diabase	1 %
Amphibole and epidote-rich schists	1 %
Sedimentary lithics	4 %
Fossils	0.5 %

Average Whole Rock and Monocrystalline Components

Monocrystalline Quartz	12 % $\pm$ 6
Plagioclase	10 % $\pm$ 6
Potassium feldspar	0.5 % $\pm$ 1
Total lithics	49 % $\pm$ 13
Chlorite	2 % $\pm$ 3
Epidote and amphibole	2 % $\pm$ 3
Accessory minerals	3 % $\pm$ 3
Calcite cement	14 % $\pm$ 13
Matrix	5 % $\pm$ 8
Others	1 % $\pm$ 2

Characteristics of Monocrystalline Components

Little potassium feldspar = 0.5 %$\pm$1 of the bulk composition
More quartz than plagioclase: quartz= 12 %$\pm$6, plagioclase= 10 %$\pm$6

TABLE 8 SOURCE AREA VERSUS LITHOLOGY

The lithic types of the Hoko River Formation are listed on the vertical axis in decreasing order of abundance with the five source areas on the horizontal axis. The relative amounts of the lithic types present in the area now are noted in the appropriate boxes. The order of abundance is 0, TR (trace), FEW, SOME, LOTS, from least to most. The areas and significance will be discussed in the text.

	LITHOLOGY	SOURCE AREAS				
		OLYMPIC CORE	COAST PLUTONIC COMPLEX	SAN JUAN ISLANDS	NORTH WEST CASCADES	SOUTHERN VANCOUVER ISLAND
DECREASING ABUNDANCE	META-SEDIMENT	LOTS	FEW	LOTS	LOTS	LOTS
	BASALT	FEW	TR	FEW	SOME	LOTS
	CHERT	TR	TR	LOTS	SOME	SOME
	POLYCRY. QUARTZ	TR	TR	SOME	LOTS	LOTS
	FELSIC & INTERMEDIATE PLUTONICS	TR	LOTS	FEW	TR CRYS.CORE	LOTS
	FELSIC & INTERMEDIATE VOLCANICS	TR	TR	FEW	SOME	SOME
	METAVOLCANICS	TR	FEW	LOTS	LOTS	LOTS
	AMPHIBOLE & EPIDOTE SCHISTS	0	TR	TR	LOTS	SOME
	GABBROIC PLUTONICS & DIABASE	TR	FEW	FEW	FEW	LOTS
	VOLCANIC GLASS	TR	SOME	TR	SOME	SOME

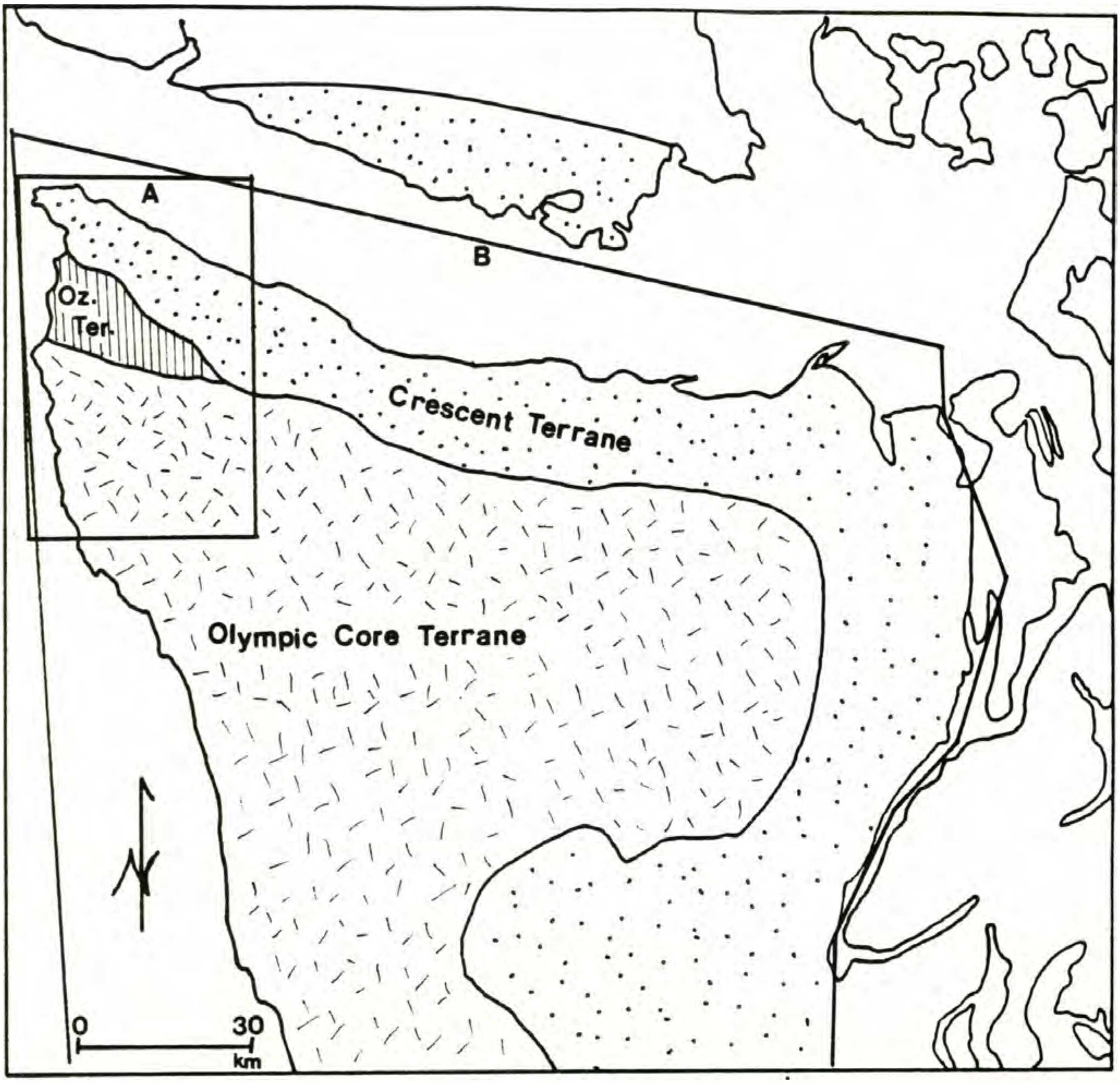


Figure 33. The three major terranes of the Olympic Peninsula and southern-most Vancouver Island (Silberling and Jones, 1984).

Olympic Core terrane

Ozette terrane

Crescent terrane

A Area mapped by Snavely and others (1986)

B Area mapped by Tabor and Cady (1978)

TABLE 9 LITHOLOGIC DIVISIONS OF THE OLYMPIC PENINSULA

Table 9 The terrane divisions of Silberling and Jones (1984) for the Olympic Peninsula with the subdivisions of Tabor and Cady (1978) for the Olympic Core terrane and the divisions of Snavely and others (1986) for the Ozette terrane. This summarizes the major lithologies and ages of units within the Olympic Core and Ozette terranes.

I. Olympic Core terrane (Silberling and Jones, 1984; subdivisions by Tabor and Cady, 1978)

Needles-Gray Wolf lithic assemblage — lower and middle Eocene
Sandstone (with detrital muscovite), siltstone, slate, schist and semischist, basalt.

Grand Valley lithic assemblage — lower Eocene
Sandstone, siltstone, semischist, basalt, and red limestone.

Elwah lithic assemblage — lower to middle Eocene
Sandstone, slate, phyllite, semischist, basalt.

Western Olympic lithic assemblage — middle Eocene to Oligocene
Dominantly thick-bedded sandstone with minor pelitic rocks (potassium feldspar commonly comprises 3 to 10% of sandstones).

Hoh lithic assemblage — upper Oligocene to lower and middle Miocene
Siltstone, sandstone, conglomerate and basalt with breccia, flows, pillows and tuff.

Undifferentiated core rocks — upper Eocene and Oligocene
Sandstone, slate, argillite, basalt.

II. Ozette terrane (Silberling and Jones, 1984; subdivisions by Snavely and others, 1986)

Terrane south of the Crescent Thrust Fault and north of the Calawah Fault — middle to upper Eocene
Lithic and arkosic sandstone, siltstone, conglomerate, mudflow, basalt pillows, lava and breccia, and tuff

Sooes terrane

Cretaceous and older
Melange, argillite, sandstone, conglomerate, mudflow breccia, gabbro, and diorite.

lower to upper Eocene
Lithic sandstone, siltstone, conglomerate, mudflows, breccia, pillow basalt, gabbro or diabase sills, dacite sills, tuff breccia.

Ozette terrane — lower Eocene to Oligocene
Sandstone, siltstone, conglomerate, mudflow conglomerate, and melange.

Discussion

The Olympic Core terrane is composed of low- to medium-grade metasediments with minor basalts and associated basaltic sediments. The metasediments range from very low grade (zeolite facies) to muscovite + (quartz) + (albite) semischist, sericite + (chlorite) + (plagioclase) + (quartz) slate, graphitic (biotite) + (chlorite) + (sericite) + (albite) + (quartz) phyllite (Tabor, 1972). The graphitic phyllites are similar to those found in the Hoko River Formation. While muscovite, chlorite and biotite are not abundant in Hoko River Formation lithics, albite + sericite + graphite + quartz assemblages are, indicating low- to medium-metamorphic grade in the source area. Therefore, the metasediments of the Olympic Core could have been a source of sediment to the Hoko River Formation. However, it is the opinion of the author that much of Olympic Core was not a subaerially exposed highland during the late Eocene. The ages of most rocks in the Olympic Core indicate deposition concurrent with the Hoko River Formation (Table 9). See the Chapter on Tectonics for further discussion of this point.

The chlorite-rich metavolcanics of the Hoko River Formation could have been derived from the Olympic Core terrane. The polycrystalline quartz of the Hoko River Formation may have been derived from the quartz-rich layers of the schists or the quartz veins that cut the metasediments of the Olympic Core terrane.

Basalts in the Olympic Core and Ozette terranes are not widespread and generally contain a groundmass extensively altered to chlorite, with quartz and epidote veins, similar to the basaltic clasts in the Hoko River Formation. These basalts are widely scattered and do not represent a large enough source to supply the quantity of basalt lithics found in the Hoko River Formation. Sphene + calcite + (chlorite) are present in the greenstones of the Olympic Core terrane (Tabor and Cady, 1978) and are not found in the basalts of the Hoko River Formation.

Chert, polycrystalline quartz, granite, diorite, rhyolites, andesites, and dacites are found in small amounts in the conglomerates of the Olympic Core and Ozette terranes (Table 9). Because these lithologies comprise such a small proportion of the Olympic core, it is unlikely they are the source of these lithic types in the Hoko River Formation. Actinolitic amphibolites, a small portion of the Hoko River Formation lithics, are not found in the Olympic Core and Ozette terranes.

Conclusions

The metavolcanics, metasediments and polycrystalline quartz of the Hoko River Formation could have been shed from the Olympic Core and Ozette terranes. However, five lithic types common in the Hoko River Formation comprise only a minor portion of the Olympic Core and Ozette terranes; they are basalt, chert, felsic and intermediate volcanics and plutonics, and amphibolites. Thus, Olympic Core and Ozette terranes are not considered source areas for the Hoko River Formation.

The Coast Plutonic Complex

The Coast Plutonic Complex (Figure 32) is composed primarily of Upper Cretaceous and early Tertiary plutons, gneisses, and migmatites with an average composition of quartz diorite (Roddick, 1983) (Table 10). Roof pendants of meta-basalt to meta-andesite and metasedimentary units with greenschist- to amphibolite- grade metamorphism comprise a small but intergral part of the southern Coast Plutonic Complex (Roddick, 1983). The flanks of the Coast Plutonic Complex are composed of meta-volcanic and meta-sedimentary rocks of late Paleozoic to Mesozoic age (Table 10). They

TABLE 10 AGES AND LITHOLOGIES OF THE SOUTHERN COAST PLUTONIC COMPLEX

Compositions and ages of units found in the Coast Plutonic complex and its roof pendants and adjacent terranes intruded by the Coast Plutonic Complex. Data are from Roddick (1983) for the Coast Plutonic Complex proper and from Roddick and others (1979) for the other units.

Chilliwack Batholith granodiorite upper Tertiary

Coast Plutonic Complex Upper Cretaceous and lower Tertiary
quartz diorite, tonalite, diorite, granodiorite, quartz monzonite, and gabbro, granite, monzonite, and quartz monzonite.

<u>Upper Cretaceous</u>

Scuzzy and Spuzzum Plutons granodiorite

Lighting Creek and Black Creek Plutons quartz diorite

<u>Lower Cretaceous</u>

Gambier Group tuff, breccia, argillite

Broken Backhill and Penisula Formation tuff, agglomerate, sandstone

Helm Formation argillite, quartzite

Empetrum, Cheakamus Formations greywacke, argillite, volcanics

Fire Lake Group pyroclastic greenstone, slate, greywacke, conglomerate, limestone

<u>Middle Jurassic</u>

Harrison Lake Volcanics andesitic, rhyolitic flows

Bullhook Creek, Mysterious Creek, Echo Island Units
tuff, sandstone, pelite, conglomerate, sandstone, shale

Cultus Formation Triassic and Jurassic
pelite, sandstone, conglomerate

Cadwallader Group Upper Triassic
Noel Formation argillite, chert, greenstone, conglomerate
Pioneer Formation greenstone, andesite, breccia, tuff, flows
Hurly Formation argillite, limestone, tuff, conglomerate

Bowen Island Group greenstone Triassic

<u>Paleozoic</u>

Twin Island Group granulite, amphibolite, gneiss, schist

Chilliwack Group graywacke, pelite, andesite, basalt

Custer gneiss Precambrian

Unnamed units unknown
gabbro, diorite, amphibolite grade migmatites, grano- and quartz-diorites

are similar to the lithologies found in the northwest Cascade Mountains (Fiugre 32) of Washington and in some cases are the northern extensions of these units.

Discussion and Conclusion

Sediments derived from the southern Coast Plutonic Complex would consist mostly of quartz, plagioclase, potassium feldspar, minor amphibole and mica, and lithic fragments of granodiorite, quartz diorite and the associated metasedimentary and metavolcanic units. The Hoko River Formation does not contain this assemblage (Table 7). The Coast Plutonic Complex contains about 10% potassium feldspar in general, while the Hoko River Formation has only 0.5 % ±1. While quartz diorite and granodiorite clasts are found in the Hoko River Formation, sources other than the Coast Plutonic Complex are closer, and therefore are more likely sources of this sediment. Also, the lack of basalt and the minor amount of chert in the Coast Plutonic Complex is significant. Because of these differences, it is probable that the Coast Plutonic Complex and its associated units were not the primary source of sediment for the Hoko River Formation.

The San Juan Islands

The San Juan Islands contain a sequence of Mesozoic thrusts, juxtaposing terranes, that have been divided into the internal units, external units, and an overlap assemblage (Brandon and others, 1988)(Table 11). The internal units are those that were directly involved in the thrusting event and have retained a high pressure-low temperature metamorphic signature of lawsonite-prehnite-aragonite. The external units were not involved in this thrusting event and do not contain the distinctive metamorphic assemblages. The overlap assemblage overlies and

TABLE 11 MAJOR ROCK UNITS WITHIN THE SAN JUAN ISLANDS TERRANES

The divisions, names, compositions, and ages within the thrust sheets, the external units and overlap assemblages of the San Juan Islands. The data are from Brandon and others (1988) except where noted.

NAME OF UNIT	AGE
External units of the San Juan Islands	
Haro Terrane	
Haro Formation	Upper Triassic
Siltstone, volcanic-lithic sandstone, conglomerate, and breecia.	
Spieden Group	Upper Jurassic- Lower Cretaceous
Volcaniclastic sandstone, conglomerate, and mudstone.	
Nanaimo Group	Upper Cretaceous
Lithic-arenite and arkosic-arenite, conglomerate, and shale. Pacht (1984).	
Paleozoic and lower Mesozoic rocks of the internal units	
Turtleback Terrane	
Turtleback Complex	Devonian and older
Meta-plutonic gabbroic to dioritic to trondjemitic plutons. Meta. ass.: greenschist of lower amphibolite and lawsonite and prehnite bearing overprints.	
Eastsound Group	Devon., Penn. and Lower Permian
Andesitic to dacitic (no potassium feldspar) pyroclastic rocks, flows, and pillows with interbedded limestones (aragonitic) and sediments. Meta. ass.: lawsonite and prehnite bearing assemblages.	
Deadman Bay Terrane	
Deadman Bay Volcanics	Lower Permian to Triassic
Meta-pillows, -breccias of mafic and intermediate compositions, and minor limestones (aragonitic marble) and chert. Meta. ass. in basalts: lawsonite-prehnite-chlorite-(epidote)-(pumpellyite).	
Orcas Chert	Triassic to Lower Jurassic
Deformed chert and basaltic volcanic rocks. Meta. ass. in basalts: lawsonite-prehnite-chlorite-(epidote)-(pumpellyite).	
Garrison Terrane	
Garrison Schist	Permian to Lower Triassic
Mafic schist and amphibolite. Meta. ass.: albite-epidote-(chlorite)-(actinolite) schist and albite-epidote amphibolite (barrositic).	

Upper Mesozoic rocks of the internal units

Constitution Fm. Jurassic to Lower Cretaceous

Massive volcaniclastic sandstone, interbedded mudstone, and minor conglomerate, and pebbly mudstone, pillow basalt, tuff, ribbon chert, Meta. ass.: prehnite-lawsonite-aragonite.

Lopez Complex Jurassic to mid-Cretaceous

Sandstone, pebbly mudstone, conglomerate, chert, basaltic pillows and breccias. Meta. ass.: lawsonite-aragonite in the sandstones; aragonite-pumpellyite-chlorite in the gabbro.

Decateur Terrane

Fidalgo complex Middle to Upper Jurassic

Dunite, pyroxenite, layers of gabbro, and mafic to intermediate volcanic flows, pillows and tuff, and quartzdiorite, diorite and quartz albitite dikes (no potassium feldspar), and aragonitic limestone. Meta. ass.: acitinolitic amphibolites.

Lummi Formation Upper Jurassic to Lower Cretaceous

Lithic sandstone mudstone, conglomerate (containing chert and volcanic clasts). Meta. ass.: calcite-prehnite-lawsonite-(pumpellyite).

Overlap Assemblage

Chuckanut Formation lower to upper Eocene

Fluvial deposits of arkosic sandstone, conglomerate, shale, and coal Johnson (1982).

postdates the thrust sheets. Overall, the San Juan Islands are a meta-volcanic, meta-sedimentary, and meta-plutonic composite of late Paleozoic to Mesozoic terranes overlain by Tertiary sediments (Table 11).

Discussion

The rocks of the San Juan Islands (Table 8) and the lithic types in the Hoko River Formation differ in a number of ways. The internal units have undergone high-pressure metamorphism producing lawsonite-, prehnite-, and aragonite-bearing assemblages, especially within the epiclastic, volcaniclastic, pyroclastic, and volcanic units (Brandon and others, 1988). Lawsonite and aragonite are not found in any of the Hoko River Formation lithics, including the metasediment, basalt, felsic and intermediate volcanics, or metavolcanic categories. Prehnite has been recognized in isolated (2) metavolcanic lithics of the Hoko River Formation. It is probable, that if the Hoko River Formation sediments had been derived from the San Juan Islands, lawsonite-prehnite-(aragonite) would have been recognized.

While many metsedimentary units are present in the San Juan Islands (Table 11), the graphite-quartz-(muscovite-sericite)-(chlorite)-(biotite) schists and phyllites of the Hoko River Formation do not occur there, making the San Juan Islands an unlikely source for these metasediments. The amphibolites of the Hoko River Formation are actinolitic, dissimilar to the barrositic amphibolites in the Garrison Schist, but similar to the amphibolites of the Fidalgo terrane (Table 11).

Because the quartz-rich lithologies of the San Juan Islands do not contain high-pressure assemblages, it is possible that similar lithologies found in the Hoko River Formation were derived from the San Juan Islands. There is a slight increase in the amount of chert in the Hoko River

Formation's most eastern exposures, which might be explained by transport of San Juan Islands chert into the Hoko River Formation depositional basin. Because other sources for these lithologies are present on southern Vancouver Island and the northwest Cascades, the presence of quartz-rich lithologies alone is inconclusive.

Conclusion

In summary, the metasediments, basalts, and metavolcanics of the Hoko River Formation were probably not derived from the San Juan Islands based on lack of some high-pressure minerals in such lithics in the Hoko River Formation. Looking at all the lithologies present in the Hoko River Formation (Table 7) and comparing them to the lithologies found in the San Juan Islands (Tables 8 and 11) shows that the total assemblage in the Hoko River Formation is unlikely to have come from the San Juan Islands. The terranes of the San Juan Islands were not the sole or primary source of sediment for the Hoko River Formation.

The Northwest and North-Central Cascade Mountains

The rock units in the northwest and north-central Cascade ranges contain probable source material for sediment now the Hoko River Formation. However, there are enough differences in composition so that the northern Cascade ranges are not considered the primary source of sediment. The pre-Tertiary rocks of the Northwest Cascades are a group of metasedimentary and metavolcanic rocks of oceanic affinity and are intruded by subordinate plutons, dikes and sills of felsic to mafic compositions and wide-ranging ages. These have been metamorphosed to blue-schist facies and structurally complicated (Misch 1966, Brown, 1986). The result is an extensive area of great compositional and structural variation.

Discussion

Metasediments There are many metasedimentary units similar to the graphitic schists and phyllites of the Hoko River Formation (Table 12). The Darrington Phyllite and the phyllitic rocks of Samish Island resemble the metasediments in the Hoko River Formation in composition. The portions of these units that are not extensively deformed are possible sources of metasediment to the Hoko River Formation. The Chilliwack and Nooksack Groups, the Skagit Metamorphic Suite, and the Cultus Formation are compositionally very different from the graphitic phyllites and schists of the Hoko River Formation and are not probable sources of this sediment.

Basalt Low grade or unmetamorphosed basalts older than the Hoko River Formation are a subordinate part of the northwest and north-central Cascades. A minor portion of the Chilliwack volcanics comprises

Table 12 Ages and Compositions of Units Comprising the North Cascades

Compilation of the major lithologic units, their ages and compositions comprising the Northwest Cascades mostly east of the Straight Creek fault, taken largely from Brown (1986), Brown and others (1986), and Brown (1987). The ages are protolith ages in all cases except when the age is followed by a lower case "m" which denotes a metamorphic age (Brown and other, 1986). Also, all metamorphic assemblages have the additional components quartz-chlorite-albite.

Formations/Units/Groups	Age
Granitic rocks of the northwest Cascade Mts and the Crystalline Core (north central Cascades) Granodiorite and quartz diorite.	Tertiary
Chuckanut Fm. and other sedimentary units. Sandstone, shale, coal, and conglomerate.	Tertiary
Skagit Metamrphic Suite Phyllite, schist, migmatitic para-gneisses and tonalitic orthogneiss Meta. ass.: muscovite-chlorite-albite-epidote-calcite-graphite-rare actinolite to biotite to garnet-hornblende, also staurolite-kyanite. (Brown and others, 1981). Chlorite-albite-actinolite-biotite-magnetite (Cary, personal communication, 1988).	Cretaceous?-m
Shuksan Metamorphic Suite	
Darrington Phyllite Quartzose-graphitic phyyllite and minor interbedded schists. Meta. ass.: quartz-chlorite-muscovite-graphite-sphene-albite, sulfides and paragonite (Haugerud, 1980; Haugerud and others, 1981).	Cretaceous? m/ Jurassic
Shuksan Greenschist Greenschist grade metabasalt and blueschist. Meta. ass.: calcite-pumpellyite-epidote-actinolite-lawsonite, also crossite-barroisite-hornblende-garnet-paragonite-albite (Brown and others, 1981).	same as above
Barrosite schist Blueschist	Jurassic-m
Baker Lake Blueschist Meta-basaltic blue- & green-schist. Meta. ass.: lawsonite-crossite (Brown and others, 1981).	Cretaceous-m
Nooksack Group Volcanic sandstone, siltstone, and argillite. Meta. ass.: prehnite-pumpellyite no lawsonite, aragonite or amphibole, also lawsonite-aragonite no actinolite, pumpellyite (Brown and others, 1981), also pumpellyite-(epidote)-(prehnite) and calcite-(actinolite)-(hematite) (Sondergaard, 1979).	Jurassic/ Cretaceous
Wells Creek Volcanics Andesite, dacite, and basalt slightly metamorphosed.	Jurassic

Formations/Units/Groups	Age

Elbow Lake Formation — upper Paleozoic-Cretaceous

Meta-ribbon chert, basalt, volcanic sandstone.

Cultus Formation

Sandstone — Triassic-lower Jurassic

Volcanic sandstone and siltstone. Meta. ass.: lawsonite-aragonite-pumpellyite-Fe-oxide. (Brown and others, 1981).

Keratophyre — same as above

Vedder Complex — upper Paleozoic-m

Amphibolite, blueschist, muscovite schist. Meta. ass.: prehnite-pumpellyite, also epidote-actinolite-Fe-oxide, also crossite-barrosite-hornblende-garnet-epidote-albite-muscovite-paragonite-chlorite (Brown and others, 1981).

Deer Peak Metavolcanics — upper Paleozoic

Meta-andesite to dacite pyroclastic deposits. Meta. ass.: calcite/aragonite-pumpellyite-Ca-amphibole, also pumpellyite-epidote- Ca-amphibole, also actinolite-albite-quartz with 1) chlorite-pumpellyite-epidote-actinolite 2) pumpellyite-calcite 3) epidote-calcite, and stilpnomelane, white mica, sphene, and opaques (Reller, 1986).

Chilliwack Group

Sediments — mid to upper Paleozoic

Slightly metamorphosed volcanic sandstone, siltstone, shale, minor limestone and chert. Meta. ass: lawsonite-aragonite-pumpellyite (Brown and others, 1981) and chlorite-(lawsonite)-(pumpellyite)-(epidote) (Blackwell, 1983; Smith, 1986).

Volcanics — same as above

Slightly metamorphosed andesitic and basaltic pyroclastic rocks. Meta. ass.: lawsonite-aragonite-pumpellyite (Brown and others, 1981, Blackwell, 1983; Christenson, 1981; Smith, 1986).

Yellow Aster Complex — upper Precambrian to lower Paleozoic

Amphibolites, meta-diorites. Meta. ass.: epidote-actinolite-Fe-oxide, also prehite-pumpellyite, also diopsidic clinopyroxene-garnet-plagioclase (albite-sericite)-epidote-sphene-Fe-oxide (Brown and others, 1981).

Phyllites of Samish Island — pre-Tertiary

Greenstone, slate and phyllite. Meta. ass.: pumpellyite-actinolite, also aragonite-lawsonite, also epidote-actinolite. (Brown and others 1981).

Ultramafics — Unknown

Twin Sisters Dunite: olivine, chromite.

essentially unmetamorphosed basalt (Zeigler, 1984). The Wells Creek Volcanics contains minor basalt that could have been source material for the Hoko River Formation. Both the Chilliwack Volcanics and the Wells Creek Formation are possible sources of basalt sediment to the Hoko River Formation.

Felsic and Intermediate Volcanics Three probable sources of felsic and intermediate volcanic lithics are the Wells Creek Volcanics, the volcanic section of the Chilliwack Group, and the Deer Peak metavolcanics (Table 12). However, based on incompatible mineralogy and degree of deformation, the Chilliwack Group and the Deer Peak metavolcanics are not probable sources of sediment. The Wells Creek volcanic series is a more likely source because it is compositionally and texturally similar to the Hoko River Formation's felsic and intermediate volcanic lithics.

Metavolcanics The metavolcanic fragments of the Hoko River Formation are generally mafic. The units in the North Cascades containing significant amounts of greenstone are the Shuksan greenschist, the mafic volcanics of the Chilliwack Group, the Skagit Metamorphic Suite, the Elbow Lake Formation and the Baker Lake Blueschist (Table 12). True blueschist, those rocks containing members of the glaucophane-riebeckite series and lawsonite, are not found in the Hoko River Formation metavolcanics. All of the above units contain high pressure-low temperature assemblages except the Skagit Metamorphic Suite, suggesting that these were not sources of sediment for the Hoko River Formation. Some of the metavolcanics may have been derived from the Skagit Metamorphic Suite. However, because the Skagit Metamorphic Suite lies inland of the other metavolcanic units, if it was a source area, one would expect to find fragments of the other metavolcanic units as well. On the basis of generally incompatible mineralogy, it is unlikely that the metavolcanic sediments in the Hoko River Formation were derived from the northwest Cascades.

Amphibolites and Epidote-rich Schists

The amphibolites of the Hoko River Formation are actinolitic in nature. Actinolite-bearing assemblages occur in the Shuksan greenschist, Vedder Complex, Deer Peak metavolcanics and Yellow Aster Complex (Table 12). All of these units, except the Deer Peak metavolcanics, also contain blueschist-facies assemblages that are not found in the Hoko River Formation, which suggests these units were not source rocks for the Hoko River Formation. Epidote usually replaces the pre-existing minerals forming the epidote-rich schists. The above units, with the addition of the Chilliwack Group, also contain epidote-rich schists. However, incompatible mineralogies suggest these units are not source rocks for the Hoko River Formation with the possible exception of the Deer Peak Metavolcanics.

Conclusions

Blueschist facies assemblages are found in the metavolcanics of the northwest and north-central Cascades. These distinct lithologies are absent from the lithic fragments of the Hoko River Formation, which provides a strong case against derivation of the Hoko River Formation from this area. Other lithologies found in the Hoko River Formation are represented in the Cascade ranges. They are basalt, graphitic phyllites and schists, polycrystalline quartz, felsic and intermediate plutonics and volcanics, and amphibole and epidote-rich schists. These lithologies are found on southern Vancouver Island; they are not restricted to the Cascade ranges. The source of these lithologies is inconclusive. The lack of blueschist mineralogies strongly suggests that the northwest and north-central Cascade ranges were not a primary source of sediment.

Southern and Central Vancouver Island

Southern and central Vancouver Island is the most probable source area for the Hoko River Formation sediment. An exact match between the Hoko River Formation sediment and a source area has not been found, but the rock units and formations of southern and central Vancouver Island are similar in composition to Hoko River grains; all of the main lithic types found in the Hoko River Formation are found there. Vancouver Island is composed of a number of Paleozoic to Mesozoic terranes of oceanic basalts and sediments intruded by Jurassic to Eocene plutons and overlain by a Jurassic and Cretaceous sedimentary sequence. The major rock units and formations of southern and central Vancouver Island, their ages and compositions are listed in Table 13. Table 14 summarizes the correlations between the Hoko River Formation sediment and the rock units of southern Vancouver Island.

Discussion

Metasediments Graphitic phyllite and schist comprise a distinctive metasedimentary lithic type in the Hoko River Formation and in the metasedimentary portion of the Leech River Complex (Table 14). Quartz-(graphite)-(chlorite)-(biotite)-(muscovite/sericite)-(plagioclase)-(epidote) schists comprise the assemblages found in the Hoko River Formation (see Sedimentary Petrology for the further descriptions). Graphitic phyllites and schists compose part of the metasedimentary unit of the Leech River Complex (Table 13). All of the metamorphic lithic types found in the Hoko River Formation can be accounted for in the Leech River Complex in low-grade portions the metasedimentary portions.

