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MAKAH FORMATION--A DEEP MARGINAL BASIN SEDIMENTARY SEQUENCE OF LATE EOCENE AND OLIGOCENE AGE IN THE NORTHWESTERN OLYMPIC PENINSULA, WASHINGTON

BY

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U.S. Geological Survey
OPEN FILE REPORT
79-581

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

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Abstract

The Makah Formation of the Twin River Group crops out in a northwest-trending linear belt in the northwesternmost part of the Olympic Peninsula, Wash. This marine sequence consists of 2,800 meters of predominantly thin-bedded siltstone and sandstone that encloses six distinctive members. The named members include four packets of thick-bedded amalgamated turbidite sandstone, an olistostromal shallow-water marine sandstone and conglomerate member, and a thin-bedded water-laid tuff member. A local unconformity of submarine origin occurs within the lower part of the Makah Formation except in the central part of the study area, where it forms the contact between the older Hoko River Formation and the Makah. Foraminiferal faunas indicate that the Makah Formation ranges in age from late Eocene (late Narizian Stage) to late Oligocene (Zemorrian Stage) and was deposited in a predominantly lower to middle bathyal environment.

The Makah strata are part of a deep marginal basin facies that crops out in the western part of the Olympic Peninsula, in southwesternmost

Washington and coastal embayments in northwestern Oregon, and along the central part of the coast of western Vancouver Island. On the basis of limited subsurface data from exploratory wells, correlative deep-marginal-basin deposits underlie the inner continental shelf of Oregon and the continental shelf (Tofino Basin) along the southwestern side of Vancouver Island.

Directional structures in the Makah Formation indicate that the predominantly lithic arkosic sandstone that forms the turbidite packets was derived from the northwest. A possible source of the clastics is the dioritic, granitic, and volcanic terranes in the vicinity of the Hesquiat Peninsula on the west coast of Vancouver Island. Vertical and lateral variations of turbidite facies suggest that the four packets of sandstone were formed as depositional lobes on an outer submarine fan. The thin-bedded strata between the turbidite packets have characteristics of basin-plain and outer-fan fringe deposits.

INTRODUCTION

The Makah Formation is part of the Twin River Group, a thick sequence of upper Eocene and Oligocene marine sedimentary rocks that crops out on the north flank of the Olympic Mountains (fig. 1) in a northwest-trending linear belt more than 100 km long. The Makah Formation was named and briefly described by Snavely, Niem, and Pearl (1978) from detailed geologic mapping in the western 35 kilometers of this belt, which includes the Makah Indian Reservation in the northwestern part of the study area. This deep-water sequence of well-bedded siltstone and thin-bedded turbidite sandstone contains six

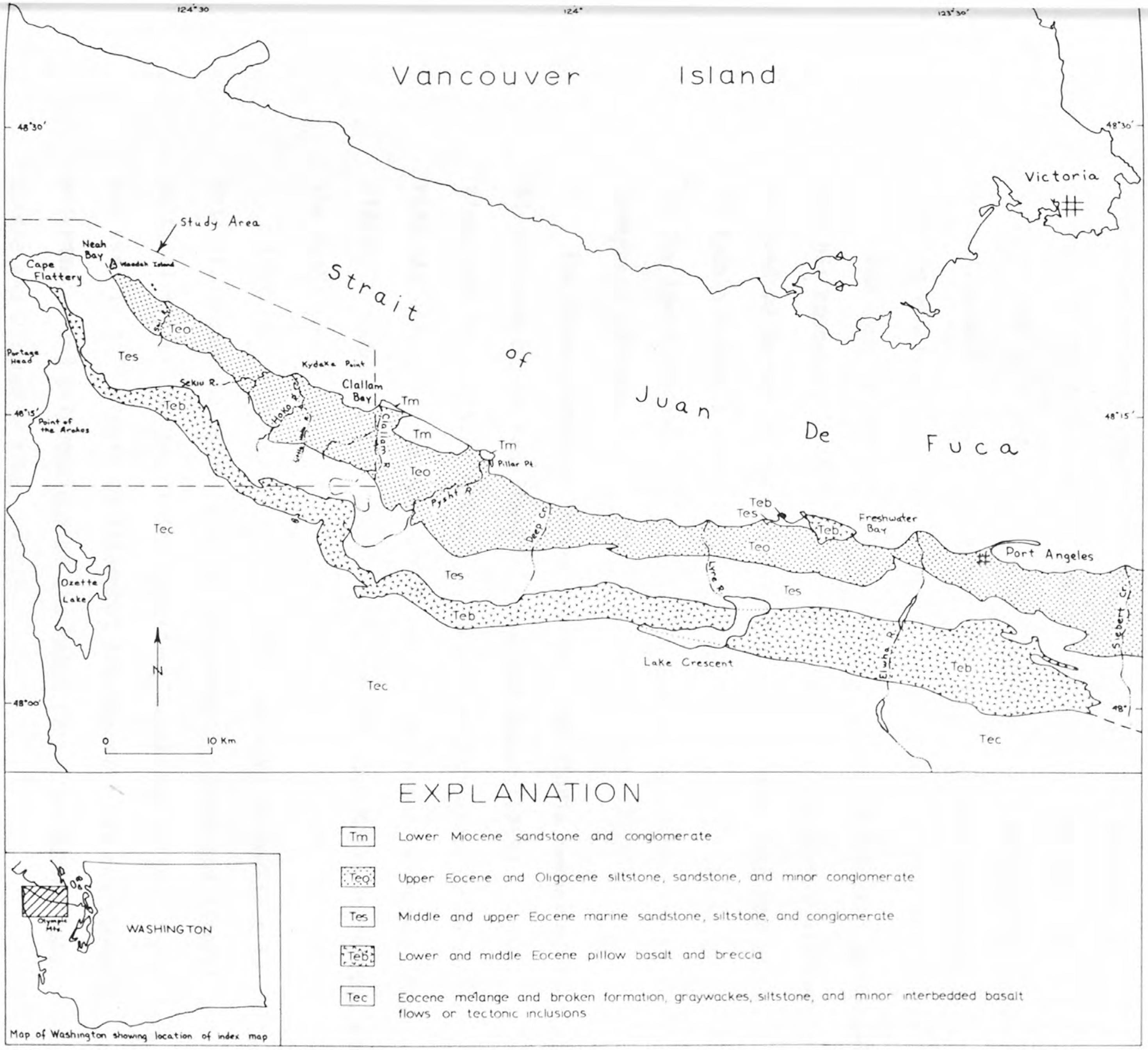


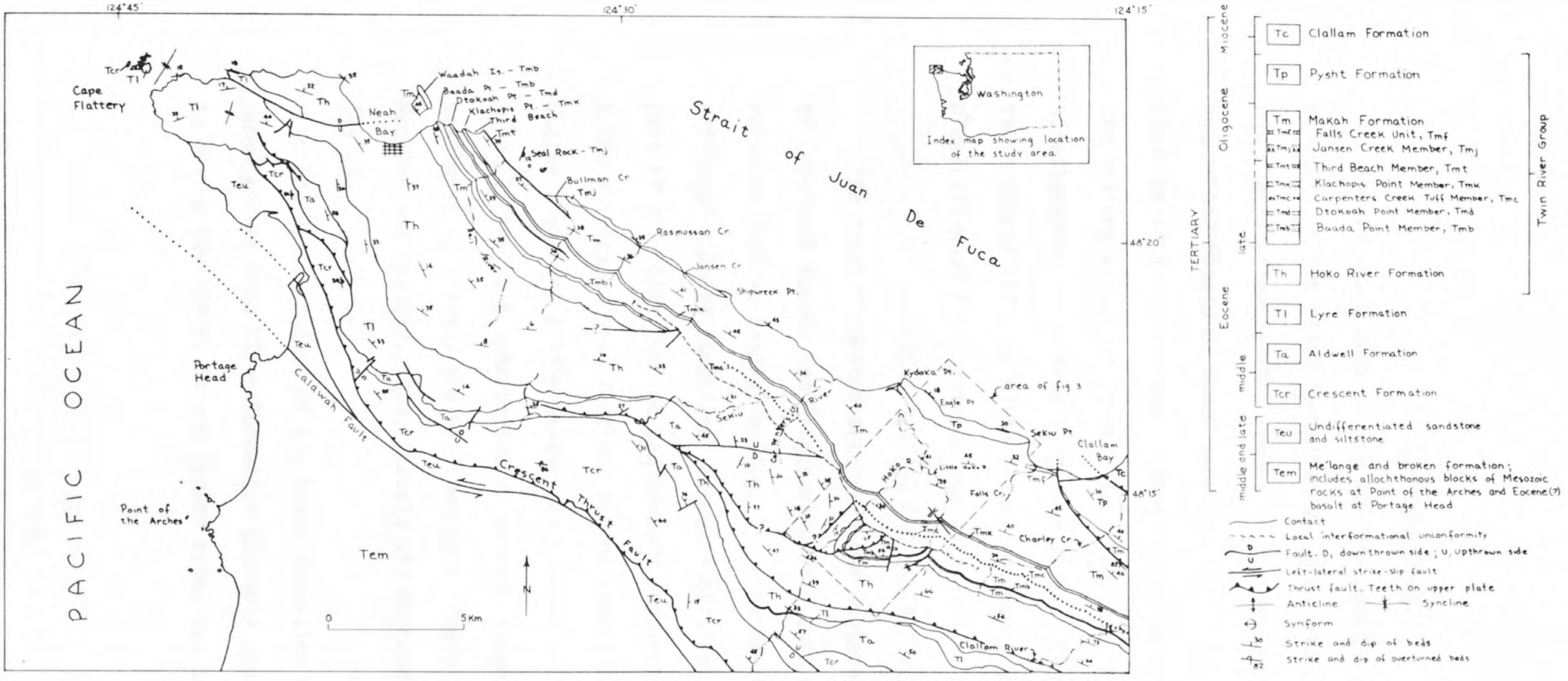
Figure 1.--Sketch map of northern Olympic Peninsula showing outline of study area and distribution of upper Eocene and Oligocene strata (Teo) in relation to other stratigraphic units.

lithologically distinctive and mappable members, described and formally named in this report, and two informal sandstone units that are mappable for only short distances. The six named members are four packets of thick-bedded amalgamated turbidite sandstone, a thin but distinctive tuff bed, and a penecontemporaneously deformed allochthonous sandstone and conglomerate member that initially was deposited in shallow water.

The type section of the Makah Formation was designated by Snavely and his coworkers (1978) as the shore cliffs and wave-cut platform exposed on Waadah Island and from Baada Point near Neah Bay eastward to Kydaka Point, a total distance of 21 km (fig. 2). Rocks exposed in the lower reaches of the Sekiu and Hoko Rivers were selected as reference sections.

The Makah Formation correlates with the middle member of the Twin River Formation as redefined by Brown and Gower (1958). Snavely, Niem, and Pearl (1978) raised the Twin River Formation to group rank and defined three new formations in the Twin River Group, from oldest to youngest, the Hoko River Formation, the Makah Formation, and the Pysht Formation.

Excellent exposures in the mapped area make it possible to collect detailed sedimentological data on dispersal patterns and lateral and vertical facies changes in the turbidite sandstone units. These data are used in this report to interpret the depositional environment, provenance, and paleogeology of the Makah Formation during late Eocene and Oligocene time.



Based on geologic mapping by P.D. Snavely, Jr., N.S. MacLeod, J.E. Pearl, and A.R. Niem, 1970-78.

Figure 2.--Generalized bedrock geology of northwest Olympic Peninsula showing the relation of the Makah Formation to other Tertiary units.

ACKNOWLEDGMENTS

The valuable data on the age and depositional environment of mollusks in the Makah Formation was provided by Warren O. Addicott. His contribution to this report is gratefully acknowledged. Holly C. Wagner and Howard D. Gower improved the quality of the report by their helpful suggestions. Mobil Oil Canada, Ltd. generously loaned the writers slides of Foraminifera and thin sections of correlative stratigraphic units from Vancouver Island, Canada. The writers express their appreciation to Diane Lander and Wendy Niem, who assisted in the preparation of illustrations and editing.

GEOLOGIC SETTING AND CONTACT RELATIONS

The Makah Formation occurs in the western part of a broad belt of uppermost Eocene and Oligocene strata that crops out along the northern Olympic Peninsula (fig. 1). The Makah is a steeply northward-dipping homoclinal sequence of strata in the upper part of a Tertiary marine sedimentary sequence that is more than 6,000 m thick. These Tertiary marine strata overlie lower and middle Eocene submarine pillow basalt and breccia of the Crescent Formation (fig. 2) that are interpreted as oceanic ridge basalts and associated seamounts by Snavely and his coworkers (Snavely and others, 1968; MacLeod and Snavely, 1973; Snavely and MacLeod, 1977) and Glassley (1974).

The basal contact of the Makah Formation with the underlying upper Eocene Hoko River Formation (Snavely and others, 1978) is exposed in only a few places in the mapped area, but the covered interval is less than 50 m wide along Carpenters Creek and Little Hoko River. The underlying massive, hackly fractured iron-stained siltstone and very thin bedded sandstone unit of the Hoko (Th on fig. 2) is readily distinguished from the well-bedded siltstone and turbidite sandstone strata of the Makah by subordinate thick lenses of dark-gray lithic (phyllite- and basalt-rich) sandstone interstratified with thick-bedded channelized lithic conglomerate and minor pebbly mudstone that occur locally. Beds of these lithologies are uncommon in the Makah Formation.

East of the mapped area, in Pysht, Lake Crescent, Port Crescent, and Port Angeles quadrangles, Brown and Gower (1958) and later Gower (1960) indicate a conformable contact between the lower and middle members (Hoko River and Makah equivalents) of their Twin River Formation. Similarly, in the Little Hoko River and in road cuts along nearby logging roads in center sec. 34, T. 32 N., R. 13 W. (D on fig. 3), the exposed lower contact of the Makah Formation appears to be conformable and gradational over a 50-m interval. At these two localities, two to three units (10 m or thicker) of thin-bedded Makah strata containing clastic dikes alternate with intervals of massive siltstone (10 m or thicker) typical of the underlying Hoko River Formation. Although beds of massive siltstone like that of the Hoko Formation occur higher in the section, well-bedded turbidite strata dominate the Makah.

