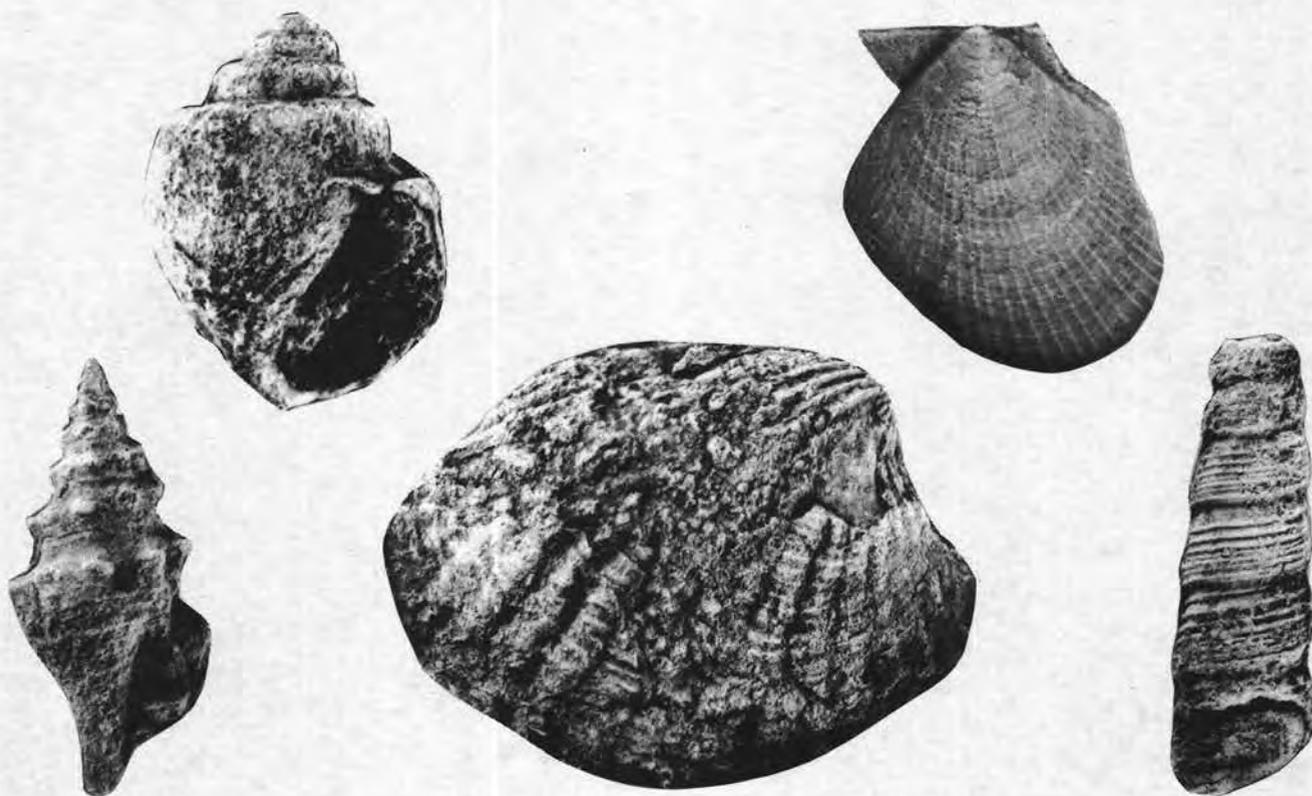

**PALEONTOLOGY AND STRATIGRAPHY OF
EOCENE ROCKS AT PULALI POINT,
JEFFERSON COUNTY,
EASTERN OLYMPIC PENINSULA,
WASHINGTON**

by
RICHARD L. SQUIRES, JAMES L. GOEDERT, and KEITH L. KALER



WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

REPORT OF INVESTIGATIONS 31

1992



WASHINGTON STATE DEPARTMENT OF
Natural Resources

Brian Boyle - Commissioner of Public Lands
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Cover: From left, *?Falsifusus marysvillensis*; *Pachycrommium clarki*; large bivalve, *Venericardia hornii* s.s.; *Delectopecten* cf. *D. vancouverensis sanjuanensis*; *Turritella uvasana hendoni*. These specimens are shown at 150 percent of the dimensions on Plates 1 and 3.

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Paleontology and Stratigraphy of Eocene Rocks at Pulali Point, Jefferson County, Eastern Olympic Peninsula, Washington

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ABSTRACT

About 45 km west of Seattle, along the beach cliff on the east side of Pulali Point, Jefferson County, northeast Olympic Peninsula, a 194-m-thick section of the Crescent Formation contains three basalt units. Each is overlain by fossiliferous pebble conglomerate, sandstone, and siltstone units. Macrofossil localities within these sedimentary interbeds yielded 40 taxa, of which 27 could be identified below the familial level. Most of the fossils are gastropods, and *Turritella uvasana hendoni* s.s. is the most abundant of these. Nine species in these interbeds have not been previously recorded from Eocene rocks as far north as northwest Washington.