Table 13 MAJOR ROCK UNITS OF SOUTHERN AND CENTRAL VANCOUVER ISLAND

A summation of the lithologies, compositions and ages of rock units on southern and central Vancouver Island. The numbers in parentheses refer to the following references:

1. Muller (1977)
2. Roddick and others (1979)
3. Muller and others (1981)
4. Fairchild and Cowan (1982)
5. Muller (1982)
6. Muller (1983)
7. Brandon (1984)
8. Pacht (1984)
9. Brandon and Massey (1985)
10. Russmore and Cowan (1985)
11. Massey (1986)
12. Bream (1987)

Name	Age
Carmanah Group	
Sooke Formation	lower Oligocene
Conglomerate, sandstone and shale of near shore origin (12,5,3).	
Hesquiat Formation	upper Eocene
Siltstone, shale, sandstone and conglomerate (5,3).	
Escalante Formation	middle to upper Eocene
Sandstone and conglomerate (5,3).	
Metchosin Volcanics (11,5)	lower to middle Eocene
Basalt flows, pillows, breccias, sheeted dikes, diabase sills & high-level gabbros, amygdules of chlorite, quartz, and epidote (1). Meta ass: low- and medium grade to epidote amphibolite (5).	
Meta-Metchosin (5)	lower Eocene ?
Volcanic breccia and tuff breccia, basaltic clasts in a recrystallized subschistose chloritic matrix, (9,5) amphibolitic or chloritic metavolcanics (6).	
Catface Intrusion	Eocene
Granite, granodiorite, tonalite, hornblende feldspar porphyry (3), also quartz diorite plutons, dikes, and sills (6).	
Sooke Gabbro	Eocene and older ?
Coarse-grained gabbro with ophitic pyroxene, plagioclase, olivine; tonalite & trondjemite (9,1), also minor quartz diorite, byotownite anorthisite, basalt and diabase dikes (5).	
Nanaimo Group	Upper Cretaceous
Marine and nonmarine siltstone, sandstone, conglomerate and sedimentary breccia derived from Vancouver Island, Northwest Cascades, San Juan Islands, and the Coast Plutonic Complex (8).	

Continued

Name	Age

Leech River Complex — Upper Jurassic-Cretaceous

Low pressure greenschist-amphibolite grade meta-pelite, sandstone, minor volcanics, chert, and conglomerate (11)

Metasedimentary unit

Thinly bedded graywacke and argillite, phyllitic slate, slate, quartz-biotite schist; meta-graywacke and meta-arkose (5). Meta. ass.: graphitic quartz-sericite-(chlorite) phyllite to staurolite-andalusite- garnet-biotite, and quartz-feldspar-(garnet)-biotite schist. Also: quartz-plagioclase-biotite-(chlorite) semischist or schist (4).

Metavolcanic and metasedimentary unit

Ribbon chert (radiolarian), cherty argillite, metarhyolite, metabasalt, chlorite schist (5). Meta. ass.: aphanitic volcanic flows with relict plagioclase-epidote-chlorite-actinolite, also chlorite-quartz-clinozoisite-(actinolite) schist, also dark green hornblende schist with quart-epidote-subordinate plagioclase (4).

Pandora Peak Unit — Upper Jurassic to Lower Cretaceous

Black mudstone, graywacke, radiolarian ribbon chert, green tuff, metabasaltic greenstone, minor pebbly mudstone, and limestone; Meta. ass.: pervasive lawsonite-(prehnite)-(calcite)-(albite-quartz-chlorite-white mica)(10), also: plagioclase-clinopyroxene-chlorite-calcite-pumpellyite-epidote-sphene (10).

Pacific Rim Complex — Upper Jurassic to Cretaceous

Volcanics, tuff, ribbon chert, siltstone, sandstone, mudstone, conglomerate, pillow lava. Meta. ass.: lawsonite-prehnite-calcite (7,3).

Bonanza Group — Lower to Middle Jurassic

Basalt, andesite, dacite, & rhyolite flows, ruffs, breccias, sills & dikes; greywacke, siltstone, & pebble conglomerate (3).

Island Intrusions — Lower Jurassic

Quartz monozonite, hornblende-granodiorite, biotite-quartzdiorite (3,1). Tonalite to gabbro (10,2).

West Coast Crystalline Complex — Lower Jurassic

Amphibolite, metasediments, quartzdiorite, tonalite, agmatites (3). Diorite (5). Meta. ass.: actinolitic schist-, hornblende plagioclase gneiss (3), also amphibolitic gneisse and quartz-plagioclase schist (10).

Continued

Table 13 Continued

Name	Age
Wark-Colquitz Complex	?

Dioritic gneiss and schist (3). Quartzo-feldspathic and calc-silicate gneiss and foliated amphibolite. Also, schistose amphibolite (blue-green hornblende, plagioclase-quartz) and felsic dikes (10).

Vancouver Group

Karmutsen Formation — Middle to Upper Triassic

Pillowed & layered basalt, pillow breccia, tuff metamorphosed from prehnite-pumpellyite to amphibolite / hornfels facies. Meta. ass.: prehnite-pumpellyite to albite-actinolite to hornblende-plagioclase (An 65-80, sericitized)(6), also quartz-epidote-prehnite-pumpellyite, also, quartz-carbonate-chlorite-prehnite-pumpellyite (5).

Quatsino Limestone

Limestone, marble (3), blueish-gray micritic limestone (5).

Parson Bay Formation

Calcareous siltstone, shale, limestone, graywacke, breccia (3), also, coquina, biosparite, chert, corals, and algal balls (5).

Sicker Group — Paleozoic

Meta-basalt to -andesite to -rhyolite up to amphibolite facies; silty limestone, argillite, breccia, greywacke, metadiabase sills. Meta. Ass.: epidote-albite-actinolite-(quartz)(3).

Limestone, graywacke, chert, argillite (5).

Radiolarian chert, diabasic sills (5). Penn. to Miss.

Silicic tuff and breccia, rhyodacitic flows, quartz-sericite schist and massive sulfides (5).

Augite porphyry pillows and breccia (uralitized), mafic tuff, also, chlorite-actinolite schist (5).

Saltspring Intrusions — Paleozoic

Meta-quartzdiorite (6).

TABLE 14 CORRELATIONS OF LITHOLOGIES

A summation of the rock units from southern Vancouver Island that probably supplied sediment to the Hoko River Formation.

Lithic Type	Unit or Formation
1. Metasediment	Leech River Complex
2. Basalt	Metchosin Volcanics or Karmutsen Formation
3. Chert	Leech River Complex, Sicker Group, and Nanaimo Group
4. Polycrystalline Quartz	Sicker Group, Leech River Complex, Bonanza Group, Metchosin Volcanics
5. Felsic and Intermediate Plutonics	Island Intrusions, Catface Intrusions
6. Felsic and Intermediate Volcanics	Bonanza Group
7. Metavolcanics	Meta-Metchosin, Leech River Complex
8. Amphibolite and epidote-rich schist and aggregates	Meta-Metchosin, West Coast Crystalline Complex, Karmutsen Formation, Metchosin Volcanics, Leech River Complex, Sicker Group

Deformation of these portions of the Leech River Complex has produced a pervasive slaty cleavage (S1) and a secondary crenulation or slaty cleavage (S2) (Fairchild and Cowan, 1982). S2 transposes S1 in some cases.

These styles of deformation are found in the Hoko River Formation graphitic metasediments, although S2 crenulations are not always present. The higher-grade portions of the Leech River Complex are not represented in the Hoko River Formation, particularly staurolite-andalusite-garnet-biotite schists and other garnet-bearing assemblages. Because the uplift age of the Leech River Complex is very similar to the age of depostion of the Hoko River Formation, it is possible that the higher temperature and pressure portions of the Leech River Complex were not yet exposed. The Leech River complex is the probable source of metasediment to the Hoko River Formation.

<u>Basalt</u> The Metchosin Volcanics and Karmutsen Formation, comprised of mainly tholeiitic basalts (Tables 13 and 14), are both possible sources of basalt lithics for the Hoko River Formation. The Karmutsen Formation has experienced prehnite-pumpellyite-grade metamorphism producing pumpellyite-prehnite-calcite fillings between pillows and quartz-calcite-chlorite-prehnite-pumpellyite within the basalts (Muller, 1982). These minerals have been found in several clasts in the Hoko River Formation sediments, suggesting that the Karmutsen Formation is a possible candidate as a source for basaltic sediment. The Metchosin Volcanics generally contain chlorite-quartz-epidote and pumpellyite fillings in veins and amygdules with a few local occurances of prehnite in the tuffs and associated pelitic sediments (Snavely and others, 1983). The two formations are very similar petrographically. Basalt clasts with minor

pumpellyite and prehnite amygdule fillings and quartz-epidote veins in the Hoko River Formation suggest that the Metchosin Volcanics and the Karmutsen Formations are probable sources of sediment to the Hoko River Formation.

Chert Chert comprises a portion of following units on southern Vancouver Island: the Pandora Peak Unit, the Pacific Rim Complex, the Sicker Group, the Leech River Complex, and conglomerate clasts in the Naniamo Group (Tables 13). The Pandora Peak Unit and the Pacific Rim Complex have experienced a high pressure-low temperature metamorphism that overprints primary mineralogies with lawsonite-calcite but in general does not disturb the siliceous cherts. The non-siliceous sediments in these units contain lawsonite-calcite, minerals absent from the Hoko River Formation. Therefore, these two units are not considered sources of Hoko River Formation chert.

The Sicker Group crops out in the southeastern portion of southern Vancouver Island, placing it in a relatively proximal location to the Hoko River Formation depositional system. The Sicker Group is a probable source of chert to the Hoko River Formation based on proximity and mineral associations. The Leech River Complex contains ribbon chert and cherty argillite in the metavolcanic and metasedimentary unit (Table 13). This unit crops out across southern Vancouver Island and is thought to have contributed metasediments and could have contributed chert fragments, as well. The Nanaimo Group contains a chert-rich lithic-arenite petrofacies (Pacht, 1984) that may also be a source of chert to the Hoko River Formation. All of these units are probable sources for the chert sediments in the Hoko River Formation. A detailed study of the radiolaria may allow better correlations.

Polycrystalline Quartz The varieties of polycrystalline quartz found on southern Vancouver Island are the same as those found in the northwest Cascades: recrystallized chert, vein quartz, and quartzose layers in metasediments. Units containing these lithologies are the Sicker Group, Leech River Complex, Pacific Rim Complex, Pandora Peak Unit, Bonanza Group, and Metchosin Volcanics (Table 13 and 14). The Pacific Rim Complex and Pandora Peak unit are excluded on the basis of a lack of lawsonite-prehnite-calcite- bearing assemblages in the Hoko River Formation. The rest of the units contain pervasive secondary quartz veins, with various amounts of recrystallized chert and quartz-rich metasediment in the Sicker Group and Leech River Complex. Polycrystalline quartz is common within these lithologic units of southern Vancouver Island and also in the northwest Cascade Mountains. The source of Hoko River Formation polycrystalline quartz is inconclusive.

Felsic and Intermediate Plutonics Three plutonic units and one mixed metamorphic and igneous unit are possible sources of granite, granodiorite, quartz diorite, and diorite to the Hoko River Formation: Jurassic Island Intrusions, the Eocene Catface Intrusions, the Saltspring Intrusions, and portions of the West Coast Crystalline Complex (Table 13). The Island Intrusions are the most probable source, because they contain felsic to intermediate lithologies similar to those found in the Hoko River Formation and their emplacement predates the late Eocene. The West Coast Crystalline Complex is composed of more mafic lithologies, including some that are not found in the Hoko River Formation (the plagioclase-hornblende gneisses), suggesting that it made only a minor contribution, if any. The Saltspring Intrusions are restricted to a small area in the eastern portion of southern Vancouver Island. The Island Intrusions are far more extensive and are, therefore, more likely sources of sediment. The Catface Intrusions are also a very small unit but, in part, intrude the Metchosin Volcanics, which are already considered source rocks. The Catface Intrusions may have provided a small local influx of felsic and intermediate plutonics to the Hoko River Formation. The Island and Catface Intrusions are the most probable sources of felsic and intermediate plutonics (Table 14).

Felsic and Intermediate Volcanics The Bonanza Group comprises andesite, dacite, rhyolite tuffs, flows and breccias, fragments of which are found in the Hoko River Formation sediments (Table 13). The Bonanza Group is widespread, of pre-late Eocene age, and has compositions and textures similar to those of the felsic Hoko River Formation lithics. It is the most probable source of felsic and intermediate volcanic sediments on southern Vancouver Island (Table 14).

Metavolcanics The Metchosin and meta-Metchosin Volcanics both contain assemblages similar to the metavolcanics of the Hoko River Formation (Tables 13). In general, the metavolcanics of the Hoko River Formation are highly altered, almost opaque basalts and semischists of chlorite, plagioclase, quartz, and rare prehnite. The Metchosin Volcanics contain chlorite, epidote, and quartz fillings in the amydules in fairly fresh basalt that are more similar to the Hoko River Formation basalt lithics than to the metavolcanic lithics. The chlorite-rich metavolcanics and the subschistose matrix of the meta-Metchosin volcanics comprise mineral assemblages similar to the Hoko River Formation lithic fragments, suggesting that they are probable source rocks. A portion of the Leech River Complex contains mafic volcanic flows with relict textures and plagioclase-(epidote)-(chlorite)-(actinolite) assemblages. Meta-Metchosin volcanics and the parts of the Leech River Complex resemble the Hoko River Formation metavolcanics and are considered sources for this sediment type (Table 13).

Amphibolites and Epidote-rich Schists Actinolitic amphibolites and aggregates are locally abundant (Table 13). The meta-Metchosin volcanics, the Karmutsen Formation and the West Coast Complex contain actinolite-plagioclase aggregates and schists like those of the Hoko River Formation (Table 14). Epidote-rich aggregates appear both as schist fragments and amygdule fillings in the Metchosin and meta-Metchosin Volcanics, a portion of the Leech River Complex, and the Sicker Group. All of these units are thought to contribute other varieties of sediment, therefore, it is probable that they also provided epidote-rich sediment to the Hoko River Formation (Table 14).

Conclusions

The following units probably contributed one or more lithic types to the Hoko River Formation: Leech River Complex; Metchosin and Meta-Metchosin Volcanics; Karmutsen Formation; Sicker Group; Bonanza Group; Island, and Catface Intrusions; West Coast Crystalline Complex; and Nanaimo Group. All of the lithic types in the Hoko River Formation can be derived from southern Vancouver Island. Prehnite and pumpellyite are pervasive in some of the units southern Vancouver Island, and these minerals are present sporadically in the Hoko River Formation. Lawsonite has not been found in the Hoko River Formation sediments, excluding the Pacific Rim Complex and the Pandora Peak Unit from consideration as source rocks. Southern Vancouver Island is the most probable source of sediment to the Hoko River Formation and the one favored by the author.

Paleocurrent Data

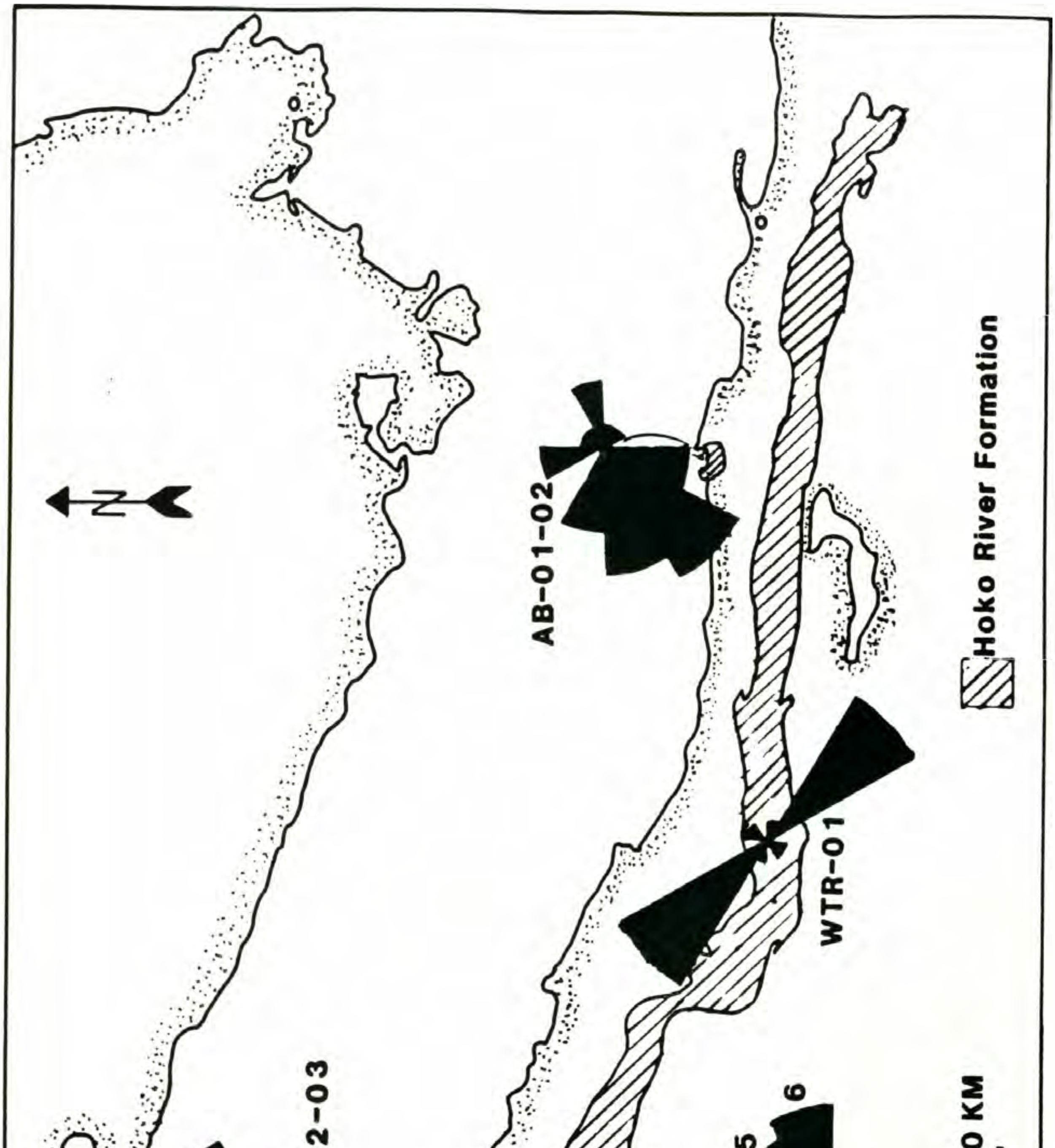
The paleocurrent data from the Hoko River Formation are taken from pebble and cobble imbrication, groove casts, and parting lineations at the locations shown in Figure 34. The western sites have been rotated 40 degrees clockwise from their original orientation (Moyer, 1985). Therefore, the results for those sites are presented both in geographic coordinates and in back-rotated coordinates.

Methods

Pebble imbrication studies were conducted by locating a suitable bed of conglomerate with pebble-, cobble-, and boulder-sized clasts. The strike and dip of the bed were taken. Flat, disk-shaped clasts were located, and the strike and dip of each clast were taken. Disks are defined as those clasts with the long (a) axis approxiamately equal to the intermediate (b) axis, and the short (c) axis very much shorter than the a- or b-axes. This type of clast is most useful for imbrication studies of conglomerates (Rust, 1975). At each site, 15 to 20 orientations were gathered. Sites from the same channel were combined, the combined sites give a more reliable direction than individual sites when the sample number at each site is less than 35-40 samples (Rust, 1975).

The data were corrected by flattening the strike and dip of the beds back to horizontal and plotting the corrected readings on stereo nets. All readings that had dips of less than 10 degrees or greater than 80 degrees in the corrected coordinates were excluded, as these are not reliable current indicators (Rust, 1975). Paleocurrent rose diagrams were plotted by passing a thirty degree window over the stereonet and tallying the number of readings (N) contained in each division. The number of

Figure 34. Paleocurrent roses for the Hoko River Formation. Sites NB-01, NB-02-03, NB-04-05 and AB-01-02 have pebble imbrication. The pie shaped wedges fan out toward the direction <u>from which</u> the current originated. Sites HR and WTR-01 are composed of lineations taken from groove casts, and they indicate only a trend. N is the number of measurements at a site.


N
AB-01-02
Hoko River Formation
WTR-01
NB-02-03
NB-01
HR
NB-04-05
1
2
3
4
5
6
N
0
10 KM

readings was plotted directly onto the paleocurrent roses.

Lineation data were handled in a similar fashion. Strike and dip of the bed were recorded, and trend and plunge of each lineation. The bedding attitude was corrected back to a horizontal orientation. The thirty-degree window was passed over these data, and tallied to form paleocurrent roses. The number of samples (N) reflects the number of lineations found.

Results

The paleocurrent data from the Neah Bay sites show a general direction of transport from the northwest (Table 15)(Figure 35). Three large channels were sampled to determine if paleocurrents changed direction up-section. The difference in current directions found at the NB-02-03 and NB-04-05 sites and the NB-01 site may be caused by actual changes in the direction of the channel flow or may be scatter due to normal variations of flow within a channel. Various channel morphologies, straight, braided, or meandering, produce diverse current directions (Bouma and Nilsen, 1978).

A northwest-southeast orientation of two groove casts was measured along the Hoko River Road (Table 15)(Figure 34). Parting lineation and groove cast orientations were measured from outcrops along West Twin River Road. The eleven lineations suggest transport in a northwest-southeast orientation (Table 15)(Figure 34). Pebble imbrication data from the Agate Beach sites come from a channel exposed along the wave-cut platform (AB-01-02). The data indicate transport from the southwest to the northeast with some scatter (Table 15)(Figure 34).

Paleocurrent Reconstruction

The results from the paleomagnetic study of Moyer (1985) indicate that the western portion of the northern Olympic Peninsula, west of the West Twin River Road, has been rotated 40 degrees clockwise since the deposition of the Hoko River Formation. Data from the Neah Bay and Hoko River sites were back-rotated to find the orientation of the flow at the time of deposition. At the time of deposition, the Neah Bay sites record flow patterns from the east-southeast (NB-01), the west-northwest and north-northwest (NB-02-03 and NB-04-05) (Table 15)(Figure 35). The Hoko River sites shift to a more westerly direction, from the west and west-northwest (Table 15)(Figure 35).

In general, the results indicate flow from the north and west at the Neah Bay, Hoko River, and West Twin River Road sites. These data suggest a depositional system originating in the northwest and flowing to the southeast.

The Agate Beach site suggests flow from the southwest, and the West Warmhouse Beach site records flow from the east-southeast. The variations in direction between the sites may result from large-scale changes of the depositional system, but it is more probable that shifts in the submarine fan channel due to meandering or braiding are the cause. Because results are so variable from site to site, paleocurrent data do not clearly support any of the possible sources.

Limitations of Interpretations

Problems with these methods lie in the diverging opinions of how to interpret pebble imbrication in resedimented conglomerates (Walker, 1975; Rust, 1975; and Walker, 1984) and in the bedding and structural corrections. It was assumed that flattening the beds back to horizontal

Table 15 Summary of paleocurrent directions in the Hoko River Formation

BACK-ROTATED LOCATIONS

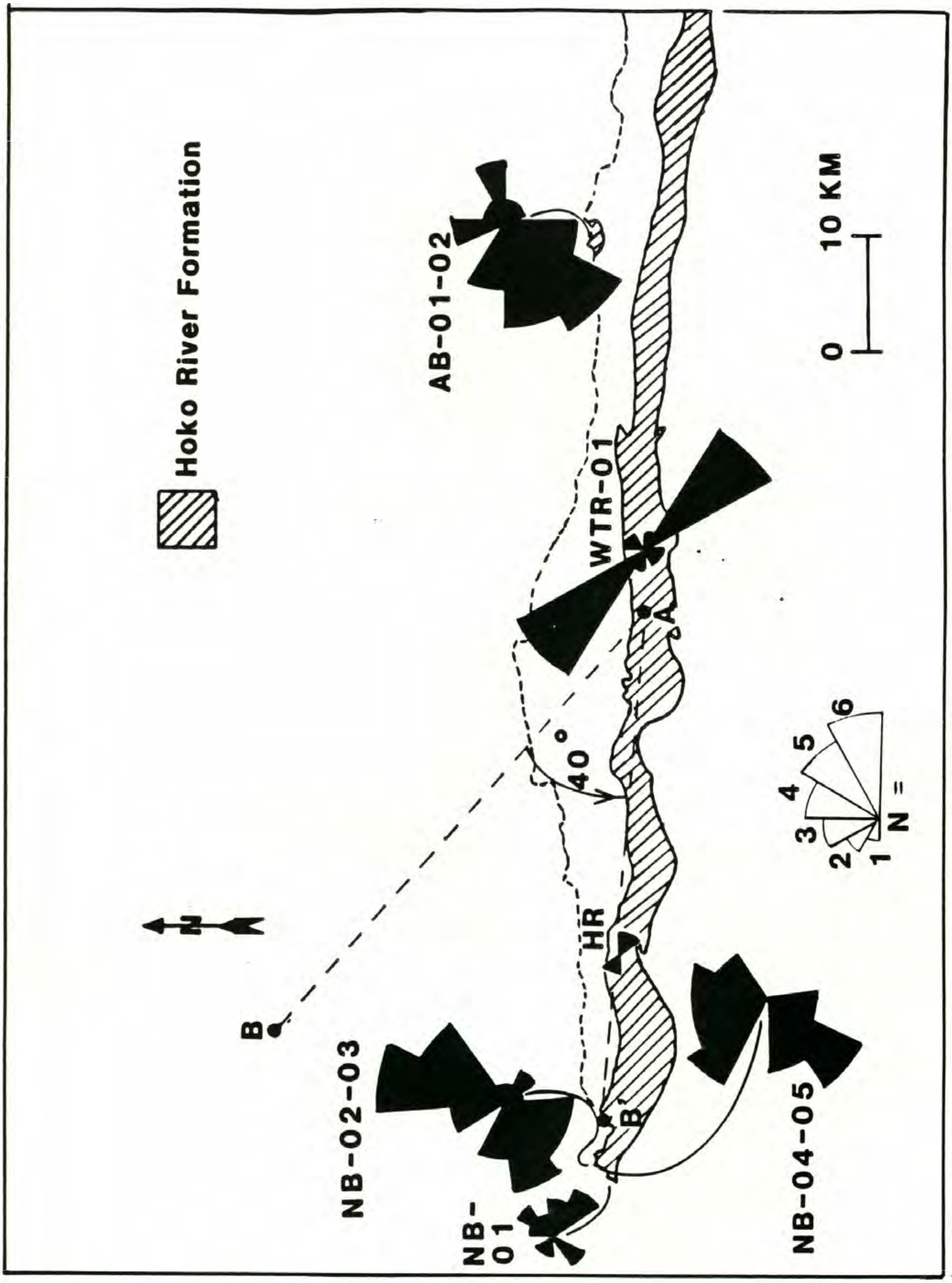
	Present day (from the ...)		Rotation corrected (from the ...)		N=	TYPE OF DATA
NB-01	SSE	(160)	ESE	(120)	13	pebble imb.
NB-02-03	NW & NNE	(315 - 20)	WNW & NNW	(275 - 340)	36	pebble imb.
NB-04-05	NW & NNE	(315 - 20)	WNW & NNW	(275 - 340)	31	pebble imb.
HR	NW	(310 - 330)	W & WNW	(270 - 290)	2	groove casts

LOCATIONS NOT ROTATED

	Present day (from the ...)	N=	TYPE OF DATA
WTR-01	NW (310 - 330)	11	groove casts
AB-01-02	SSW & WNW (190 - 280)	33	pebble imb.

The Neah Bay and Hoko River locations have been backrotated to account for the 40 degree clockwise rotation found by Moyer (1985).

Figure 35. Paleocurrent roses for the Hoko River Formation at the time of deposition, 40-41 Ma. The western half of the study area was rotated about a veritcal axis located at point A, 40 degrees counterclockwise after Moyer (1985). The outline of the present shoreline was also rotated for reference. Compare with Figure 34.


Hoko River Formation
AB-01-02
WTR-01
NB-02-03
NB-01
NB-04-05
HR
B
B'
A
40°
N
0
10 KM
N =
1
2
3
4
5
6

would remove later strutural events, when removing a plunge and then a strike and dip may have been more correct. Poor structural control of the northern Olympic Peninsula may have allowed an oversimplification of bedding corrections. There may be local small-scale rotations about vertical poles that just have not been recognized.

General Conclusions About Source Areas

The five major regions surrounding the Hoko River Formation are the Olympic Core and Ozette terranes of the Olympic Peninsula, the Coast Plutonic Complex, the San Juan Islands terranes, the northwest and north-central Cascades, and southern and central Vancouver Island (Table 8). The Olympic Core and Ozette terranes contain metasedimentary rocks, basalt, and polycrystalline quartz; however, all the other lithic types of the Hoko River Formation are lacking, suggesting that the Olympic Peninsula is not a probable source area. The Coast Plutonic Complex contains mostly felsic to intermediate plutonics with lesser amounts of metasediments and metavolcanics; basalt and chert are subordinate. Sediment derived from the Coast Plutonic Complex would contain more felsic and intermediate plutonics and monocrystalline potassium feldspar by percentage than the Hoko River Formation does. Other sources of these lithic types can be found closer to the probable basin of deposition of the Hoko River Formation and are more likely sources. The San Juan Islands contain abundant metavolcanics and chert but are lacking the low-grade basalts of the Hoko River Formation. Lawsonite-bearing assemblages common in the San Juan Island metasediments and metavolcnaics are not found in the Hoko River Formation. This suggests that the San Juan Islands are probably not a primary source area. An increase in chert in the eastern portion of the Hoko River Formation may be due to a local influx of chert-rich sediment from the San Juan Islands.

The northwest Cascade Mountains comprise all of the lithic types found in the Hoko River Formation. However, the high pressure-low temperature assemblages found in many of the metavolcanic and metasedimentary rocks of the northwest Cascade Mountains are absent from the Hoko River Formation.

This lack forms the basis for selection of southern Vancouver Island over the northwest Cascade Ranges. Southern and central Vancouver Island contain all of the lithologies found in the Hoko River Formation. Vancouver Island is also proximal to the probable depositional basin of the Hoko River Formation suggesting that it is the most likely source area.

DEPOSITIONAL ENVIRONMENT OF THE HOKO RIVER FORMATION

The late Eocene Hoko River Formation formed in marine water of bathyal depths (greater than 200m), according to the paleontologic studies of Rau (1964). The rocks were deposited on a submarine fan, with inner fan deposition at the Neah Bay section and middle fan deposition everywhere else in the study area. Overall, the Hoko River Formation was deposited in progressively quieter, deeper water, with deepening caused by subsidence or by an increase in sea-level. A cessation of tectonic uplift, plus erosion reducing the relief of the source area, may have accompanied either of these effects.

Descriptions of the facies associated with different submarine fan environments follow, beginning with slope and inner-fan deposits and moving basinward through the channeled middle-fan, depositional lobes of the middle-fan, and outer-fan deposits (Figure 36). Studies of both ancient and modern fans define these facies associations (Mutti and Ricci-Lucchi, 1972; Walker and Mutti, 1973; Ricci-Lucchi, 1975; Bouma and Nilsen, 1978; and Walker, 1984). The lithologies that comprise facies within these environments are compiled in Table 16 and include the following: conglomerates, pebbly sandstones, pebbly mudstones, massive sandstones, proximal and distal turbidites, overbank deposits, chaotic deposits, and hemipelagic sediments, compiled from Mutti and Ricci-Lucchi (1972), Walker and Mutti (1973), Suczek (1978), and Bouma and Nilsen (1978).