A local unconformity occurs within the lower part of the Makah Formation from a point about 2 km west of Jansen Creek eastward to

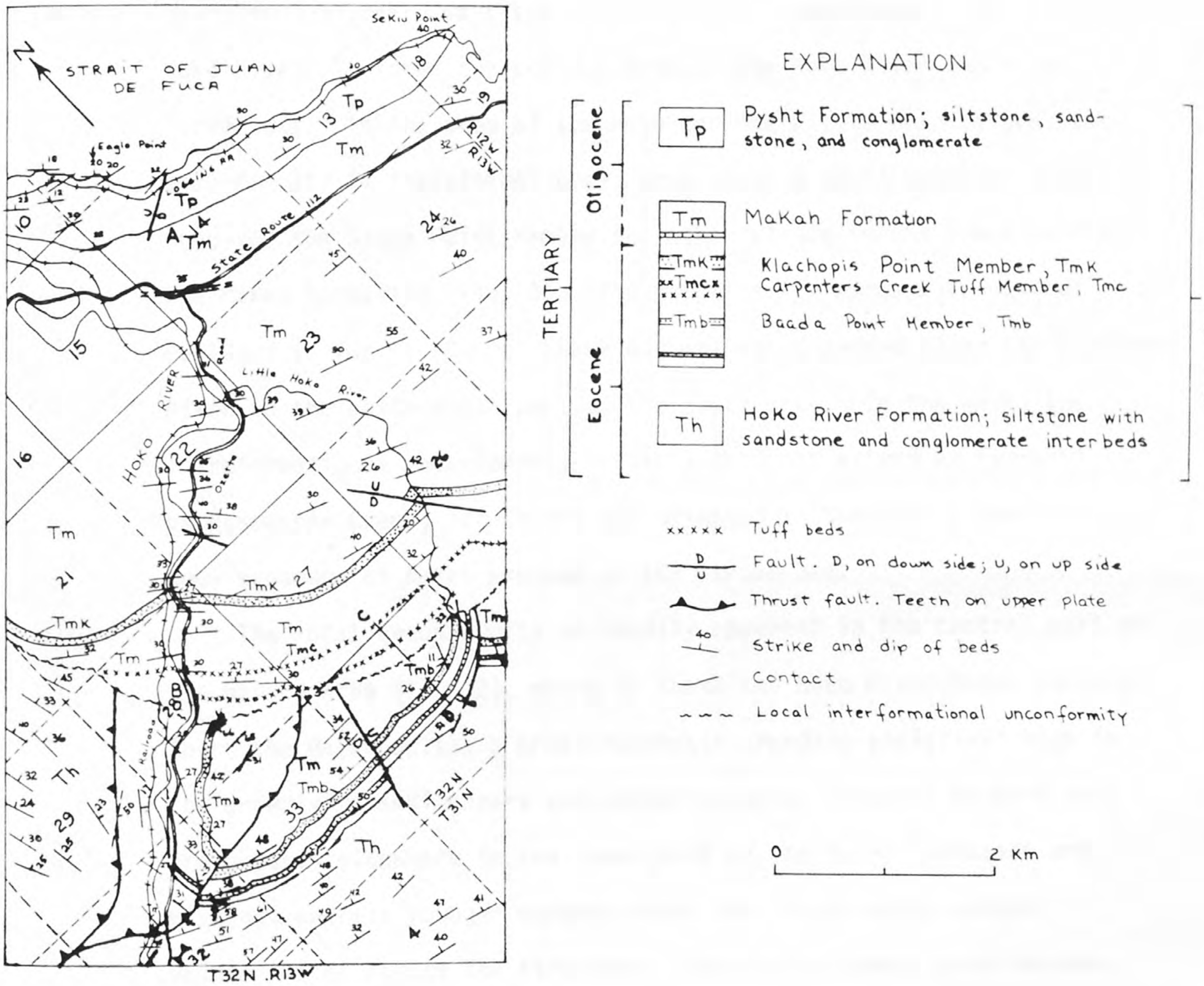


Figure 3.--Generalized geologic map showing the distribution of the Makah Formation at its composite reference section along the Hoko River from point A (1.6 km east of its mouth) to point B (near the center of section 28) and near the Little Hoko River (between points C and D).

near Charley Creek (wavy contact, fig. 2). From Jansen Creek to the Hoko River, it forms the contact between the Hoko River and Makah Formations. In the area of the Hoko and the Little Hoko Rivers, the unconformity is intraformational, truncating a small syncline that involves the Baada Point Member and other strata in the lower part of the Makah Formation (fig. 3). The unconformity appears to extend eastward as far as Charley Creek but was not observed along the Clallam River in the easternmost part of the study area. To the west, the intraformational unconformity probably does not extend as far west as Rasmussan Creek, for it was not observed in the almost continuous sequence of Makah exposed in the stream bed.

The local unconformity is readily apparent in the central part of the mapped area (fig. 2), where it forms the Hoko River-Makah contact. There the Makah onlaps a broad northeast-trending anticlinal high in the underlying sedimentary and volcanic rocks. Several members that are exposed elsewhere in the lower part of the Makah Formation are missing, whereas younger members above the unconformity extend uninterrupted across the structure. The lack of basal conglomerate, the local nature of the unconformity, and the occurrence of deep-water upper Eocene strata directly above and below the unconformity suggest that it is of submarine origin.

The small northeast-trending faulted syncline that lies between the Hoko and Little Hoko Rivers (figs. 2 and 3) is interpreted as a small flexture that developed on the east flank of the broad northeast-trending anticlinal fold. The structural trends of strata in both the Hoko and

Makah Formations define this small asymmetric syncline that formed prior to the local unconformity. A thrust fault in the upper part of the Hoko Formation along the eastern flank of the syncline may account for the asymmetry of the fold (fig. 3). The axial part of the syncline is complicated by several small thrust faults. These and other faults not recognized in the poorly exposed axial part of the syncline probably account for the thicker section of strata apparent between the Baada Point Member and the local unconformity (fig. 3).

The Makah Formation underlies an upper Oligocene sequence of thick-bedded sandstone, boulder-and-pebble conglomerate, and massive siltstone (figs. 2 and 3) that occurs at the base of the Pysht Formation as defined by Snavely, Niem, and Pearl (1978). In most places, the contact between the Makah and Pysht Formations is masked by glacial drift. The contact between them is conformable in a cut on a side road 0.8 km southwest of Eagle Point (NW 1/4, sec. 14, T. 32 N., R. 13 W.), where very thick bedded sandstone and channelized boulder-to-pebble conglomerate of the Pysht Formation is intercalated with Makah-type thin-bedded siltstone and sandstone. Where exposed in quarry and road cuts immediately north of the airport 0.6 km northwest of Sekiu, a submarine channel conglomerate and sandstone of the Pysht Formation rests unconformably upon an irregular surface cut into thin-bedded Makah siltstone and sandstone with as much as a meter of relief, indicating that submarine erosion has taken place locally.

A thickness of 2,800 m for the Makah Formation is estimated at the type section from the base of the unit near the town of Neah Bay to the upper contact at Kydaka Point (figs. 2 and 4). The minimum thickness of the composite section along the Hoko and Little Hoko Rivers is approximately 2,500 m (figs. 3 and 5). The Makah thins over the broad anticlinal high in the central part of the mapped area, where 700 to 850 meters of strata in the lower part of the sequence are missing.

PHYSICAL CHARACTERISTICS

The most common lithologic type in the Makah Formation is made up of beds of siltstone 1 to 10 cm thick rhythmically alternating with thin beds of turbidite sandstone (Tm on fig. 2). The sandstone is fine to very fine grained, medium gray, and quartzo-feldspathic. It is generally parallel laminated to micro-cross-laminated, has sharp bottom and top contacts, and forms resistant ledges or ribs in outcrop. In wave-cut exposures, the thin sandstone beds typically display Bouma (1962) turbidite sequences that lack the basal "a" division ($T_{\underline{b-e}}$ through $T_{\underline{de}}$), although some beds are entirely ripple micro-trough cross-laminated throughout the bed thickness. The siltstone is medium light gray, hackly fractured, and commonly contains very fine grained sandstone stringers and carbonaceous laminae. Siltstone interbeds do not stand out as boldly as the numerous sandstone beds that form ribs and ledges. Thin-bedded Makah of this typical lithology occurs between several thick-bedded amalgamated sandstone members and is well exposed in the road cuts along Ozette Road adjacent to the Hoko River and on the wave-cut platform along the Strait of Juan de Fuca (figs. 2 and 3).

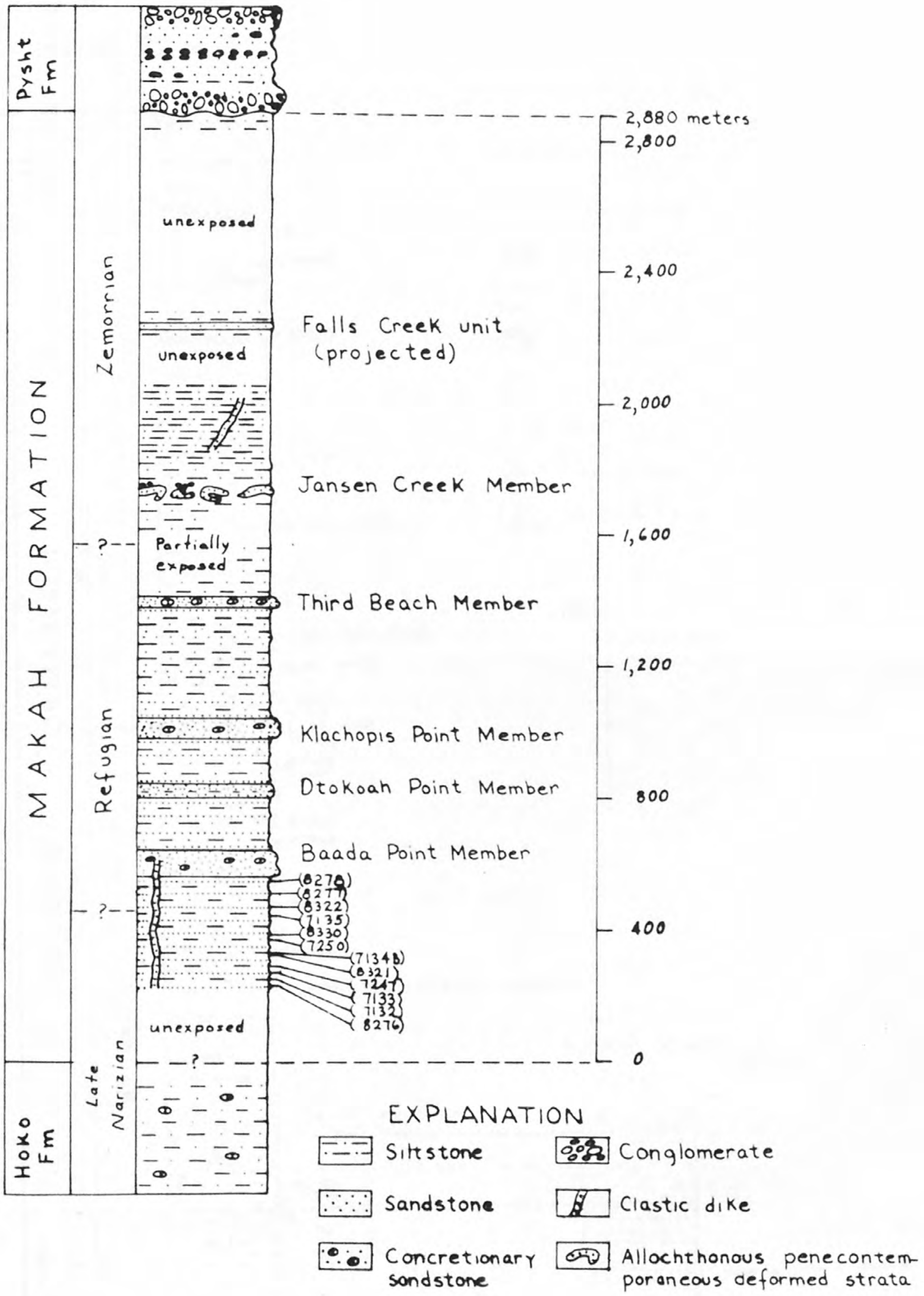


Figure 4.--Composite stratigraphic section of the Makah Formation along the type section from Waadah Island and Baada Point to Kydaka Point. Numbers in parenthesis are Foraminifera sample locality numbers (table 1), Waadah Island.

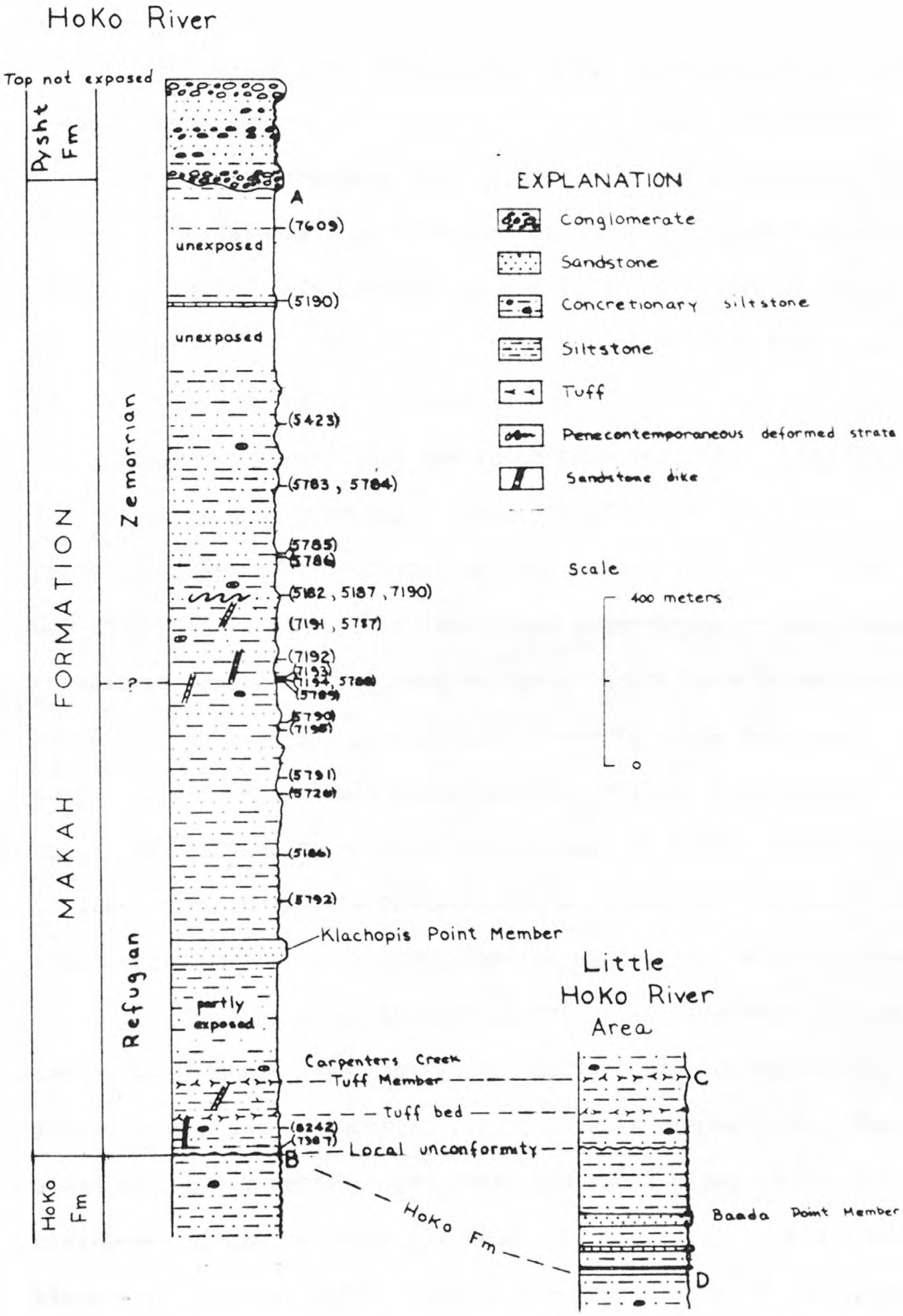


Figure 5.--Composite stratigraphic section of the Makah Formation along the Hoko River from point A in section 14 (1.6 km southeast of its mouth) to point B (near the center of section 28) and between points C and D near the Little Hoko River. Locations are shown on figure 3. Numbers in parenthesis are Foraminifera sample locality numbers (table 2).

The thick- to very thick-bedded amalgamated sandstones commonly contain Bouma sequences that start with the basal "a" division. Typically, these sandstone beds consist of a thick structureless "a" division overlain by a much thinner carbonaceous parallel-laminated "b" division and less commonly an overlying convolute or rarely micro-cross-laminated "c" division. Some very thick beds form a series of amalgamated Bouma "a" divisions.

Calcareous concretions are found throughout the Makah Formation; they range in size from small spheroids 60 to 150 mm in diameter to resistant zones of ellipsoidal to interconnected elongate concretions 0.5 to 4 m in length. Some spheroidal concretions in the siltstone contain concentrations of worm burrows; others have formed around pseudomorphic crystals of calcite similar to those described by Boggs (1973). Many small calcareous concretions lack obvious nucleii, but a few contain fragments of crustaceans or carbonized plant debris. Scattered throughout the thick-bedded amalgamated sandstones at the type section are tiny spherical pyrite concretions with oxidized rims.