The extrusion of each basalt unit caused shoaling of the marine waters. Erosion by storm waves at the top of each basalt unit produced basalt rubble that makes up most of the pebble conglomerates. The rubble was transported into shallow subtidal depths where it became inhabited by substrate-attached and mobile macrofaunas dominated by mollusks indicative of warm-water and normal-salinity conditions. A few of the molluscan genera are Old World Tethyan immigrants that arrived in the northeastern Pacific Ocean during the early Eocene. Sandstones and siltstones successively overlie the pebble conglomerates. These are essentially barren of macrofossils but contain microfaunas indicative of outer neritic to bathyal conditions that existed during the subsidence and/or sea-level rise that followed each basalt extrusion.

The Crescent Formation at Pulali Point is late early Eocene in age on the basis of the contained calcareous nannofossils, benthic foraminifers, and macrofossils. This age is equivalent to the calcareous nannofossil CP10–CP11 Zones and to the benthic foraminiferal Penutian and Ulatisian Stages. The CP10 and CP11 Zones straddle the boundary between the molluscan “Capay Stage” and “Domengine Stage”.

A 72-m-thick sedimentary unit that unconformably overlies the Crescent Formation at Pulali Point is herein tentatively equated to the Aldwell Formation. The basal part is a basalt-boulder conglomerate, and the clasts were most likely derived from the Crescent Formation. There are macrofossils of Eocene age in some reworked concretions in this unit. The conglomerate is overlain by silty sandstone enclosing allochthonous, 2-m-long blocks of Eocene macrofossil-bearing sandstone, as well as reworked concretions. Upsection, a siltstone unit contains abundant carbonaceous debris and localized “mud-pecten” communities. The macro- and microfaunas of the siltstone indicate cold conditions at bathyal depths. The basal basalt-boulder conglomerate of the Aldwell(?) Formation at Pulali Point is the proximal part of a submarine fan, the silty sandstone with allochthonous blocks of sandstone is a submarine slump or mudflow, and the siltstone is the distal part of the submarine fan. The Aldwell(?) Formation at Pulali Point is middle Eocene in age on the basis of the contained benthic foraminifers. This age is equivalent to the benthic foraminiferal Narizian Stage.