Brief descriptions of the rock types found in each measured section and then interpretations of the depositional environments follow. Some conventions are used throughout the descriptions. Bed thicknesses are described using the definitions of Ingram (1954): very thinly bedded (1-3

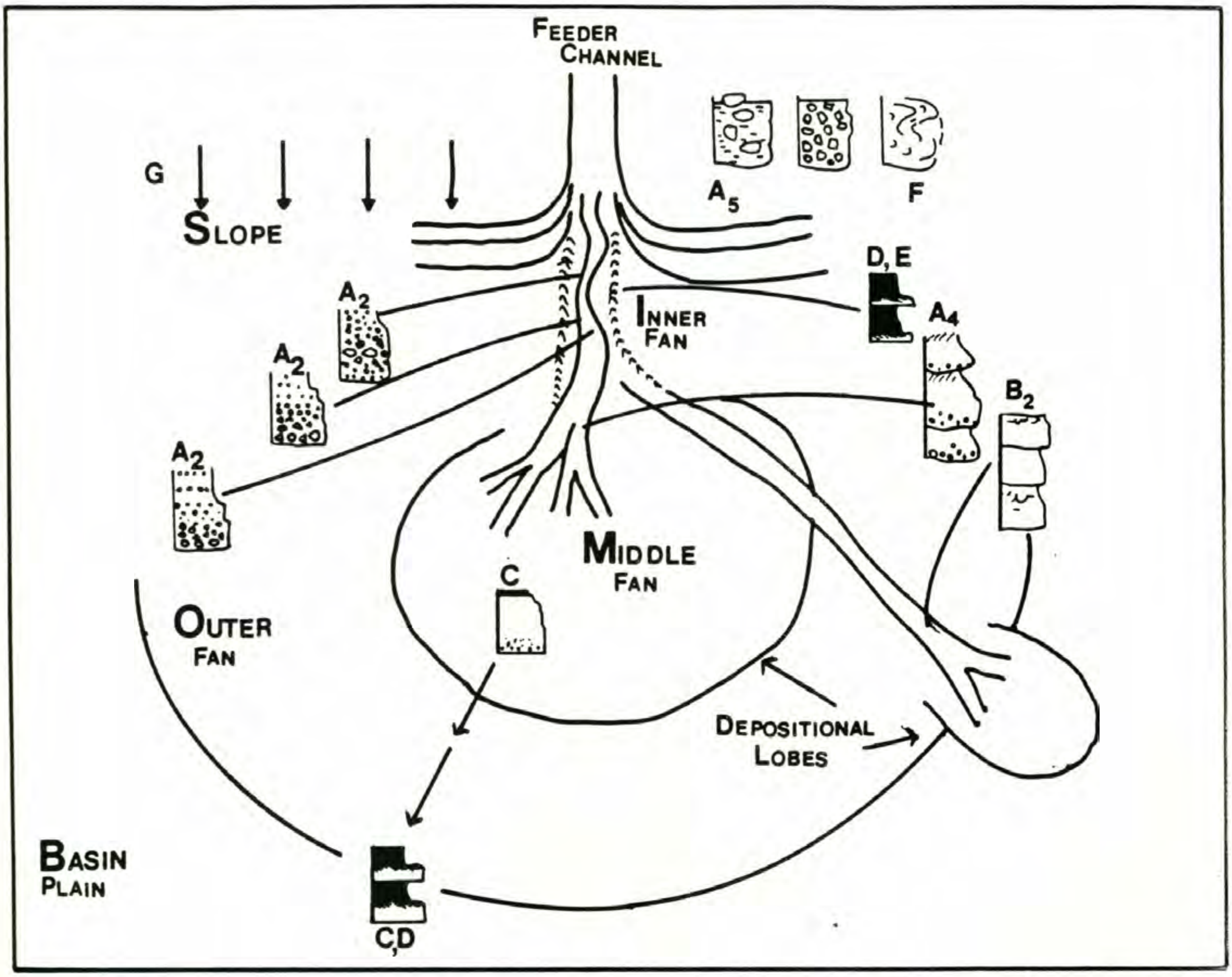


Figure 36. Proposed model of a submarine fan after Walker (1978) and Walker (1984). The letter-number abbreviations refer to the depositional facies of Table 16.

FACIES	NAME	SAND: SHAPE	SEDIMENT TYPES	BOUMA SEQUENCE	BED THICKNESS	BED SHAPE	STRUCTURES
A1	DISORGANIZED CONGLOMERATE	-	pebble, cobble, boul. w/ sand (no mud)	T-a	1 to several meters	irregular contacts very irregular	Lack of : internal structure, graded bedding, clast elongation, and imbrication.
A2	ORGANIZED CONGLOMERATE	-	same as A1 clast supported	T-a	10's of cm to several meters	irregular	Normal and reversed graded bedding, crude horizontal layers, preferred clast orientation and imbrication.
A3	DISORGANIZED PEBBLY SANDSTONE	10:1	coarse to v. coarse sand w/ gran. and peb.	-	50 cm to 10 m	irregular	Not graded, amalgamated.
A4	ORGANIZED PEBBLY SANDSTONE	10:1	coarse to v.c. sand	-	20 cm to 2 m	irregular	Graded bedding, shale partings are rare, preferred clast orientation, and imbrication, flutes and scours.
A5	DISORGANIZED PEBBLY MUDSTONE	10:1	coarse sand w/ pebbles	-	20 cm to 2 m	irregular	Rare.
A6	ORGANIZED PEBBLY MUDSTONE	10:1	coarse sand w/ pebbles	-	20cm to 2 m	irregular	Normal grading, preferred imbrication, scours and flutes.
B1	MASSIVE SANDSTONE W/ DISH STRUCTURES	-	coarse sand to med. sand with granules	-	50cm to 2 m (30 - 2 m)	thick, massive lenticular	Inclined to parallel lamination, scoured bases, rare amalgamation, dish structures associated with fluid escape structures.
B2	MASSIVE SANDSTONE W/OUT DISH STRUCTURES	10:1	coarse sand to granule	-	10's cm to 2m (20 - 80 cm)	massive, strongly lenticular	Crude subparallel layering, amalgamated beds, scoured bases common. (large scale beds, small scale laminae). Ass. w/ A4 & E.
C1	CLASSIC PROXIMAL TURBIDITES	5:1	coarse to fine sand poor sorting	complete T-a-e T-ae common T-ace, T-b & T-d often absent	50cm to 3m	regular, tabular	Amalgamation is present but uncommon, plane parallel at outcrop scale. Ass. w/ B2.
C2	CLASSIC PROXIMAL TURBIDITES	1:1	medium to fine sand, mod. sorting	more complete Bouma sequences T-a-e, T-abce, T-acde.	50cm to 3m	regular, tabular	Amalgamation sporadic, plane parallel at outcrop scale.

D1	CLASSIC DISTAL TURBIDITE, BASE CUTOUT TURBIDITE	1:1 or less	fine sand to silt	T-bcde, T-bde, T-cde, T-de	(3 to 40cm)	even and parallel	Sole markings can be abundant not amalgamated, bioturbated.
D2	BASE CUTOUT TURBIDITES	1:2 to 1:9	sandstone and shale	similar to D1	(3 to 150cm)	even and parallel	Same as D1, grades into E.
D3	BASE CUTOUT TURBIDITES	very low	all silt	T-e	(3cm to 2m)	even and parallel	Same as D1.
E	OVERBANK DEPOSITS	1:1	sandstone and shale less well sorted than D	-	(3 to 20cm)	irregular, flaser and lenticular bedding	Bedding wedges out on outcrop scale. Top of sandstone is sharp and wavy, does not grade into shale. Non graded sandstone climbing ripples, high angle cross laminae, shale partings are discontinuous.
F	CHAOTIC DEPOSITS	–	matrix supported congl., landslides, slumps, slump breccias, olistostromes, pebbly mudstones, mudflows, disturbed and slurried beds.	-	variable up to 300 m	sheet-like geometry between regular bedding sequences	All beds that have experienced downslope mass movement after deposition. Deformation structures are common.
G	HEMIPELAGIC OR PELAGIC SEDIMENTS	-	pelites, silt, and shales	-	thin to 60cm	plane parallel	Deposition from nepheloid or turbid layers, different lithologies than turbidites.

Table 16 Compilation of sedimentary facies found within submarine fan environments. Data is from Mutti and Ricci-Lucchi (1972), Walker and Mutti (1973), Suczek (1977) and Bouma and Nilsen (1978).

cm), thinly bedded (3-10 cm), medium bedded (10-30 cm), thick bedded (30-100 cm), very thickly bedded (greater than 1 meter). The Bouma sequence is represented with the following notation, T-a = massive or graded sandstone, T-b = laminated sandstone, T-c = rippled or convoluted sandstone, T-d = laminated mudstone (siltstone with or without mudstone), and T-e = massive mudstone (siltstone with or without mudstone). A complete Bouma sequence is referred to as T-a-e, whereas a partial sequence would be expressed as T-abc, or T-ae.

Submarine Fan and Slope Facies Associations Model

Sequence analysis is a prominant diagnostic tool for interpreting depositional environments and changes with time in the specific environment of a submarine fan. The technique has been described by various authors (Mutti and Ricci-Lucchi, 1972; Walker and Mutti, 1973; Bouma and Nilsen, 1978; and Walker, 1984). Positive megasequences are defined by beds that thin and fine successively upward. Negative megasequences are those that thicken and coarsen up-section. Positive sequences are generally thought to represent channel fillings, while negative sequences are indicative of lobe progradation or gradual channel migration (Walker, 1984)(Figure 37). Sequence analyses combined with facies determinations are the basis for interpretation of position within a submarine fan environment.

Slope deposits consist of mostly pelagic and hemipelagic sediment (Facies G) cut by channels of conglomerate (Facies A)(Figure 36)(Table 16). Sand- to cobble-sized material usually bypasses the slope area in channels or in incised submarine canyons. Slumps (Facies F) move previously-deposited sediment downslope and into the channels and canyons (Figure 36).

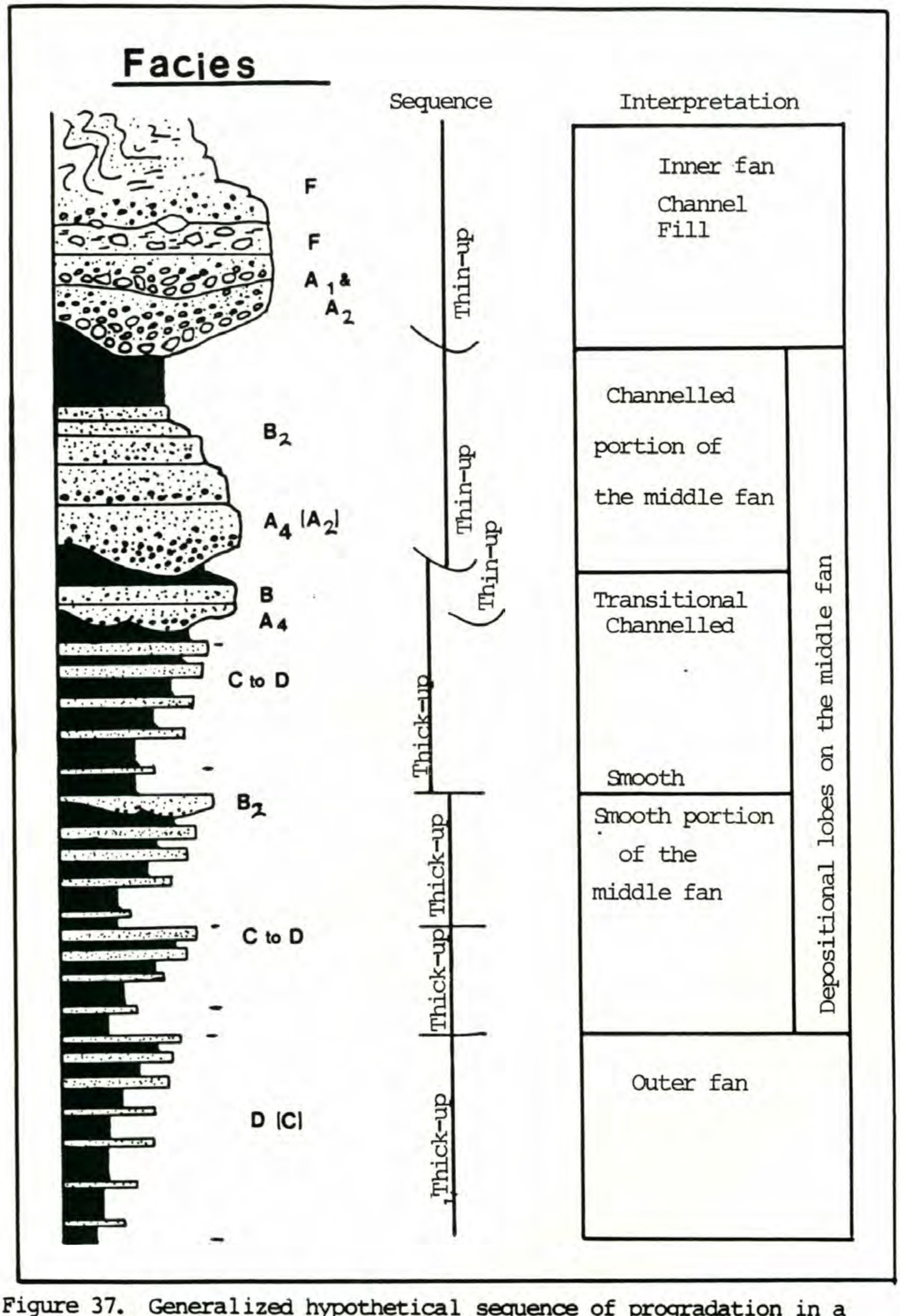


Figure 37. Generalized hypothetical sequence of progradation in a submarine fan after Walker (1978) and Walker (1984). The letter-number abbreviations refer to the depositional facies of Table 16.

Inner-fan deposits are similar to slope deposits in that they are composed of sandstone (Facies B) and conglomerate (Facies A) confined to channels cut into surrounding fine silt and sand (Facies E, D2, and D3) and hemipelagic sediments (Facies G)(Figure 36)(Table 16). The channels may be straight, braided, or meandering (Bouma and Nilsen, 1978; EOS, 1987). Slumps are less common on the inner fan then in slope environments (Facies F)(Table 16). Gravel is the most common sediment in the active channels. When channels are abandoned, they may be abandoned slowly or virtually instantly. A thinning- and fining-up sequence results when the channel is slowly abandoned (Figure 37). Rapid abandonment results in a drape of fine sediment over a thickening-upward sequence (Walker, 1984).

Middle-fan deposits can be divided into two groups, inner-middle fan channelized deposits and outer-middle fan depositional lobe deposits (Walker, 1984)(Table 16)(Figures 36 and 37). The channeled middle fan is characterized by thinning- and fining-upward sequences of conglomerate (Facies A1 and A2) and pebbly sandstone (Facies A3 and A4) overlain by classic proximal turbidites (Facies C) and some distal turbidites (Facies D1)(Table 16)(Figures 36 and 37). Levees are a distinctive part of the middle fan channels and are composed of overbank deposits (Facies E) and base-cut-out turbidites (Facies D2 and D3) that interfinger with interchannel hemipelagic sediments (Facies G)(Table 16)(Figures 36 and 37). Most interchannel deposits are overbank deposits interbedded with distal turbidites and hemipelagic sediments.

The depositional lobes of the middle fan, also known as suprafan lobes (Normark, 1978; Bouma and Nilsen, 1978; Walker, 1984), are composed of classic proximal turbidites (Facies C1 and C2) overlying distal turbidites (Facies D1)(Table 16)(Figures 36 and 37). These in turn are overlain by distributary-channel-mouth deposits of channelized massive sandstone (Facies B2), that have prograded across the top of the depositional lobe (Figure 37) forming thickening- and coarsaning-upward sequences (Walker and Mutti, 1973; Bouma and Nilsen, 1978; and Walker, 1984).

Outer-fan deposits are not channelized and are the most laterally extensive facies. Thickening-up sequences of distal turbidites (Facies D1- D3) dominate the outer-fan (Table 16)(Figures 36 and 37)(Walker, 1984). The further from the active middle-fan depositional lobe, the finer and thinner these deposits become; grading basinward from Facies D1 (T-bcde) to D2 (T-cde) to D3 (T-de)(Bouma and Nilsen, 1978). Outer fan deposits interfinger with hemipelagic and pelagic sediment (Facies G) (Table 16)(Figure 36).

Paleoecology

The Hoko River Formation was deposited in upper bathyal to lower neritic depths (1000 to 300 ft) with isolated deposits occuring in water greater than 1000 feet (Rau, 1964)(Table 17). Rau also found foraminifera that occur in cold, open ocean water. Studies by Loney (1951), Drugg (1958), Bagley (1959), Carroll (1959), Strain (1964) and McWilliams (1965) also suggest neritic to upper bathyal depths of deposition with some variation (Table 17). Most studies indicate a change from shallow to deeper water upwards in the section. Cool water connected to the open ocean is indicated. Variations in the water depths indicated by fauna may be due to redeposition of faunas. Shallow water foraminifera may have been brought in by turbidites. Deeper water foraminifera could have been reworked from the underlying Aldwell Formation (Rau, 1964). The Hoko River Formation was connected to a cold or cool, open ocean.

Table 17 Summary of paleoecology for the Hoko River Formation (HRF) from previous studies.

Author	Water Depth	Water Temp.	Open Ocean (?)	Location of Study
Loney (1959)	deeper neritic to upper bathyal	cold	marine	Crescent Bay
Drugg (1958)	upper bathyal	cool	-	Hoko River
Bagley (1959)				
lower HRF	deep	cold	yes	Sekiu River
upper HRF	deep	cold	yes	
Carroll (1959)				
two faunas present in the HRF	mid- to lower bathyal	cool	yes	Hoko River
	neritic to upper bathyal	warmer	-	
Strain (1964)	bathyal to neritic up section	cooled up section	yes	Twin Rivers
McWilliams (1965)				
lower HRF	littoral to sublittoral	-	-	Lake Crescent
upper HRF	upper and lower bathyal	-	yes	

Depositional Environments within the Hoko River Formation

Neah Bay

The section at Neah Bay was measured along the wave-cut platform, sea-cliffs, and headlands just west of the town of Neah Bay. The section begins at the boundary between sections 5 and 6 of T 33 N, R 15 W and ends at the edge of the wave-cut platform in section 3, T 33 N, R 15 W, offshore of Koitlah Point (Figure 18, page 51). This section is contained in the fifteen-minute quadrangle of Cape Flattery, Washington. It is a reference section for the Hoko River Formation, as defined by Snavely and others (1978).

The top and bottom contacts were not described, because they are covered and inaccessible, respectively. They have been described as gradational by Snavely and others (1986). Inner-fan conglomerates, debris flows and siltsones that are succeeded by middle-fan channel deposits are found at the Neah Bay exposures (Table 18). This interpretation is consistant with the water depths of at least mid-bathyal (200 m to 2000m) from Ansfield (written communication, 1987). Table 18 lists the facies that predominate in this section (Plate 1).

The sediment found in this section is gravel and silt with fine sand. The conglomerates (Facies A1, A2, and F) are confined to large channels and isolated medium to thick beds (Facies A1 and A2) within a thick stack of laminated silt with wispy sand stringers. The siltstone with wispy sandstone is best described as distal base-cut-out turbidites (Facies D3) and hemipelagic sediment (Facies G). The siltstone and very fine

Table 18 Facies contained in measured sections.

FACIES	TYPE OF DEPOSIT
Neah Bay	
A1	disorganized conglomerate
A2	organized conglomerate
B2	massive sandstone without dish structures
C1	proximal turbidites (T-ae)
D1 & D2	distal turbdites
D3	base-cut-out turbdites
F	debris flows / slumps / redeposited material
G	hemipelagic sediment
Hoko River and Hoko River Road	
A1	disorganized conglomerate
A2	organized conglomerate
A4	organized pebbly sandstone
C1	classic proximal turbidites (T-ae)
D1	distal turbdites
D3	distal base-cut-out turbidites
E	crevass splay
G	hemipelagic sediment
West Twin River Road	
A1	disorganized conglomerate
A2	organized conglomerate
B2	massive sandstone without dish structures
C1	classic proximal turbidites (T-ae, T-ace)
C2	classic proximal turbidites (T-acde)
D3	distal base-cut-out turbdites
E	overbank deposits
Elwah River Sections	
Old Elwah River Road	
A1	disorganized conglomerate
A2	organized conglomerate
A4	pebbly sandstone
Elwah River Rappel	
B1	sandstone with dish structures
C1	classic proximal turbidites (T-ae, T-ace)
C2	classic proximal turbidites (T-abce, T-acde)
D1	distal base-cut-out turbidites
D3	distal base-cut-out turbidites
G	hemipelagic sediment
Morse Creek	
A1	disorganized conglomerate
A2	organized conglomerate
B1	massive sandstone without dish structures
D3	distal base-cut-out turbidites
F	debris flows / slumps
G	hemipelagic sediment

sandstone have been extensively burrowed and are considered interchannel deposits.

The conglomerates are varied and can be divided by grain size, presence or lack of mud, whether they are matrix-supported or clast-supported, and whether they have internal stratification or not. Most of the isolated conglomerate beds are less than one meter thick, graded or structureless, composed of granules and pebbles, and clast-supported (Facies A1 and A2)(Tables 16). These are considered spill-over deposits from a near- by channel. Channel deposits may be either matrix-supported or clast-supported, are composed of cobbles and boulders, and are structureless (Facies F and A1)(Tables 16). These are debris flows, and mudflows that have filled channels within the inner submarine fan. Slumps containing preserved internal stratigraphy comprise a minor portion of the channel fill deposits. The conglomerates in this section are probably inner-fan channel deposits (Figure 38).

The uppermost channel is composed of medium-grained sandstones (Facies B2 and minor A4)(Tables 16) with concretions weathering-out in cannonball-like spheres. It is overlain by interchannel sediments (Facies D3 and G)(Tables 16) that form a fining- and thinning-upward sequence.

Hoko River

The Hoko River section is one of the two type sections. It was measured along the bed of the Hoko River and the Hoko River Road. The section is located on the Lake Pleasant Quadrangle of the fifteen-minute map series. The section begins downstream of the pools and canyon formed by the resistant Lyre Formation in the SE 1/4 of the SE 1/4 of section 6 of T 31 N, R 13 W. The top of the section is located at the tributary stream that enters the Hoko River from the west in the SE 1/4 of the SE

Figure 38. Inner fan channel filled with conglomerate, debris flows and slumps at east Warmhouse Beach point in the Neah Bay section. The channel is cut into interchannel siltstones and sandstones (Facies D3 and G). Arrow points to a log approximately 3 meters long for scale.

1/4 of section 29 of T 32 N, R13 W. This was the Hoko River Formation - Makah Formation boundary as described by Tabor and Cady (1978), which has since been moved about 500 meters downstream by Snavely and others (1986).

The basal contact is gradational with the underlying Lyre Formation, which is primarily organized pebbly conglomerate. The Hoko River Formation is marked by a decrease in grain size from pebbly and granule sandstone to alternating beds of sandstone, siltstone, and conglomerate. The type section is dominated by massive spheroidal- or hackly-fractured massive to laminated siltstone (Figure 39) deposited as base-cutout turbidites (Facies D3) and hemipelagic sediments (Facies G)(Tables 16 and 18)(Plate 2). Individual medium- or thick-bedded strutureless sandstones sporadically break the fine-grained sediment (Facies C1). At the 550 meter mark, a lens of sandstone and conglomerate with minor siltstone interupts the section. The sandstone is medium- to thick-bedded, with very thin silt partings between beds (Facies B2)(Table 16). Thin- to medium-bedded, graded or massive sandstone are proximal turbidites (Facies C1) and are associated with the sandstones (Facies B2)(Table 16). The conglomerate is medium- to thick-bedded but otherwise structureless, of granules and pebbles, with a slightly lenticular bed geometry (Facies A2)(Table 16). Medium to thick-bedded organized pebbly sandstone (Facies A4)(Table 16) is interbedded with the conglomerates.

This section represents middle-fan interchannel and channel deposits. Most of the silt (Facies D3 and G) is interchannel sediment with occasional spill-overs from channels represented by the isolated T-ae sandstone beds. The conglomerates, pebbly sandstones, and proximal turbidites are bed load and channel-fill of the middle-fan. The overall succession is distal interchannel over proximal channel deposits.

Figure 39. Spheroidally weathering siltstone, the dominant lithology in the Hoko River section. Facies D3 and G.

West Twin River Road

The section is reached by travelling west on state route 101, then north and east on the West Twin River Road, and then turning north onto the Twin Loop road. The base of the measured section lies about a quarter mile up the road from the intersection of the West Twin River Road and the Twin Loop Road. The section is located on the Pysht, Washington 15 minute quadrangle in T 30 N, R 10 W (incompletely surveyed), beginning in the center of section 7, and ending in the SE 1/4 of section 6. The lower and upper contacts of the Hoko River Formation are not exposed.

The Hoko River Formation along the West Twin River Road comprises packages of proximal turbidites (Facies C1 and C2) and distal turbidites (Facies D1 and D2)(Figure 40) set in thin-bedded, massive to laminated siltstone (Facies D3 and G)(Tables 16 and 18). Well-rounded, well-sorted, poorly cemented granule and pebble conglomerate beds (Facies A1 and A2) are present in approximately one third of the packages (Plate 3).

The granule and pebble conglomerates are thin- to medium-bedded, graded or structureless with flat to wavy bottoms and gradational tops (Facies A1 and A2)(Table 16). Commonly, beds of one meter or less are internally stratified or graded with parallel top and bottom contacts. The conglomerates are associated with thick-bedded proximal turbidites (Facies C1)(Table 16).

Large-scale cross bedding is found in some of the thick-bedded sandstones (the cross-beds are 20-50cm high in outcrop). These are bounded above and below by proximal turbidites (Facies C1 and C2) or conglomerates (Facies A1 and A2). The cross-bedded units may be part of a bar within a middle fan distributary channel (Figure 37).

The thin- to medium-bedded sandstone and thin-bedded siltstone

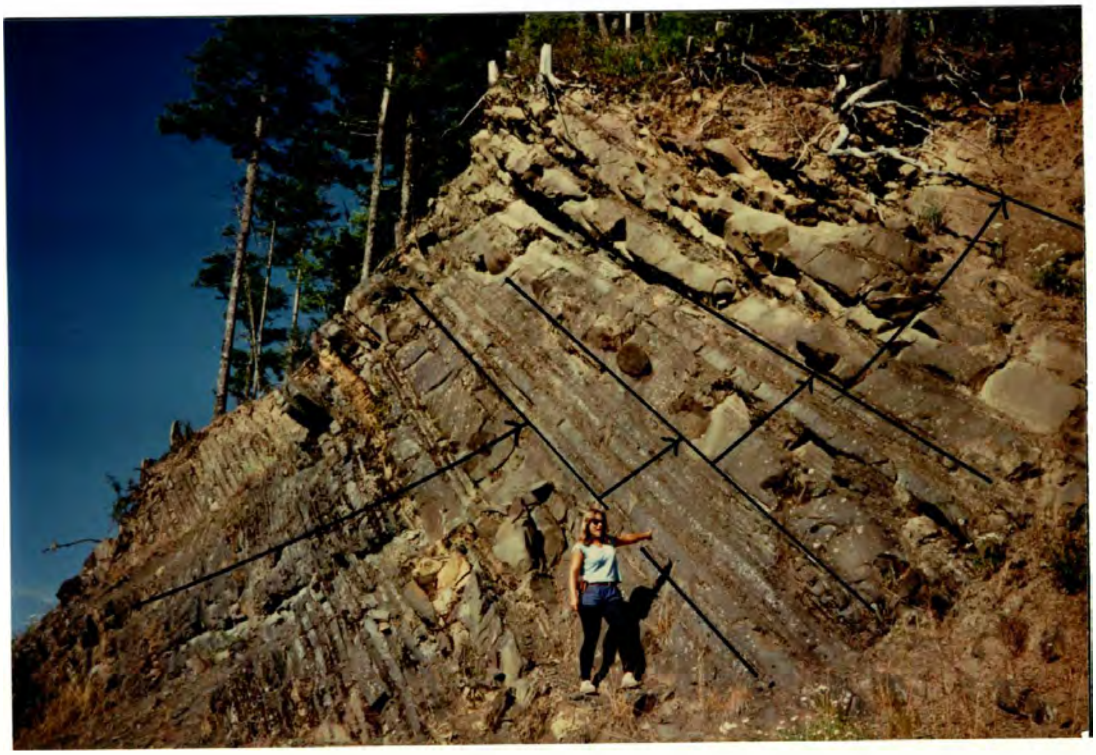


Figure 40. Proximal (Facies C) and distal (Facies D) turbidites along the West Twin River Road. A lower thickening-up sequence is overlain by three thinning-up sequences. These mark middle-fan lobe deposition and subsequent increases and decreases of activity.

packages are middle-fan channel fill, and channel lag deposits. The channels are characterized by thick-bedded proximal turbidites (Facies C1 and C2)(Table 16). Lag deposits in these channels are represented by conglomerates (Facies A2) and are overlain by proximal turbidites (Facies C1 and C2). The bars that form and shift within these channels create the cross-bedded sandstones.

Detailed observations lead to the conclusion that this portion of the Hoko River Formation was deposited in middle-fan channels, interchannel areas, and proximal depositional lobes. The lower portion of the section is dominantly a proximal middle-fan lobe. The middle part is composed of middle-fan channel deposits. Near the top are active channel, channel-fill and lobe deposits with the uppermost rocks marking abandonment of a channel. Together the sequences show progradation of the active middle-fan channel over its lobe deposits, and subsequent abandonment.

Elwah River

Two sections were studied along the Elwah River. The lower section was not measured, but is located along the Old Elwah River Road on the east side of the river, from the bridge southeast and up the road to the last outcrop. This site is on the north limb of a large east-west-trending syncline, which explains the south-dipping strata. This site will be referred to as the Old Elwah River Road section. The second location is along state route 112 on the west side of the new bridge on the south side of the road. The section was measured in two rappels and will be referred to as the Elwah River Rappel (Plate 4). The second section lies stratagraphically above the first section an unknown distance and is not adjacent to the upper or lower formation contacts. Both locations are located on the Elwah, Washington, 7 1/2 minute quadrangle.

The Old Elwah River Road is in the NE 1/4 of the NE 1/4 of section 10, T 30 N, R 7 W. The Elwah River Rappel is in the SW corner of the SE 1/4 of section 10, T 30 N, R 7 W.

Old Elwah River Road Section The Old Elwah River Road Section is a short section of (100 m) organized and disorganized conglomerate (Facies A2 and A1) and pebbly sandstone (Facies A4)(Figure 41). These sandstones and conglomerates are middle- or inner-fan channel deposits (Figure 36). Strata are medium to thickly bedded with crude interanl lamination. The preponderance of conglomerate suggests high energy- deposition. Scoured bottom contacts that mark channel bottoms and the lack of fine sediment are further evidence for a high energy of deposition. The most distinctive feature at this location is the off-white calcite cement surrounding well-sorted, well-rounded, spherical granules and pebbles. Some layers comprise well-rounded, spherical pebbles and cobbles as well as the typical smaller sediment size. This type of sorting and rounding suggests long transport. It is probable that a middle-fan channel is the environment of deposition.