Clastic dikes occur throughout the Makah Formation (fig. 6). The sandstone in these dikes is fine to medium grained, moderately well sorted, and micaceous quartzo-feldspathic in composition. Most dikes are nearly vertical and pinch and swell along strike. Some have been injected along small faults or fractures that had minor displacements, whereas others have been emplaced in an en enchelon pattern along fractures with no apparent displacement. The general trend of the clastic dikes perpendicular to the strike of the Makah outcrop,

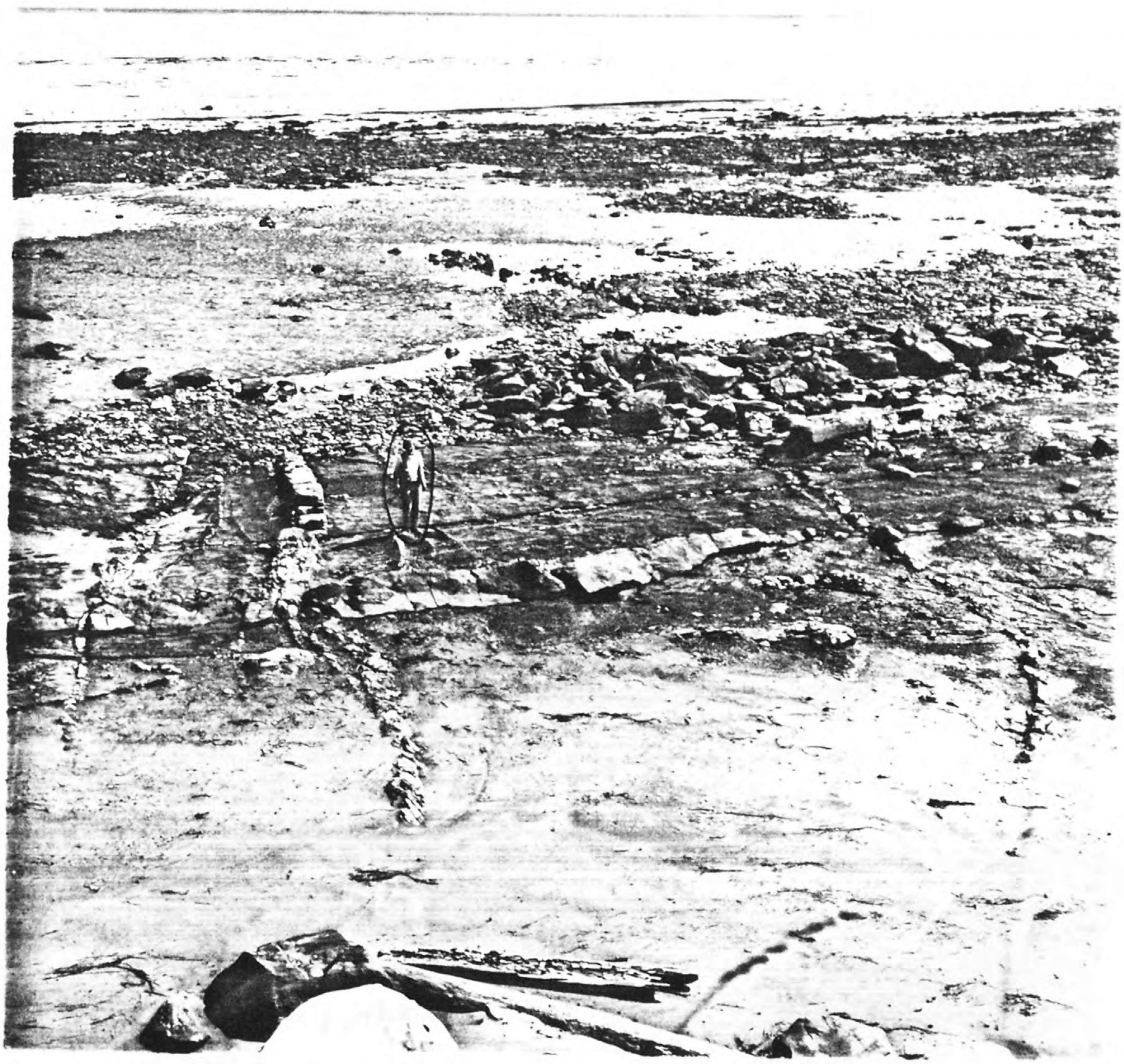


Figure 6.--Northeast-trending sandstone dikes cutting a sandstone channel (0.7 m thick at axis) and thin-bedded siltstone and sandstone in the upper part of the Makah Formation on wave-cut platform 0.4 km west of the mouth of the Sekiu River. Man for scale in left center.

suggests that the dikes were intruded along small tear faults formed when segments of the upper part of the thick sedimentary prism crept basinward or that the sand was injected along fractures perpendicular to the direction of minimum compressional stress in a manner similar to that of basalt dikes (Nakamura, 1977).

Sandstone dikes range in width from 20 mm to 1 m and commonly form carbonate-cemented resistant ridges that stand above the adjacent strata. On the wave-cut platform on the southern shore of Waadah Island, a distinctive set of resistant dikes, 0.9 m and 0.75 m wide, can be traced for more than 300 m southwestward across the thick-bedded Baada Point turbidite member and the underlying thin-bedded strata before they extend so far below sea level that they can no longer be seen. At Klachopis Point, a 1-m-wide quartzo-feldspathic sandstone dike can be traced for 37 m before it disappears beneath the Strait of Juan de Fuca.

Zones of penecontemporaneously deformed strata to several meters thick occur locally in the thin-bedded Makah sequence. The disrupted turbidite sandstone beds in these zones appear to have been hydroplastically deformed. Broad slump folds, pull-apart structures, and small recumbent folded sandstone blocks in structureless concretionary siltstone are the most common features.

Several diastems with angular discordance of as much as 10° are present within the thin-bedded Makah sequences exposed in road cuts adjacent to the Hoko River. These unconformities involve several tens of meters of thin-bedded turbidite strata. The angular discordances probably resulted from minor slumping and rotation of large cohesive blocks of sediments that were later covered by hemipelagic silt and turbidite sand. Some angular discordance between juxtaposed sequences of thin-bedded Makah strata may be caused by broad channeling and deposition of turbidite sand beds within the channels with initial dips different than those of the underlying truncated strata.

The six formally named members of the Makah Formation differentiated on the map (fig. 2) are described below from oldest to youngest.

Baada Point Member

The packet of thick-bedded amalgamated turbidite sandstones named the Baada Point Member is 120 m thick at the type locality at Baada Point, where it is well exposed on the wave-cut platform and headland (fig. 7). The member is also very well exposed on the wave-cut platform of Waadah Island northwest of Baada Point (fig. 8). At the type section, the Baada Point Member is approximately 450 m above the base of the Makah Formation and displays gradational contacts with the overlying and underlying thin- to medium-bedded Makah strata. At this section, the contacts are arbitrarily chosen at the lowest and uppermost amalgamated sandstones that exceed 1.2 m in thickness.

The Baada Point Member can be mapped southeastward for about 12.5 km to where it abruptly terminates against the west side of an anticlinal high and is unconformably overlapped by younger Makah strata in the central part of the mapped area (fig. 2). East of the Hoko River, the

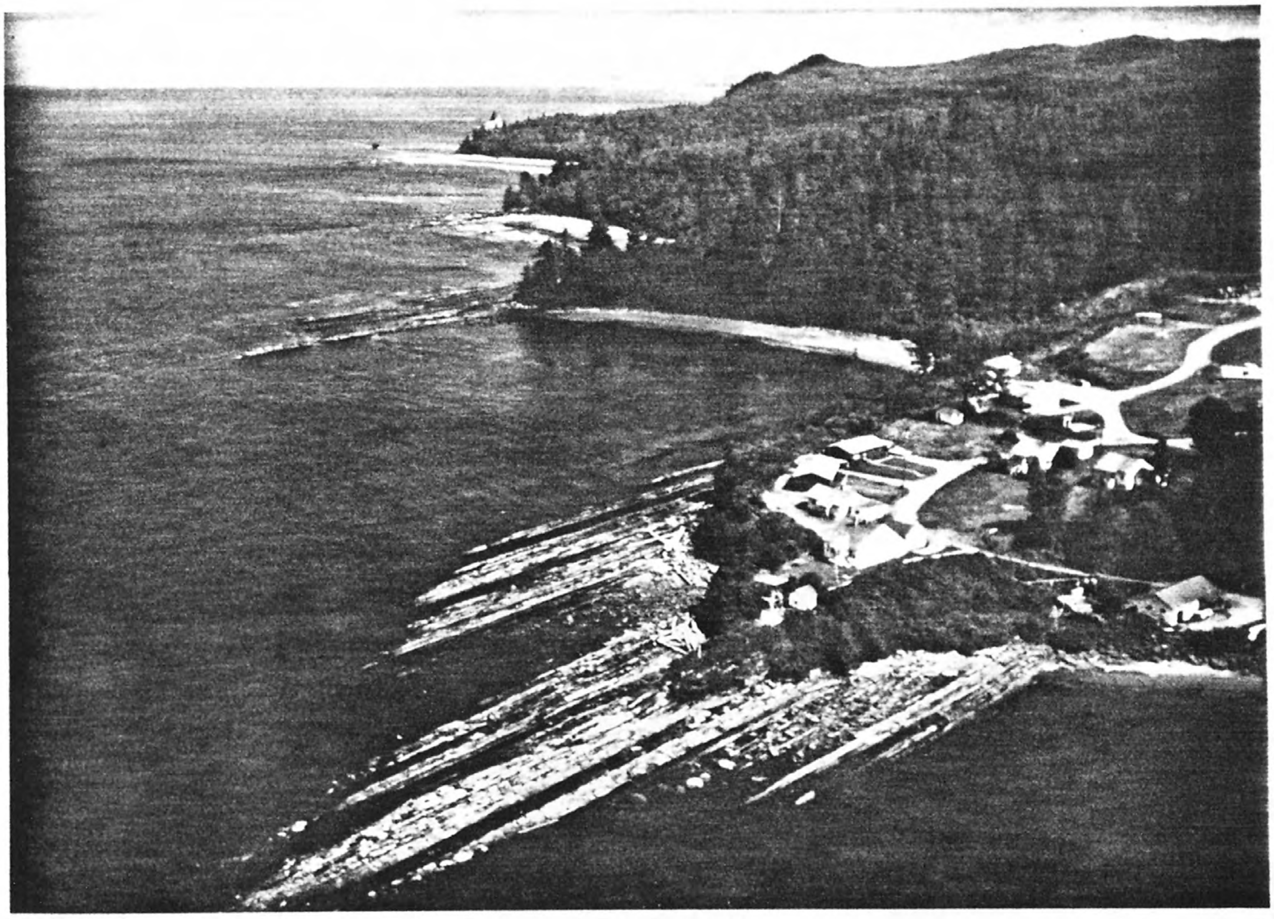
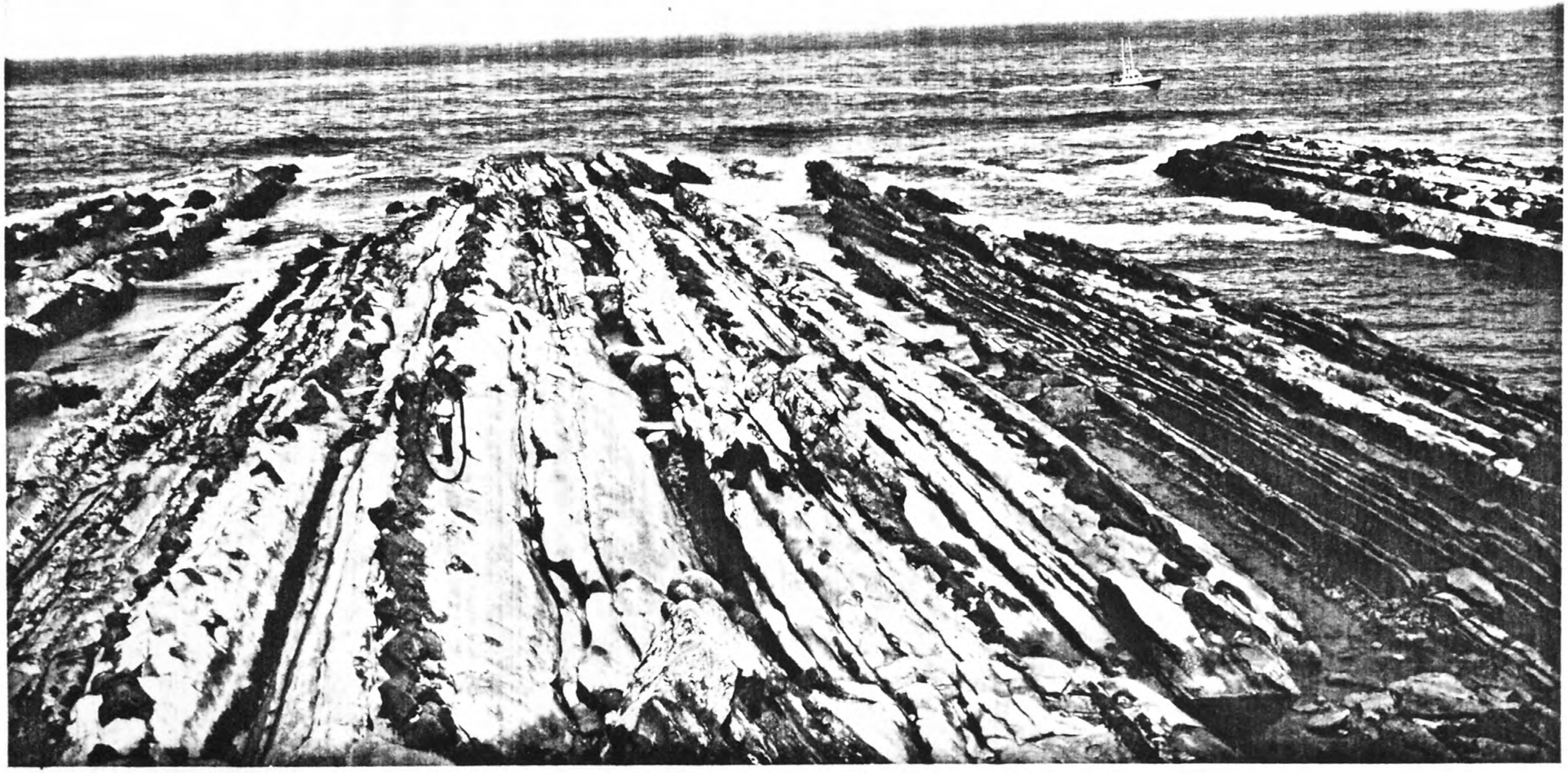


Figure 7.--Aerial view toward southeast of prominent headlands formed by the four turbidite members in the lower part of the Makah Formation. Headland in foreground is formed by turbidites of the Baada Point Member. The second headland is Dtokoah Point; the third Klachopis Point; the fourth lies beyond Third Beach.

Figure 8.--Medium- to very thick-bedded turbidite sandstone beds of the Baada Point Member of the Makah Formation exposed on the northwest wave-cut platform of Waadah Island along the Strait of Juan de Fuca north of Baada Point. Note dark-colored zones of calcareous concretions. Man for scale in left center foreground.



Baada Point Member crops out again in a northeast-trending faulted syncline and extends relatively undeformed southeastward for a distance of about 13 km to the eastern limits of the mapped area and beyond.

The member thins from 120 m at the type section to 43 m in the Clallam River in the easternmost part of the mapped area. Between these two localities, the sandstone to siltstone ratio decreases from 2.5:1 to 1:1. On Waadah Island and at Baada Point, 3- to 5-m-thick amalgamated sandstone beds are common in the member, whereas in the Clallam River the thickest sandstone bed is 1.2 m. More than 100 individual medium to thick beds of sandstone occur at the type section.

Baada Point sandstone is typically light olive gray on fresh surfaces and weathers to a "dirty appearing" yellow brown. It is porous, quartzo-feldspathic in composition, predominantly fine to medium grained, and moderately well sorted.

The member consists of several ridge-forming units of thick-bedded amalgamated turbidite sandstones and intervening sequences of less resistant thin-bedded sandstone and siltstone. In shoreline exposures, the sandstones form prominent ribs and thin-bedded sandstone and siltstone form inlets that are partly covered during high tides (fig. 7 and 8). Layers of resistant light-brown calcareous concretions are common throughout the thick amalgamated sandstones fig. 8). Concretions are lenticular to spheroidal in shape, are light medium gray when freshly broken, and display a case-hardened honeycomb weathering pattern on the wave-cut platform.

Bedding in the thick amalgamated sandstones is defined by surface indentations produced by differential erosion of less resistant thin beds of laminated to convolute carbonaceous sandstone and rare siltstone (fig. 8). Normal grading in the amalgamated beds is characterized by upward change from massive fine-grained sandstone to laminated or convolute bedded very fine grained carbonaceous sandstone that forms the upper several centimeters of each 0.5- to 3-m-thick bed. In the northwestern part of the outcrop area, scattered dark coarse-grained lithic fragments and concentrations of small light-gray siltstone rip-ups serve to differentiate thinner turbidite beds within seemingly structureless thick amalgamated sandstones. Bouma $T_{\underline{a}}$, $T_{\underline{ab}}$, and $T_{\underline{abc}}$ sequences are common in thick beds, whereas the thin sandstone beds in the intervening sandstone-siltstone units mostly display Bouma $T_{\underline{bcd}}$ and $T_{\underline{b-e}}$ sequences. The sharp bases of many thick sandstone beds contain load casts, and, less commonly burrow, flute, and groove casts.