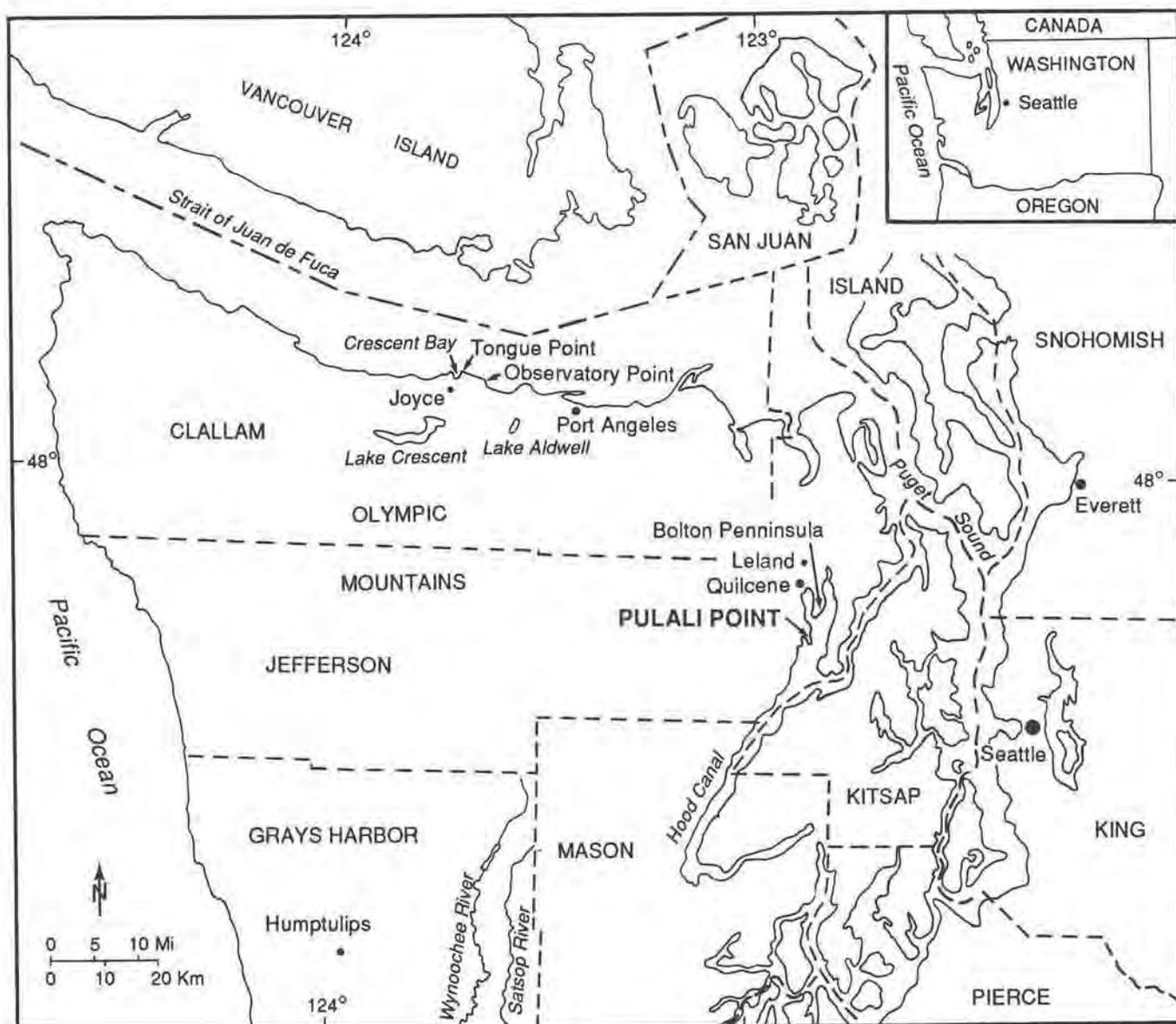


Figure 1. Location of the Pulali Point study area in northwestern Washington.

INTRODUCTION

Rocks of the Pulali Point area along the west side of Dabob Bay, Jefferson County, northwestern Washington (Fig. 1), have previously been mapped as upper Crescent Formation basalt (Tabor and Cady, 1978). Our studies show that the Eocene Crescent Formation, composed of basalts interbedded with fossiliferous sedimentary rocks, crops out in this area and is unconformably overlain by Eocene sedimentary rocks that we term Aldwell(?) Formation.

Sedimentary deposits within the Crescent Formation are not common, and macrofossils are scarce in most such outcrops. The type section of the Crescent Formation at Crescent Bay (Arnold, 1906) along the north shore of the Olympic Peninsula (Fig. 1) is the only other area from which macrofossils in this formation have been studied in

taxonomic detail. These studies date back to the 1940s and earlier.

The geology of the Pulali Point area has received little attention. Danner (1966) mentioned sedimentary units interbedded with basalt in this area. He noted the presence of macrofossils in some of the sandy interbeds, but he gave no precise locality information. Field work (discussed herein) indicates that Danner (1966) was probably referring to the macrofossils from reworked concretions in the Aldwell(?) Formation.

H. W. Schasse (Washington Division of Geology and Earth Resources) found a fossil crab in the Pulali Point area and informed K. L. Kaler, who, in turn, told R. E. Berglund (Bainbridge Island) and J. L. Goedert. In 1989, Berglund and Goedert visited the area and discovered more macrofossils.