Elwah River Rappel The Elwah River Rappel consists of thin-, medium- and thick-bedded medium-grained sandstone (Facies B1, C1, C2, and D1) with interbeds of laminated thin-bedded siltstone (Facies D3, and G)(Table 16). The sandstone units contain Bouma divisions T-ae, T-abc, T-ab, T-abce, T-bde and T-bcde (Facies C1, C2, D1)(Table 16). Dish structures have also been preserved in some beds (Facies B1). The siltstones vary from well-laminated to structureless and are probably distal, base-cutout turbdites (Facies D3) and hemipelagic sedimentation (Facies G) (Figure 42).

The basal portion forms a thickening- and coarsening-upward sequence of proximal and distal turbidites (Facies C1 and D1). The

Figure 41. Granule conglomerate of the Old Elwah River Road section showing bedding planes. Facies A1, A2 and A4. Sign is 1.75 meters high.

Figure 42. The Elwah River Rappel section containing thick-bedded sandstone (Facies C1, C2 and B1) with thin-bedded sandstone-siltstone (Facies D1 and D3) interbeds. See Plate 5 for details.

section then fines upward to the middle of the section, indicating waning deposition on the suprafan lobe. The two meters of mudstone and very fine sandstone (Facies D3 and G) at meters 14 to 16 are considered interchannel deposits. Two very thickly bedded proximal turbidites occur (T-ab) at the base of the next fining-up sequence and suggest active deposition switching back into the outcrop area. The rest of the section is dominated by very regular, thin to medium bedded turbidites.

The presence of proximal and distal turbidites (Facies C1, C2, D1, D2, and D3) and the lack of conglomerate in the Elwah River Rappel section constrains deposition to a middle fan depositional lobe. A decrease in proximal turbidites and the increase of distal-base-cut-out turbidites up-section indicates deposition farther from the feeder channels on the suprafan lobe. In general, distal deposits are overlain by proximal, suggesting that deposition was shifting to another portion of the lobe.

Morse Creek

The Morse Creek section was measured in the stream bed of Morse Creek on the Morse Creek 7 1/2 minute quadragle. The section begins about 40 meters above the Port Angeles Dam in the NE 1/4 of the SW 1/4 of section 5, T 29 N, R 5 W and ends in the NW 1/4 of the NE 1/4 of section 5, T 29 N, R 5 W (at the border of section 5, T 29 N, R 5 W and section 32, T 30 N, R 5 W). The section is 810 meters from the basal contact with the Aldwell Formation to the contact with the above Makah Formation (Plate 5).

The basal contact of the Hoko River Formation at Morse Creek is conformable against the underlying Aldwell Formation. The contact can be recognized by the abrupt change from the laminated, massive-to-thinly bedded silt and very fine sand of the Aldwell Formation to a disorganized pebble to cobble conglomerate, the basal portion of the Hoko River

Formation. The upper contact between the Hoko River Formation and the overlying Makah Formation is gradational. This contact can be recognized by the change from laminated silt with fine wispy sand stringers of the Hoko River Formation to a medium-bedded granule conglomerate of the Makah Formation.

Facies associated with this section are disorganized conglomerate (Facies A), sand-rich units (Facies B2), slumped units (Facies F), isolated classic proximal turbidites (Facies C1), and distal base-cut-out turbidites (Facies D2 and D3) associated with hemipelagic sediment (Facies G)(Table 18). These are most often found in middle-fan channels and interchannel. The top of the section is marked by the abrupt influx of coarse sediment, the basal conglomerates of the Makah Formation.

One kaolinized tuff or ash layer and two medium-bedded organized conglomerate units occur at 97, 480, and 720 meters, respectively. One sandstone dike was located at 540 meters. Concretionary layers are present in numerous locations, more commonly in the middle and upper portions of the section.

The basal 140 meters of this section were probably deposited in or near a middle fan channel. Facies A2, A4 and B2 are common within middle-fan-channel environments (Figures 36 and 37). Moderately well-rounded pebbles and cobbles are more common in middle fan channels than inner fan channel. The thick stack of proximal medium- to thick-bedded sandstone is more characteristic of a middle-fan-channel environment. The slumps found in this section are relatively small (5 meters thick) and involve mostly pebbly mudstones. These could occur in either inner fan or middle fan channels.

The next 790 meters of mostly distal base-cut-out turbidites were deposited in the interchannel area of the middle fan (Figure 36). The wispy nature of these mudstone and sandstone turbidites is due to bioturbation. Burrowed sediment is well preserved in the concretions within this section. The wispy sandstone beds (T-c) are often further disrupted by loading from overlying sediment. The few conglomerates that were deposited higher up in the section are probably crevass splays or runouts from subaqueous mudflows or debris flows (Figure 43).

In summary, the Morse Creek section comprises thickly bedded, coarse proximal deposits overlain by thinly bedded fine distal deposits. This sequence was formed by middle fan channel deposition and subsequent abandonment.

Agate Beach and Crescent Beach

The Agate and Crescent Beach sections were not measured but observations were made about the lithologies present. Well-rounded, well-sorted conglomerates directly overlie the Crescent Formation and are probably channel deposits. They are associated thick-bedded structureless sandstones, similar to those of the Elwah River Rappel. A middle-fan channel and lobe are the probable depositonal environments. The Crescent-Hoko River Formation contact, an angular unconformity, is located on the western cliff face of Little Agate Beach.

Agate Beach Well-rounded, well-sorted conglomerates (Facies A2) are exposed in the wave-cut platform along the east cliff-face of Agate Beach. The clasts are granules to cobbles. The conglomerates are well- bedded, imbricated and contain low-angle cross stratification; they are channel conglomerates of the middle fan. On the west cliff-face of Agate Beach lies a 50 meter cliff of thick-bedded sandstones. They are overlain by conglomerates (Facies A2 and F) that truncate some of the upper

Figure 43. Concretionary layers of siltstone with wispy very fine sandstone interbeds, typical of the Morse Creek section. Facies D3 and G.

sandstones. Some of the conglomerates are well bedded and some are chaotically deposited, suggesting slumping of the nonlithified material. Thick-bedded sandstones associated with conglomerates occur in middle-fan channels (Figure 36). Proximal middle-fan channels are the probable depositional environments of the strata at East and West Agate Beaches.

Crescent Beach The east cliffs of Crescent Beach are Crescent Formation basalts overlain by siltstone. Isolated outcrops of granule conglomerates are located in cliffs that parallel the beach. The conglomerates are clast supported, but too poorly exposed for bedding characteristics to be discussed. These conglomerates may be lateral equivalents to those of Agate Beach.

Conclusions

The Hoko River Formation was deposited in inner and middle fan environments. The Neah Bay section represents inner fan followed by middle fan deposition. The Hoko River section records shifts from middle-fan channel to interchannel, then back to channel and to interchannel deposition. The West Twin River Road section contains middle fan lobe and channel deposits. The Old Elwah River Road section comprises middle fan channel deposits. The Elwah River Rappel comprises middle fan lobe deposits. The Morse Creek section is a middle fan channel that grades into interchannel deposits. The Agate and Crescent Beach sections are probably middle fan channel deposits. Overall, the Hoko River Formation was deposited in gradually deeper water, placing relatively distal strata over proximal strata. A gradually subsiding basin, a decrease in the volume of sediment influx or a sea level transgression can produce this relationship.

The question remains, was the Hoko River Formation deposited by one large submarine fan or by a series of smaller submarine fans. A submarine fan the size of the Astoria fan or even smaller could have produced a single fan large enough to cover the study area (Figure 44). The area of southern and central Vancouver Island is large enough to contain a river of sufficient size. A river or a number of smaller streams could have transported sediment out to the shelf, from which it was later swept offshore into a submarine channel.

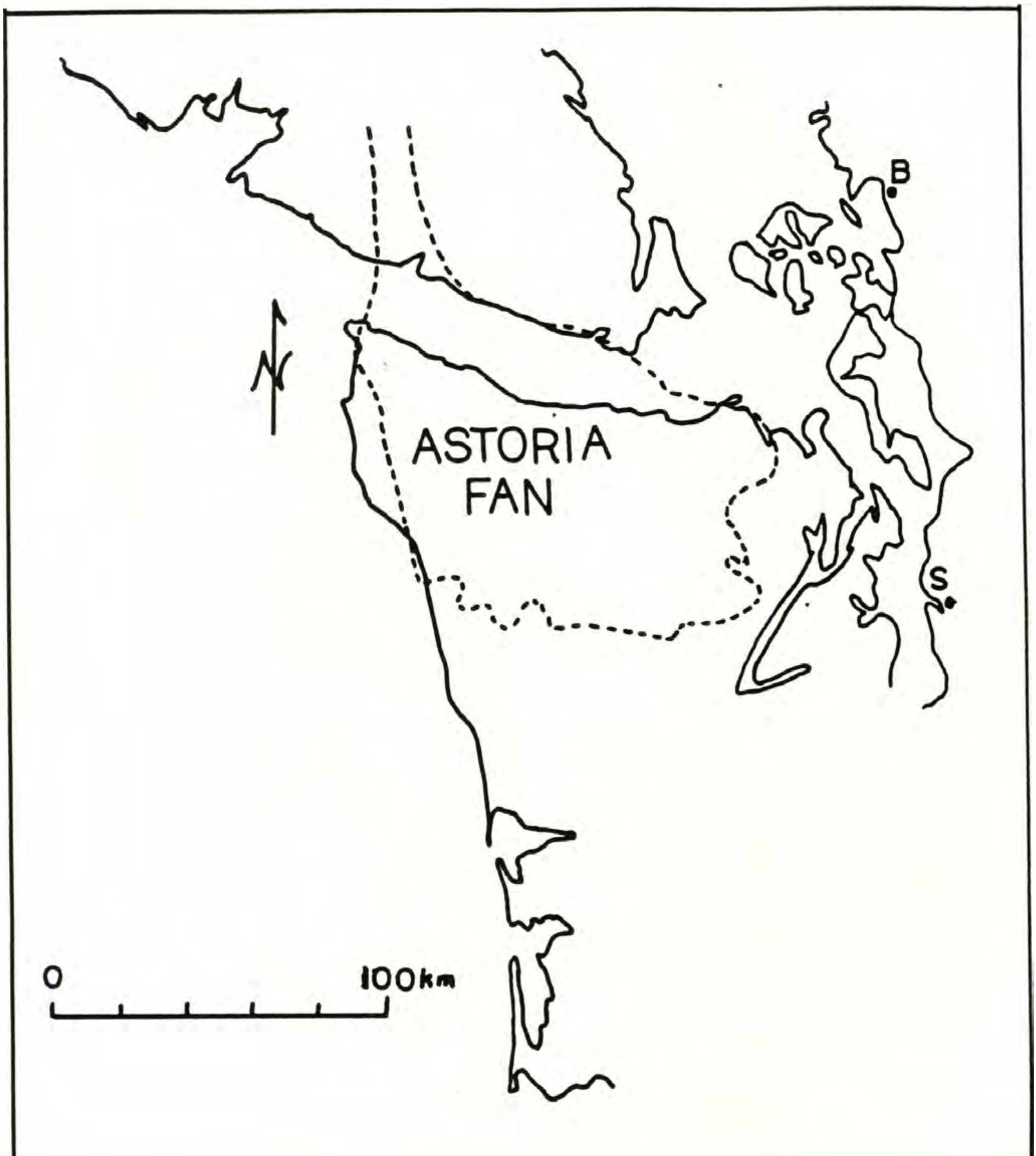


Figure 44. Comparison of relative sizes of the Astoria fan located offshore of the mouth of the Columbia River at the Oregon-Washington border and the area of the present day northern Olympic Peninsula. B = Bellingham, S = Seattle

EOCENE PALEOGEOGRAPHY

The rocks of the Crescent terrane on the northern Olympic Peninusla provide information on changes that occurred in their depositional basin. When near-by coeval units are compared to the rocks of the Crescent terrane, specifically the Hoko River Formation, a regional picture becomes apparent. The regional paleogeography will be discussed, then the structural events specific to the Crescent terrane will presented and finally the paleogeographic implications of the Hoko River Formation will be discussed.

Coeval Units

Other sedimentary units deposited during the late Eocene (late Narizian) in the Pacific Northwest are parts of the Chuckanut Formation, the Escalante and Hesquiat Formations of the Carmanah Group, the Puget sequence of central western Washington, and rocks of the Olympic Core terrane, including the Western Olympic Assemblage and the undifferentiated rocks of the Olympic Core (Figures 45, 46, and 47).

Chuckanut Formation

This comparison with Chuckanut Formation compositions adds weight to my conclusion (see Source Area chapter) that the Hoko River Formation was not derived from the North Cascades. Sediment from that source would have to have passed through the Chuckanut fluvial system before reaching the Hoko River depositional basin, but the differences in composition rule out that transport pattern. Therefore, the Northwest Cascade Mountains must not have been a source for the Hoko River Formation.

The Chuckanut Formation spans most of the Eocene; its upper Eocene members are the Maple Falls, Warnick, and Bald Mountain Members. Point-

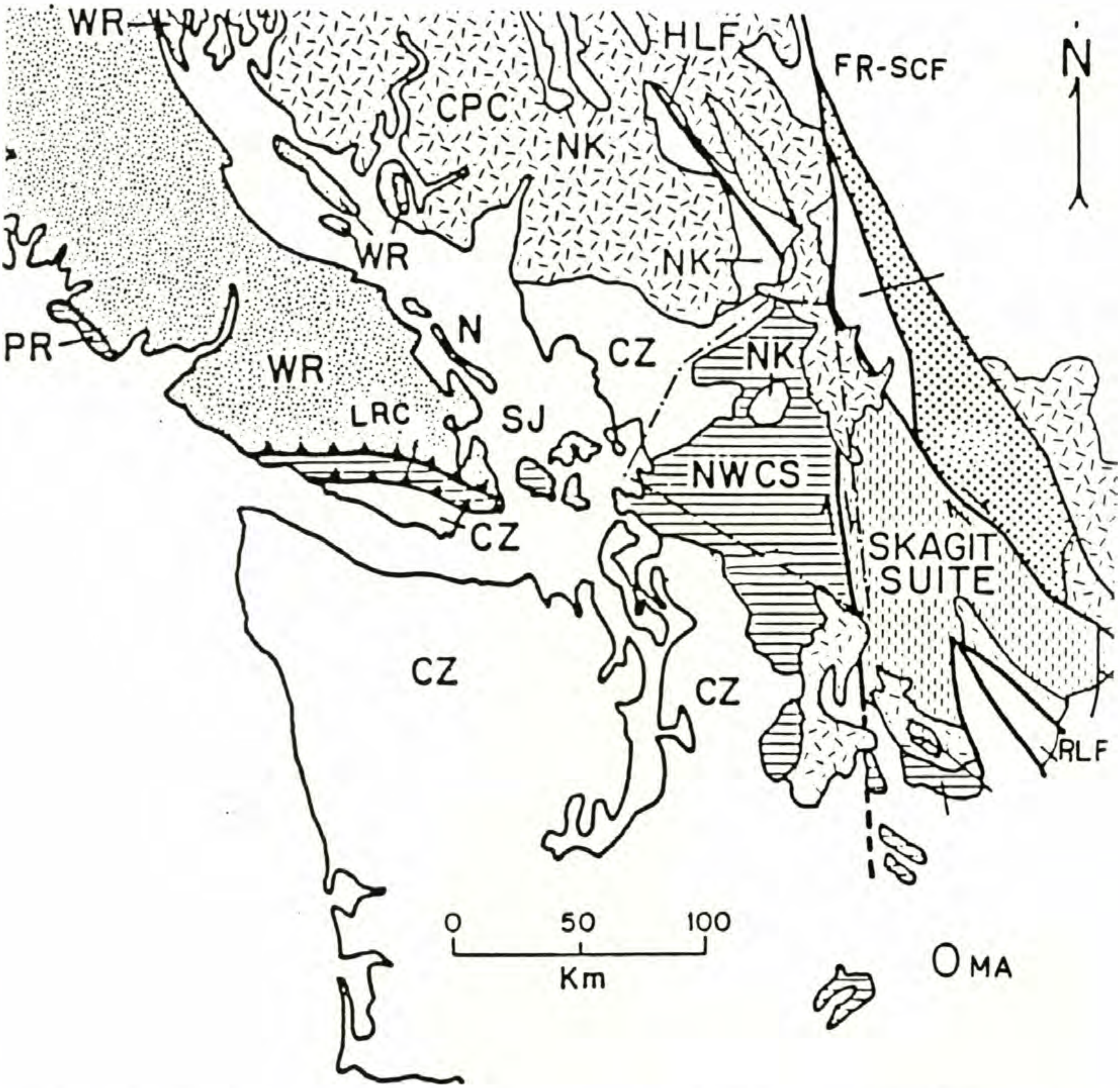


Figure 45. Base map showing the present day (0 Ma) regional geology surrounding the Olympic Peninsula modified from Brown (1987). Use this as a comparison for figures 46 and 47. Same as Figure 4.

CZ	Cenozoic sediments and volcanics
CPC	Coast Plutonic Complex
LRC	Leech River Complex
NK	Nooksack terrane
NWCS	Northwest Cascades System
PR	Pacific Rim Complex
SJ	San Juan Islands
HLF	Harrison Lake fault
FR-SCF	Fraser River-Straight Creek fault
RLF	Ross Lake fault

Figure 46. Paleogeographic reconstruction of the Juan de Fuca basin and its surrounding regions, showing depositional systems and subaerial regions (source areas) at approximately 40 Ma.

The Carmanah Group was being deposited just offshore of southern Vancouver Island (Muller and others, 1981).

The Chuckanut fluvial system lies to the north and east of the Juan de Fuca basin. A barrier separates the Chuckanut and Juan de Fuca basins. the distal portions of the Chuckanut Formation may have been transported south and west of the Juan de Fuca basin. These sediments may have formed part of the present day Western Olympic Assemblage and undifferentiated rocks of the Olympic Core (Heller, personal communication, 1987).

The Puget Sequence was active as both andesitic volcanic centers and a fluival-deltaic system during the late Eocene. There was no connection between this system and the Juan de Fuca basin. See text for supporting discussion.

Later movement across the Leech River and San Juan faults narrowed the exposure of Leech River Complex (Fairchild and Cowan, 1982, and Yorath and others, 1985).

Carmanah Group

Chuckanut Formation

Western Olympic Assemblage and undifferentiated rocks of the Olympic core

Puget Sequence

Hoko River Formation

LRC = Leech River Complex

LRF = Leech River fault

SJF = San Juan fault

Subaerially exposed areas (highlands)

Submarine ridge dividing the Juan de Fuca basin from other late Eocene basins.

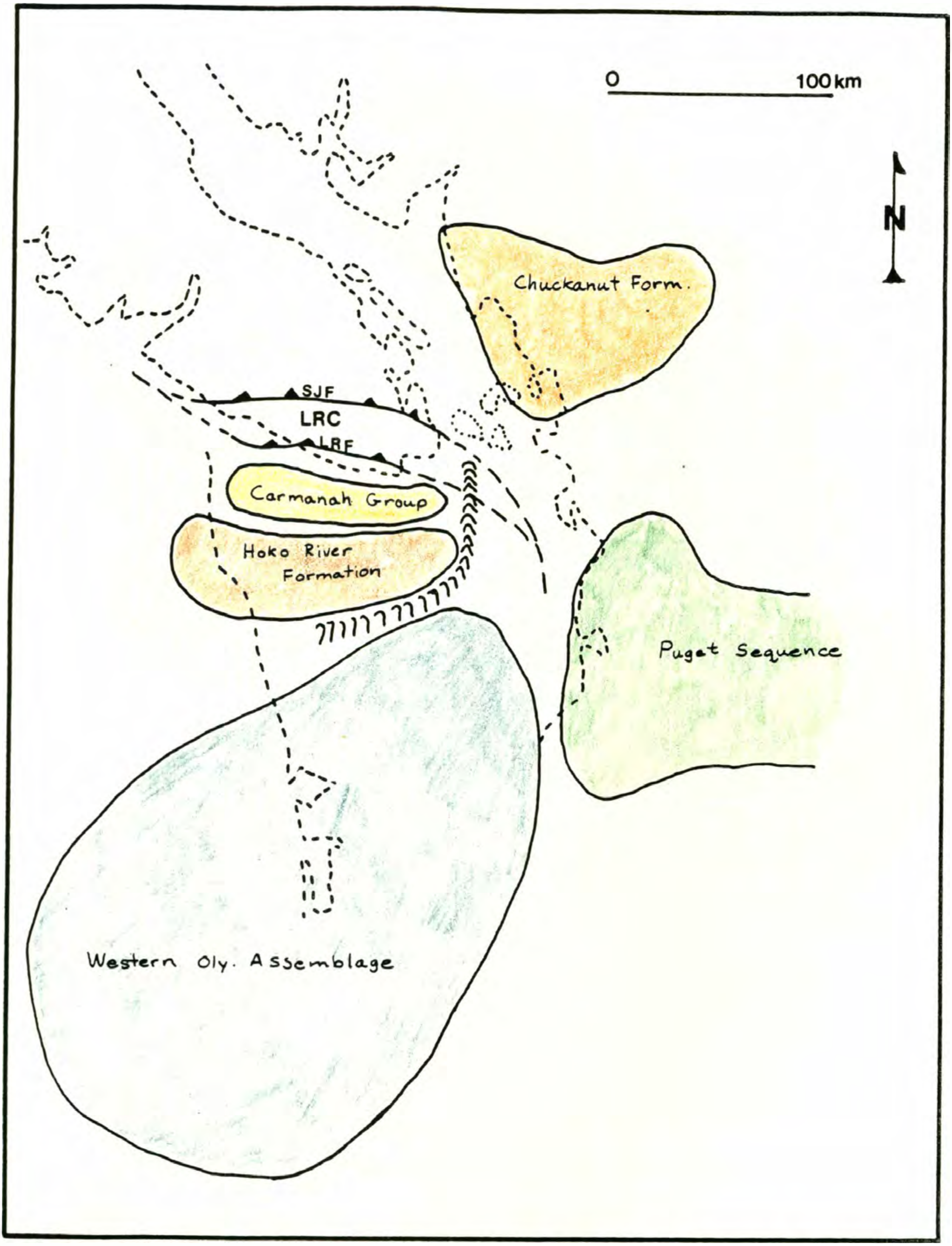

0
100 km
N
Chuckanut Form.
SJF
LRC
LRF
Carmanah Group
Hoko River
Formation
Puget Sequence
Western Oly. Assemblage

Figure 47. Paleogeographic reconstruction of the Juan de Fuca basin and the surrounding regions. The purpose is to depict the areas of fluvial-deltaic, shallow marine and deep marine deposition. The subaerial regions have been shaded differently. Also note there are two basins south and west of southern Vancouver Island, or one basin with two distinct regions.

Compare with Figure 45 for bedrock geology and Figure 46 for active fluvial systems.

Fluvial or fluvial-deltaic

Shallow marine

Deep marine

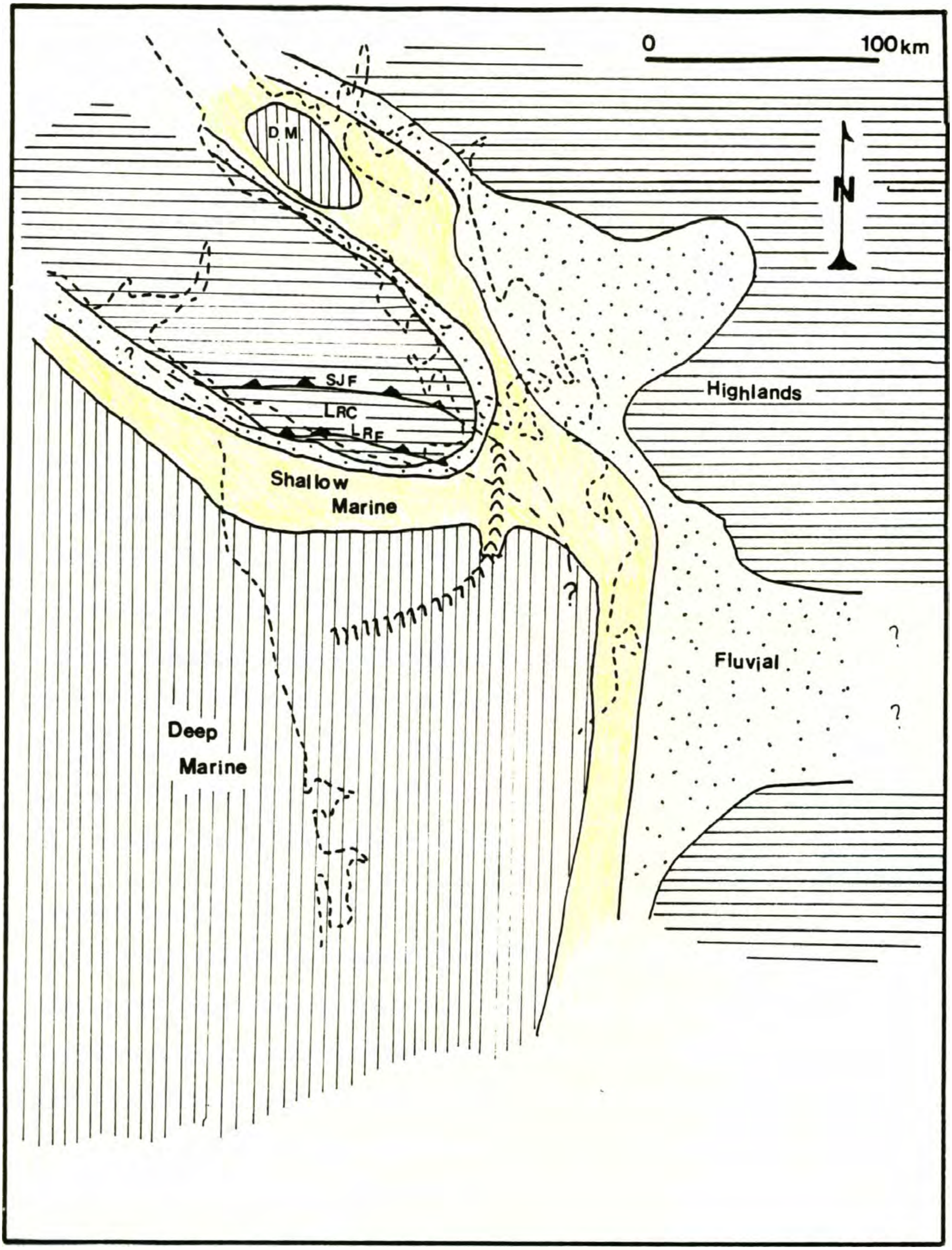
Highlands

SJF = San Juan fault

LRF = Leech River fault

LRC = Leech River Complex

Ridge dividing Juan de Fuca basin from other late Eocene sedimentary basins, origin unknown.


0
100 km
N
D.M.
SJF
LRC
LRF
Highlands
Shallow
Marine
Fluvial
Deep
Marine

count data from these three members (Johnson, 1982) were plotted on ternary diagrams to compare their sedimentary petrology and provenance to that of the Hoko River Formation. On the Q-F-L diagram (Figure 48), the three Chuckanut Formation members plot well away from the Hoko River Formation average. The Qm-F-Lt and Qm-P-K triangular diagrams (Figures 49 and 50) show that two of the upper Eocene members of the Chuckanut Formation lie within one standard deviation of the Hoko River Formation. The differences between the Hoko River Formation and the upper Eocene members of the Chuckanut Formation are most pronounced on the lithic ternary diagram (Figure 51). The Hoko River Formation contains fewer polycrystalline quartz grains and more volcanic, metavolcanic, sedimentary, and metasedimentary lithic grains than the Chuckanut Formation members. Polycrystalline quartz grains are very resistant lithic types and would be expected to increase in concentration downflow. Also the number of rapidly weathered grains, such as volcanic, metavolcanic, sedimentary and metasedimentary grains, would be expected to decrease downflow rather than increase. The actual relationship is the reverse, so the Hoko River Formation is probably not the marine equivalent of the upper Eocene Chuckanut Formation.

Carmanah Group

The Carmanah Group, exposed along the west-central edge of Vancouver Island, contains two formations that are, in part, Eocene, the upper Eocene or Oligocene Escalante Formation and the upper Eocene or Oligocene Hesquiat Formation (Muller and others, 1981)(Figure 46 and 47). The Hesquiat Formation has been correlated with the Makah Formation based on similar "lithology, age, and depositional environment" (Snavely and others, 1980, p. 19) and it will be excluded from further consideration.

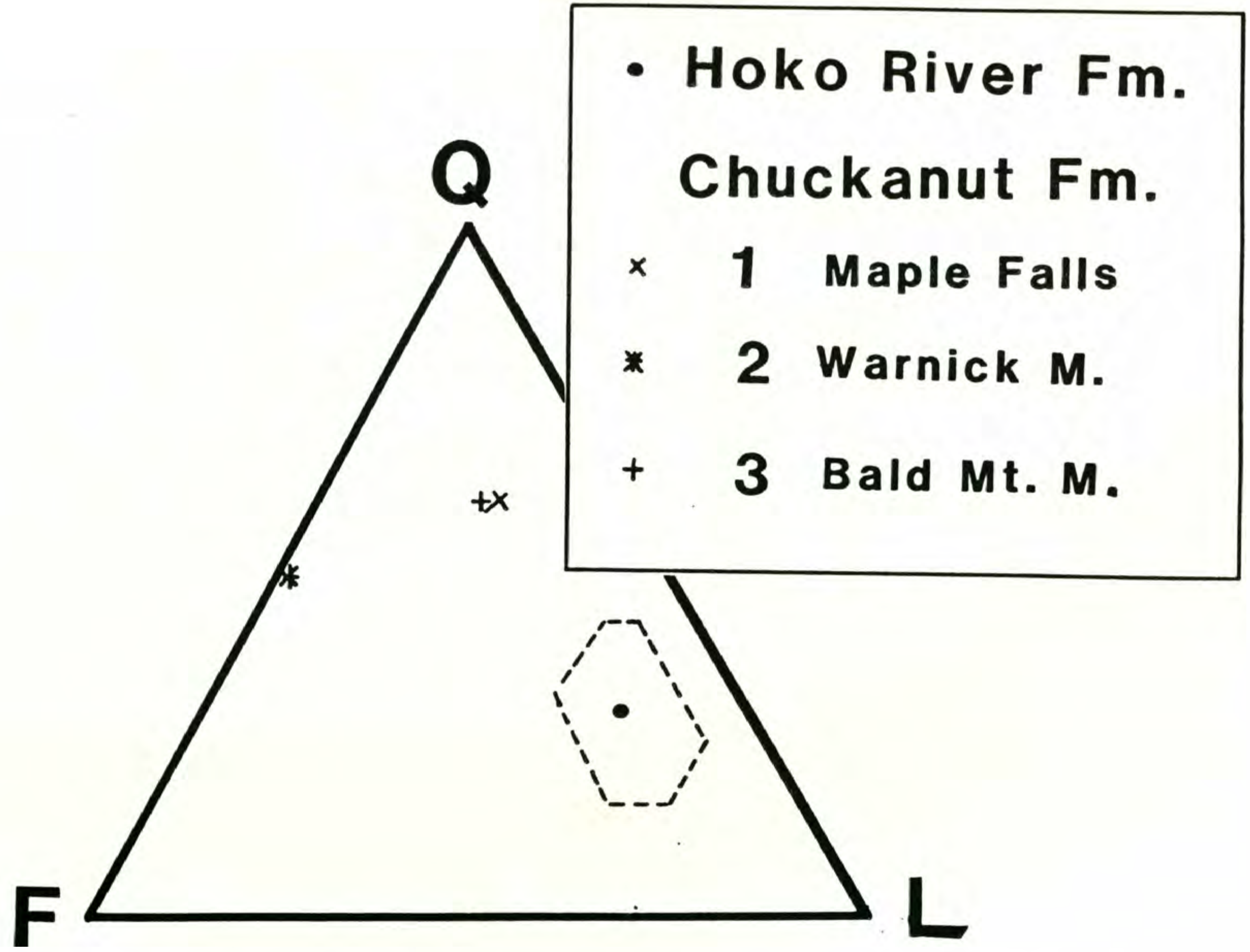


Figure 48. Q-F-L ternary diagram comparing the average composition of the Hoko River Formation to the late Eocene members of the Chuckanut Formation. Data from this thesis and Johnson (1982).