Dtokoah Point Member

The packet of turbidite sandstone named the Dtokoah Point Member is 65 m thick at the type locality, where it forms the wave-cut platform and headland (Dtokoah Point) east of Baada Point (fig. 7). The unit is separated from the underlying Baada Point Member by 165 meters of very thin bedded siltstone and very fine grained sandstone (Tm on fig. 2), exposed during low tides. The Dtokoah Point Member displays gradational lower and upper contacts with the thinner bedded strata enclosing it. The bottom and top of the member are arbitrarily defined as the lowest and uppermost sandstones greater than 0.3 m thick. The member has been mapped for 9 km southeast to where it apparently pinches out east of Bullman Creek (fig. 2).

Dtokoah Point sandstone is fine to very fine grained, moderately well sorted, and weathers to olive gray. The sandstone appears to be compositionally and texturally similar to the Baada Point sandstone; it is rich in matrix, contains lithic fragments, and is quartzofeldspathic. Unlike the Baada Point sandstone, however, sandstone in the Dtokoah Point Member is commonly much thinner bedded, the beds generally ranging in thickness from 20 mm to 0.4 m, and contains only a few thick amalgamated beds (fig. 9).

At the type section, the unit forms a low, commonly tide-covered wave-cut platform composed of numerous thin- to medium-bedded sandstone ribs with intervening swales of less resistant laminated medium-gray siltstone beds, 20- to 70-mm-thick. The more than 170 sandstone beds in the member commonly display sharp bottom and top contacts. Common features are parallel laminations, convolute bedding, micro-trough-or-ripple cross-laminations, and graded bedding. Bouma $T_{\underline{b-e}}$, $T_{\underline{bc}}$, and $T_{\underline{de}}$ sequences predominate.

A 2-m-thick amalgamated sandstone bed near the top of the unit forms a broad lens that pinches and swells laterally (R on fig. 9). Graded beds within this sandstone are defined by concentrations of siltstone rip-ups, shell fragments, convolute and parallel laminations, and phyllite- and basalt-rich grits. Overlying this sandstone lens is 2

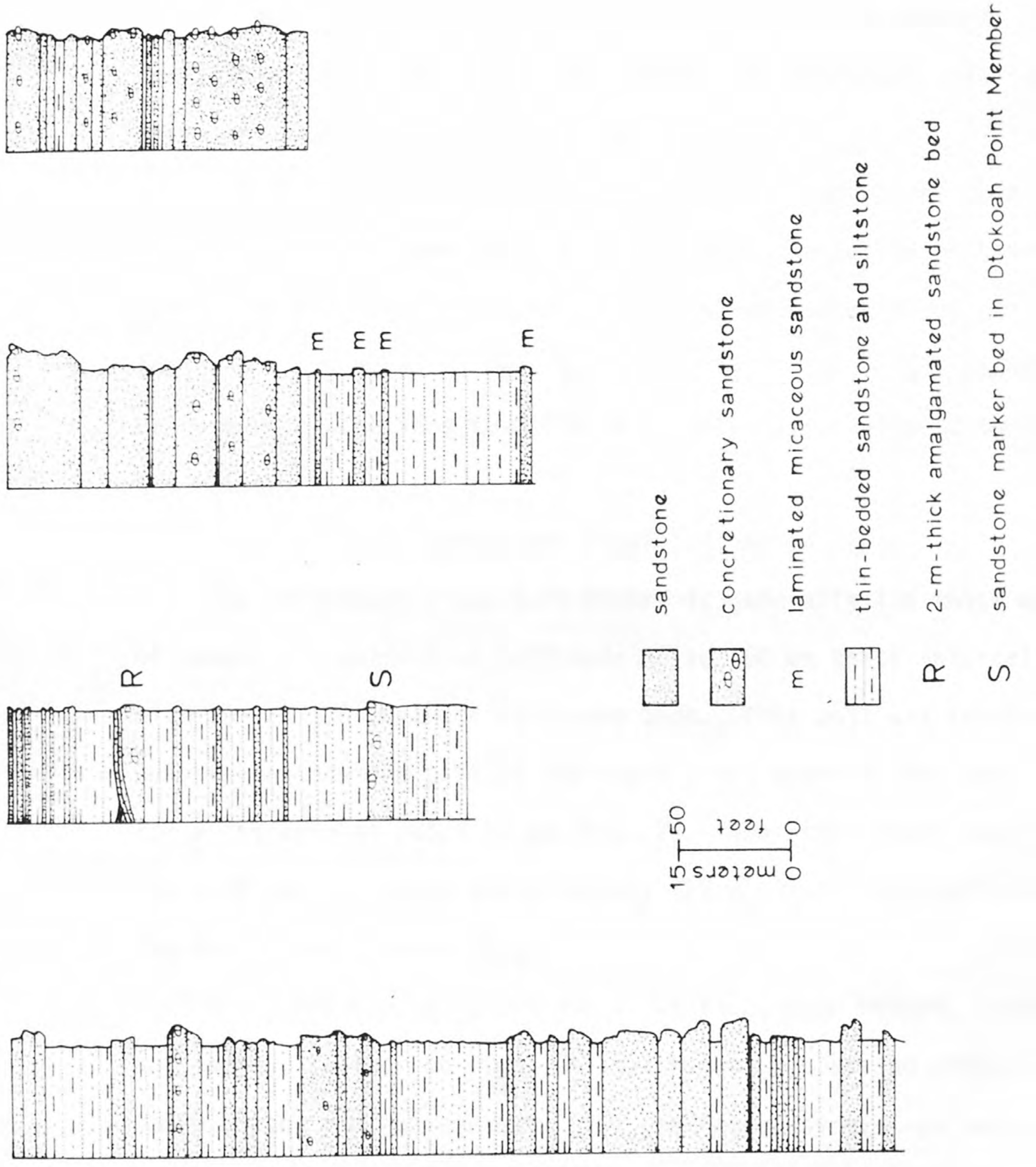


Figure 9.--Generalized stratigraphic sections of the four turbidite members of the Makah Formation in the type section. A = Baada Point Member; B = Dtokoah Point Member; C = Klachopis Point Member; D = Third Beach Member. Beds represented by R and S referred to in text.

to 4 meters of thin-bedded turbidites that are channelized, pinch out laterally, and display cross-cutting stratigraphic relations (beds overlying R sandstone bed, fig. 9).

A distinctive 3-m-thick amalgamated sandstone marker bed occurs near the base of the member (S on fig. 9). This concretionary sandstone forms a prominent ridge and contains well-developed flute marks that indicate a dispersal pattern to the southeast (fig. 10). Spheroidal calcareous concretions to 0.2 m in diameter are scattered throughout the member.

Carpenters Creek Tuff Member

The Carpenters Creek Tuff Member is generally 1 m thick and consists of seven thin water-laid tuff beds 40 to 150 mm thick intercalated with 30- to 150-mm-thick siltstone beds. This unit was recognized only in the eastern part of the study area, where it has been mapped for a distance of about 20 km (fig. 2). Near the Little Hoko River, the tuff member occurs approximately 325 m stratigraphically above the Baada Point Member (fig. 5).

The tuffs are calcified and silicified, even bedded, form thin resistant ledges, weather to light-yellowish-gray blocks and chips, and display sharp bottom and top contacts with the intervening, less resistant, hackly fractured siltstone. Individual tuff beds are generally structureless to faintly laminated. More rarely, they are cross-laminated. This unit may be significant in correlating other units along the north side of the Olympic Peninsula because it defines a time horizon.

Figure 10.--Flute casts (above hammer) at base of thick amalgamated sandstone of the Dtokoah Point Member at the type section showing southeastward (arrow) dispersal pattern.

The Carpenters Creek Tuff Member is best exposed near the top of a 20-m-high road cut in thin-bedded Makah strata along Ozette Road east of the Hoko River in the NE 1/4 sec. 28, T. 32 N., R. 13 W. Other good exposures of the tuff member occur in Carpenters Creek, in the Little Hoko River, and along an abandoned railroad grade adjacent to the west bank of the Hoko River (fig. 2).

Another tuff unit consisting of two to three 20- to 50-mm-thick light yellowish-gray beds with thin intervening siltstone occurs 100 m below the Carpenters Creek Tuff Member (fig. 5); it can be traced for approximately 3 km east of Ozette Road (fig. 3). In the easternmost part of the study area along the Clallam River, several tuff beds occur below the Carpenters Creek tuff in the lower part of the Makah Formation. Since these tuff beds have not been recognized west of the Clallam River, the source of the ash probably was from the east.

Klachopis Point Member

The packet of thick-bedded turbidite sandstone named the Klachopis Point Member occurs 155 m stratigraphically above the Dtokoah Point Member. This 73-m-thick member forms the third wave-resistant platform and headland east of Neah Bay at Klachopis Point, the type section for the member (fig. 7). The unit displays a gradational contact with the underlying thin-bedded Makah siltstone and sandstone. At the type section, the upper contact is covered with beach sand. The contacts are arbitrarily drawn at the lowest and uppermost sandstone beds that exceed 0.7 m in thickness.

The Klachopis Point Member consists of 40 or more thick- to very thick-bedded amalgamated sandstones that form a strike ridge entirely across the mapped area, a distance of 32 km (fig. 2). It gradually thins eastward. At Charley Creek, in the eastern part of the area (fig. 2), the member is 49 m thick. It is well exposed on Bullman Creek, along the Sekiu and Hoko Rivers (fig. 11), and along State Highway 112. Sandstone of the Klachopis Point Member is characteristically more micaceous and feldspathic and is better sorted than that of the Baada Point and Dtokoah Point Members. Coarse grained flakes of muscovite and biotite are ubiquitous. The sandstone typically is fine to medium grained, moderately well sorted, and porous. At the type section on the coast, this unit, like the Baada Point Member, contains resistant layers of interconnected dark olive-black-stained calcareous concretions.

The lower one-third to one-half of the member typically consists of well-laminated micaceous, carbonaceous sandstone with siltstone interbeds (fig. 9). Varying concentrations of carbonized plant debris and muscovite and biotite flakes along laminae impart a distinctive platy character to the sandstone. Each sandstone bed has sharp upper and lower contacts with the intercalated medium-dark-gray siltstone and very fine grained carbonaceous sandstone.

The upper one-half to two-thirds of the member forms a thick resistant ridge composed of several even-bedded, predominantly structureless amalgamated sandstone beds (fig. 9). These beds

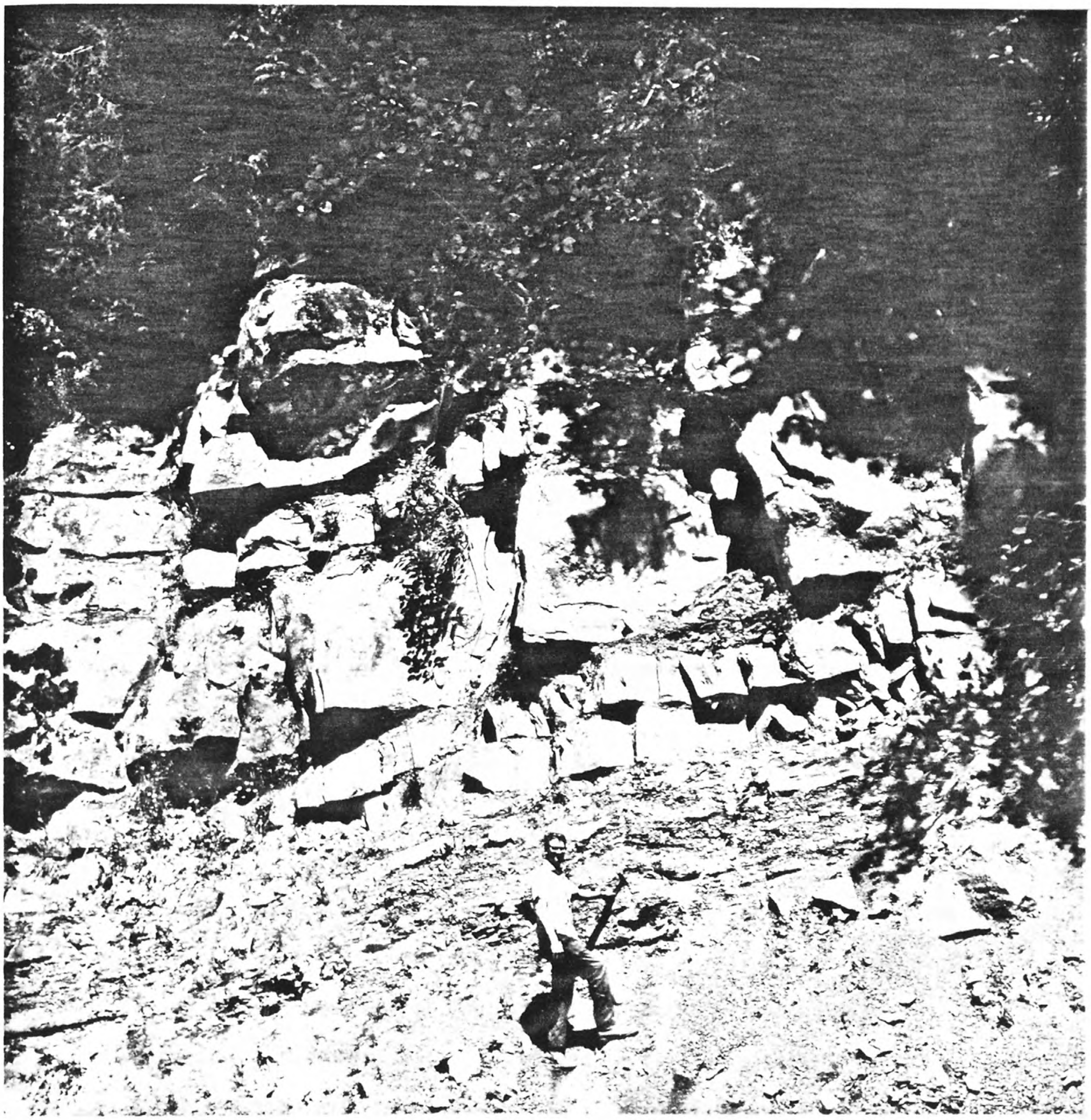


Figure 11.--Thick beds of turbidite sandstone in the Klachopis Point Member exposed at section line 21-28, T. 32 N., R. 13 W. along the Ozette Road.

are 1 to 5 m thick and are separated by very thin intervals of less resistant laminated siltstone and thin- to medium-bedded sandstone. Sandstone-to-siltstone ratios vary from 10:1 to 60:1.

Each amalgamated sandstone bed is composed of two or more predominantly structureless parts that range in thickness from 0.15 m to 1 m. Stratification is defined by minor concentrations of siltstone rip-ups, scattered coarse sand-sized lithic fragments, and thin beds of less resistant very fine grained carbonaceous sandstone. The carbonaceous sandstone that commonly forms the thin upper part of many structureless beds is parallel laminated to convolute laminated and rarely cross laminated. Bouma $T_{\underline{a}}$, $T_{\underline{ab}}$, and $T_{\underline{abc}}$ sequences are common.

Other sedimentary features in the Klachopis Point sandstone beds are sharp bottom contacts and gradational upper contacts, bifurcating *Scalarituba* worm burrows, rare dish structures, and flute, frondescent load, and groove casts.

Third Beach Member

The type section of the Third Beach Member is designated as the resistant wave-cut terrace and headland immediately east of Third Beach (fourth headland in fig. 7). This packet of amalgamated turbidite sandstones is 43 m thick and occurs 290 m stratigraphically above the Klachopis Point Member. The two members are separated by an interval of rhythmically alternating very thin- to thin-bedded siltstone and very fine grained sandstone that is seasonally covered by beach sand.

The Third Beach Member forms a spectacular linear dip-slope seacliff from the type locality 2 km southeastward to Sail River. The member terminates abruptly at Bullman Creek (fig. 2), possibly the result of post-depositional uplift and slumping, as biotite-rich arkosic sandstone blocks similar in composition to sandstone in the Third Beach Member occur in a younger penecontemporaneously deformed siltstone unit 5 km farther east near Jansen Creek (fig. 2). The position of the siltstone unit that contains these indurated sandstone blocks approximately 100 m stratigraphically above the Third Beach Member precludes their origin by submarine landsliding of Third Beach sandstone alone; rather, the sandstone was buried and indurated before it was uplifted and slumped in the basin.

Because the lower and upper contacts on the Third Beach Member are generally covered by beach sand at the type section, the contacts are arbitrarily placed at the uppermost and lowest amalgamated sandstone beds more than 3 m thick.