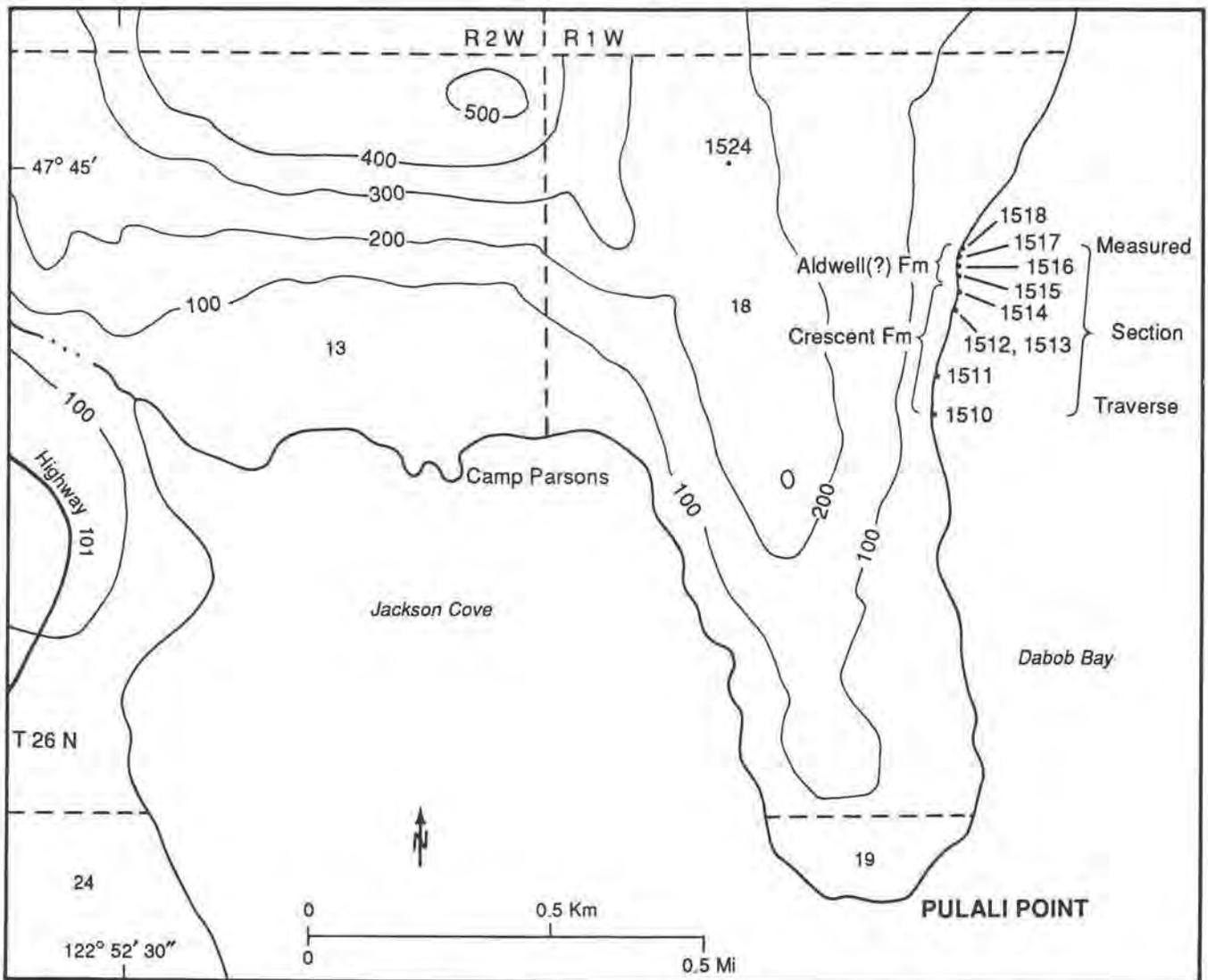


Figure 2. Map of the study area showing the location of the measured-section traverse and California State University, Northridge, macrofossil collecting localities. Base from U.S. Geological Survey Seabeck, Brinnon, and Quilcene 7.5-minute topographic quadrangle maps. Contour interval is 100 ft.

For simplicity, the study area will be referred to as Pulali Point, even though most work was done about 0.8 km north of the tip of that peninsula. The purpose of the study is to describe the paleontology and depositional environments of the sedimentary rocks exposed at Pulali Point, as well as to indicate that more detailed work is needed on stratigraphic nomenclature and tectonic history of this geologically complex area. Our work is also intended to aid ongoing studies by other researchers of the stratigraphy of the Crescent Formation and the crab fauna of the Aldwell(?) Formation.

METHODS

Field work was conducted intermittently from 1989 to 1991, and macrofossils were collected from the study area during several visits. Outcrops could be studied only during low tide. A section was measured with a 30-m-tape

and Brunton compass, and the measured-section traverse is shown on Figure 2. Stratigraphically below the measured section, south toward Pulali Point, is a thick section of basalt, much of which could be safely studied only by boat. No sedimentary interbeds were found below those in the measured section.

Clast sizes were measured in the field, and grain-size terms are from Wentworth (1922). Clasts larger than granule size were measured by using a metric scale. Clasts smaller than granule size were measured by using a hand-held card with small patches of sorted grains glued onto it. (This grain-size field kit is commercially available from the Geological Specialty Company, Houston, Texas.) Lithologic names and grain roundness terms follow those used in Compton (1985).

Three siltstone samples from the Crescent Formation were sent to the Unocal Corporation, Ventura, California,

for processing and identification of microfossils. One siltstone sample from the Aldwell(?) Formation was sent to W. W. Rau, of the Washington Division of Geology and Earth Resources, for processing and identification of the benthic foraminifera.

Lower Tertiary marine strata in the Pacific Northwest have been traditionally correlated by means of the benthic foraminifera-based zonation devised by Mallory (1950) and applied by Rau (1981). In recent years, many biostratigraphers correlating lower Tertiary sections using planktonic microfossils have noted discrepancies in correlations and ages when comparing them with Mallory's zonation. These workers are listed in Almgren and others (1988). Poore (1980), by means of comparing calcareous plankton and benthic foraminifera age determinations, demonstrated significant time overlap from the Ynezian through Ula-tisian Stages of Mallory (1959). Almgren and others (1988) agreed that benthic foraminiferal assemblages, which are the basis for correlating Mallory's stages, significantly transgress time only for the deep bathyal assemblages which developed in early Eocene time. They retained Mallory's stage names, which are based on type sections in southern and central California, but they emended the time significance of these stage names. They also included a "Penutian" (persistent deep water) zone for areas where deep-water conditions continued, and microfaunal elements of the early Eocene Penutian Stage, as used by them, can be found in rocks of the lower middle Eocene. The microfossil biostratigraphic zonation of Almgren and others (1988) is used for the strata at Pulali Point.