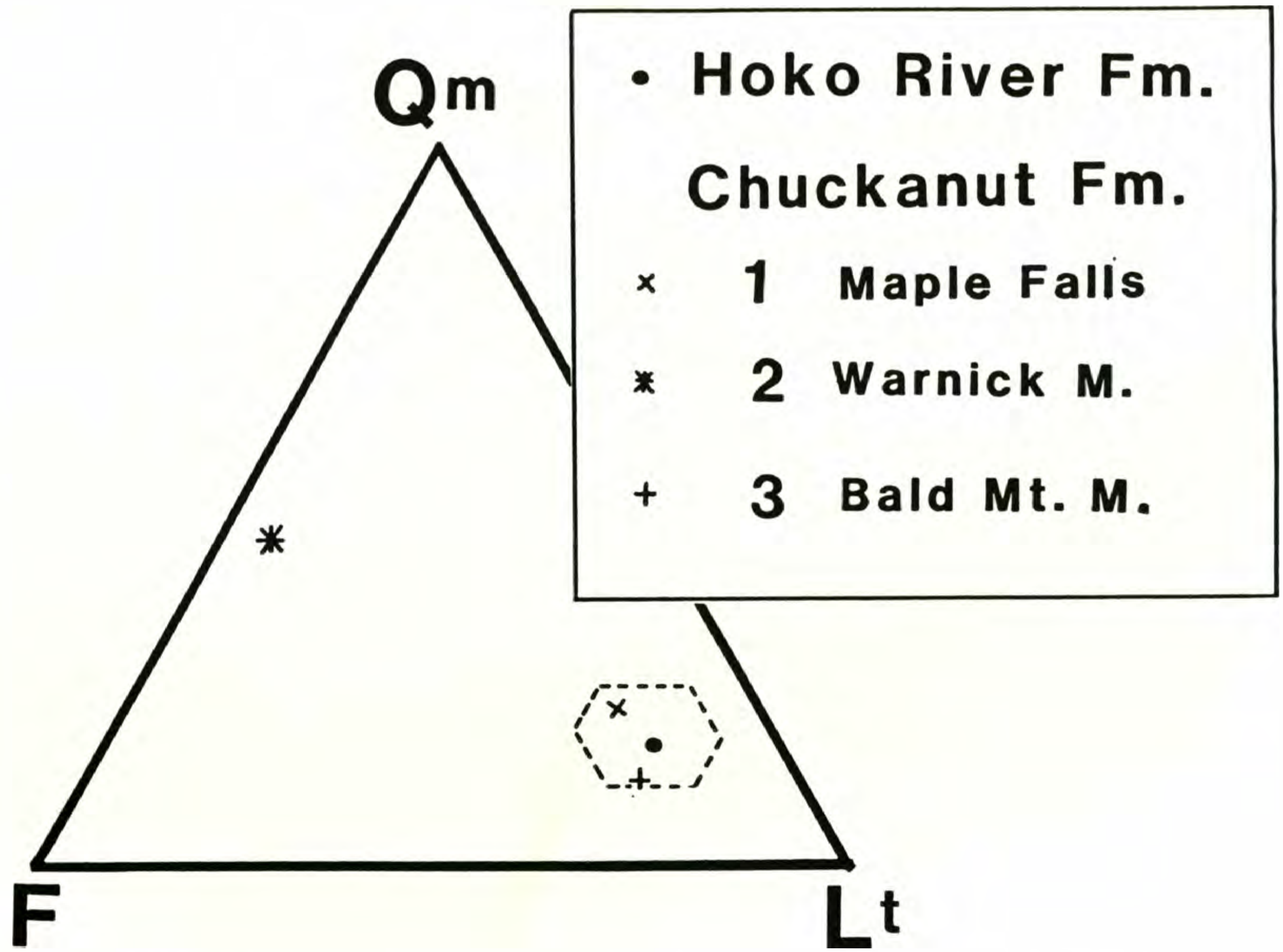


Figure 49. Qm-F-Lt ternary diagram comparing the average composition of the Hoko River Formation to the late Eocene members of the Chuckanut Formation. Data from this thesis and Johnson (1982).

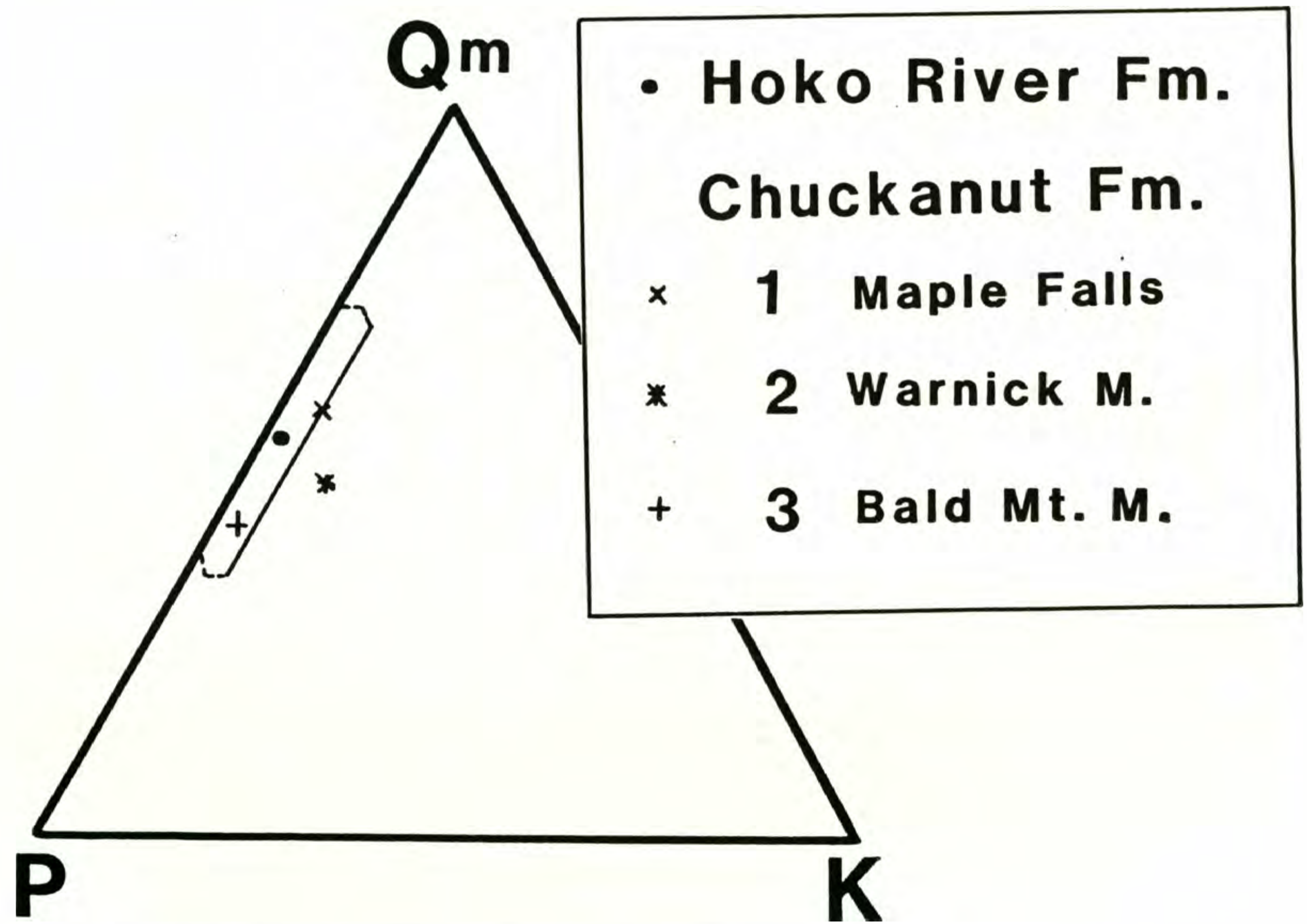


Figure 50. Qm-P-K ternary diagram comparing the average composition of the Hoko River Formation to the late Eocene members of the Chuckanut Formation. Data from this thesis and Johnson (1982).

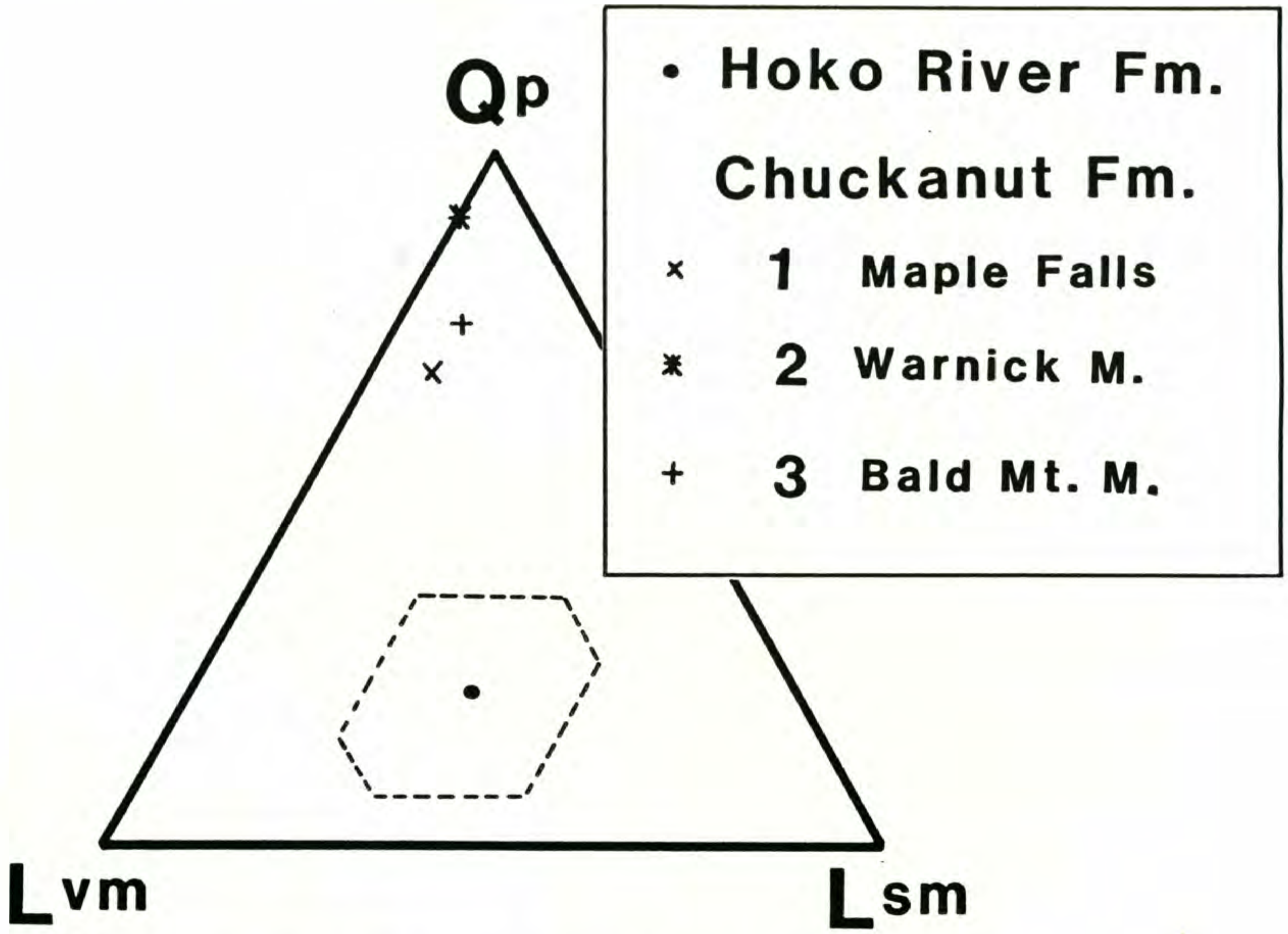


Figure 51. Qp-Lvm-Lsm ternary diagram comparing the average composition of the Hoko River Formation to the late Eocene members of the Chuckanut Formation. Data from this thesis and Johnson (1982).

The Escalante Formation (Refugian) comprises sandstone and minor conglomerate unconformably overlying crystalline basement. It formed as shallow marine deposits that evolved into a deep marine (outer neritic or upper bathayl) system (Muller and others, 1981). This evolution may reflect the change from upper bathyal to bathyal deposition found between the Lyre and Hoko River Formations. Based on similar depositional environments, the upper portion of the Escalante Formation is the part most likely to correlate with the Hoko River Formation. Further study of the petrology of the sandstones and conglomerates of the Escalante Formation may lead to clearer correlation with the Hoko River Formation with which it may have formed part of a single depositional system.

Puget Sequence

The Eocene Puget sequence is located south and east of the northern Olympic Peninsula (Figure 45). Upper Eocene sedimentary members of the Puget sequence are the Renton, Spiketon, and Skookumchuck Formations and the Puget Group proper. The three formations are Puget Group-correlatives and combined with the Puget Group will be referred to as the Puget deltaic sequence (Buckovic, 1979). The Puget deltaic sequence combined with the associated terrestrial volcanics, the Tukwila and Northcraft Formations, will be referred to as the Puget sequence. The Puget deltaic sequence comprises fluvial-deltaic deposits originating in a granitic highland in the east and extending westward into a marine embayment and offshore onto the continental shelf (Buckovic, 1979). The Tukwila and Northcraft Formations are andesitic terrestrial volcanic systems that lasted from the middle Eocene to the early late Eocene (Buckovic, 1979). They are part of the Puget sequence and interfinger with the Puget deltaic sequence. They consist of proximal flows, agglomerate, breccia; alluvial fan deposits of debris and sheet-flows; and, most distally, andesitic volcaniclastics (Buckovic, 1979).

Deep water equivalents of the Puget system were presumably being deposited offshore, somewhere to the west. The Hoko River Formation did not comprise these sediments (Figures 46 and 47). Intermediate volcanic fragments are only a small portion of the lithic population of the Hoko River Formation, so it cannot have been fed through the deltas of the Puget system. Sediments of the Hoko River Formation are not considered the deep marine equivalents of the Puget system.

Upper Eocene Units of the Olympic Core Terrane

The middle Eocene to Oligocene Western Olympic Assemblage includes most of the upper Eocene rocks of the Olympic Core terrane (Figure 45). It is composed of thick-bedded sandstones, occasional turbidites, siltstones (less than 40%) and granule conglomerates (Tabor and Cady, 1978). The sandstones are angular, poorly sorted, lithic to feldspathic arenites. They contain 3% to 10% potassium feldspar (Tabor and Cady, 1978). The conglomerates contains chert, quartzite, volcanic, limestone, and sedimentary clasts (Tabor and Cady, 1978). The assemblage is now metamorphosed in its eastern exposures to slate, argillite, phyllite and semischist. The metamorphic minerals are laumontite, epidote, chlorite, and pumpellyite, indicating low pressure and temperature facies (Tabor and Cady, 1978).

The upper Eocene (?) and Oligocene (?) undifferentiated rocks of the Olympic Core are similar to the Western Olympic Assemblage and are located in the south-central Olympic Core terrane. The sandstones are micaceous, volcanic-lithic to feldspathic, angular, and poorly sorted (Tabor and Cady, 1978). The potassium feldspar content is variable, from essentially zero to up to 3 to 10%. (Tabor and Cady, 1978). They are thick-bedded and contain much cross-bedding and graded bedding. Turbiditic sandstones are uncommon everywhere, but they are more abundant to the south. Argillite, slate, siltstone, and conglomerate comprise 40% of this unit (Tabor and Cady, 1978).

These units were probably all marine. The turbidites suggest possible submarine fan deposition but are not exclusive for that environment. The main differences between these units and the Hoko River Formation are the amounts of feldspar. The potassium feldspar content of the Western Olympic Assemblage and of the undifferentiated rocks of the Olympic Core terrane ranges from 3 to 10%, which is much more than the 0.5% $\pm$ 1 found in the Hoko River Formation. Heller (personal communication, 1987) has suggested that the core rocks are the deep-marine equivalents of the Chuckanut Formation. Two separate basins must have existed during the late Eocene, one just south of southern Vancouver Island in which the Hoko River Formation was deposited and another south and west of the present Olympic Core terrane in which the Western Olympic Assemblage and undifferentiated rocks of the Olympic Core were deposited (Figures 46 and 47).

Structural Events

Local Tectonics

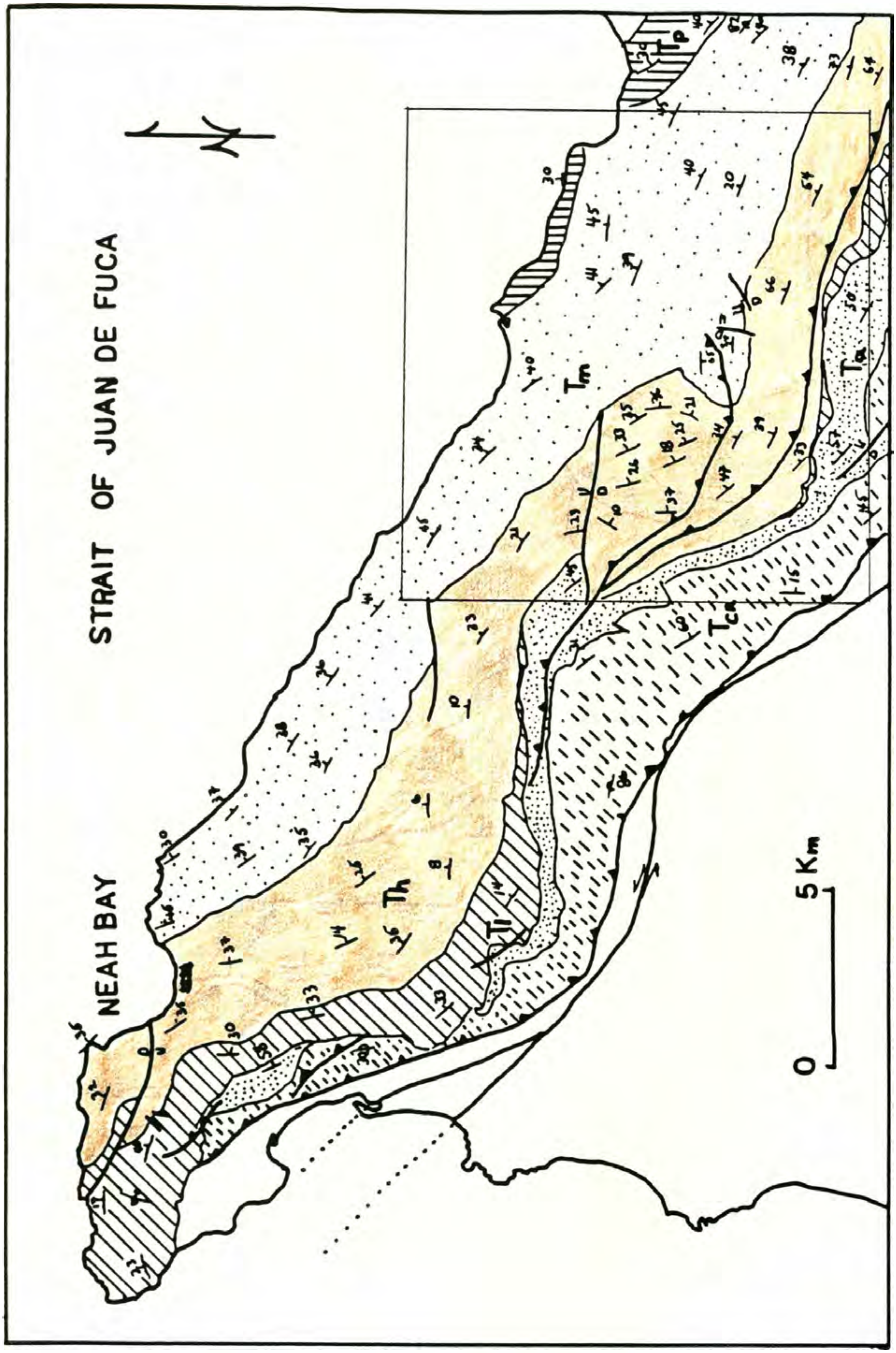
Before the deposition of the Lyre Formation, a compressional structural event gently folded the rocks of the Crescent terrane about northeast-southwest-trending axes (Tabor and Cady, 1978)(Figure 52). The Lyre Formation appears to have been deposited in the valleys of these early-stage folds. The Lyre Formation also is folded, although more gently than the underlying units. Folding is less pronounced in the Hoko River Formation and is even more gentle in the overlying upper Eocene to Oligocene Makah Formation. Folding was an event of long duration, from the middle Eocene to the early Oligocene.

Locally important thrusting occurred after the deposition of the Hoko River Formation and before the deposition of the Makah Formation. These faults do not reach the overlying Makah Formation or the underlying Lyre Formation (Figure 53)(Snavely and others, 1986). There is a local angular unconformity between the Hoko River Formation and the Makah Formation in the Seiku area.

A final structural event, described by Moyer (1985), was the bending about a vertical axis of the western portion of the northern Olympic Peninsula (from Cape Flattery to Pysht), which produced the 40 degrees of clockwise rotation that was recorded in the magnetization of the Hoko River Formation and Makah Formation sediments (Figure 54). Folds and faulting possibly associated with this event are found in the Clallam Formation, suggesting that this deformation occurred after the deposition of the Miocene Clallam Formation (Moyer, 1985).

Figure 52. Bedrock geology of a portion of the Crescent terrane, the northwestern Olympic Peninsula from Snavely and others (1980). Note the discontinuous outcrop pattern of the Lyre Formation. It is probable that this formation was deposited on an undulating surface formed by prior folding of the Crescent and Aldwell Formations. Area enclosed by rectangle is the region shown in figure 53.

Tp	Pysht Formation	
Tm	Makah Formation	
Th	Hoko River Formation	North and east of the Crescent thrust fault
Tl	Lyre Formation	
Ta	Aldwell Formation	
Tcr	Crescent Formation	
	thrust fault	
	fault - movement unknown	
U / D	fault - upthrown (U) and downthrown (D) sides labelled	
	left lateral strike-slip fault	


STRAIT OF JUAN DE FUCA
NEAH BAY
0
5 Km

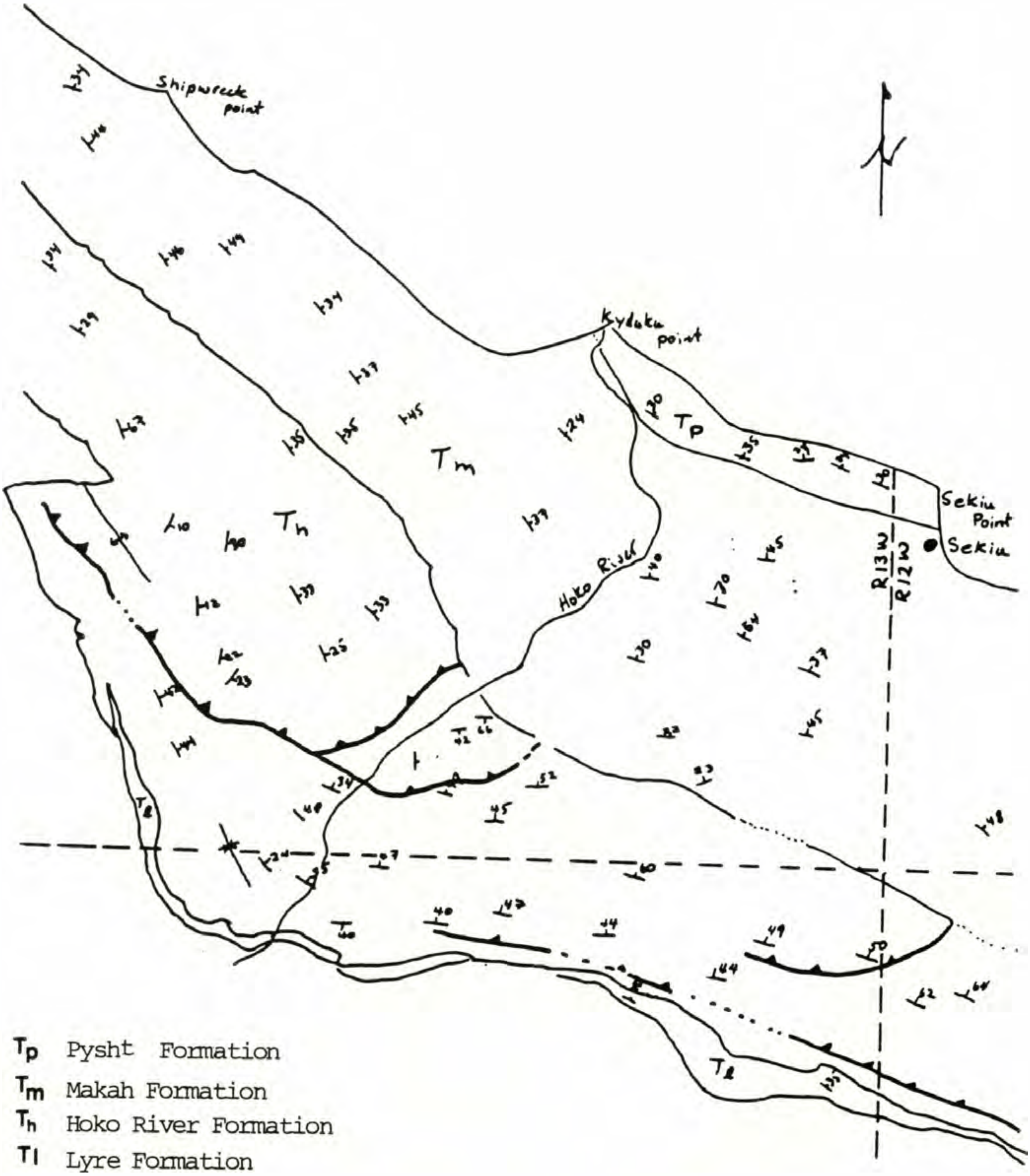


Figure 53. Sketch map of the bedrock geology in the Sekiu area, northern Olympic Peninsula (Snavely and others, 1986). The purpose is to show the location of the thrust faults contained in the Hoko River Formation.

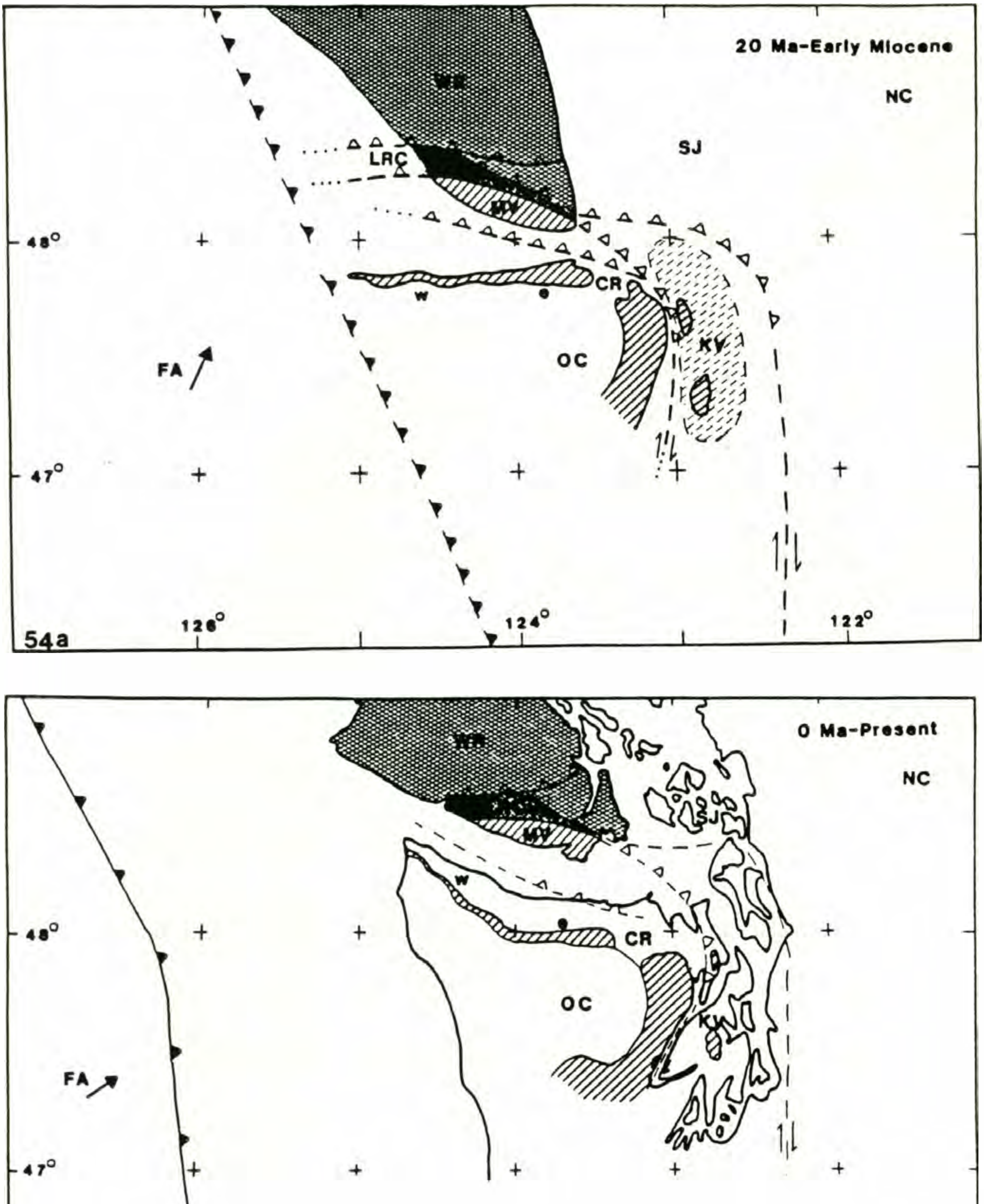


Figure 54a and b. Paleomagnetic reconstruction from Moyer (1985) depicting the 40 degrees of clockwise rotation of the western half of the northern Olympic Peninsula that occurred between 20 Ma and the present. Figure 54a represents geology in a pre-rotational setting and figure 54b presents the geology after this rotation occurred.

Depositional History of the Hoko River Formation

The upper Eocene Hoko River Formation formed in marine waters of bathyal depths (Rau, 1964; Snavely and others, 1978; Ansfield, 1987). The rocks were deposited in inner fan followed by middle fan depositional environments at the Neah Bay section and middle fan depositional environments elsewhere (Figure 18, p. 52). The Hoko River Formation was deposited in progressively quieter, deeper water, indicating either subsidence of the basin or a rise in sea-level during deposition.