Third Beach sandstone is similar to the upper half of the underlying Klachopis Point sandstone, being predominantly thick to very thick-bedded, concretionary, clean, micaceous, and feldspathic (fig. 9). It differs by containing more abundant and larger (to 1.5 mm), ubiquitous black biotite flakes that impart a distinctive salt-and-pepper appearance to fresh hand specimens. More than 45 sandstone beds occur in the member. The sandstone weathers to an iron-stained grayish orange to light gray and is fine to medium grained.

At the type section, the Third Beach Member consists of three very thick bedded amalgamated sandstone ridges separated by a few beds of less resistant thin- to medium-bedded turbidite sandstone and siltstone (fig. 9). Each sandstone ridge consists of three or more 0.5- to 6-m-thick predominantly structureless concretionary beds. Less resistant laminated and convolute-bedded very fine grained carbonaceous sandstone in the upper part of each bed delineates stratification within the amalgamated sandstones. Trough cross-laminations, large penecontemporaneous slump folds, siltstone rip-ups, and rare dish structures are present. Bouma $T_{\underline{a}}$, $T_{\underline{ab}}$, and, less commonly, $T_{\underline{abc}}$ sequences occur.

Between the amalgamated sandstones, several thin rib-forming sandstone beds are intercalated with laminated siltstone and very fine grained carbonaceous sandstone. The fine- to medium-grained sandstone beds have sharp bottom and gradational upper contacts, even bedding, load casts, rare siltstone rip-ups, and $T_{\underline{ab}}$, $T_{\underline{abc}}$, and $T_{\underline{ae}}$ Bouma sequences.

Jansen Creek Member

The Jansen Creek Member is composed of a penecontemporaneously deformed mixture of deep and shallow-water marine sandstone and siltstone that in places encloses large tabular blocks of shallow-water marine conglomerate and sandstone. The type section of this olistostromal unit is designated as the discontinuous exposures in the sea cliffs, wave-cut platforms, and sea stacks from the headland 0.5 km east of Bullman Creek to a point 0.7 km southeast of Brush Point (fig. 2). The Jansen Creek Member is approximately 200 m thick and has been mapped for more than 9.5 km from Seal Rock southeastward to near Brush Point (Tmj on fig. 2). It is separated from the underlying Third Beach Member by about 250 meters of thin-bedded siltstone and sandstone. In the type section, large tabular blocks of interbedded fossiliferous shallow-marine basaltic sandstone and pebble conglomerate as much as 15 m in length are common. These blocks are infolded or enclosed in deep-water marine thin-bedded turbidite sandstone and siltstone and massive hackly fractured concretionary siltstone. The type section contains very thick bedded fossiliferous shallow-water marine sandstone that forms massive resistant overhanging cliffs that can be traced for several kilometers along strike. In places the sandstone beds are folded into broad antiforms and synforms. The yellowish-gray basaltic to feldspathic sandstone is mottled and bioturbated and contains irregular olive-gray calcareous concretionary masses. Scattered fossils in the allochthonous fine- to medium-grained sandstone include the mollusks Conchocele and Lucinoma, Ostrea, and a few bryozoans and Teredo-bored carbonized wood fragments. Several thin coquinalike beds consist of pelecypods, gastropods, and encrusting stromatolitic calcareous algae.

The sandstone beds are interbedded with, and overlain by, well-stratified basalt-pebble conglomerate as much as 10 m thick. The calcite-cemented olive-black conglomerate beds are best exposed at low tide on the wave-cut terraces, where they form resistant ribs or large loose blocks. Individual conglomerate layers are moderately to poorly sorted and range in thickness from 80 mm to 0.2 m. The well-rounded to subrounded pebbles and cobbles consist predominantly of finely crystalline to aphanitic basalt, discoid to spherical in shape and locally imbricated.

On the wave-cut platform from Seal Rock to Shipwreck Point, basaltic pebble conglomerate and shallow-marine sandstone form a series of disharmonic folds with axes dipping as much as 50^o to the north or south. The amplitude of these infolds is as much as 100 m. Locally, undeformed clastic dikes cut across the penecontemporaneously deformed strata.

The basal contact of the allochthonous shallow-marine sandstone and conglomerate blocks with the underlying undeformed deep-water marine Makah strata is planar to irregular with little or no shearing. In the wave-cut platform at the mouth of Rasmussan Creek, the contact between the Jansen Creek Member and older strata is sharp and appears conformable. However, in several road cuts along State Highway 112 between Bullman Creek and Rasmussan Creek, the basal contact is discordant. Thin siltstone beds within overturned blocks of the massive shallow-marine sandstone display 60^o to 90^o disparity in attitude with the underlying Makah strata. The Jansen Creek Member is overlain by undeformed thin-bedded siltstone and sandstone that contain a few broad channels of sandstone. This upper contact is sharp in the few places where it is exposed during very low tides.

Near Brush Point the member is overlain by Makah strata that consist of interbeds of basaltic sandstone and pebble conglomerate that contain displaced shallow water mollusks. These basaltic strata are exposed in the Makah only at Brush Point and eastward on the wave-cut platform as far east as the mouth of the Sekiu River. In these coastal outcrops they are gently flexed and are interbedded with typical thin-bedded siltstone and arkosic sandstone of the Makah. The composition of the basaltic sandstone and conglomerate is similar to that found in some detached blocks and infolds in the Jansen Creek Member, suggesting that these basaltic sediments were derived from a source area similar to that of the basaltic beds of the olistostromal Jansen Creek Member but were deposited by normal sedimentary processes.

Other Units

Falls Creek informal unit

A poorly exposed sequence of amalgamated turbidite sandstones, informally called the Falls Creek unit, crops out in the northeastern part of the mapped area (Tmf on fig. 2). This thick-bedded lithic arkosic sandstone unit forms a dip slope along the southwestern margin of Clallam Bay and is well exposed in Falls Creek 1.1 km southeast of Sekiu Point. It is overlain by numerous beds of thin- to medium-bedded siltstone and sandstone, exposed along the beach at low tide. The unit is more than 30 m thick and is separated from the underlying Jansen Creek Member by an estimated 580 meters of poorly exposed thin-bedded Makah strata (fig. 4). Although both the upper and lower contacts are poorly exposed, the unit has been mapped along strike for 1.4 km. A poorly exposed sandstone bed more than 5 m thick in the road cut on State Highway 112 at the junction of the Ozette Road (fig. 3) may correlate with the Falls Creek unit.

Unnamed sandstone unit

A 15-m-thick unnamed unit composed of approximately 11 0.15- to 1.5-m fine-grained sandstone beds crops out between the Little Hoko River and the NE 1/4 of section 32, T. 32 N., R. 13 W. (fig. 3) approximately 75 m stratigraphically below the Baada Point Member. The sandstone beds display sharp to amalgamated contacts and convolute bedding. The unit may correlate with a similar thick 11-bed unit that crops out in the Clallam River about 8 km east.

PETROGRAPHY

Sandstones of the Makah Formation range in composition from basaltic to arkosic wacke and arenite but are predominantly lithic arkose (fig. 12). They are generally fine to medium grained and are compositionally and texturally submature. Most Makah sandstones are moderately sorted (range: very poorly sorted to moderately well sorted) and are composed of angular to subangular grains.

Matrix abundance of both detrital and diagenetic varieties ranges from a trace to 22 percent. The more abundant diagenetic matrix was formed from *in situ* alteration and crushing of the groundmass of adjacent framework volcanic-rock clasts (pseudomatrix of Dickinson, 1970). Matrix consists of celadonite, chlorite, and scattered angular silt-sized quartz, feldspar, and mica flakes.

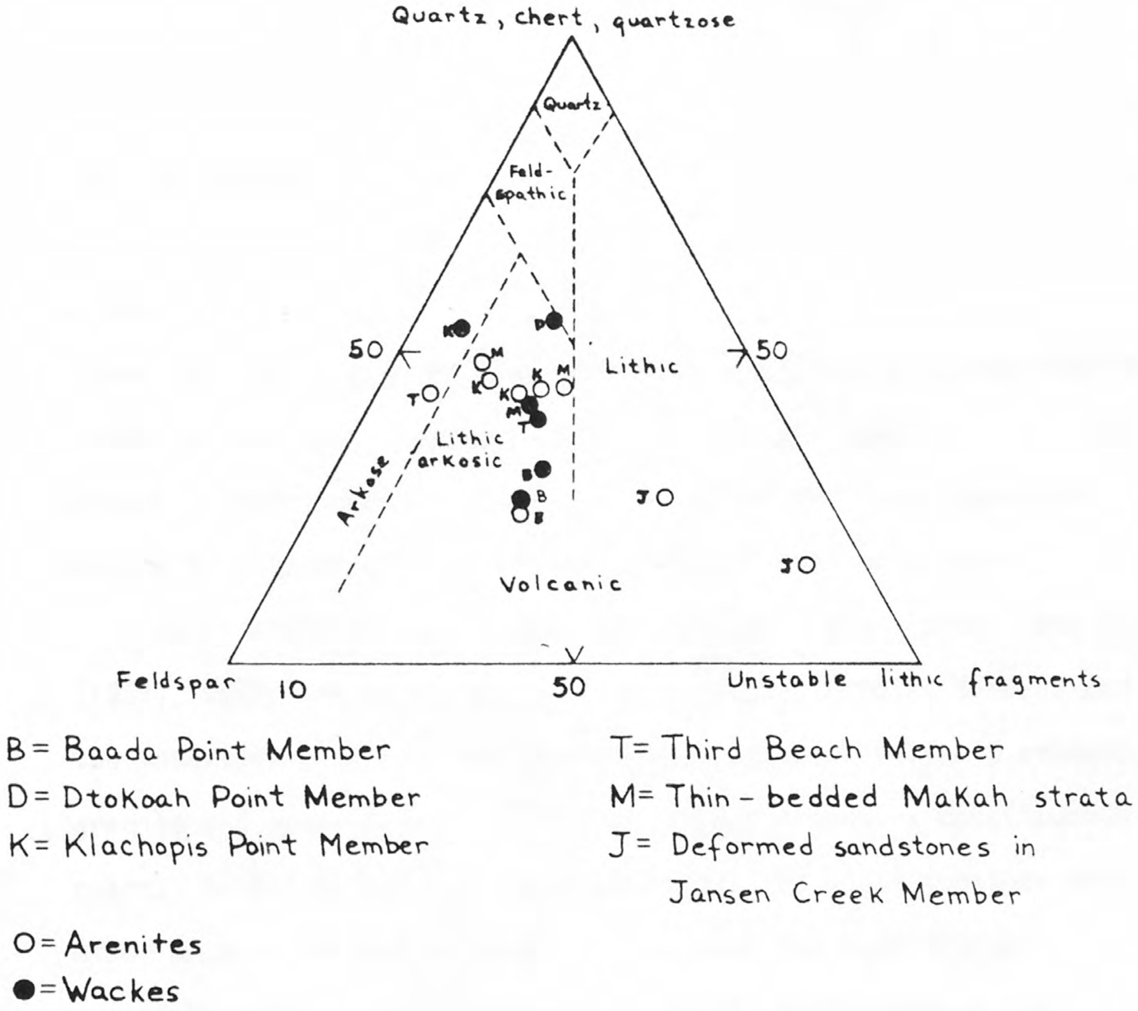


Figure 12.--Ternary diagram modified from Williams, Turner, and Gilbert (1954) showing composition of sandstones in the Makah Formation.

Common cementing materials are calcite in the concretionary sandstones (10 to 50 percent; fig. 13) and diagenetic clays (including chlorite and celadonite) in the more abundant wackes. Other cements include hematite, limonite, and sparse laumontite. Sparry calcite cement apparently formed early in the burial history of the concretionary sandstones prior to formation of diagenetic clay matrix. Framework clasts are supported and partially replaced and embayed by the surrounding pore-filling calcite cement. The number of grain-to-grain contacts and percentage of clay matrix is abnormally low. As a result, the calcareous sandstones are compositionally arenites. Minor chlorite and/or celadonite cements are present as coatings on lithic grains and as pore fillings in some sandstones. Plagioclase grains in some samples are partially laumontized, and laumontite occurs locally as cement that preserves chlorite or celadonite coats.

Using a classification modified from Williams, Turner, and Gilbert (1954), sandstone in the Baada Point and Dtokoah Point Members and in the intervening thin-bedded Makah strata is chiefly lithic arkosic arenite and wacke (figs. 12 and 14). Major framework constituents are quartz, feldspar, volcanic rock fragments, and micas together with minor amounts of heavy minerals and metamorphic rock fragments.

Subangular to subrounded quartz is the most abundant grain type, making up 10 to 34 percent of the sandstone. Quartz varieties include strained and unstrained monocrystalline quartz, polycrystalline quartz, and chert. Tiny fluid inclusions containing oscillating bubbles

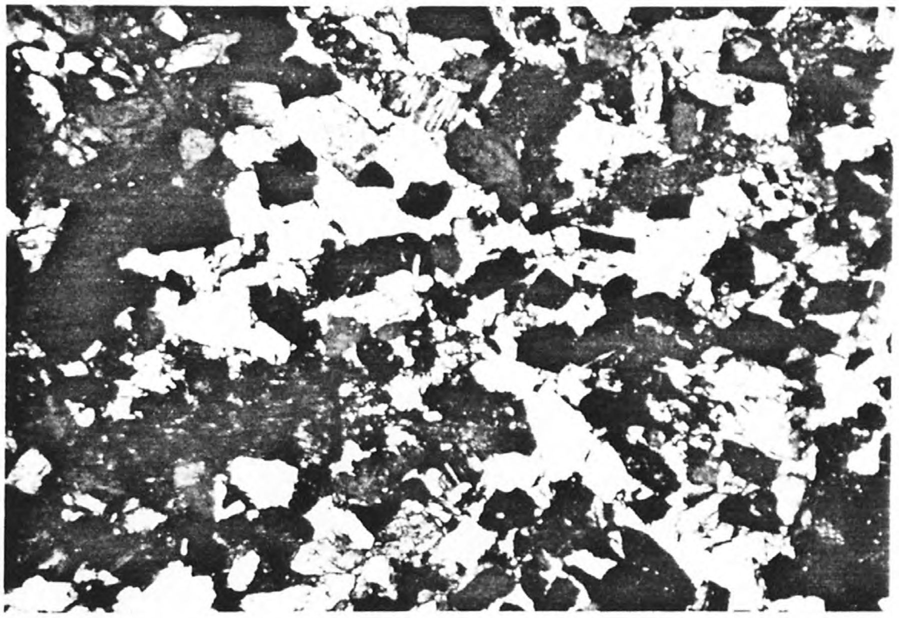


Figure 13.--Calcite-cemented biotite-bearing arkosic sandstone in the Third Beach Member. Horizontal field of view, 3.5 mm (crossed nicols).

Figure 14.--Lithic arkosic wacke from Baada Point Member. Horizontal field of view, 1.25 mm (crossed nichols).

(2-phase fluid inclusions) are present in some monocrystalline quartz grains.

Feldspar constitutes 13 to 31 percent of the sandstone; it includes both albite-twinned plagioclase (An_{3-64}) and minor potassium feldspar. The plagioclase-to-potassium feldspar ratio is approximately 4:1. Orthoclase and microcline are the most abundant potassium feldspars. Lithic fragments are mainly basalt and andesite (3 to 10 percent), celadonite-replaced amygdaloidal basalt, metabasalt (greenschist facies), and silicic volcanic fragments. Other lithic fragments include minor elongate carbonaceous phyllite clasts, quartz mica schist, and metaquartzite fragments. Biotite flakes form 1 to 4 percent of the sandstone, chlorite flakes 1 to 7 percent. Traces of muscovite are present. Heavy minerals are dominated by clinozoisite, actinolite, epidote, zircon, pink and colorless garnet, hypersthene, apatite, magnetite, and pyrite.

Sandstone in the Klachopis Point and Third Beach Members ranges from micaceous arkosic to lithic arkosic arenite and wacke (fig. 12). The sandstone contains less matrix, has a somewhat higher abundance of quartz, micas, and feldspar, and contains fewer lithic fragments than sandstone in the Baada Point and Dtokoah Point Members (compare figs. 13 and 14). In general, the composition and relative abundance of the different lithic and mineral types in all four members is nearly the same except that Third Beach sandstone contains more coarse-grained biotite flakes than sandstone in the other members.