For a comparison between Mallory's (1959) original usage of his stage names and how most other workers would now use them, see figures 2 and 3 of Almgren and others (1988).

The molluscan stages used in this report stem from Clark and Vokes (1936), who proposed five mollusk-based provincial Eocene stages: "Meganos", "Capay", "Domen-gine", "Transition", and "Tejon". The stage names are in quotes because they are informal terms. Givens (1974) modified the use of the "Capay Stage". It is in this modified sense that "Capay Stage" is used herein. Saul (1983) correlated the stages to the calcareous nannofossil zonation of Okada and Bukry (1980).

Most of the Pulali Point macrofossil specimens are housed in the paleontology collection of the Department of Geological Sciences, California State University, Northridge (CSUN). Invertebrate fossil specimens used for illustrations in this report are deposited at the Los Angeles County Museum of Natural History Invertebrate Paleontology collection (LACMIP). The shark tooth illustrated in this report has been deposited at the Los Angeles County Museum of Natural History Vertebrate Paleontology collection (LACM). Identifications of the macrofossils were made by comparisons with published figures and descrip-

tions, as well as by comparisons with selected type and non-type specimens deposited at CSUN and LACMIP.

GEOLOGIC SETTING

Basement rock in the Olympic Peninsula is the upper Paleocene to lower middle Eocene Crescent Formation (Snaveley, 1987). The formation consists mostly of submarine basalt but also includes some interbedded marine sedimentary rocks and subaerial basalt. Along the eastern periphery of the Olympic Peninsula, the Crescent Formation consists of more than 15 km of basalt flows; these stand almost vertically with flow tops to the east. This may be the thickest section of mafic marine volcanic rocks known anywhere in the world. Basalts of the Crescent Formation are chiefly oceanic tholeiite but differ from all known ridge tholeiites in being much thicker and locally underlain by sedimentary rocks and by interfingering with sedimentary rocks. The sedimentary rocks are chiefly turbidites.

The Crescent Formation basalts also differ from most ridge tholeiites in that the upper third ranges from a deep-to-shallow marine environment to one that is locally terrestrial (Cady, 1975). The lower 10 km of the tholeiite is characterized by pillowed and massive basalts with interbeds of red limestone (Garrison, 1973). This tholeiite grades upward into shallow-water marine and, locally, terrestrial tholeiite that makes up the upper 5 km. The upper tholeiite is characterized by random joints, and, especially near the top, by columnar joints and scoria (Cady, 1975).

Several models have been proposed for the origin of the Washington-Oregon basalt basement, and these have been reviewed by Snaveley (1987). Most of the models envisage accretion of seamounts. The seamounts could have originated on an oceanic ridge, at an oceanic hot-spot, or along transform faults related to an oceanic ridge. One other model (Wells and others, 1984; Snaveley, 1984), however, proposes in-place eruption of the basalts during continental-margin rifting and extension.

The Crescent Formation crops out near the periphery of the Olympic Peninsula on the north, east, and south in a horseshoe pattern (Cady, 1975, fig. 1). Throughout its outcrop area, the formation is overlain stratigraphically by middle Eocene to middle Miocene marine clastic sedimentary rocks. Stratigraphic relations are complex, and the nomenclature of the stratigraphic units on the north and east sides of the "horseshoe" differs from that on the south side. In addition, on the south, the rocks that overlie the Crescent Formation are in turn overlapped unconformably by upper Miocene and Pliocene marine clastic sedimentary rocks. Inside the "horseshoe" are complexly faulted, so-called "core rocks". These are chiefly slightly metamorphosed turbidites, tens of thousands of meters thick, that range in age from possible Paleocene to middle Miocene. During the Miocene, the core rocks and flanking strati-