A proximal source is indicated for the Neah Bay exposures because of very large (greater than 2 m) angular clasts. These are concentrated in debris flows, indicative of slumping and mobilization of previously deposited sediments (Ansfield, 1987). The Agate Beach and Elwah River conglomerates are well-rounded and well-sorted, suggesting longer transport before reaching the submarine fan comlex. The variations in percentages of two lithic types suggest that two submarine fan complexes were actively depositing sediment. One was contributing sediment to the Elwah River and Morse Creek areas, and the other was actively depositing everywhere else.

The composition of sand grains suggests that southern Vancouver Island was the source of the Hoko River Formation. But, because there are no lithic types in the Hoko River Formation that definitively tie the Hoko River Formation to southern Vancouver Island, other sources are possible. Southern Vancouver Island is favored because it provides a good match petrologically, it is proximal to the Hoko River Formation, and no contra-indications in clast type were found. In addition, current indicators show the dominant direction of flow was from the north and west to the south and east. Vancouver Island lies to the north and northwest of the present-day Olympic Peninsula.

Sea Level Changes

The sea level curves of Vail and others (1977) indicate that during the deposition of the Hoko River Formation (Bartonian) sea level was rising very slowly (Figure 55). Sea-level changes of larger magnitude occurred during the deposition of the upper Eocene to middle Oligocene (Bartonian to Chattian) Makah Formation. These are not tied to depositional changes in the Makah Formation; it was deposited entirely within a deep marine environment (Snavely and others, 1980). Because relatively large sea level changes caused no apparent change in the depositional environment of the Makah Formation, the lesser sea-level change during deposition of the Hoko River Formation was probably not an important cause of changes in depositional style. This conclusion agrees with the conclusions that Armentrout (1988) drew for south-western Washington; he concluded that the transgressive and regressive cycles present in the Tertiary of south-west Washington were not controlled by global climatic changes.

The depositional environment of the Hoko River Formation at the Neah Bay site changed from inner to middle fan, which indicates a local deepening of the basin. As a sea level change does not appear responsible for this change, subsidence of the basin is indicated.

Depositional History of the Crescent Terrane

The Hoko River Formation and other formations of the Crescent terrane represent the middle Eocene to early Miocene geologic history of the northern Olympic Peninsula. The lowest member of the Crescent terrane is the lower to middle Eocene Blue Mountain unit. It is a continentally-derived middle fan sequence (Cady, 1975). The Coast Plutonic Complex and San Juan Islands were sources of sediment to the Blue Mountain unit

Global Cycles of Sea Level Changes

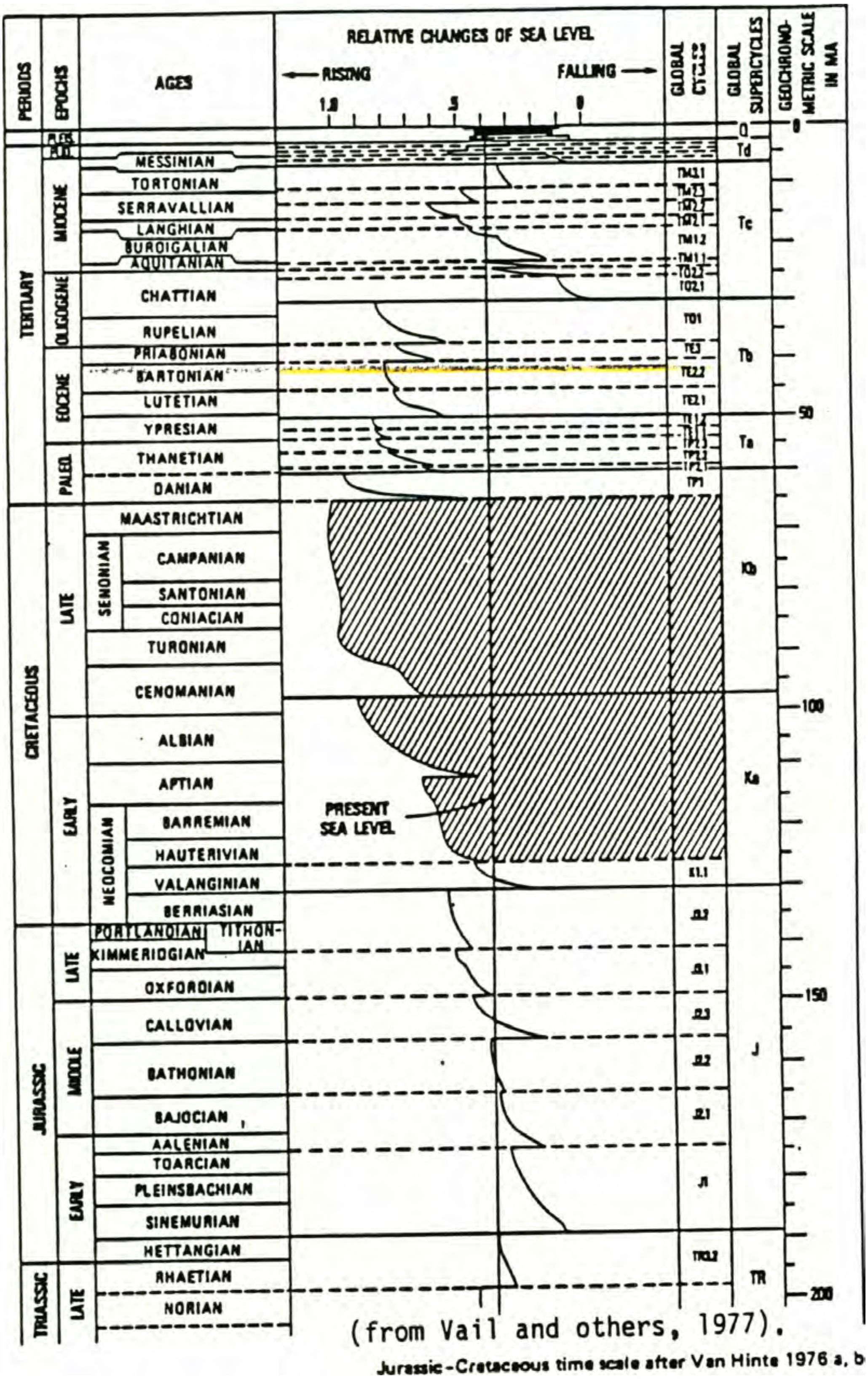


Figure 55. Global cycles of sea level change from Vail and others (1977). The time of deposition of the Hoko River Formation, late Eocene, is shaded.

(Einarsen, 1987). Two distinct petrofacies (one plagioclase-rich and the other chert-rich) were found along with a third facies (composed of equal amounts of the previous two)(Einarsen, 1987). These petrofacies implie that sediment from at least two transport and depositional systems was being mixed in the Juan de Fuca basin during the middle Eocene (Einarsen, 1987). The two petrofacies are heterogenously mixed both stratigraphically and by sample location (Einarsen, 1987). The Blue Mountain unit underlies and interfingers with the basalts of the Crescent Formation (Einarsen, 1987; Tabor and Cady, 1978).

The lower to middle Eocene Crescent Formation marks a time of general shoaling from basalt pillows with interbedded limestone to subaerial basaltic flows (Tabor and Cady, 1978). The emplacement of the basalts of the Crescent Formation disrupted sedimentation patterns in the basin. The origin of the Crescent Formation is under much dispute, see Snavely and others (1983), Wells and others (1984), Einarsen (1987), Einarsen and Engebretson (1987), Armentrout (1988), and Clark (1989). A marginal basin, possibly associated with the passage of the Kula-Farallon Ridge is the model preferred by Wells and others (1984), Einarsen and Engebretson (1987), and Clark (1989) for the formation of the Crescent Formation.

The Juan de Fuca basin is an informal name used here to refer to the basin into which the sedimentary units of the Crescent terrane were deposited with the Crescent Formation as the basement. This basin is similar to the Tofino-Juan de Fuca basin of Snavely and others (1983) but differs in its extent and sedimentation patterns (see Figure 56 for comparison of the two). The Tofino-Juan de Fuca basin extends from the Brooks Peninsula, Vancouver Island, to the Lyre River, on the Olympic Peninsula. The Juan de Fuca basin extends from Sequim Bay on the Olympic Peninsula westward along the coast of Vancouver Island a distance of

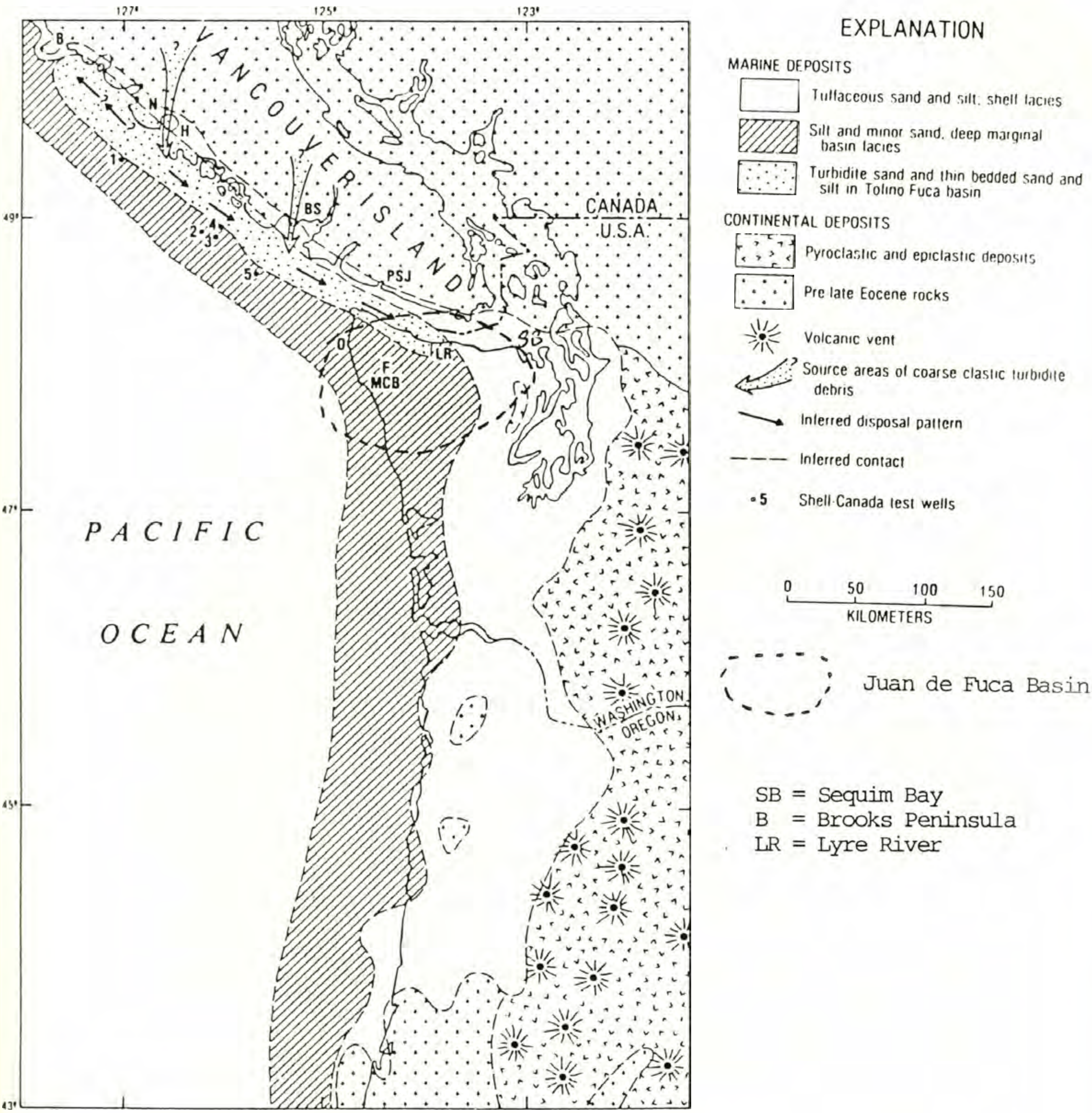


Figure 56. This diagram shows the relative sizes and locations of the Tofino-Juan de Fuca basin of Snavely and others (1980) and the Juan de fuca baisn of this project. Use for reference. After Snavely and others (1980).

approximately 150 km (Figure 56). The Tofino-Juan de Fuca basin of Snavely and others (1983) refers to the latest Eocene and early Oligocene, while Juan de Fuca basin covers the middle late Eocene to the early Miocene. Lastly, the Tofino-Juan de Fuca basin is correlated to a number of deep marginal basins along the coast of western North Amercia and such correlations are not sought by the author of this projcet. Therefore, the term Juan de Fuca basin will be used.

The lower to middle Eocene Aldwell Formation overlies and interfingers with the Crescent Formation. Its western half is a chert-rich lithic arenite derived from southern Vancouver Island, and its eastern half is a basaltic lithic arenite derived from the rocks presently found near Striped Peak (Marcott, 1984). No sites contain both petrofacies. The western petrofacies of Marcott (1984) is the chert-rich petrofacies, which is the opposite of the results for the Hoko River Formation. The Juan de Fuca basin may have had a geographic high dividing it into eastern and western halves during deposition of the Aldwell Formation. The Aldwell Formation was deposited as outer fan and basin plain deposits on the fringes of a submarine fan (Marcott, 1984). Bathyal depths are indicated by the associated foraminifera (Rau, 1964). The fine sediment size in most of the Aldwell Formation suggests a distal source area. Tectonism in the Striped Peak area produced debris flows in the eastern field area, indicating a local uplift.

The upper Eocene Lyre Formation was derived from southern Vancouver Island (Ansfield, 1972). Its lateral equivalent, the upper Eocene Flattery breccia, was derived from southern Vancouver Island (Ansfield, 1972; A.B. Shilhanek, personal communication, 1989). Both were deposited in much shallower water than the Aldwell Formation, on the apron of a fan-delta (Ansfield, 1972; A.B. Shilhanek, personal communication, 1988), respectively. Shallowing of the basin may have occurred before the deposition of the Lyre Formation. Alternately, an increase in the sedimentation rate may have produced a shallow system through rapid progradation of the fan-delta. Because the Lyre Formation and the Flattery breccia are comprised of coarse sediment, dramatic uplift in the source area and subsequent erosion were probably significant processes during the late Eocene.

The upper Eocene Hoko River Formation also was derived from southern Vancouver Island and was deposited at outer neritic to bathyal depths in middle-fan channels, inner-fan channels and depositional lobes (Figure 57). Distal facies overlie proximal facies indicating channel switching, subsidence or tectonic downwarping, since sea level rose only slightly during deposition. The Hoko River Formation was deposited in deeper water than the Lyre Formation and Flattery breccia, although not as deep as the Aldwell Formation (Rau, 1964).

The Hoko River Formation is composed of siltstone, sandstone and conglomerate, a change from the coarser sediment of the upper Lyre Formation. The gradational nature of this change is apparent at the Neah Bay, Hoko River, Burnt Mountain Road, and Old Elwah River sections (Figure 18, p.52). At these locations coarse sedimentation gradually waned and fine sedimentation took over (see Depositional Environments Chapter). The Juan de Fuca basin was receiving sediment from Vancouver Island as recorded by the petrology of the Hoko River Formation sediments.

The late Eocene and Oligocene Makah Formation marks continued bathyal deposition on middle-fan depositional lobes and channels (Snavely and others, 1980) in the Juan de Fuca basin. Its contact with the Hoko River Formation is gradational and mainly conformable, except locally (see

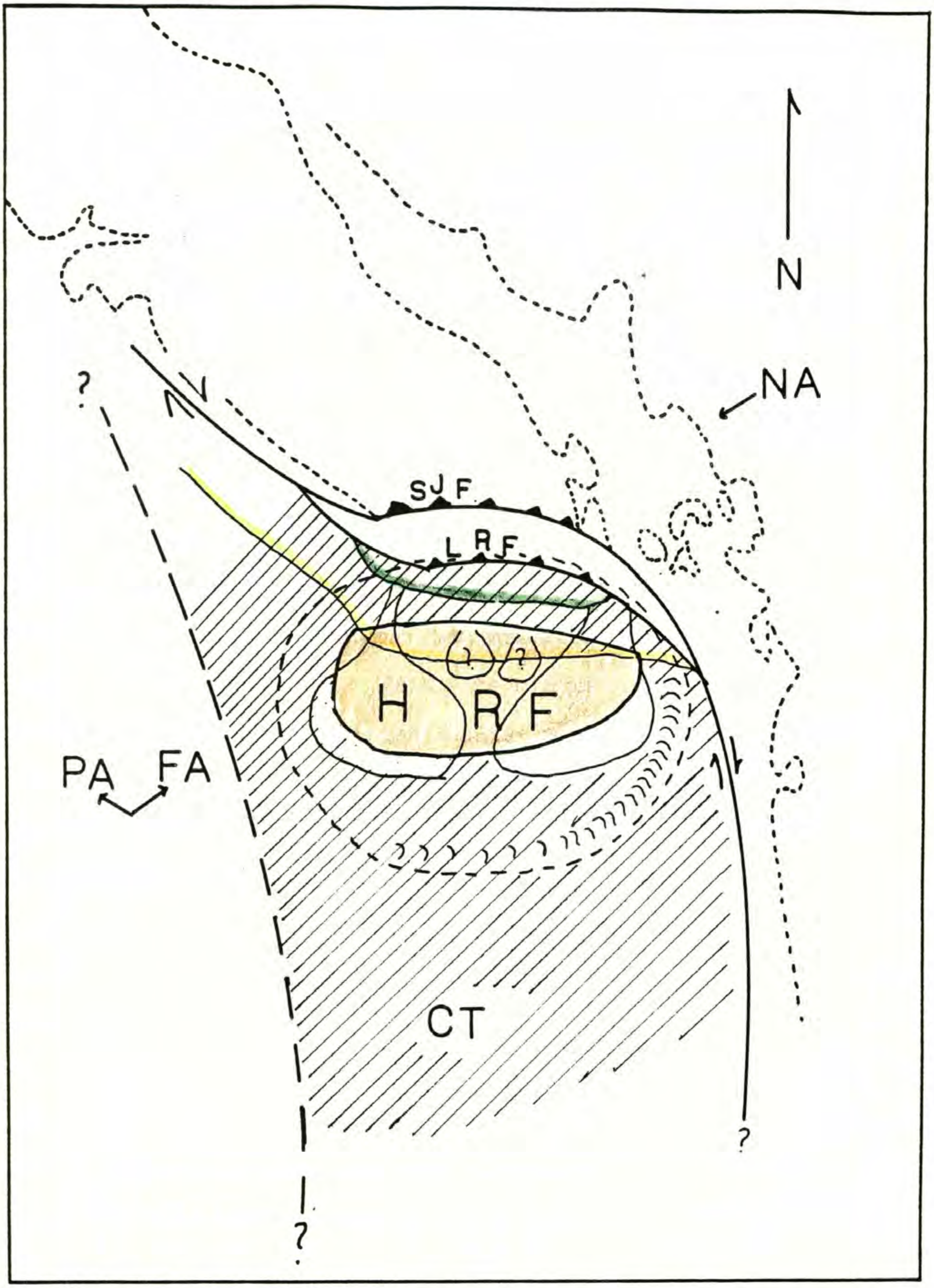
Figure 57. Paleogeographic reconstruction of deposition of the Hoko River Formation into the Juan de Fuca basin at 40 Ma ± 1.

The present day coastline is dashed in for reference.

The Hoko River Formation was deposited in the Juan de Fuca basin as middle fan and inner fan deposits on a submarine fan complex. Sediment was derived from southern Vancouver Island. The strandline and shelf-slope break are drawn in for reference.

Relative velocity vector for North America (NA), the Pacific (PA), and the Farallon (FA) plates were added to help describe the tectonic regime (Engebretson and others, 1985). The location of the PA-FA-NA triple junction is not known.

▬▬	strandline
▬▬	shelf-slope break
------	outline of the Juan de Fuca basin
CT	Crescent terrane
SJF	San Juan fault
LRF	Leech River fault
HRF	Hoko River Formation
))))	Submarine ridge or landform capable of separating the Juan de Fuca basin from other depositional basins.


N
NA
SJF
LRF
HRF
PA
FA
CT
?
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?
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Depositional Environments Chapter). The Carpenter Creek member, a tuff, marks silicic volcanic activity. Southern Vancouver Island is also the probable source of sediment to the Makah Formation (Snavely and others, 1980).

The upper Oligocene Pysht Formation was deposited in a deep marine environment (Snavely and others, 1983) that shoaled upward to shallow marine at the top (Anderson, 1985). Snavely and others (1983) concluded that the Pysht was derived from southern Vancouver Island and that the shallow marine fauna and rip-up clasts were transported down a submarine channel system into the deep marine environment.

Gradationally overlying the Pysht Formation is the lower Miocene Clallam Formation. This formation contains a number of shoaling-upward sequences within a prograding deltaic environment (Anderson, 1985). The formation was deposited within shallow marine and deltaic distributary-mouth environments (Anderson, 1985). The sources for sediment include southern Vancouver Island, the San Juan Islands, and the Cascade Range (Anderson, 1985). Anderson (1985) recognized a continuum of deposition from the upper Pysht Formation into the Clallam Formation; they are both part of a shallow marine sequence.

CONCLUSIONS

The Hoko River Formation is a thick sequence of marine sedimentary rocks located on the northern Olympic Peninsula. It is composed of massive siltstone, turbidites, conglomerate channels, and debris flows. Depositional facies found in the Hoko River Formation are middle fan channels, middle fan depositional lobes, interchannel deposits on the middle fan, and inner fan channel debris flows and slumping. The formation records subsidence of the western-most depositional basin.

The most common current indicators used are pebble and cobble imbrications from inner-fan channels and debris flows. Rare lineations from the bottoms of sandstone beds are the other source of current indicators. Overall, the current seems to have flowed from the north and west to the south and east.

The Hoko River Formation is a medium- to very coarse-grained lithic arenite ($Q = 29 \pm 14$ %, $F = 15 \pm 9$ %, $L = 55 \pm 12$ %). Dominant lithic components are basalt, metasedimentary lithics, chert, polycrystalline quartz, metavolcanic fragments, and felsic and intermediate plutonic and volcanic fragments. Lithic compositions do not vary from east-to-west except that a significantly greater percent of chert was found from the Elwah River eastwards. The grains range from spherical and very well-rounded, to elongate and well-rounded to moderately spherical and angular. This range of textures suggests a mixing of sources.

Petrologic data allow constraints on possible source areas for the Hoko River Formation, although no unique determination can be made. The Hoko River Formation could have been derived from an exotic source; however, a local source seems more likely, given the paleocurrent data and the variety of source areas near at hand.

The Olympic Core terrane cannot be a source because of age incompatabilities and the lack of basalt, chert, polycrystalline quartz, metavolcanics and metasediments in the Core during the late Eocene. The Hoko River Formation contains too few potassium feldspar grains to have been derived from the Coast Plutonic Complex. The San Juan Islands can be ruled out on the basis of their distinctive lawsonite-prehnite-aragonite assemblage. While prehnite has been recognized in rare Hoko River samples, lawsonite and aragonite have not been recognized in the Hoko River Formation. Also, graphitic phyllites and schists and slightly metamorphosed basalts, common in the Hoko River Formation, are not found in the San Juan Islands.

The Northwest Cascades comprise a diverse suite of rocks that seem to provide all of the lithic varieties described for the Hoko River Formation. However, the Hoko River Formation lacks the distinctive high-pressure, low-temperature, blue-schist assemblages found in the Northwest Cascades. Also, the Chuckanut fluvial system was active and draining the Northwest Cascades during the late Eocene. Sediment coming from the Northwest Cascades must have passed through this system. Petrographic data from the Chuckanut and Hoko River Formations do not overlap when plotted on the same discrimnatory ternary diagrams. This dissimilarity is strong evidence that the Hoko River Formation was not derived from the Northwest Cascades.

Southern and central Vancouver Island could have provided all of the lithologies found in the Hoko River Formation in approximately the correct proportions. Formations and units that probably contributed sediment to the Hoko River Formation are the following: Metchosin and meta-Metchosin volcanics; Karmutsen Formation; the Leech River Complex; Island and Catface Intrusions; Bonanza Group; West Coast Crystalline Complex; the

Nanaimo Group; and the Sicker Group.

Earliest evidence for deposition into the Juan de Fuca basin began with the Blue Mountain unit. This unit was derived from the Coast Plutonic Complex and the San Juan Islands (Einarsen, 1987). The deposition of the Crescent Formation interupted sedimentation patterns within the basin. After this, the Juan de Fuca basin existed as a persistant geomorphic feature to the south of southern and central Vancouver Island. Sedimentation into the Juan de Fuca basin from late Eocene through Oligocene was derived from southern Vancouver Island. The Juan de Fuca basin was isolated from the basin receiving distal sediments of the Chuckanut fluvial system from the late Eocene (Lyre Formation) through the late Oligocene (Pysht Formation) time. The Miocene Clallam Formation may have been derived from the North Cascades (Anderson, 1985), which would indicate a change in sedimentation patterns.

The late Eocene Escalante Formation of the Carmanah Group may be a lateral or distal equivalent of the Hoko River Formation. A petrologic comparison of the Hoko River Formation and the Carmanah Group would test this hypothesis.

The Hoko River Formation is composed of sedimentary rocks deposited in the middle- and inner-fan environments of one or two submarine fans. Sandstone composition shows that the source areas for the Hoko River Formation were terranes of southern and central Vancouver Island. Petrologic differences between the Hoko River Formation and coeval sandstone units indicate that rivers draining the North Cascades did not supply the Hoko River Formation with sediment and probably drained to the south of the Juan de Fuca basin.

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APPENDICES

APPENDIX 1 WHOLE ROCK COUNT DATA: RAW DATA

Sample Number	Qm	K	P	Ch	Acc	C	M	Lt	O	E-Amp	Total
MC-06	5	0	7	9	5	32	16	225	1	0	300
MC-16	35	0	24	4	1	0	10	224	1	1	300
MC-18	12	0	9	3	1	66	3	197	9	0	300
MC-36	32	0	3	0	0	48	8	208	1	0	300
MC-41	40	2	21	0	0	0	38	198	0	1	300
MC-42	30	0	29	2	6	0	47	180	0	6	300
ER-07	65	0	23	6	1	71	0	132	0	2	300
ER-08	48	1	13	1	7	80	0	150	0	0	300
ER-20	43	1	5	1	0	138	0	112	0	0	300
ER-25	46	2	15	3	1	72	0	161	0	0	300
ER-26	52	2	4	1	4	74	1	152	0	1	291
ER-27	40	3	6	0	6	0	33	210	2	0	300
FC-13	34	9	49	20	3	0	24	138	17	6	300
FC-19	20	3	32	0	1	119	3	116	2	4	300
FC-20	30	8	51	18	7	0	41	126	17	2	300
FC-22	22	15	62	3	8	0	31	148	4	6	300
FC-27	30	6	62	15	7	0	60	91	23	6	300

Sample Number	Qm	K	P	Ch	Acc	C	M	Lt	O	E-Amp	Total
CB-07	66	0	28	2	4	82	3	108	1	16	310
CB-08	71	2	21	0	0	66	6	113	12	9	300
CB-11	48	4	38	1	10	82	1	108	3	12	307
CB-12	9	1	50	5	21	76	0	113	0	30	305
WAB-01	34	1	30	9	15	69	9	112	0	21	300
WAB-04	23	3	56	11	24	65	0	98	0	20	300
WAB-05	10	2	31	7	20	85	0	134	1	10	300
TR-01	57	0	35	3	12	0	25	168	18	0	318
WTR-39J	34	1	34	3	0	4	0	171	29	23	299
WTR-43J	23	1	26	35	7	51	7	145	5	0	300
WTR-44	19	1	30	1	8	42	0	188	0	11	300
WTR-47	21	1	80	14	20	1	0	133	19	11	300
BMR-52	69	0	31	3	6	0	5	154	4	27	300
BMR-53	79	1	15	4	5	0	3	179	2	12	300
BMR-54	56	1	9	0	6	0	2	204	17	5	300
BMR-55	70	2	25	10	5	0	0	180	3	5	300
BMR-58	47	0	23	3	1	0	1	171	3	2	300
HR-08	63	1	14	5	7	0	2	192	12	4	300
HR-10	35	1	18	2	15	1	24	190	1	13	300
HRR-02	10	1	31	16	3	65	10	153	1	10	300
HRR-10	12	0	27	10	13	0	151	96	1	40	350
HR-45B	32	2	28	8	9	58	8	145	1	9	300

APPENDIX 1 CONTINUED: WHOLE ROCK COUNT DATA: RAW DATA

Sample Number	Qm	K	P	Ch	Acc	C	M	Lt	O	Amp-E	Total
FSB-04	36	1	50	22	10	59	1	119	0	2	298
FSB-11	30	0	27	8	11	56	35	134	0	0	301
FSB-16	31	2	29	8	10	83	0	135	0	2	300
CF-01	50	0	70	3	12	28	0	121	0	15	300
CFT-01	28	2	41	22	6	75	2	124	0	0	300
CFT-09	39	0	41	21	40	43	38	78	0	0	300
CFT-11B	27	0	33	8	12	77	24	119	0	1	300
CFT-32	31	0	38	5	4	37	25	160	0	0	300
CFT-57	29	2	21	19	13	36	58	122	0	0	300
CFT-61	31	1	28	10	5	111	0	109	0	5	300
CFT-62	44	2	32	2	13	54	24	129	1	6	307

Qm = Monocyrstalline quartz
K = Potassium feldspar
P = Plagioclase feldspar
Ch = Chlorite
Acc = Accessory minerals except where counted separately
CC = Calcite cement
M = Matrix
Lt = Total Lithics
O = Other Lithics
Amp-e = Amphibole and epidote
Total = Total number of points in the whole rock count

APPENDIX 2 WHOLE ROCK COUNT DATA: PERCENTAGES

Sample Number	Qm	K	P	Ch	Acc	Cc	M	Lt	O	E-Amp	Total
MC-06	2	0	2	3	2	11	5	75	0	0	100
MC-16	12	0	8	1	0	0	3	75	0	0	99
MC-18	4	0	3	1	0	22	1	66	3	0	100
MC-36	11	0	1	0	0	16	3	69	0	0	100
MC-41	13	1	7	0	0	0	13	66	0	0	100
MC-42	10	0	10	1	2	0	16	60	0	2	101
MEAN	10	0	5	1	1	8	7	68	1	0	
STD.DEV.	4	0	4	1	1	10	6	6	1	1	
ER-07	22	0	8	2	0	24	0	44	0	1	101
ER-08	16	0	4	0	2	27	0	50	0	0	99
ER-20	14	0	2	0	0	46	0	37	0	0	99
ER-25	15	1	5	1	0	24	0	54	0	0	100
ER-26	18	1	1	0	1	25	0	52	0	0	98
ER-27	13	1	2	0	2	0	11	70	1	0	100
MEAN	16	1	4	1	1	24	2	51	0	0	
STD.DEV.	3	1	3	1	1	15	4	11	0	0	
FC-13	11	3	16	7	1	0	8	46	6	3	98
FC-19	7	1	11	0	0	40	1	39	1	1	101
FC-20	10	3	17	6	2	0	14	42	6	1	101
FC-22	7	3	21	1	3	0	10	49	1	2	97
FC-27	10	2	21	5	2	0	20	30	8	2	100
MEAN	9	2	17	4	6	8	7	41	4	2	
STD.DEV.	2	1	4	3	2	18	6	8	3	1	
CB-07	21	0	9	1	1	26	1	35	0	5	99
CB-08	24	1	7	0	0	22	2	38	4	3	101
CB-11	16	1	13	0	3	27	0	36	1	4	101
MEAN	14	1	12	1	3	25	1	37	1	6	
STD.DEV.	11	1	4	1	3	2	1	2	2	3	
WAB-01	11	0	10	3	5	23	3	37	0	7	99
WAB-04	8	1	19	4	8	22	0	33	0	7	102
WAB-05	3	1	10	2	7	28	0	45	0	3	99
MEAN	7	1	13	3	7	24	1	38	0	6	
STD.DEV.	4	1	5	1	4	3	2	4	0	2	
TR-01	18	0	11	1	4	0	8	53	6	0	101
WTR-39J	11	0	11	1	0	1	0	57	10	8	99
WTR-43J	8	0	9	12	2	17	2	48	2	0	100
WTR-44	6	0	10	0	3	14	0	63	0	4	100
WTR-47	7	0	27	5	7	0	0	44	6	4	100
MEAN	10	0	14	4	3	6	2	53	5	3	
STD.DEV.	5	0	7	5	3	8	3	7	4	3	