The shallow marine sandstone in the Jansen Creek Member differs significantly from the turbidite sandstone members in composition and texture; it is volcanic arenite (fig. 12) and is generally coarser grained. Metabasalt (greenschist facies) and basalt fragments make up as much as 24 percent of this sandstone. Other characteristic grain types are monocrystalline quartz, plagioclase, silicic volcanic rock fragments, actinolite (to 5 percent), clinozoisite, chlorite, and molluscan shell fragments. Minor constituents include biotite, augite, pyrite, magnetite, epidote, and algal stromatolites. Calcite cement is ubiquitous and constitutes as much as 53 percent of the rock.

Granule-and-pebble basalt clasts in the Jansen Creek conglomerate are round to subround. Basalt, gabbro, and metabasalt are the predominant clast types. Other pebble constituents include minor silicic volcanic rock, metatuff, and molluscan shell fragments.

The tuff member is composed of abundant sickle and rarer bubble wall-glass shards set in a devitrified siliceous clay matrix. Shards are commonly altered to a cherty groundmass. Other constituents include scattered grains of plagioclase, monocrystalline quartz, biotite, muscovite, and chlorite flakes, rare cherty siliceous volcanic fragments, hypersthene, ilmenite grains altering to limonite, and clinozoisite. Patches of secondary sparry-calcite cement are locally abundant. Deposition of this rhyodacitic ash in a marine environment is indicated by the presence of a few Foraminifera.

RESERVOIR POTENTIAL OF TURBIDITE SANDSTONE MEMBERS

Three surface-sandstone samples from thick amalgamated turbidites of the Baada Point and Klachopis Point Members have relatively low permeabilities and moderately low effective porosities based on quantitative laboratory analyses. The low porosities and permeabilities probably result from the abundance of detrital and diagenetically formed clay matrix and the calcite and rarer limonite, hematite, and laumontite cements that have almost completely filled the pore spaces between framework grains. This make-up is particularly evident in the two matrix-rich Baada Point samples, each with low porosity (20.4 to 20.7 percent) and low permeability (2.0 to 7.5 millidarcies) and probably in the calcareous concretionary zones of all the members.

The sample from the Klachopis Point Member has the highest effective porosity and a moderately high permeability (24.6 percent and 657 millidarcies) and also tends to be more friable and cleaner in thin section than the Baada Point and Dtokoah Point sandstones. It could act as a permeable reservoir rock in the subsurface. At one locality, a 1-m-thick sandstone bed in the Klachopis Point unit emitted a petroliferous odor when freshly broken. The Third Beach clean arkosic sandstone, like the Klachopis Point sandstone, generally contains less pore-filling clay matrix than the more lithic Baada Point, Dtokoah Point, and Jansen Creek sandstones, and may represent an important permeable unit.

All the amalgamated sandstone members are enclosed by thick (hundreds of meters) sequences of thin- to very thin-bedded siltstone and turbidite sandstone that could act as both cap rocks and contiguous source rocks in the subsurface. Hydrocarbon analyses (reported in Snavely, Pearl, and Lander, 1977, table 3), however, of surface samples by George Claypool indicate that upper Eocene and Oligocene siltstone in this area is generally geothermally immature, containing only minor quantities of light hydrocarbons.

The Klachopis Point Member, being the thickest, most widespread, and highest in permeability and porosity, and to a much lesser extent the Baada Point Member, probably have the highest reservoir potential. The Third Beach and Dtokoah Point Members have much more limited distribution and thickness in outcrop and therefore lower reservoir capacity (particularly the Dtokoah Point Member). The olistostromal shallow-marine sandstone and conglomerate of the Jansen Creek Member are too discontinuous, chaotically arranged, and tightly cemented by calcite to represent an important reservoir unit in the subsurface.

Onshore, where the homoclinal sequence is breached by erosion, the petroleum potential of the four northward-dipping turbidite Members is limited. Stratigraphic-type traps may exist in the lower part of the Makah Formation, where it laps onto the broad anticlinal high in the central part of the study area. As these units dip and strike beneath the Strait of Juan de Fuca, structural and/or stratigraphic traps may exist in this area.

AGE AND REGIONAL CORRELATIONS

Foraminiferal assemblages, sparse and varied throughout the Makah Formation, indicate that the sequence ranges in age from late Eocene to late Oligocene. Foraminifers from the lower part of the sequence at Waadah Island (table 1) indicate that the lower 700 meters of the Makah Formation (below the Baada Point Member, fig. 4) ranges in age from the late Narizian Stage of Mallory (1959) to the Refugian Stage of Schenck and Kleinpell (1936).

On the basis of the known range of species within the Tertiary of the Pacific Northwest (Rau, 1958, 1964, 1966; Fulmer, 1975; Armentrout and Berta, 1977), the 100 meters of strata stratigraphically below the Baada Point Member on Waadah Island is best referred to the Refugian Stage (fig. 4). This age assignment is based on the presence of *Melonis halkyardi*, *Elphidium californicum*, *Sigmomorphina* cf. *S. schencki* and in particular *Ceratobulimina washburni* (table 1). Foraminifers from the interval 100 to 300 m below the Baada Point Member on the east side of Waadah Island have greater affinities for the Narizian Stage than for the Refugian Stage. The highest occurrence of *Vulvulina curta*, *Anomalina garzaensis*, *Pleurostomella nutalli*, and *Quinqueloculina goodspeedi* all signify a Narizian age.

The upper part of the Makah Formation, strata between the Third Beach Member and the base of the Pysht Formation (fig. 4), are Oligocene (Zemorrian Stage) in age. The checklist of foraminifers (table 2) shows the occurrence of species in the middle

Table 1.--Checklist of Foraminifera from the Waadah Island section of the Makah Formation. [Symbols of frequency of occurrence: C, common; F, Few; R, rare; ?, questionable identification].

	Pacific Northwest Reference Collection No.											
Species	8278	8277	8322	7135	8330	7250	7134B	8321	7247	7133	7132	8276
Quinqueloculina spp.	R	R	R	R	R		R	R		R	R	
Dentalina cf. D. pauperata (d'Orbigny)	F	R		R	R	?			R			
Stilostomella sp. (large final chamber)	R											
Nodosaria longiscata d'Orbigny	R	R	F	R	R	R	C	F	F	R	F	F
Pseudoglandulina inflata (Bornemann)	F	?				?	?		?		R	?
Gyroidina soldanii d'Orbigny	C				R		R	R	F			R
Melonis pompilioides (Fichtel and Moll)	?							?				
Fursenkoina (Virgulina) sp.	R											
*Melonis halkyardi (Cushman)	F											
Cibicides cf. C. lobatulus (Walker and Jacob)	R			?	?			?				
*Elphidium californicum Cook MS	R											
Globigerina spp.	R	F	R	F	R	R	F		F	R	R	R
Guttulina irregularis d'Orbigny	R											
Eggerella bradyi (Cushman)	?		R	?	R			R	?	R		R
Karreriella chilostoma (Reuss)	R	R									?	
*Cassidulina galvinensis Cushman and Frizzell	?				?							
Globocassidulina globosa (Hantken)	?							R	?			R
Cibicides cf. C. elmaensis Rau	R	F		R			F	R		R		
*Ceratobulimina washburni Cushman and Schenck	R											
Cibicides spp.	R	R	R	R	R	R	R			R		
Spiroloculina cf. S. texana Cushman and Ellisor		R							R	R		
*Sigmomorphina cf. S. schencki Cushman and Ozawa		R										
Vaginulinopsis saundersi (Hanna and Hanna)		R										
Bulimina cf. B. instabilis Cushman and Parker		R			F		?			?		
?Alabamina sp.		R										
Anomalina cf. A. californiensis Cushman and Hobson		R			R				R	F	R	R
Eponides umbonatus (Reuss)		?			?		R	R	R	R		F
Pullenia bulloides d'Orbigny		?			R		?	R	F	R		F
Globobulimina cf. G. pacifica Cushman		R	R	?	R		?					
Martinottiella cf. M. nodulosa Cushman			R								R	
Sigmoilina sp.			R									
Cornuspira sp.			R									
Stilostomella cf. S. Sanctaecrucis (Kleinpell)			F	R	F	?	F	F	R	R	R	R
Chilostomelloides cf. C. cyclostoma (Rzehak)			R		R	R			F	F	F	R
Cancris joaquinensis Smith			R	?			?	R				
Gyroidina soldanii d'Orbigny var. (rounded edges)				R				R		R	F	
*Vulvulina curta Cushman and Siegfus					?		F	F	F			
Nodosaria clavaeformis Neugeboren					R							
Nodosaria pyrula d'Orbigny					R							
Praeglobobulimina cf. P. pyrula (d'Orbigny)					R			R				
*Anomalina garzaensis Cushman and Siegfus					R			?				?
Valvulineria jacksonensis welcomensis Mallory					R							
Plectofrondicularia sp.					R	R						
*Pleurostomella nuttalli Cushman and Siegfus					R					R		?
Gyroidina condoni (Cushman and Schenck)							R			?		
Lenticulina spp.								R	R	R		R
Plectofrondicularia cf. P. gracilis H. P. Smith								R		?		
Cibicides spiropunctatus Galloway and Morrey								?				
Cibicides sp. (large, variable, incised sutures, coarse perferate)								R	F			
Cassidulina sp. (discoid, rounded perf.)								R				
?Fursenkoina(Virgulina) sp. (narrow)								R				
Pyrgo sp.									R			
Quinqueloculina imperialis Hanna and Hanna									R			
*Quinqueloculina goodspeedi Hanna and Hanna									?	?		R
Pullenia salisburyi R.E. and K. C. Stewart										?		
Praeglobobulimina cf. P. ovata (d'Orbigny)							R			F		?
	Refugian ?			Narizian								
	Late Eocene											

*Key species

and upper Makah in the Hoko River reference section (A to B on figs. 3 and 5). *Dentalina quadrulata*, *Uvigerina* cf. *U. gesteri*, and *U. gallowayi* are among diagnostic Zemorrian species occurring in the upper part of the Hoko section between localities 7191 and 7609 (table 2, fig. 5).

The precise boundary between the Zemorrian and Refugian Stages is difficult to define in the Hoko River section, as several key species found elsewhere in the Pacific Northwest (Rau 1958, 1964, and 1966) that define the Zemorrian Stage and the Refugian Stage occur together in a 1,200-m-thick stratigraphic interval (table 2, fig. 5, localities 7387 to 7191). If the total assemblage is considered, the Refugian-Zemorrian boundary is best placed between localities 5789 and 5788 (table 2, fig. 5).

Several siltstone samples collected on Waadah Island and near the Little Hoko River contain Foraminifera indicative of Ulatisian and early Narizian ages. These anomalous Foraminifera are probably reworked from older Eocene strata. Submarine erosion across growing broad anticlinal highs in the pre-Makah strata, as at Cape Flattery and in the central part of the study area (fig. 2), undoubtedly contributed reworked older sediments and their Ulatisian to Narizian microfossils to the younger strata that were being deposited in synclinal low areas.

Foraminiferal assemblages from the Makah Formation (see tables 1 and 2) clearly indicate deep-water open-sea conditions. Almost all of

Table 2.--Checklist of Foraminifera from the Hoko River section of the Makah Formation. [Symbols of frequency of occurrence: C, common; F, few; R, rare; ?, questionable identification].

Species	Pacific Northwest Reference Collection No.																								
	7609	5190	5423	5783	5784	5785	5786	5182	5187	7190	7191	5787	7192	7193	7194	5788	5789	5790	7195	5791	5726	5186	5792	8242	7387
Lenticulina cf. L. inornatus (d'Orbigny)	C	R				R			?		R				R	R						R	R		
Marginulina glabra d'Orbigny	?	R									?	?													
Stilostomella cf. S. sanctaecrucis (Kleinpell)	R				R	?	?				R			R	R	R	R		?			?			
Dentalina pauperata (d'Orbigny)	?	F			R																				
Dentalina consobrina d'Orbigny	?	F		?				?					?						?		?	?			
Nodosaria cf. N. soluta (Reuss)	R											R									R				
*Dentalina quadrulata Cushman and Laiming	F	F			R					R															
Sigmoilina sp.	R					R	R							R		R							R		
Stilostomella frizzelli (Rau)	R																								
Stilostomella advena (Cushman and Laiming)	R	R											?	?									?		
Eponides umbonatus (Reuss)	?	?				R	?					R			F	R				R					F
*Anomalina californiensis Cushman and Laiming	F	F		R	?				C	F	F		F	?					?		?		?		
Guttulina cf. G. problema d'Orbigny	R																								
Gyroidina soldanii d'Orbigny	R	F			F		?	?	F		F	F	R	R	R		R	R	R	R	F	R	R		R
Praeglobobulimina cf. P. ovata (d'Orbigny)	R				R	?					?		?	R		?	C	F			F	R			
*Uvigerina cf. U. gesteri Barbat and von Estorff	R			R																					
Uvigerina garzaensis Cushman and Siegfus	C	R				F					R			?	R	R	R	F			R		C		
*Sphaeroidina variabilis Reuss	C															R	R								
Globigerina sp.	R			R	R		R			F	R	R			R			R				R	F	R	R
Globobulinina cf. G. pacifica Cushman	R	R							R											F					
Nodosaria longiscata d'Orbigny		R		R	R		R	R		R	R			R		F	R	R	R	F	R	R	R		R
Pseudoglandulina inflata (Bornemann)		F	R	R	R	R	R	R			R	R		R	R	F									R
Melonis pompilioides (Fichtel and Moll)		R																							
Fissurina sp.		R		R					R	R						R				R		R			
*Bulimina alsatica Cushman and Parker		F				R	R			R	R	R			R	R			R	?	F		F		
*Florulis cf. F. incisum (Cushman)		F			?	?	F						?	R									R		
Quinqueloculina weaveri Rau		?											F							R					
*Cassidulina crassipunctata Cushman and Hobson		C			F		?			?	C		F	?			R						?		
Fursenkoina (virgulina) sp.		?															R								
Martinottiella cf. M. nodulosa (Cushman)			R	R	R				R							R				R					
Pyrgo spp.			R	R											F		R	R		F		R			
Epistomina eocenica (Cushman and Hanna)			?	?	F				R									R							
Cibicides spp.				R							R														R
*Uvigerina gallowayi Cushman				F	C																				
*Cassidulinoides sp.					R																		R		
*Buccella mansfieldi oregonensis (Cushman, R. E. and Stewart, K.C.)					?			?																	
Quinqueloculina cf. Q. imperialis Hanna and Hanna						R						?				R			?	?					
Spiroloculina cf. S. texana Cushman and Ellisor						R	R								F	R									
Chilostomelloides sp.						R						R				R	F								
Plectofrondicularia cf. P. gracilis Smith						F	R								R	R	R	R	R		R	R	R		
Plectofrondicularia vaughani Cushman						R	R				R	R	R		R		R	R		?	R		R		
Bolivina sp.						R	R																		
Nodosaria pyrula d'Orbigny							R	R													R	?			R
Eggerella bradyi (Cushman)							?					R			R										
Pullenia bulloides (d'Orbigny)							R	R		?				R		?	R	R		R			R		R
Cassidulina cf. C. globosa Hantken							R			R															
Siphonodosaria(?) verneuili (d'Orbigny)									F	F						?		F							
Cassidulina cf. C. kernensis Smith											R	R													
Lenticulina cf. L. texana (Cushman and Applin)												R													
*Lenticulina cf. L. calcar (Linné)												R						?							
Cibicides cf. C. pseudougerianus evolutus Cushman and Hobson												R	F	?		R	F	?	?	?	?				
Gaudryina alazanensis Cushman													F												
Guttulina cf. G. frankei Cushman and Ozawa													R												
Pseudoglandulina aff. P. inflata (Bornemann)													F							R					
Plectofrondicularia sp. (thick)													R												
Quinqueloculina spp.														R			R	R	R	R	R	R			R
Uvigerina sp. (small, fine costae)														R											
Karreriella washingtonensis Rau																R	R		?						
Lagena cf. L. becki Sullivan																R	R								
Cyclogyra (Cornuspira) cf. C. byramensis (Cushman)																	R								
*Karreriella chilostoma (Reuss)																	R			R			F		
?Elphidium sp.																	R								
Guttulina problema d'Orbigny																		R							
Eponides? sp.																				R			R		
*?Cibicides hodgei Cushman and Schenck																							R		
Glomospira charoides corona Cushman and Jarvis																								R	
?Anomalina sp.																									R

*Key species

Zemorrian | Refugian

Oligocene | Late Eocene

those foraminifers consistently occurring throughout the formation suggest bathyal conditions. Moreover, most of these taxa support no less than middle bathyal depths. Many, such as *Gyroidina soldanii*, *Stilostomella*, hispid uvigerinids, *Bulimina alsatica*, and *Pullenia bulloides* probably thrived at lower bathyal depth. The minor but consistent occurrence throughout the formation of planktonic taxa (*Globigerina*) supports open-sea conditions.