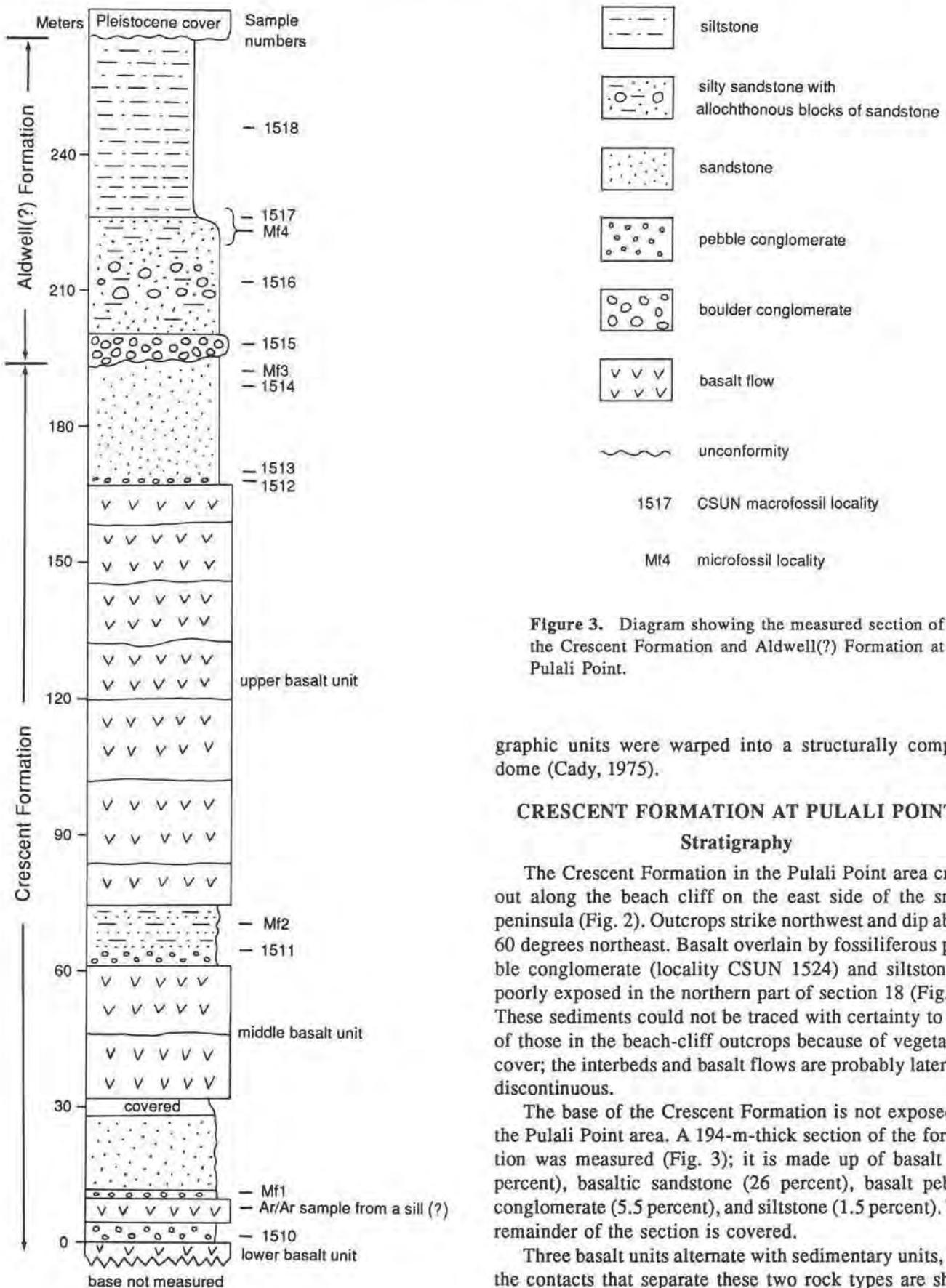


Figure 3. Diagram showing the measured section of the Crescent Formation and Aldwell(?) Formation at Pulali Point.

graphic units were warped into a structurally complex dome (Cady, 1975).

CRESCENT FORMATION AT PULALI POINT Stratigraphy

The Crescent Formation in the Pulali Point area crops out along the beach cliff on the east side of the small peninsula (Fig. 2). Outcrops strike northwest and dip about 60 degrees northeast. Basalt overlain by fossiliferous pebble conglomerate (locality CSUN 1524) and siltstone is poorly exposed in the northern part of section 18 (Fig. 2). These sediments could not be traced with certainty to any of those in the beach-cliff outcrops because of vegetative cover; the interbeds and basalt flows are probably laterally discontinuous.

The base of the Crescent Formation is not exposed in the Pulali Point area. A 194-m-thick section of the formation was measured (Fig. 3); it is made up of basalt (65 percent), basaltic sandstone (26 percent), basalt pebble conglomerate (5.5 percent), and siltstone (1.5 percent). The remainder of the section is covered.

Three basalt units alternate with sedimentary units, and the contacts that separate these two rock types are sharp



Figure 4. The richest macrofossil-bearing bed (locality CSUN 1511) of the Crescent Formation at Pulali Point. Hammer is 40 cm in length.

and appear to be erosional. The basalts, which are black to grayish green on weathered surfaces, are dense near their bases. They grade upward into vesicular basalt with scoriaceous tops that are brecciated and oxidized. The 92-m-thick interval of basalt in the middle of the measured section contains at least six zones of brick-red scoriaceous breccia, possibly related to flow tops.