APPENDIX 2 CONTINUED: WHOLE ROCK COUNT DATA: PERCENTAGES

Sample Number	Qm	K	P	Ch	Acc	Cc	M	Lt	O	E-Amp	Total
BMR-52	23	0	10	1	2	0	2	51	1	9	100
BMR-53	26	0	5	1	2	0	1	60	1	4	100
BMR-54	19	0	3	0	2	0	1	68	6	2	101
BMR-55	23	1	8	3	2	17	0	60	1	2	100
BMR-58	16	0	8	1	0	0	0	57	1	1	101
MEAN	21	0	7	1	2	3	1	59	2	4	
STD.DEV.	4	0	3	1	1	7	8	6	2	3	
HR-08	21	0	5	2	2	0	1	64	4	1	100
HR-10	3	0	8	3	4	0	43	27	0	11	99
HRR-02	3	0	10	5	1	22	3	51	0	3	98
HRR-10	3	0	8	3	4	0	43	27	0	11	99
HR-45B	11	1	9	3	3	19	3	48	0	3	100
MEAN	8	0	8	3	3	8	19	43	1	6	
STD.DEV.	8	0	2	1	1	11	20	14	2	4	
FSB-04	12	0	17	7	3	20	0	40	0	1	100
FSB-11	10	0	9	3	4	19	12	45	0	0	102
FSB-16	10	1	10	3	3	28	0	45	0	1	101
CF-01	17	0	23	1	4	9	0	40	0	5	99
CFT-01	9	1	14	7	2	25	1	41	0	0	101
CFT-09	13	0	14	7	14	14	13	26	0	0	101
CFT-11B	9	0	11	3	4	26	8	40	0	0	101
CFT-32	10	0	13	2	1	12	8	53	0	0	99
CFT-57	10	1	7	6	4	12	19	41	0	0	100
CFT-61	10	0	10	3	2	37	0	36	0	2	100
CFT-62	14	1	10	1	4	18	8	42	0	2	100
MEAN	10	0	13	4	4	20	6	41	0	1	100
STD.DEV.	2	1	4	2	3	8	7	7	0	2	

HOKO RIVER FORMATION TOTAL

	Qm	K	P	Ch	Acc	Cc	M	Lt	O	E-Amp
MEAN	12	.5	10	2	3	14	5	49	1	2
STD.DEV.	6	1	6	3	3	13	8	13	2	3

APPENDIX 3 LITHIC COUNT: RAW DATA

Sample	Lgran	Ldior	Lgab	Lmsp	Lmv	Lms	Lsed	Fssl	Other	Amp/ep	Chert	Qp	Lvm	Lvi	Lvf	Lvgl	Total
MC-06	0	0	0	7	2	0	67	1	2	0	14	5	37	7	4	54	200
MC-16	1	3	0	31	44	5	0	0	0	1	54	32	14	3	12	0	200
MC-18	0	0	0	0	1	2	40	2	10	0	4	3	23	0	2	113	200
MC-36	1	0	0	35	37	2	34	0	6	0	28	11	25	2	4	15	200
MC-41	5	6	0	3	49	17	23	0	1	0	31	29	10	7	17	2	200
MC-42	0	14	0	19	44	2	1	0	0	8	49	40	5	5	2	11	200
ER-07	5	3	0	48	39	3	2	3	2	1	39	34	6	6	6	3	200
ER-08	6	0	0	34	59	3	0	2	3	4	33	34	10	2	9	1	200
ER-20	0	1	0	29	95	13	1	0	0	0	40	18	2	0	4	1	204
ER-25	0	1	0	26	63	6	2	0	0	0	35	33	23	2	3	6	200
ER-26	6	5	0	26	72	10	0	0	0	1	30	20	9	0	18	3	200
ER-27	1	1	0	14	10	10	1	0	2	0	58	52	28	10	23	7	217
WAB-01	11	34	1	30	10	11	0	0	3	3	3	6	68	1	9	10	200
WAB-04	16	20	8	36	1	16	0	0	5	8	0	9	68	0	5	10	203
WAB-05	7	12	1	37	11	18	0	0	0	0	0	2	92	2	3	15	200
CB-07	5	15	16	58	39	27	1	0	0	0	14	18	9	3	4	4	203
CB-08	4	3	14	62	31	20	0	0	13	1	6	31	10	0	3	3	201
CB-11	7	13	2	61	1	11	0	0	2	4	23	23	26	5	17	5	200
CB-12	1	9	37	5	0	28	0	0	0	0	0	1	98	3	10	8	200
FC-13	14	18	0	73	42	10	0	0	3	3	8	7	22	0	0	1	200
FC-19	10	20	0	58	50	3	6	0	4	9	8	7	20	0	4	1	200
FC-20	11	2	0	79	52	1	0	0	3	7	8	24	13	0	0	0	200
FC-22	11	2	0	79	52	1	0	0	3	7	8	24	13	0	0	0	200
FC-27	10	11	0	64	58	4	0	0	8	3	6	24	6	0	0	7	200
TR-01	10	11	0	46	28	14	0	0	30	0	3	15	35	0	0	8	200
WTR-38J	0	8	7	26	13	4	7	0	1	3	0	13	85	0	0	8	200
WTR-43J	4	4	7	6	8	2	5	0	0	0	1	15	67	47	15	16	197
WTR-44J	3	13	0	23	45	8	19	11	0	11	4	8	34	11	2	8	200
WTR-47J	0	21	8	13	5	11	9	5	2	0	1	8	73	28	4	14	202

APPENDIX 3 LITHIC COUNT: RAW DATA (continued)

Sample	Lgran	Ldior	Lgab	Lmsp	Lmv	Lms	Lsed	Fssl	Other	Amp/ep	Chert	Qp	Lvm	Lvi	Lvf	Lvgl	Total
BMR-52	0	2	1	80	53	7	0	0	2	5	9	13	18	11	5	4	200
BMR-53	1	7	0	100	30	3	0	0	0	2	8	18	14	8	5	4	200
BMR-54	0	0	0	81	44	32	0	0	0	2	3	19	5	0	31	11	200
BMR-55	1	1	0	87	22	21	0	0	0	6	18	28	13	0	0	3	200
BMR-58	1	11	0	74	43	4	2	0	0	5	11	31	15	0	0	3	200
HR-08	4	2	0	45	40	26	2	0	0	3	19	26	29	0	1	3	200
HR-10	6	13	14	2	2	38	6	1	5	4	1	3	80	0	12	14	201
HRR-10	1	17	3	14	8	4	60	0	1	2	0	1	45	26	2	16	200
HRR-02	6	18	1	6	6	7	20	17	0	4	0	2	79	10	6	27	209
HR-45B	3	33	0	39	29	8	8	1	9	3	11	27	21	1	3	4	200
FSB-16	4	23	0	35	42	8	0	1	0	2	39	31	7	0	7	0	200
FSB-04	8	18	0	49	51	21	0	0	3	0	7	33	1	3	6	1	201
FSB-11	11	7	2	54	32	17	1	0	0	3	23	25	13	3	8	1	200
CFT-01	3	14	9	14	25	17	8	0	2	0	21	41	29	12	4	1	200
CF-01	0	40	0	13	23	5	2	0	0	1	38	26	33	1	18	0	200
CFT-09	31	60	0	7	23	8	0	0	0	0	18	15	24	6	8	0	200
CFT-11B	10	16	1	50	47	15	0	1	6	0	23	14	10	3	1	30	200
CFT-32	5	24	0	35	30	17	25	0	2	0	3	15	26	10	3	5	200
CFT-57	7	9	5	32	12	7	13	0	3	0	36	31	42	4	17	4	202
CFT-61	5	22	0	57	29	21	0	0	0	2	26	10	16	0	12	2	202
CFT-62	6	45	0	51	21	11	26	5	1	2	19	13	1	7	3	0	205

Formation Mean and Standard Deviation :

	Lgran	Ldior	Lgab	Lmsp	Lmv	Lms	Lsed	Fssl	Other	Amp/ep	Chert	Qp	Lvm	Lvi	Lvf	Lvgl	Total
Mean	3	6	1	19	14	5	4	0.5	1	1	8	9	14	2	3	4	201
Std Dev.	2	7	4	13	11	5	8	2	3	2	8	6	9	4	4	9	--

LITHIC TYPES AND ABBREVIATIONS:

Lgran = felsic plutonics
Lgab = mafic plutonics
Lmv = metavolcanics
Lsed = sedimentary
Other = other
Chert = chert
Ldior = intermediate plutonics
Lmsp = graphitic phyllite and schist
Lms = metasediments (other than Lmsp)
Fssl = fossil
Amp/ep = amphibolite and epidote-rich schists
Qp = polycrystalline quartz
Lvm = mafic volcanics
Lvf = felsic volcanics
Lvi = intermediate volcanics
Lvgl = volcanic glass

APPENDIX 4 PERCENTAGES FOR LITHIC VARIATION ANALYSIS

Sample	Lvm	Lvgl	Lvfi	Lmsp	Lms	Lmst	Lmv	Cht	Qp	Lpfi	Lpg	Am-ep
MC-06	17	24	5	3	1	4	0	6	2	0	0	0
MC-16	5	0	6	12	17	29	2	21	12	1	0	0
MC-18	10	49	1	0	0	0	1	2	1	0	0	0
MC-36	11	6	3	15	16	31	1	12	5	0	0	0
MC-41	4	1	9	1	19	20	6	12	11	4	0	0
MC-42	2	4	3	7	17	24	1	19	16	5	0	3
MEAN	8	14	5	6	12	18	2	12	8	2	0	0
STD.DEV	5	19	3	6	9	13	2	7	6	2	0	1
ER-07	2	1	3	14	11	25	1	11	10	2	0	0
ER-08	3	0	4	12	20	32	1	11	12	2	0	1
ER-20	1	0	1	10	22	32	4	14	6	0	0	0
ER-25	8	2	2	9	22	31	2	12	12	0	0	0
ER-26	3	1	6	9	24	33	3	10	7	4	0	0
ER-27	10	2	12	5	4	9	4	21	19	0	0	0
MEAN	4	1	5	10	17	27	3	13	11	1	0	0
STD.DEV	4	1	4	3	8	9	1	4	5	2	1	0
CB-07	2	1	2	14	9	23	6	3	4	2	4	0
CB-08	2	1	1	16	8	24	5	2	8	2	4	0
CB-11	6	1	5	15	0	15	3	6	6	5	0	1
CB-12	24	2	3	1	0	1	7	0	0	2	9	0
MEAN	8	1	3	12	4	16	5	3	3	3	4	0
STD.DEV	10	1	2	7	5	11	2	2	4	1	4	0
WAB-01	17	2	2	8	2	10	3	1	2	11	0	1
WAB-04	14	2	1	7	0	7	3	0	2	7	2	2
WAB-05	29	5	2	11	3	14	6	0	1	6	0	0
MEAN	20	3	2	9	2	10	4	0	2	8	1	1
STD.DEV	8	2	1	2	2	4	2	1	1	3	1	1
FC-13	5	0	0	18	10	28	2	0	1	9	0	1
FC-19	6	1	1	19	16	35	1	3	2	9	0	3
FC-20	2	3	0	20	10	30	1	1	3	8	0	1
FC-22	4	0	0	22	15	37	0	2	7	4	0	2
FC-27	1	1	0	12	11	33	1	1	5	4	0	1
MEAN	4	1	0	18	12	33	1	1	4	7	0	2
STD.DEV	2	1	-	4	3	4	1	1	2	3	-	1

APPENDIX 4 (CONTINUED)

Sample	Lvm	Lvgl	Lvfi	Lmsp	Lms	Lmst	Lmv	Cht	Qp	Lpfi	Lpg	Am-ep
TR-01	17	24	5	3	1	21	0	6	2	0	0	0
WTR-39J	25	1	8	8	4	12	1	0	4	2	2	1
WTR-43J	20	5	19	2	2	4	1	0	5	2	2	0
WTR-44J	12	3	5	8	16	24	3	1	3	6	0	0
WTR-47J	16	3	7	3	1	4	2	0	2	5	2	0
MEAN	17	3	8	7	6	13	2	0	4	4	1	1
STD.DEV	6	1	7	4	6	9	1	1	1	2	1	1
BMR-52	5	1	4	20	13	33	2	2	3	1	0	1
BMR-53	4	1	4	30	9	39	3	2	5	2	0	1
BMR-54	2	4	1	28	15	43	11	1	6	0	0	1
BMR-55	4	1	0	26	7	33	6	5	8	0	0	2
BMR-58	5	1	0	25	15	40	1	4	11	4	0	2
MEAN	4	2	2	26	12	38	5	3	7	1	0	1
STD.DEV	1	1	2	4	4	4	4	2	3	2	-	1
HR-08	9	1	0	14	13	27	8	6	8	2	0	1
HR-10	11	1	3	28	11	39	3	0	8	2	0	1
HRR-02	25	9	5	2	2	4	2	0	1	8	0	1
HRR-10	19	3	3	0	0	0	9	0	1	4	3	1
HR-45B	7	1	1	12	9	21	2	3	8	11	0	1
MEAN	14	3	2	11	7	18	5	2	5	5	1	1
STD.DEV	8	3	2	11	6	16	3	3	4	4	1	0
FSB-16	2	0	2	11	13	24	2	12	10	7	0	0
FSB-04	0	0	2	12	13	25	5	2	8	7	0	0
FSB-11	4	0	4	17	10	27	5	7	8	6	1	1
CFT-01	8	0	4	4	7	11	5	6	11	5	3	0
CF-01	7	0	4	3	5	8	1	8	6	9	0	0
CFT-09	4	0	3	1	4	5	1	3	3	17	0	0
CFT-11B	3	0	1	15	14	29	3	7	4	8	0	0
CFT-32	9	2	4	12	10	22	6	1	5	10	0	0
CFT-57	11	1	6	9	3	12	2	10	8	4	1	0
CFT-61	4	1	3	16	8	24	6	7	3	7	0	1
CFT-62	0	0	3	14	6	20	3	5	4	12	0	5
MEAN	5	0	3	10	8	19	4	6	6	8	0	1
STD.DEV	4	1	1	5	4	8	2	3	3	4	1	1

HOKO RIVER FORMATION AVERAGES

	Lvm	Lvgl	Lvfi	Lmsp	Lms	Lmst	Lmv	Cht	Qp	Lpfi	Lpg	Am-ep
MEAN	8	3	3	12	9	22	3	7	6	5	1	2
STD.DEV	7	8	3	8	7	12	2	12	4	4	2	7

APPENDIX 4 (CONTINUED)

LITHIC TYPES AND ABBREVIATIONS:

POINT COUNT CATEGORIES-numbers converted to ANALYSIS CATEGORIES-percents

lvm = Lvm = mafic volcanic (Basalt)
lvg = Lvg = volcanic glass
lvf + lvi = Lvfi = felsic and intermediate volcanics
lmsp = Lmsp= graphitic schist and phyllite (Phyll)
lms = Lms1= metasedimentary lithics (Msed1)
lms + lmsp = Lmst = total metasedimentary lithics (Metaseds)
lmv = Lmv = metavolcanics (Mvol)
lpf + lpi = Lpfi = felsic and intermediate plutonics
lpg = Lpg = gabbro and diabase
chert = Cht = chert
Qp = Qp1 = polycrystalline quartz
Amp/ep= am-ep1 = amphibolite and epidote-rich schist

All of the numbers presented here are normalized based on the % of ltihic grains in the whole rock count, the total number of points in both the whole rock and lithic counts, and the number of points in the whole rock count that were neither cement nor matrix. Only some of the lithic types counted were used in this analysis. For the raw data from the lithic counts refer to Appendix 3.

The results of these analyses were used in two sets of diagrams: 1) lithic type (including standard deviation) versus west to east location and 2) 2 or 3 related lithic types versus west to east location.

N = Number of points in whole rock count
M = Number of points in the lithic count
C9 = Number of points of cement in whole rock count
C10= Number of points of matrix in whole rock count
C6 = Number of lithic in the whole rock count
Li = Number of points in the lithic count of the type you are interested in.
J = Intermediate factor

$$J = \frac{C6}{N - (C9 + C10)} \times \frac{1}{M}$$

J x Li x 100 = Li % of total grains

= percent of the lithic type one is interested in of the total grains

APPENDIX 5 MODAL PERCENTAGES FOR TERNARY PLOTS

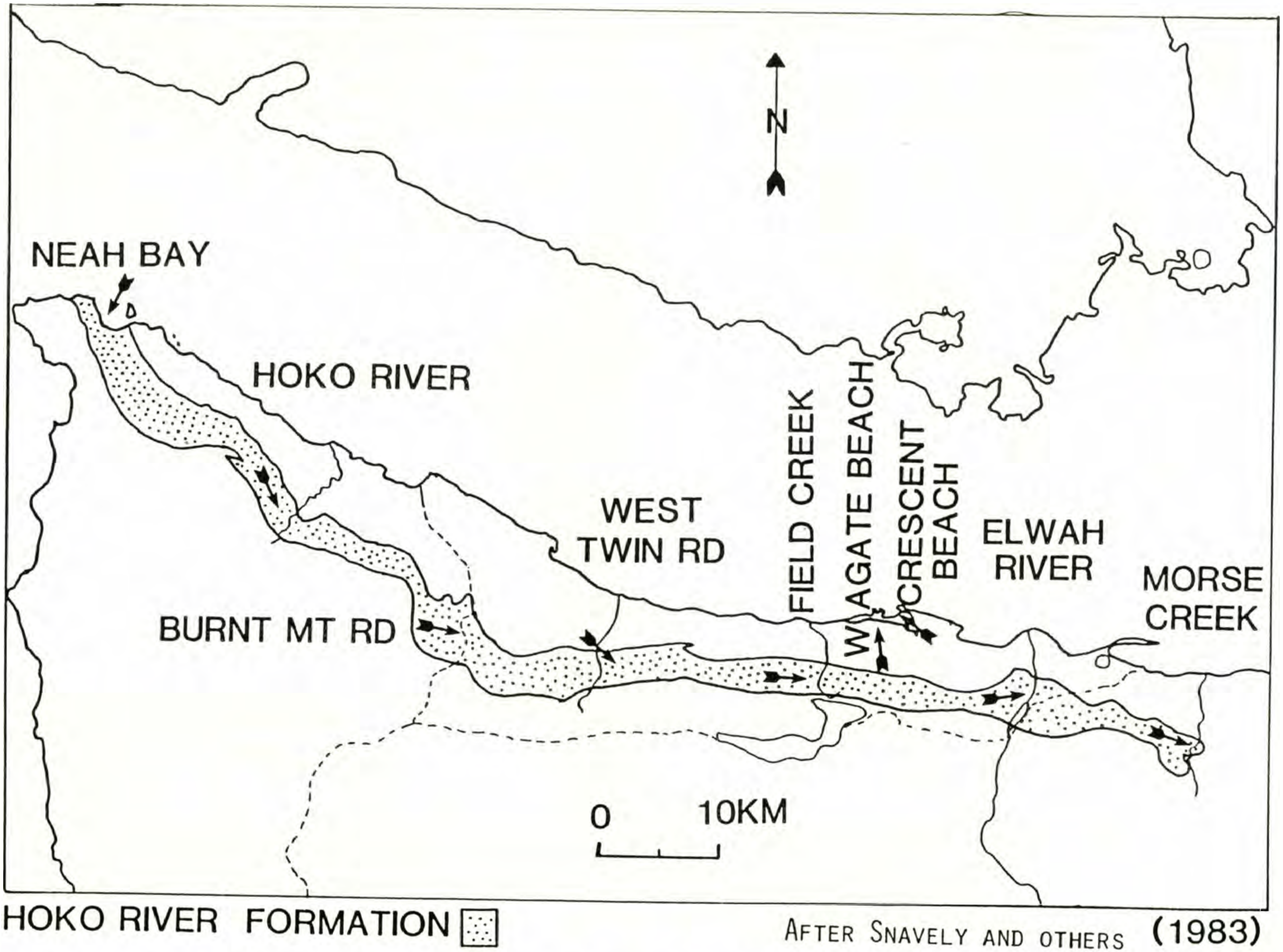
Sample Number	Q	F	L	Qm	F	Lt	Qm	P	K	Qp	Lvm	Lsm	Lm	Lv	Ls
MC-06	12	3	85	2	3	95	42	58	0	10	53	37	5	57	38
MC-16	46	9	45	12	8	79	59	41	0	44	21	35	73	27	0
MC-18	9	4	87	6	4	90	57	43	0	4	74	22	2	76	22
MC-36	31	1	68	13	1	86	91	9	0	20	29	51	48	30	22
MC-41	34	9	57	15	9	76	64	33	3	60	19	21	43	40	17
MC-42	46	12	42	13	12	75	51	49	0	50	16	34	73	26	1
MEAN	30	6	64	10	6	84	61	39	1	31	36	33	40	17	43
STD.DEV.	16	4	9	5	4	8	17	17	1	23	23	11	31	14	20
ER-07	51	10	38	30	10	60	74	26	0	39	17	43	80	18	2
ER-08	57	3	40	23	6	71	77	21	2	36	16	48	81	19	0
ER-20	47	2	51	27	4	69	88	10	2	42	17	41	72	26	2
ER-25	45	8	47	21	8	71	73	24	3	34	22	44	73	25	2
ER-26	43	3	54	25	3	72	90	7	3	34	22	44	78	18	4
ER-27	57	3	40	15	4	81	82	12	6	52	37	11	33	66	1
MEAN	50	5	45	23	6	71	81	17	3	38	42	20	70	2	28
STD.DEV.	6	3	7	5	3	7	7	8	2	7	2	8	8	1	19
FC-13	20	25	55	15	25	60	37	53	10	10	50	40	84	16	0
FC-19	17	20	63	12	20	68	36	58	6	10	41	49	78	18	4
FC-20	19	27	54	14	27	59	34	57	9	10	44	46	87	13	0
FC-22	19	31	50	9	31	60	22	63	15	18	29	53	91	9	0
FC-27	23	36	41	16	36	48	31	63	6	18	53	49	91	9	0
MEAN	20	28	52	13	28	59	32	59	9	13	39	48	86	1	13
STD.DEV.	2	6	8	3	6	7	6	4	4	4	8	5	5	2	4
CB-07	41	14	45	33	14	53	70	30	0	18	36	46	84	14	1
CB-08	44	11	45	34	11	55	76	22	2	22	32	46	88	12	0
CB-11	37	21	42	24	21	55	53	42	4	27	47	26	58	42	0
CB-12	6	29	65	5	30	65	15	83	2	1	96	3	22	78	0
MEAN	32	19	49	24	19	57	54	44	2	17	53	30	63	37	0
STD.DEV.	18	8	11	13	8	5	27	27	2	11	30	20	31	31	0
WAB-01	22	18	60	19	18	63	52	46	2	9	72	22	37	63	0
WAB-04	15	33	52	13	33	54	28	68	4	6	74	19	39	61	0
WAB-05	6	19	75	6	18	76	23	72	5	1	78	21	37	63	0
MEAN	14	23	62	13	23	64	34	62	4	4	75	21	38	62	0
STD.DEV.	8	8	12	7	9	11	15	14	2	3	3	2	1	1	0

APPENDIX 5 (CONTINUED) MODAL PERCENTAGES FOR TERNARY PLOTS

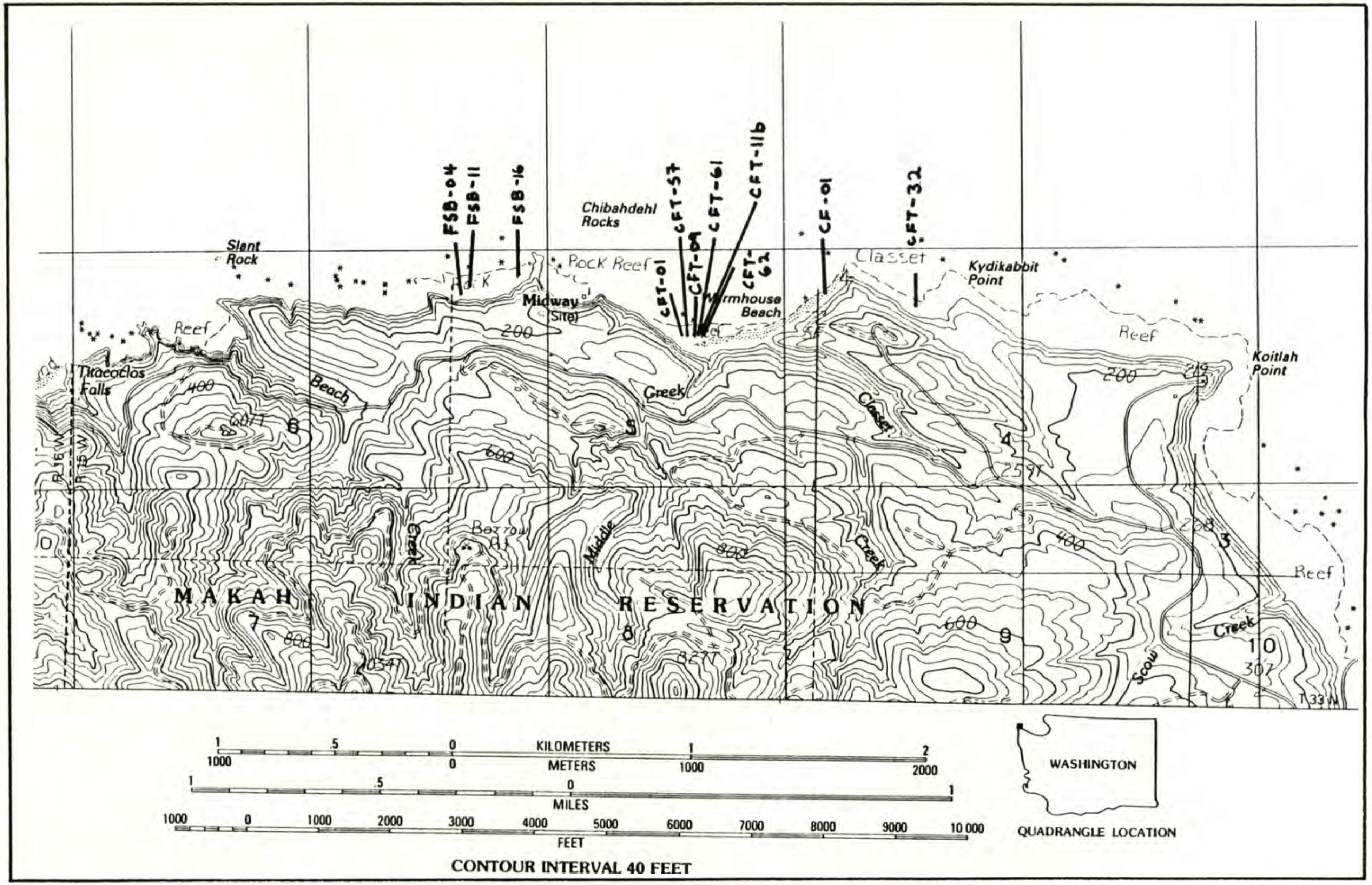
Sample Number	Q	F	L	Qm	F	Lt	Qm	P	K	Qp	Lvm	Lsm	Lm	Lv	Ls
TR-01	28	13	59	22	13	65	62	38	0	12	52	36	67	33	0
WTR-39J	19	15	66	14	15	71	49	49	2	7	74	19	26	70	4
WTR-43	18	14	68	12	14	74	46	52	2	9	83	8	10	87	3
WTR-44	13	13	74	8	13	79	38	60	2	7	45	48	51	36	13
WTR-47	11	35	54	9	34	57	20	78	1	5	82	13	18	76	6
MEAN	18	18	64	14	16	70	43	55	1	8	67	25	35	60	5
STD.DEV.	7	10	8	6	9	8	15	15	1	3	18	17	24	24	5
BMR-52	34	12	54	27	12	61	69	31	0	11	37	52	79	21	0
BMR-53	37	6	57	29	6	65	83	16	1	14	36	51	83	17	0
BMR-54	29	4	67	21	4	75	85	14	1	17	27	56	90	10	0
BMR-55	40	10	50	25	10	65	72	26	2	35	26	39	75	25	0
BMR-58	35	10	55	19	10	71	67	33	0	23	26	51	87	12	1
MEAN	35	8	57	24	8	68	75	24	1	20	30	50	83	17	0
STD.DEV.	4	3	6	4	3	6	8	9	1	9	6	6	6	6	-
HR-08	40	5	55	23	6	71	81	18	1	24	39	37	67	33	0
HR-10	23	8	69	14	8	78	65	33	2	18	40	42	72	28	0
HRR-02	6	17	77	5	17	78	24	74	2	1	80	19	15	51	34
HRR-10	10	20	70	9	20	71	31	69	0	1	55	44	12	76	12
HR-45B	30	16	54	16	14	75	52	45	3	25	33	42	67	26	7
MEAN	22	13	65	13	13	74	50	48	2	13	50	37	47	42	11
STD.DEV.	14	6	10	7	6	4	24	24	1	12	19	10	30	21	14
FSB-04	29	24	47	17	25	57	41	58	1	23	30	47	92	8	0
FSB-11	33	14	53	16	15	69	53	47	0	27	36	37	80	19	1
FSB-16	39	16	45	16	16	68	50	47	3	36	40	24	60	33	7
CF-01	37	20	34	21	29	50	42	58	0	40	39	21	43	55	2
CFT-01	34	22	44	14	22	64	39	58	3	36	40	24	51	42	7
CFT-09	33	26	41	25	26	49	49	51	0	30	45	25	50	50	0
CFT-11B	28	18	54	15	19	66	45	55	0	22	31	46	87	13	0
CFT-32	20	16	64	14	16	70	45	55	0	11	44	45	54	29	17
CFT-57	38	13	49	17	13	70	56	40	4	34	44	22	43	48	9
CFT-61	30	17	53	16	15	69	53	47	0	32	37	31	69	29	2
CFT-62	31	17	52	21	17	62	56	41	3	21	28	51	69	9	22
MEAN	32	19	49	18	20	62	48	51	1	25	36	39	65	28	7
STD.DEV.	5	5	8	3	5	8	6	7	2	11	11	6	17	16	8