Mollusks are sparse in the deep-water sedimentary rocks of the Makah Formation, where they occur chiefly in olistostromal blocks of shallow-water basaltic sandstone and conglomerate in the Jansen Creek Member. Addicott (written communs., 1973-1977) identified the following species collected from the Jansen Creek Member on the coast near the southwest corner of section 22, T. 33 N., R. 14 W.:

Gastropods:

Acrilla n. sp. ? aff. *A. olympicensis* Durham
Naticid
?*Perse* sp.
Turritella cf. *T. porterensis* Weaver
Undet. fragments - 3 spp.

Pelecypods:

Conchocele cf. *C. disjuncta* (Gabb)
?*Crenella* sp.
Cyclocardia hannibali (Clark)
Lucinoma cf. *L. columbiana* (Clark and Arnold)

Nemocardium cf. N. weaveri (Anderson and Margin)

Ostrea sp.

Scaphopods:

Dentalium porterensis Weaver

Addicott assigned a late Eocene age, Lincoln Stage, to this collection and suggested a middle or outer sublittoral environment of deposition for the basaltic sandstone. Foraminiferal assemblages in the Jansen Creek Member indicate a late Eocene age, the Refugian Stage (a Lincoln equivalent), and a shallow-water depositional environment. The penecontemporaneously deformed member is both underlain and overlain by younger (Zemorrian) Makah strata that were deposited at lower to middle bathyal depths. This relation supports the interpretation that the shallow-marine sandstone and conglomerate of the Jansen Creek Member are allochthonous deposits derived from uplifted older (Refugian) strata along an ancient narrow shelf that bordered the Makah deep marginal basin to the north. These shallow-water Refugian deposits were transported into the deep marginal basin by a large submarine slide during Zemorrian time.

The Makah Formation represents part of an upper Eocene to Oligocene deep marginal marine facies that crops out only in the northwestern part of the Olympic Peninsula, on western Vancouver Island, in southwesternmost Washington, and in northwestern Oregon but is also widespread on the inner continental shelf of Oregon (Snavely and others, 1977). The Makah is coeval with the middle member and lower part of the upper member of the former Twin River Formation of Brown and Gower (1958) and Gower (1960) (now Twin River Group) as exposed in the north-central part of the Olympic Peninsula. The Makah Formation is in part correlative with late Eocene and Oligocene strata of the Hoh Rock Assemblage in the Hoh-Quillayette area of the western coastal area of the Olympic Peninsula (Rau, 1973, 1975).

Correlative strata similar to the Makah Formation in lithology, age, and depositional environment are exposed in the Hesquiat Peninsula and Nootka Island area along the central west coast of Vancouver Island. This sequence, described in detail by Jeletzky (1954, 1973, 1975) and Cameron (1971, 1972, 1973, 1975), was named the Hesquiat Formation by Jeletsky (1975).

Shallow-water sandstone, siltstone, and conglomerate that correlate with the Makah Formation fringe the south side of Vancouver Island from Sombrio Point westward to near the entrance to Nitinat Lake. These strata were referred to the Carmanah Formation by Clapp (1912) and are mapped and described by Muller (1971, 1977).

In Washington, correlative shelf facies, in addition to parts of the Twin River Group, are the Lincoln Creek Formation (Weaver, 1937; Beikman and others, 1967) in southwestern Washington and the deep-water marine Blakeley Formation (Weaver, 1912; Fulmer, 1975; McLean, 1977) in the Puget Sound area. In the southern and central Oregon Coast Range, the time-stratigraphic equivalents are the shallow-marine Eugene Formation on the southeastern flank of the range and the deep-water marine Alsea Formation along the central Oregon coast (Snavely and others, 1975). In the northern Oregon Coast Range, the formation is coeval with the shallow-marine Pittsburg Bluff Formation (Schenck, 1927; Moore, 1976), the upper member of the Keasey Formation (Schenck, 1927; Moore and Vokes, 1953) in the northeastern part of the range, and the lower part of the deep-water marine mudstone of Oswald West on the northwestern flank of the range (Niem and Van Atta, 1973).

DEPOSITIONAL ENVIRONMENT

The Makah Formation consists of a 2,800-m-thick sequence of thin-bedded turbidite sandstone and siltstone punctuated by four distinct, areally widespread packets of thick-bedded amalgamated turbidite sandstones and one olistostromal unit of penecontemporaneously deformed shallow-marine strata. The microfossil assemblages from siltstone beds throughout the formation indicate deposition in an open-marine lower to middle bathyal environment. The paleoecology, total thickness, turbidite nature, and geometry of this upper Eocene and Oligocene sedimentary sequence indicate rapid deposition in a submarine fan setting.

Applying the criteria developed by Mutti and Ricci Lucchi (1972, 1975) for recognizing turbidite facies in ancient submarine-fan sequences, the vertical and lateral turbidite facies variations of the Makah Formation best fit the depositional lobe setting of an outer submarine fan. The amalgamated sandstone members appear to have been deposited as lobes; the thick sequences of thin-bedded strata between the sandstone packets have the sedimentary characteristics of basin-plain and outer-fan fringe deposits.

In the turbidite facies scheme of Walker and Mutti (1973), the sandstones of the Baada Point, Klachopis Point, and Third Beach Members appear to be a sequence of alternating proximal C and B turbidite facies with minor intervening D facies. The high sandstone-to-siltstone ratio, several thickening-upward cycles, abundant $T_{\underline{a}}$, $T_{\underline{ab}}$, and $T_{\underline{abc}}$ Bouma sequences, thick even bedding, coarse tail grading, and overall sheetlike geometry are characteristic of turbidite sands deposited on a depositional lobe of an outer submarine fan (Mutti and others, 1978). The minor sequences of thin-bedded turbidites within each thick amalgamated sandstone member (facies D of Walker and Mutti, 1973) may reflect deposition between shifting lobes.

The Dtokoah Point Member, being thinner bedded and less amalgamated, and having more $T_{\underline{bcd}}$ turbidite sequences and a lower sandstone-to-siltstone ratio than the other turbidite sandstone members, may represent a transition from sedimentation on a depositional lobe to sedimentation on an outer-fan fringe. The local thin-bedded channelized strata in this member appear to be a channel margin of interchannel facies of a depositional lobe as described by Mutti (1977). The very thick bedded amalgamated facies B turbidite sandstone units of the Klachopis Point and Third Beach Members at the type section with thick intervals of Bouma "*a*" divisions and some dish structures may reflect a transition from depositional-lobe to a middle-fan channelized facies.

In the thick sequences of thin-bedded Makah strata between the amalgamated sandstone members, the sandstone-to-siltstone ratio is low. Thin to very thin, sharp, even turbidite sandstone beds alternate with siltstone beds, and internal sedimentary structures occur in Bouma $T_{\underline{b-e}}$ through $T_{\underline{d-e}}$ sequences. No systematic upward thickening or thinning cycles are recognized. These feature are characteristic of sediments deposited in the basin-plain or outer-fan fringe environment (turbidite facies D and G of Walker and Mutti, 1973; Mutti and Ricci Lucchi, 1972; Ricci Lucchi, 1975). Deposition on a slope and subsequent overloading and slumping of the sedimentary pile is indicated by minor intraformational unconformities and by clastic dikes and prolapsed bedding observed throughout the formation.

Higher in the section, conglomerate in the olistostromal blocks of the Jansen Creek Member which contains a displaced Refugian fauna consists of well-rounded basalt clasts that are well bedded, moderately sorted, and imbricated and contain scattered broken molluscan valves. These features suggest that the conglomerate was originally deposited in a littoral zone in Refugian time. Massive bioturbated basaltic sandstone that is interstratified with the conglomerate contains coquinas of disarticulated fossil shells and scattered articulated gastropods, pelecypods, particularly Ostrea, and stromatolitic algae. These characteristics and faunas (Addicott, written communs., 1972-1977) indicate that sand deposition occurred in fluctuating high-energy conditions in neritic water depths.

At the present time, no lithologically similar shelf facies of Refugian age is exposed on the southwestern part of Vancouver Island, but the Oligocene section there is incompletely preserved. The nearest outcrops of compositionally similar thick-bedded basaltic sandstone and conglomerate containing molluscan coquinas and metabasalt clasts are in the younger Sooke Formation of southern Vancouver Island (Clapp, 1912, 1913; Clapp and Cooke, 1917), an upper Oligocene and lower Miocene strandline formation also derived from erosion of the Eocene Metchosin Volcanics (correlative of the Crescent Formation). The Sooke Formation depositional setting may therein be analogous to the environment that produced the compositionally and lithologically similar, but older, Refugian Jansen Creek Member strata that slid into the Makah marginal basin in Zemorrian time.

The olistostromal blocks and penecontemporaneous folds of the Jansen Creek Member form a thin stratigraphic unit that is traceable for 9 km. The linear trend of this olistostromal belt parallel to the presumed shelf margin suggests that the lithified blocks slid off an ancient fault scarp or elongate high along the northern margin of the Fuca basin.

PALEOGEOLOGY

During late Eocene and Oligocene time, deep-water sediments were deposited in the Pacific Northwest in several marginal basins that may have been interconnected but had different sediment-source areas

(Snavely and Wagner, 1963). The Makah strata are part of this deep marginal basin facies that now crops out only in the northwestern Olympic Peninsula, in southwestern Washington and northwestern Oregon, and along the coast of central western Vancouver Island. On the basis of limited subsurface data from exploration wells, correlative deep marginal basin deposits of late Eocene and Oligocene age also underlie the inner continental shelf of Oregon (Snavely and others, 1977) and the Tofino basin along the western side of Vancouver Island (Shouldice, 1971). In all but the northernmost basin, Tofino-Fuca basin (fig. 15), the upper Eocene and Oligocene strata consist chiefly of deep-water siltstone with minor sandstone interbeds. The Tofino-Fuca basin in which the Makah occurs was unique because of the abundance of turbidite sands deposited in it.

The Tofino-Fuca basin (fig. 15), an elongate deep, narrow depositional basin or trough, is inferred to have extended from the Kyuquot uplift near the Brooks Peninsula in northern Vancouver Island (Tiffin and others, 1972) southeastward to the vicinity of the Lyre River on the central part of the northern flank of the Olympic Peninsula, a distance of more than 350 km (fig. 15). The southwestern margin of the basin, though now difficult to delineate because of post-early Miocene deformation, erosion, and cover by younger strata, may once have been along a welt of lower and middle Eocene volcanic rock. And this welt may have been defined by the Prometheus magnetic high (Shouldice, 1971; MacLeod and others, 1977) and a ridge formed by the Crescent

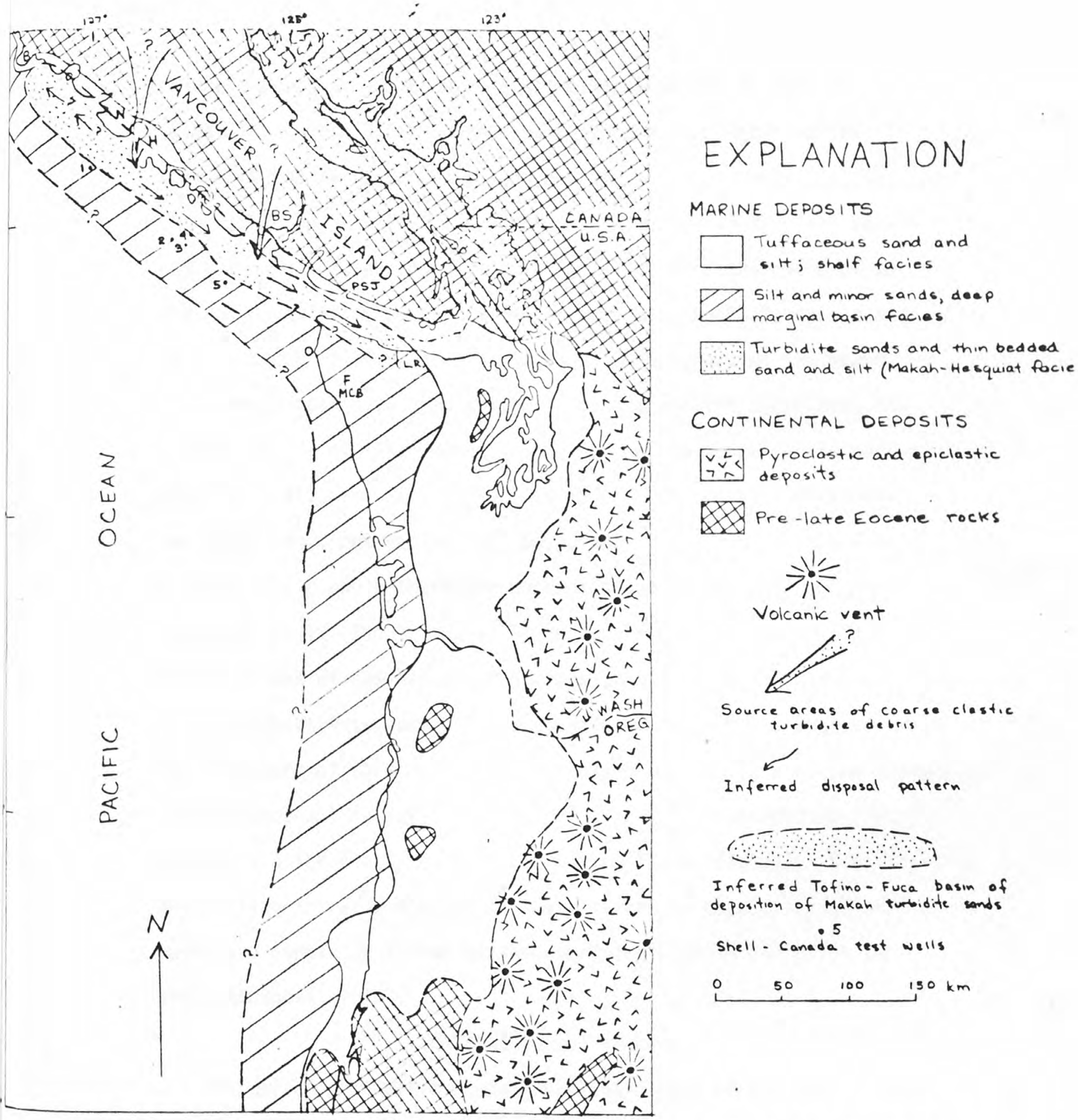


Figure 15.--Paleogeographic map showing the inferred margins of the Tofino-Fuca basin (stippled) relative to other deep-water marginal basin facies in the Pacific Northwest during the late Eocene-Oligocene. Modified from Snavely and others (1975). B, Brooks Peninsula; N, Nootka Island; H, Hesquiat Peninsula; BS, Barkley Sound; PSJ, Port San Juan; LR, Lyre River; O, Ozette Island; MCB, Minter Creek Basin; and F, Forks. Numbers represent Shell Canada Ltd. offshore exploration wells: 1, Apollo; 2, Zeus I-65; 3, Zeus D-14; 4, Pluto; and 5, Prometheus.

volcanic rocks along the northwestern flank of the Olympic Mountains (figs. 1 and 2). Upper Eocene and Oligocene deep-water marine turbidite strata on Nootka Island and the Hesquiat Peninsula (Cameron, 1973, 1975) suggest that the northeastern margin of the late Eocene and Oligocene basin probably was a few kilometers shoreward of the present coast of Vancouver Island between the Brooks Peninsula and Barkley Sound (Tiffin and others, 1972). Southeast of the sound, this margin must have been southwest of the present shoreline, for neritic strata of late Eocene and Oligocene age (Carmanah Formation of Clapp, 1912; see also Muller, 1971) crop out locally along the Vancouver coast between Barkley Sound and Sombrio Point. This deep marginal basin would therefore encompass the Tofino basin on the Vancouver shelf (Shouldice, 1971) and the Fuca basin along the northwestern flank of the Olympic Mountains (fig. 15).

Paleobathymetry based on foraminiferal assemblages suggests that the Fuca part of this marginal basin was deep from late Eocene through late Oligocene time during deposition of the Makah Formation (Tm on fig. 2) and the overlying Pysht Formation (Tp on fig. 2). Shoaling and filling in early Miocene time was marked by deposition of shallow-water and nonmarine strata of the overlying Clallam Formation (Gower, 1960; Addicott, 1976).