A sample of the 5.4-m-thick basalt unit, just below microfossil sample locality Mf1 near the base of the measured section (Fig. 3), was radiometrically dated (R. S. Babcock, Western Washington Univ., and R. A. Duncan, Oregon State Univ., written commun., 1991). Their sample (DU 48) consisted of fresh microphenocrysts of plagioclase and pyroxene with a green-brown, partially devitrified glass matrix. The age they obtained will be discussed under "Age". This basalt unit may be a sill because it is younger than the overlying sedimentary rock. Furthermore, the basalt lacks vesicles (indicating that the lava was under pressure as it cooled), and lacks scoriaceous flow-top breccia. Also, the top is not an erosional contact. It displays slickensides aligned with bedding and is associated with a 75-cm-thick zone of altered (baked?) conglomerate directly above the contact. The lower contact is poorly exposed, but the underlying conglomerate has a reddish color that may be due to baking. In addition, the thin basalt is not underlain by muddy siltstone like the other basalt units in the Crescent Formation here; rather, it is underlain and overlain by the same type of conglomerate, as if it had been intruded into the sedimentary unit.

Pebble-conglomerate beds overlie the basalt flows. Most of these beds weather grayish green, but some weather reddish brown to red. The beds range in thickness from 3 cm to 1.5 m. Clasts are angular to rounded, but most are subangular. They range in size from small pebble to large cobble, but most clasts are medium-size pebbles. Clasts are matrix supported by muddy siltstone, which makes up about 30 percent of the rock. Clasts are predominantly basalt and are probably derived from the underlying basalt flows. Some clasts consist of well-indurated, maroon siltstone. Macrofossil remains are a minor component, except at locality CSUN 1511 where they make up about 15 percent of the clasts (Fig. 4).

The pebble conglomerates fine upward into coarse sandstone or into siltstone without any intervening sandstone. Near locality CSUN 1511, thin beds of pebble conglomerate alternate with siltstone, and this alternation is repeated in several cycles.

The sandstone beds weather green to light brown. Beds range in thickness from 0.5 m to 16 m. Grains are moderately well rounded and appear to be moderately well sorted. They range in size from fine to coarse. Most grains appear to be basalt, and fossil remains are very rare.

The siltstone beds weather green to grayish green. Beds range in thickness from 5 cm to 3 m. Grains appear to be mostly basalt, and some microfossils are present.

Macropaleontology

Macrofossils are largely confined to the pebble conglomerates and occur as an indiscriminate mix with the rubble. Specimens are more common in the upper parts of the beds. Most of the macrofossils are less than 3 cm in maximum dimension, but at locality CSUN 1511 an unbroken, 10-cm-tall valve of *Ostrea* sp. was collected. Also at this locality, a 9-cm-long fragment of a nautiloid was found. Most of the gastropods are nearly complete, although many are internal molds or badly weathered. The most abundant fossils are *Turritella uvasana hendoni* s.s. Many have their spiral ribbing intact. Other gastropods have retained sharp nodes on the body whorl or their long delicate siphonal canal. Most of the brachiopods are articulated. Nearly all the bivalves are single valves, but one articulated specimen of *Ostrea* sp. was found. Possible