HOKO RIVER FORMATION TOTAL

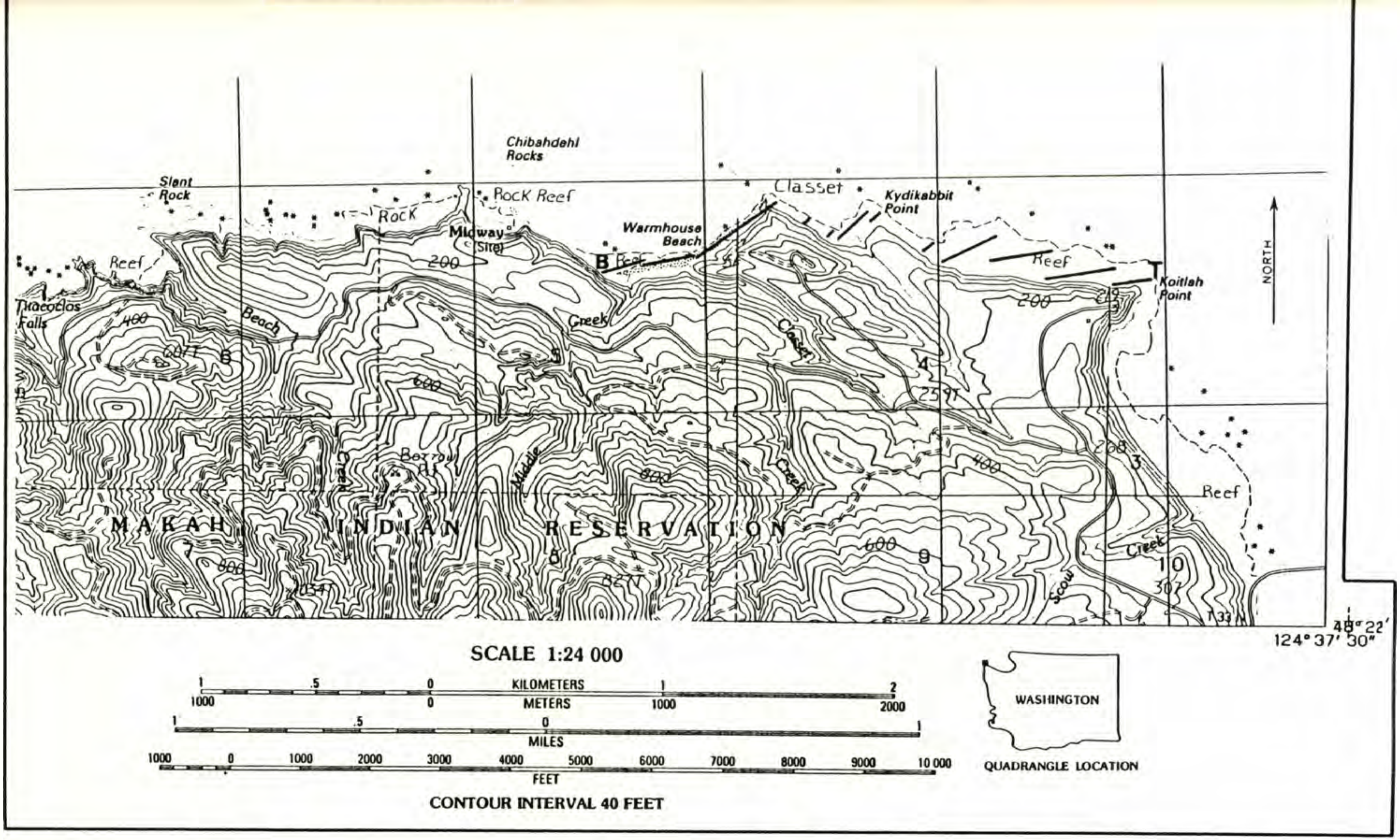
	Q	F	L	Qm	F	Lt	Qm	P	K	Qp	Lvm	Lsm	Lm	Lv	Ls
MEAN	29	15	55	17	15	68	55	43	2	21	36	43	60	35	5
STD.DEV.	14	9	12	7	9	10	20	20	3	15	14	20	26	22	9



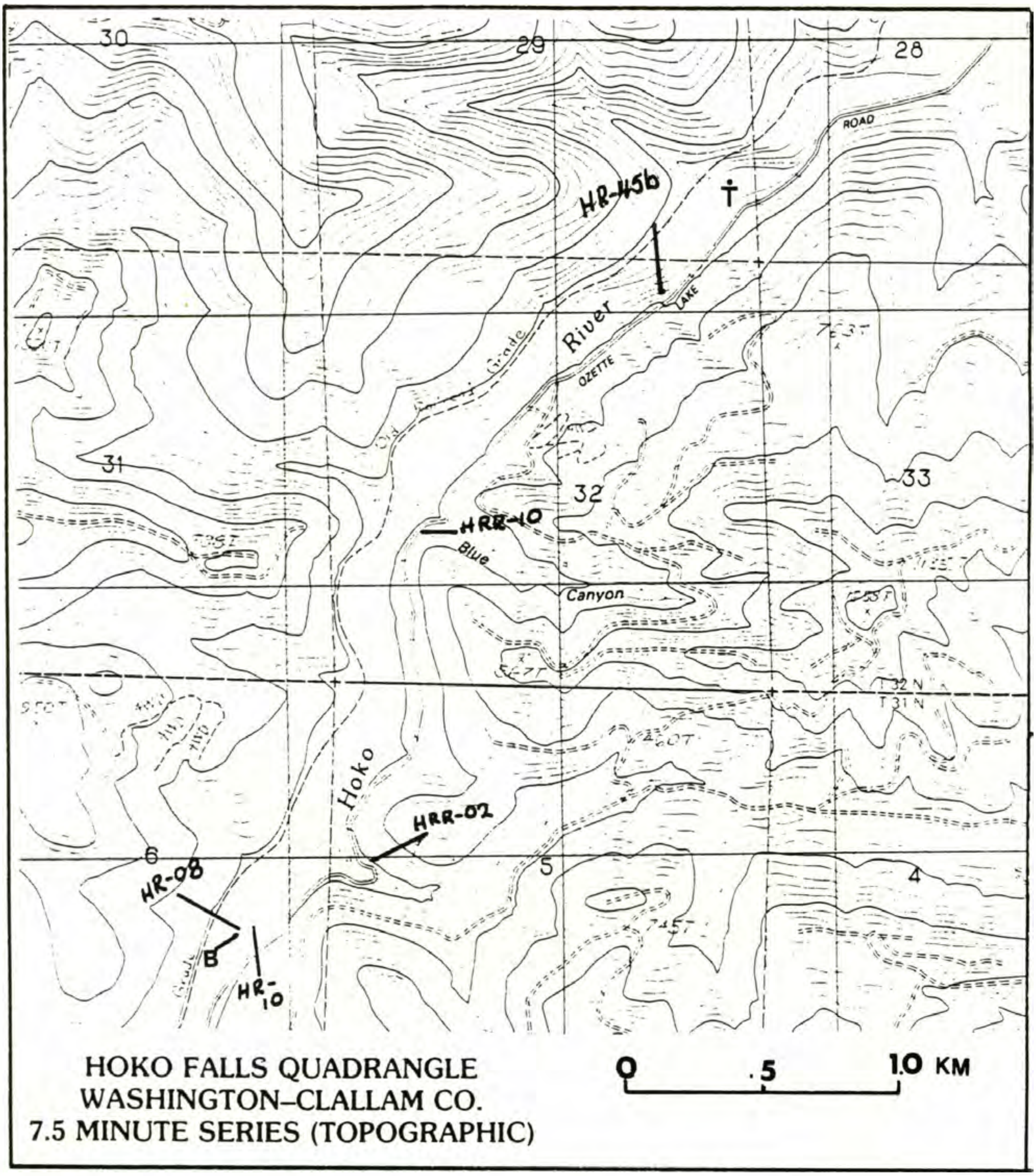
Map 1 General location map of sample locations and stratigraphic sections on the northern Olympic Peninsula.



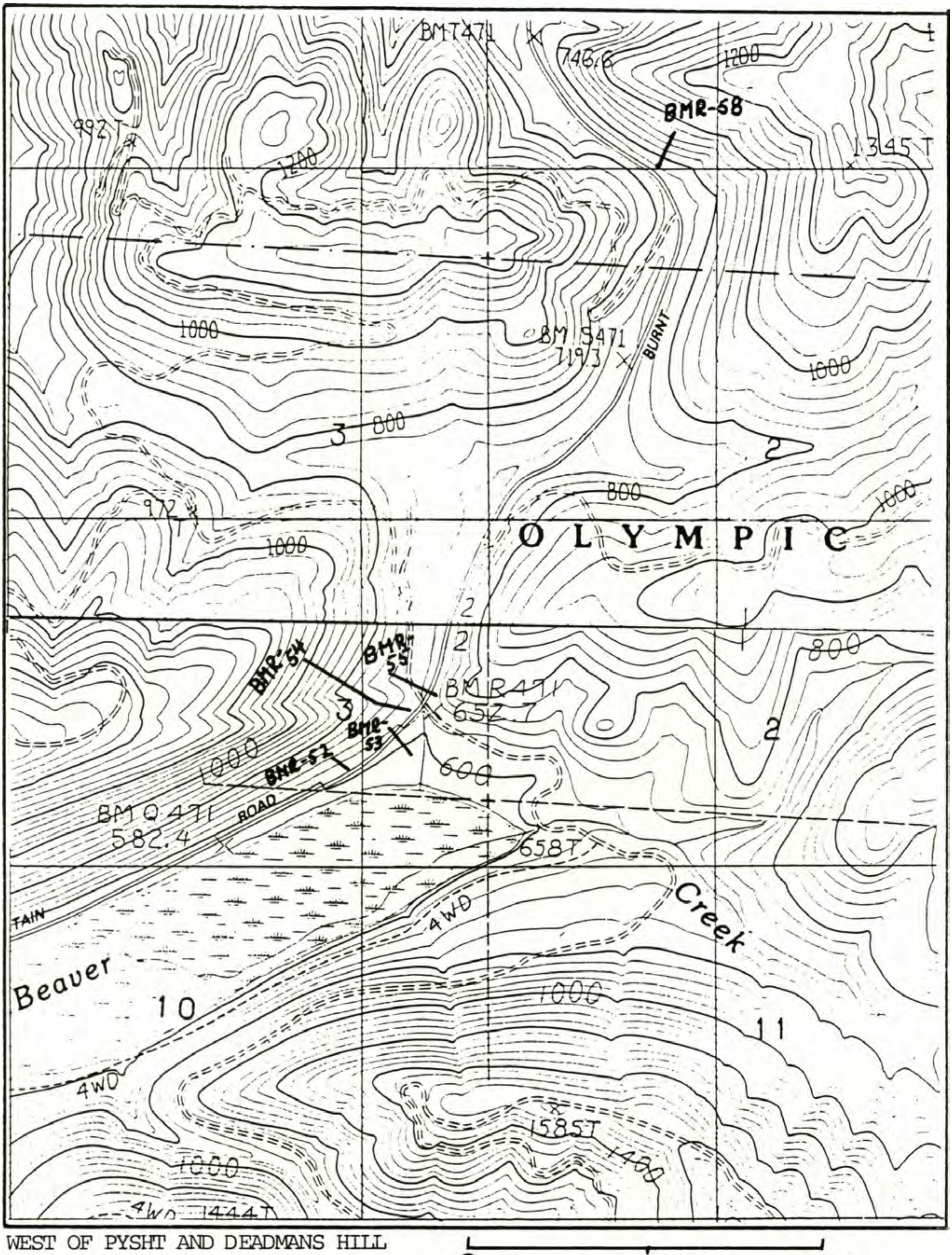
Map 2 Map showing the location of petrographic samples of the Hoko River Formation from the Neah Bay section.



Map 3 Location map of the measured section at Neah Bay of a portion of the Hoko River Formation. The top of the section is located at the T and the bottom is located at the B.



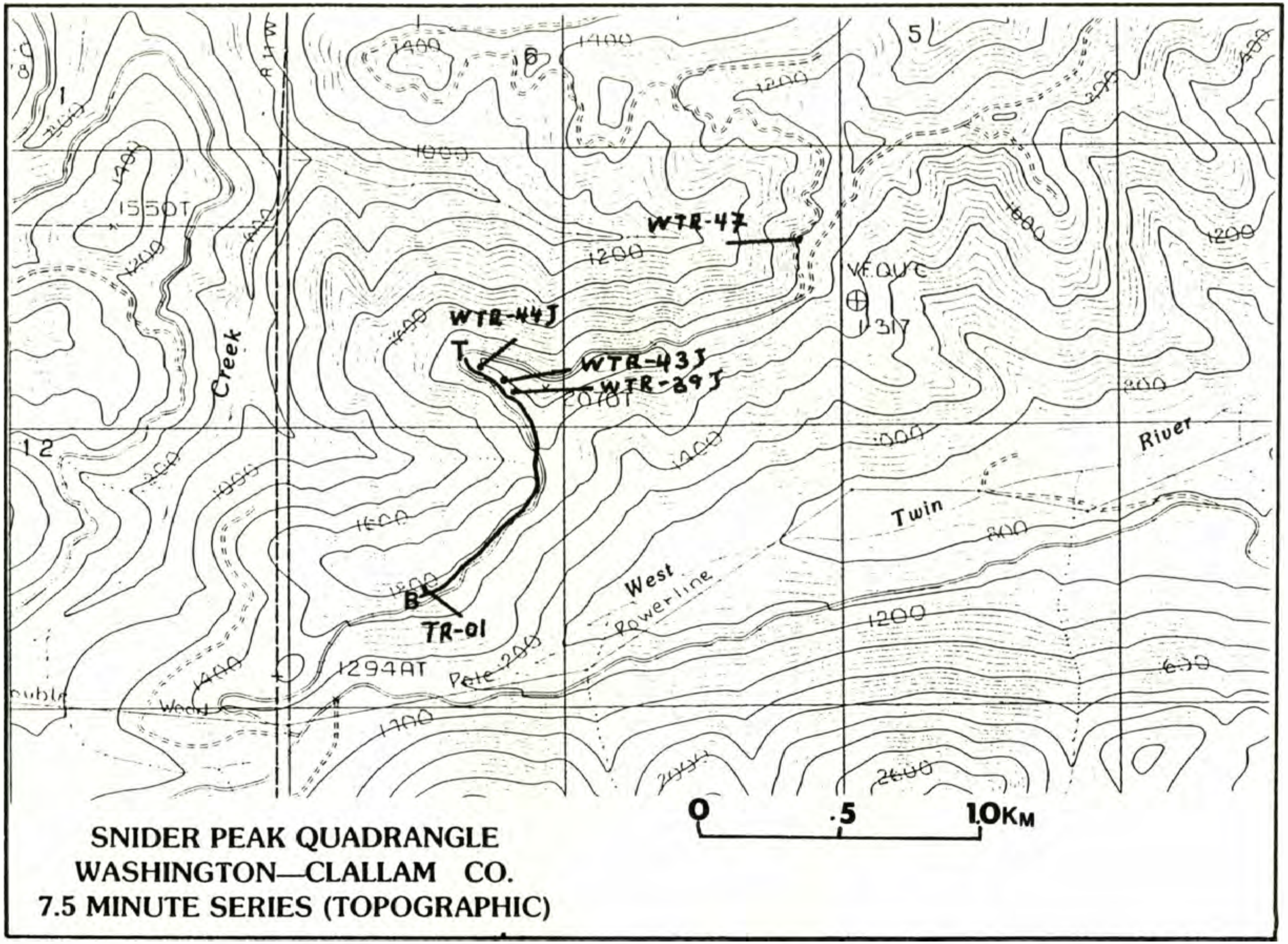
Map 4 Location map of petrographic samples of the Hoko River Formation from the Hoko River section. Also shown are the bottom (B) and the top (T) of the measured stratigraphic section.



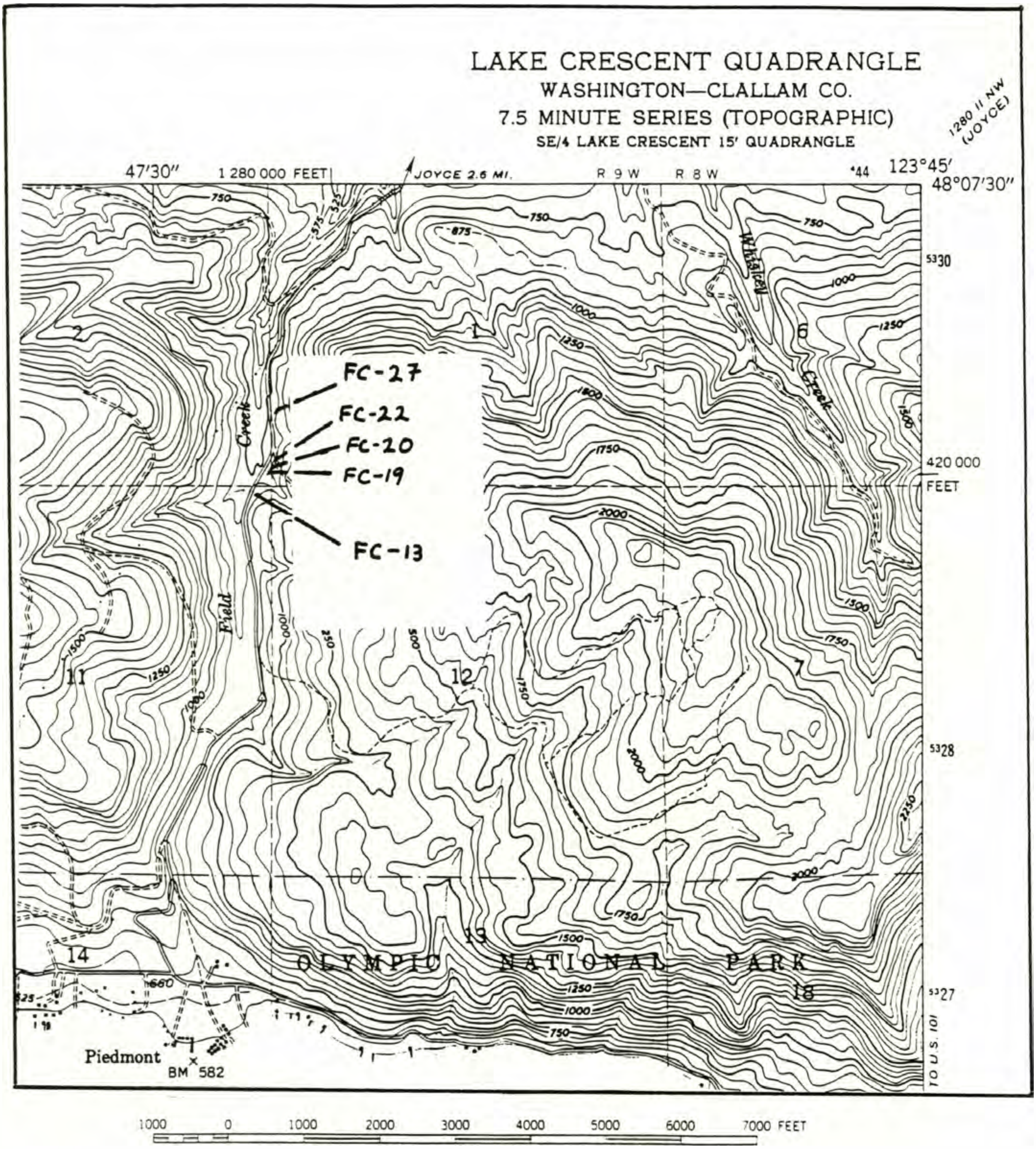
WEST OF PYSHT AND DEADMANS HILL QUADRANGLES, WASHINGTON-CLALLAM COUNTY. 7.5 MINUTE SERIES

0 .5 1.0 Km

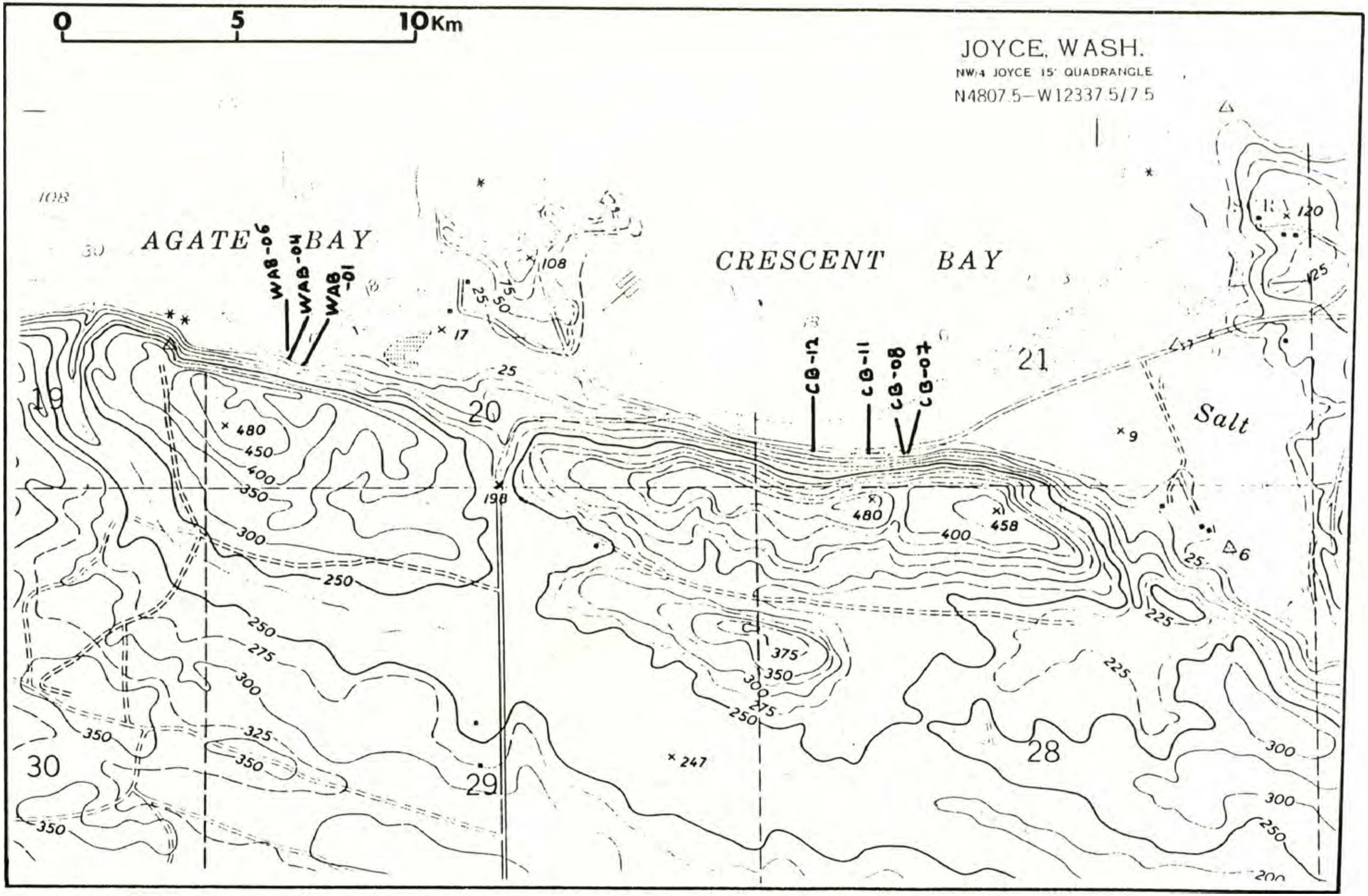
Map 5 Location map of petrographic samples of the Hoko River Formation from the Burnt Mountain Road section.



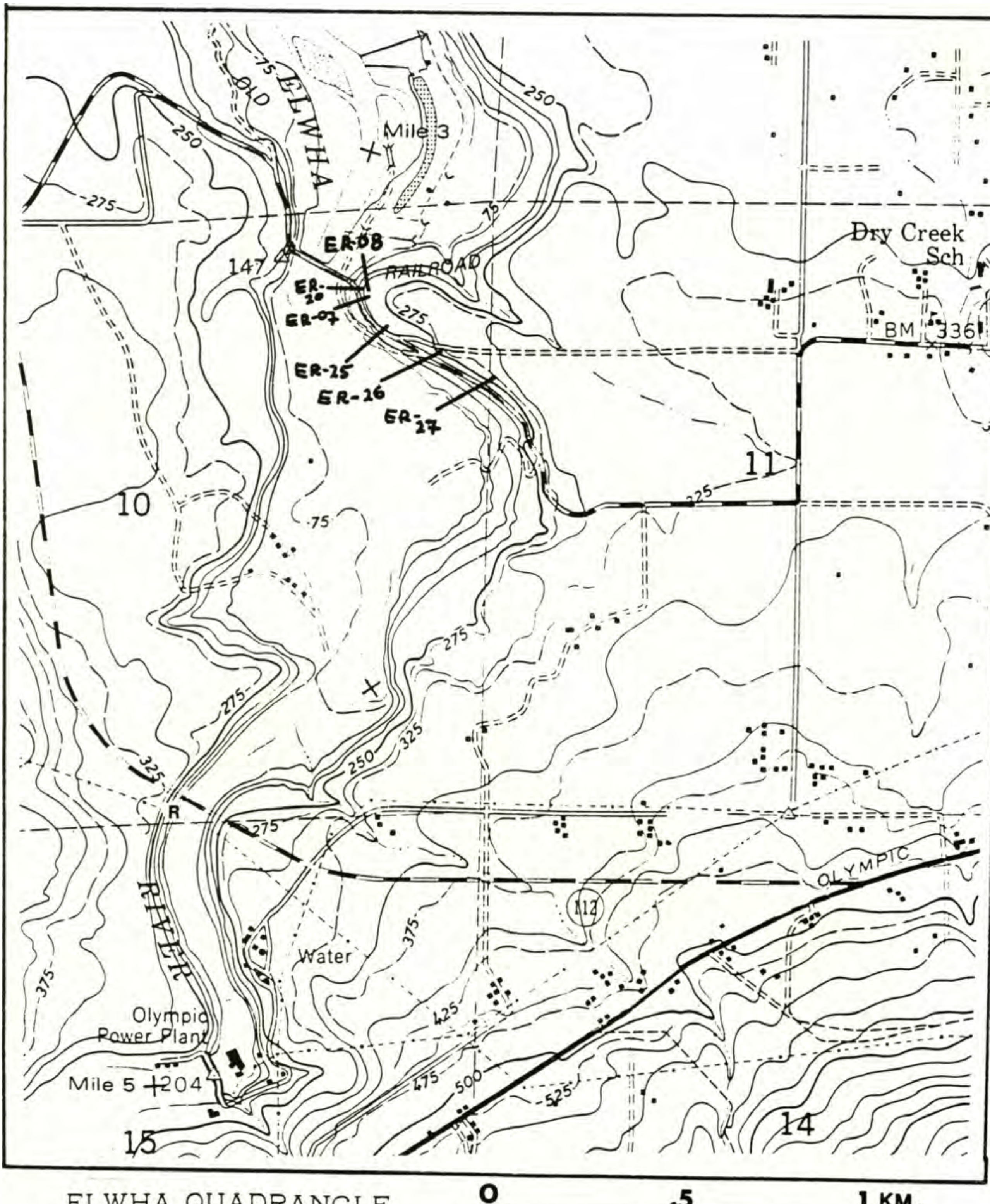
Map 6 Location map of petrographic samples of the Hoko River Formation from the West Twin River Road section. Also shown is the line along which the stratigraphic section of the Hoko River Formation along the West Twin River Road was measured. The bottom (B) and the top (T) are marked.



Map 7 Location map of petrographic samples of the Hoko River Formation from the Field Creek section.



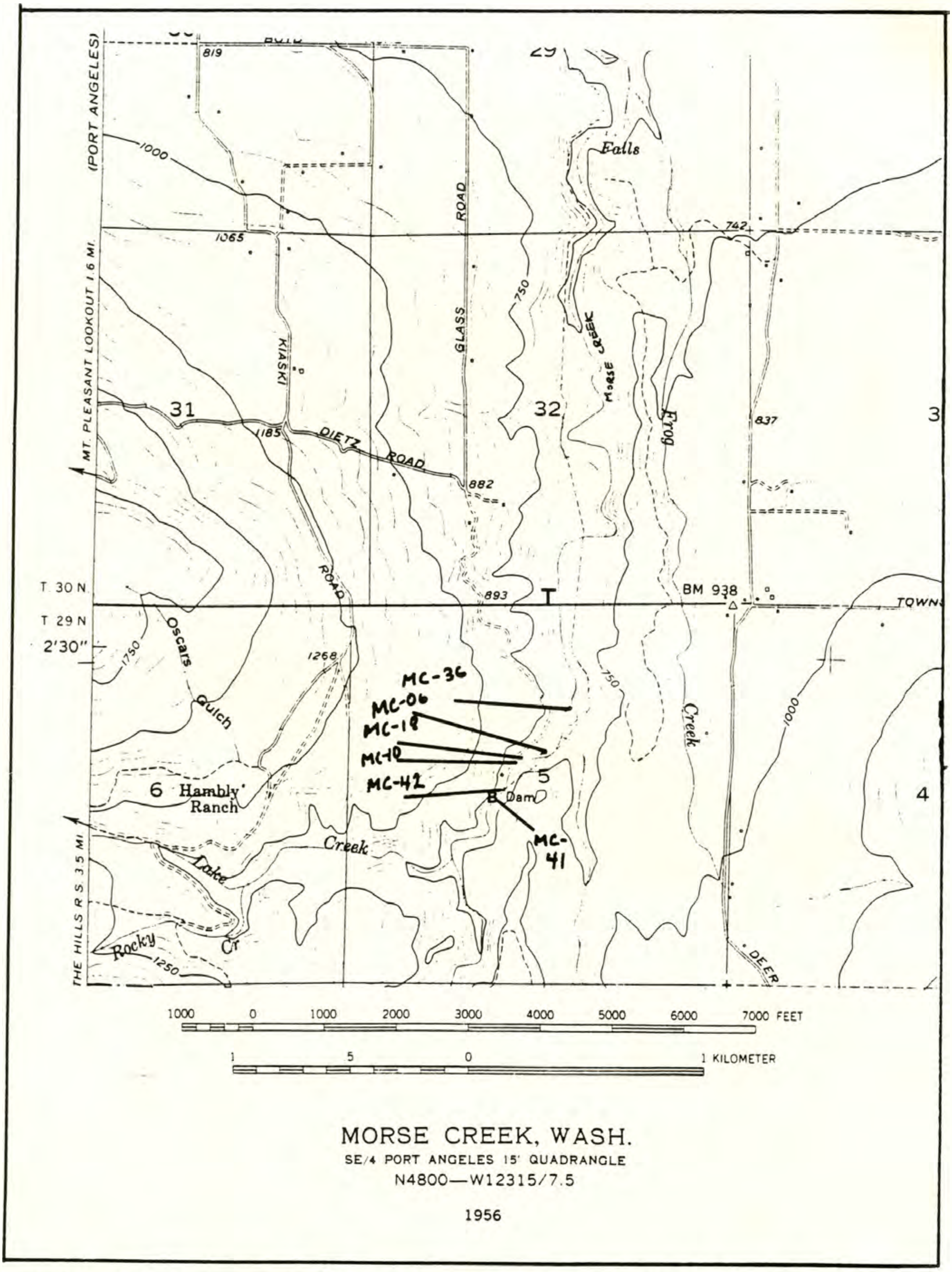
Map 8 Location map of petrographic samples of the Hoko River Formation from the West Agate Beach and Crescent Beach sections.



0 .5 1 KM.

ELWHA QUADRANGLE
WASHINGTON—CLALLAM CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
SE/4 JOYCE 15' QUADRANGLE

Map 9 Location map of petrographic samples of the Hoko River Formation from the Old Elwah River Road section. Also shown is the location of the Elwah River Rappel section by a letter R.



Map 10 Location map of petrographic samples of the Hoko River Formation from the Morse Creek section. Also shown are the bottom (B) and the top (T) of the measured stratigraphic section.