Paleodispersal pattern

Dispersal of clastics into the Olympic part of the Tofino-Fuca basin during Makah time was from two distinct directions. The turbidite sandstone was introduced from the northwest by longitudinal filling from sources that may have existed near Barkley Sound and the Hesquiat Peninsula (fig. 15). The other dispersal direction is represented by submarine landslide blocks of shallow-marine basaltic sandstone and conglomerate that contain basalt and metabasalt where they occur in the Jansen Creek Member. These conglomerates were derived from the locally metamorphosed basalt in the Metchosin Formation that crops out along the southern margin of Vancouver Island.

A northwestern source area for the four thick amalgamated turbidite members of the Makah Formation and the intervening thin-bedded strata is indicated by a general coarsening and thickening of turbidite sandstone beds and increase of total thickness of each member in that direction and because paleocurrent directions of flute marks in these units display a southeastward dispersal pattern parallel to that of groove cast orientation (fig. 16).

Projecting the dispersal pattern and thickening trend of the Makah turbidites northwestward, thick turbidite sandstone beds are expected to occur in the Tofino basin. Rocks of the Hesquiat Formation that crop out on the Hesquiat Peninsula and Nootka Island area of western Vancouver Island (the northeasternmost part of the upper Eocene to Oligocene Tofino-Fuca basin; fig. 15) lie along this northwest trend. This correlative unit consists predominantly of a sequence of sandstone and siltstone more than 1,500 m thick and minor channel conglomerate (Jeletzky, 1954, 1973, 1975; Cameron, 1971, 1972, 1973, 1975).

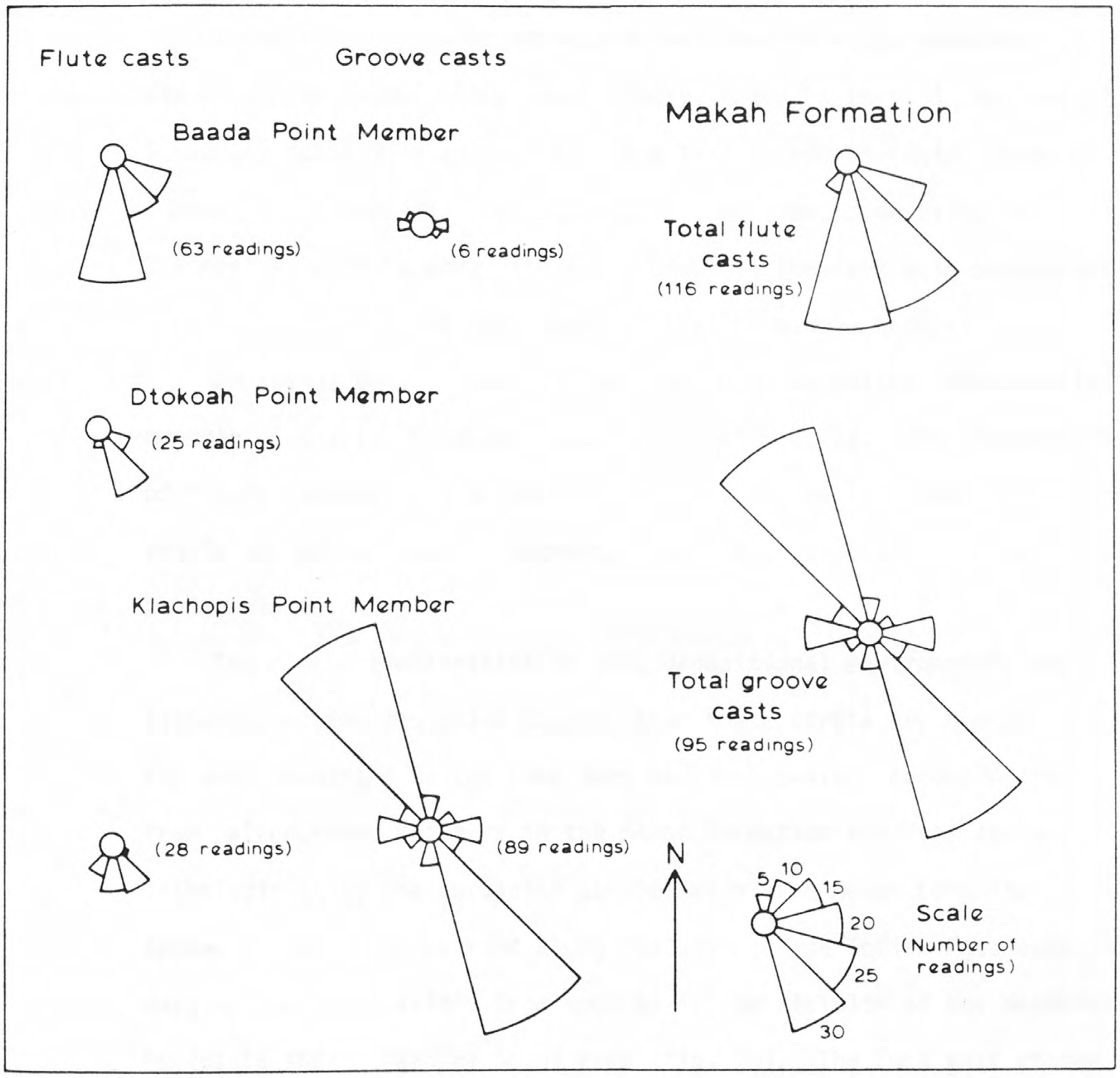


Figure 16.--Rose diagrams showing orientation of flute casts and groove casts in three members of the Makah Formation. Bearings are plotted to the nearest 30° after correcting for tectonic tilt of beds.

Foraminifera from stratigraphic sections from the Hesquiat Formation along the Vancouver Island coast kindly loaned to the U.S. Geological Survey by Mobil Oil Canada, Ltd., are late Eocene (Refugian Stage of Schenck and Kleinpell, 1936) and Oligocene (Zemorrian Stage of Kleinpell, 1938) in age. These microfossils indicate cold deep-water conditions that ranged from upper bathyal to middle bathyal.

The sandstones of the Hesquiat and Makah Formations have similar amounts of quartz, feldspar, muscovite, and biotite. The proportions of lithic components are nearly identical, and basalt, andesite, and felsic volcanic-rock fragments predominate over phyllite and schist clasts.

The marked similarities in age, depositional environment, and lithology of the two units suggest that these strata are coeval and were deposited in the same deep marginal basin. Accordingly, from paleocurrent patterns in the Makah Formation and from age and lithologic data, the turbidite sandstones of the Makah Formation apparently were transported along the axis of the Tofino-Fuca deep marginal basin, possibly from sources in the vicinity of the Hesquiat Peninsula and/or Barkley Sound area (fig. 15). The Fuca part of the basin in which the Makah Formation occurs was apparently deeper, as it acted as a sink for turbidite deposits and as a result is 1,000 m thicker than the Hesquiat sequence.

A difficulty with this paleogeographic reconstruction is that thick sandstone units are absent in two offshore wells drilled in the west-central part of the Tofino basin between the outcrops of upper Eocene and Oligocene sandstone on the Hesquiat and Olympic Peninsula. These two wells, Shell Canada Ltd. Zeus I-65 and Pluto (wells 2 and 4 on fig. 15), penetrated a predominantly deep-marine siltstone section of late Eocene and Oligocene age (Shouldice, 1971). The absence of upper Eocene and Oligocene turbidite sandstone in these two test wells can be interpreted in three ways: (1) a structural high existed along the southwestern margin of the Tofino basin during the late Eocene and Oligocene, and turbidite sands were not deposited across it; (2) most sands from the Hesquiat Peninsula source area bypassed the Tofino basin and were deposited as a turbidite facies in the deeper part of the marginal basin (Fuca basin) to the southeast. Because the upper Eocene and Oligocene sequence in the study area is almost twice as thick as that reported by Shouldice (1971) for the correlative sequence in the Tofino basin, this part of the deep marginal basin must have subsided at a faster rate than the Tofino basin during the late Eocene and Oligocene, forming a natural depositional sink for turbidite sand transported through the Tofino basin; (3) post-late-middle Miocene left-lateral strike-slip movement along the offshore extension of the Calawah fault (fig. 2), which lies along the seaward margin of the Tofino-Fuca basin (MacLeod and others, 1977), offset correlative Makah turbidite sandstone south of the fault to the southeast and brought a predominantly siltstone sequence into the position of Shell Canada's Zeus I-65 and Pluto wells (fig. 2).

The third hypothesis is supported by the presence of infolded strata and blocks (broken formation) of Oligocene turbidite sandstone that occur in mélange along the northwestern Olympic coast as on Ozette Island and in Minter Creek basin, 14 km south of Forks (fig. 15). Some of these infolded sandstone masses and blocks are compositionally similar to the micaceous quartzo-feldspathic sandstone of the Makah Formation. We suggest that these Oligocene turbidite sandstone units were originally deposited along the southwestern margin of the Tofino basin and were offset to their present locations by left-lateral movement along the Calawah fault (fig. 2) in post-middle Miocene time. If this interpretation is correct, then the Oligocene section penetrated in Shell Canada's Pluto and Zeus I-65 exploratory wells (Shouldice, 1971), would lie south of the offshore extension of the Calawah fault (MacLeod and others, 1977) and was deposited farther northwest in the basin, possibly northwest of the major source of the coarse clastic detritus derived in the Hesquiat Peninsula source area.

A seismic reflection profile (24-fold) made by the U.S. Geological Survey across the offshore extension of the Calawah fault about 40 km northwest of Cape Flattery further supports the strike-slip hypothesis. This profile shows more than 2,500 meters of northeastward-dipping strata on the northeast side of the fault that are unconformably overlain by a gently deformed unit of probable Miocene(?) and Pliocene(?) age. The 2,500 m section lies along the strike of the thick upper Eocene and Makah sedimentary sequences onland. On the southwest side of the fault, this sequence, probably late Eocene and Oligocene in age, is missing, and the Miocene and Pliocene strata rest unconformably on a high-velocity acoustic basement, probably basalt of the Crescent Formation that forms the Prometheus magnetic anomaly (MacLeod and others, 1977). Shell Canada's Prometheus test well (fig. 15) drilled 30 km north of the seismic profile (near the axis of the Prometheus magnetic anomaly) penetrated 1,785 meters of Miocene and younger strata unconformably overlying basalt similar to that of the Crescent (Shouldice, 1971). Southwest of the Calawah fault, the upper Eocene and Oligocene turbidite strata either were never deposited, were removed by erosion following post-Oligocene uplift (Shouldice, 1971; Tiffin and others, 1972), or were displaced southeastward to the west coast of the Olympic Peninsula by left-lateral movement along the Calawah fault prior to the unconformable deposition of the late Miocene and younger strata on the Crescent volcanic basement.

Source Areas

The abundant strained and unstrained monocrystalline quartz, coarse-grained flakes of biotite, especially in the Klachopis Point and Third Beach Members, and grains of sodic and calcic plagioclase, orthoclase, and microcline in the Makah turbidite sandstone indicate a volumetrically important dioritic to granitic source area for the Makah Formation. Extensive Eocene plutons and the mid-Jurassic Island Intrusions (Muller, 1971, 1977; Carson, 1972) crop out on Vancouver Island east of the Barkley Sound-Hesquiat Peninsula area. These rocks may have been the granodiorite and gneissic sources for the quartzo-feldspathic and micaceous Makah turbidite sand. Pearl (1977), in a scanning electron microscope study, noted the close similarity of Fe/Mg ratios of biotite in the Makah turbidite sandstone beds and biotite from a granodiorite intrusive body midway between Barkley Sound and Port San Juan.

The subordinate amount of basalt, andesite, metabasalt, and silicic volcanic fragments and associated heavy minerals in the Makah turbidite sandstone units also indicates a contribution of lithic detritus from a volcanic terrane. On Vancouver Island, possible sources include rocks of the Paleozoic Sicker and the Mesozoic Bonanza and Karmutsen Groups that surround the granodiorite intrusive bodies north of the San Juan fault (Muller, 1971, 1977). A southwestward dispersal pattern noted in the coeval Hesquiat Formation (Cameron, oral commun., 1978) suggests that west-central Vancouver Island probably was a major source area for the lithologically similar Makah turbidite sand (fig. 15).

The only other nearby source area likely to have been exposed during the late Eocene and Oligocene lay due north or northeast across the Strait of Juan de Fuca on southern Vancouver Island. If the paleodispersal of the Makah turbidite sandstone had been from the northeast prior to Olympic tectonism, graphitic schist and phyllite detritus from the Paleozoic Leech River Formation and basalt from the Eocene Metchosin Formation that form much of southern Vancouver Island (Muller, 1971, 1977) should be more abundant in these sandstone beds. This terrane does appear to be a source of detritus in the underlying Hoko River Formation, which contains abundant phyllite and basalt clasts in sandstone and conglomerate channels. Although these source rocks probably were exposed during Makah time, as they are major constituents in the coeval nearshore sedimentary rocks on southern Vancouver Island and the Jansen Creek basaltic sandstone, the mineralogy of the Makah sandstone suggests little contribution from these sources. A source area directly to the north is unlikely for the Makah turbidites because the coeval neritic facies strata that crop out along the coast between Port San Juan and Barkley Sound are predominantly of neritic massive tuffaceous siltstone and well-bedded to massive concretionary sandstone that contain abundant mollusks.

A volumetric problem exists when one attempts to explain the high abundance of framework minerals derived from dioritic and granitic rocks relative to volcanic and metamorphic clasts in the Makah sandstone, because the crystalline basement of Vancouver Island consists chiefly of Mesozoic and Paleozoic volcanic and metamorphic rocks (Muller, 1971, 1977). Possibly the fine grain of the Makah sandstone precludes the presence of many lithic fragments from other Vancouver source rocks, since metamorphic, volcanic, and intrusive clasts commonly are chemically altered to clays before they are reduced to a fine sand size (Pettijohn, 1975). The large Mesozoic Coast Range batholith on the British Columbia mainland may be an alternative source for the thick micaceous quartzo-feldspathic Makah sandstone. Detritus shed from this upland area in late Eocene and Oligocene time may have been transported via a major westward flowing river(s) across a low-lying ancestral Vancouver Island to the late Eocene and Oligocene shoreline somewhere east of the present Hesquiat Peninsula-Barkley Sound area, and hence by turbidity flows into the Tofino-Fuca basin.

SUMMARY

In late Eocene and Oligocene time, a submarine fan that now forms the Makah Formation prograded over the hemipelagic siltstone and rarer interbedded phyllitic sandstone and conglomerate channels of the underlying upper Eocene (Narizian) sequence (Th on fig. 2), forming a gradational contact. The geometry of the sandstone packets, together with the paleocurrent orientations, suggests that growth of the fan was by sand and silt turbidity flow that swept southeastward down the axis of the Tofino-Fuca basin (fig. 15).

A well-developed active submarine channel system on the upper and middle fan (presumably located northwest of the study area) temporarily funneled many sheetlike high-density flows into the outer-fan depositional environment in rapid succession to form thick widespread depositional lobes. Several changes in the channel system led to shifting of lobe sedimentation over outer-fan deposits to form the interstratification of thin-bedded outer-fan and basin-plain strata with four thick amalgamated sandstone members. The farthest extent of the prograding depositional lobe was the Klachopis Point

Member, which spread across and beyond the study area.

A local submarine unconformity in the lower part of the Makah Formation that formed prior to deposition of the Klachopis Point lobe was produced by minor compressional folding and faulting of underlying Eocene sedimentary and volcanic rocks as well as the lower part of the Makah Formation locally.

In middle(?) Zemorrian time, deposition of the Makah submarine fan - basin-plain strata was interrupted by a large landslide that carried olistostromal blocks of Refugian basaltic conglomerate and sandstone into the basin from the continental shelf to the north, thus producing the deformed zone of sedimentary rocks, the Jansen Creek Member. Basin-plain - outer-fan sedimentation of the Makah resumed after the Jansen Creek Member episode, temporarily interrupted by progradation of a minor depositional lobe that formed the unnamed amalgamated turbidite unit at Falls Creek.

Outer-fan and basin-plain deposition of the upper Makah Formation was followed by the accumulation of the conformably overlying upper Oligocene conglomerate, sandstone, and siltstone of the Pysht Formation (Tp on fig. 2). Clasts in these deep-water channel conglomerates and thick-bedded sandstones were derived from metamorphic and volcanic sources and from a neritic fossiliferous sandstone that lay northward across the Strait of Juan de Fuca on southern Vancouver Island.

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