Table 1. Macrofossils from the Crescent Formation at Pulali Point

<p>Locality CSUN 1510 (pebble conglomerate, 2 m above base of measured section)</p> <p>Brachiopod</p> <p>Gastropods:</p> <p> ficopsid</p> <p> naticid</p> <p>Bivalves:</p> <p> <i>Venericardia hornii</i> s.s. (Gabb)</p> <p> anomiid (<i>Pododesmus</i>-like, new genus?)</p> <p> oysterid</p>	<p>Locality CSUN 1511 (<i>Continued</i>)</p> <p>Nautiloid</p> <p>Echinoids:</p> <p> cidaroid spine (sea-urchin)</p> <p> spatangoid (unidentified)</p>
<p>Locality CSUN 1511 (pebble conglomerate, 63 m above base of measured section)</p> <p>Wood fragment</p> <p>Corals:</p> <p> ? <i>Trochocyathus nomlandi</i> Bentson (solitary coral)</p> <p> colonial coral</p> <p>Brachiopods:</p> <p> <i>Hemithiris reagani</i> Hertlein and Grant</p> <p> terebratulid?</p> <p>Scaphopod:</p> <p> <i>Dentalium</i> sp.</p> <p>Gastropods:</p> <p> <i>Calorebama dilleri lineata</i> (Gabb)</p> <p> <i>Cryptochorda</i> (<i>Cryptochorda</i>) <i>californica</i> (Cooper)</p> <p> <i>Cylichnina tantilla</i> (Anderson and Hanna)</p> <p> <i>Ectinochilus</i> (<i>Macilentos</i>) <i>macilentus oregonensis</i> Turner</p> <p> ? <i>Falsifusus marysvillensis</i> (Merriam and Turner)</p> <p> <i>Pachycrommium clarki</i> (Stewart)</p> <p> <i>Polinices</i> (<i>Euspira</i>) <i>nuciformis</i> (Gabb)</p> <p> <i>Polinices</i> (<i>Polinices</i>) <i>gesteri</i> (Dickerson)</p> <p> <i>Scaphander</i> (<i>Mirascapha</i>) <i>costatus</i> (Gabb)</p> <p> <i>Tejonia moragai</i> (Stewart)</p> <p> <i>Turritella uvasana hendoni</i> s.s. Merriam</p> <p> cassid</p> <p> ficopsid</p> <p> volutid</p> <p>Bivalves:</p> <p> <i>Brachidontes</i> sp.</p> <p> <i>Corbula</i> cf. <i>C.</i> (<i>Caryocorbula</i>) <i>dickersoni</i> Weaver and Palmer</p> <p> <i>Nemocardium linteum</i> (Conrad)</p> <p> <i>Ostrea?</i> sp.</p> <p> <i>Pitar</i> sp.</p> <p> anomiid (<i>Pododesmus</i>-like, new genus?)</p> <p> glycymerid</p> <p> oysterid</p>	<p>Locality CSUN 1512 (pebble conglomerate, 169 m above base of measured section)</p> <p>Calcareous? sponge</p> <p>Solitary coral:</p> <p> ? <i>Trochocyathus nomlandi</i> Bentson</p> <p>Bryozoans (encrusting)</p> <p>Brachiopods:</p> <p> <i>Hemithiris reagani</i> Hertlein and Grant</p> <p> <i>Terebratalia</i> n. sp.?</p> <p> <i>Terebratulina</i> aff. <i>T. unguicula weaveri</i> Hertlein and Grant</p> <p>Serpulid worm:</p> <p> <i>Rotularia</i> (<i>Rotularia</i>) <i>tejonense</i> (Arnold)</p> <p>Gastropods:</p> <p> <i>Ectinochilus</i> cf. <i>E.</i> (<i>Macilentos</i>) <i>macilentus oregonensis</i></p> <p> Turner</p> <p> ficopsid</p> <p>Bivalves:</p> <p> <i>Parvamussium</i> sp.</p> <p> anomiid (<i>Pododesmus</i>-like, new genus?)</p>
	<p>Locality CSUN 1513 (sandstone, 171 m above base of measured section)</p> <p>Gastropod:</p> <p> <i>Turritella uvasana hendoni</i> s.s. Merriam</p> <p>Locality CSUN 1514 (sandstone, 188 m above base of measured section)</p> <p>Bivalves:</p> <p> <i>Teredo?</i> sp. (in wood?)</p> <p> oysterid</p> <p>Crab:</p> <p> <i>Glyphithyreus weaveri</i> (Rathbun)</p> <p>Echinoid</p>
	<p>Locality CSUN 1524 (sandstone, 0.5 km west of beach outcrops)</p> <p>Brachiopods:</p> <p> <i>Terebratulina unguicula weaveri</i> Hertlein and Grant</p> <p> terebratulids?</p>

boring bivalve (*Teredo?* sp.) specimens were found in a 30-cm-long intergrown mass of ribbed to smooth tubes at locality CSUN 1514 in siltstone near the top of the formation. Float from that siltstone yielded a crab and a poorly preserved spatangoid echinoid.

About 250 macrofossil specimens were collected from six localities in the Crescent Formation in the Pulali Point area (Fig. 2). Preservation of the specimens ranges from fair to very poor; however, with diligent collecting, some fairly well preserved specimens can be found. Diversity is very low except at locality CSUN 1511, where 1 wood fragment, 1 solitary coral, 1 colonial coral, 2 brachiopod,

1 scaphopod, 1 nautiloid, and 2 echinoid taxa were found in addition to 14 gastropods and 8 bivalves.

A total of 40 taxa (Table 1), 27 (or 68 percent) of which are mollusks, were collected. Only 27 of the 40 taxa could be identified to genus or species/subspecies. These include 1 solitary coral, 4 brachiopods, 1 serpulid worm, 1 scaphopod, 11 gastropods, 8 bivalves, and 1 crab. All are illustrated in Plate 1. Also shown in Plate 1 is a possible new genus of anomiid bivalve that resembles the genus *Pododesmus*. Other taxa too poorly preserved for generic identification include a fragment of wood, a calcareous(?) sponge, a colonial coral, a few encrusting bryozoans, some

Table 2. Microfossils from the Crescent Formation at Pulali Point. Calcareous nannofossils identified by M. V. Filewicz, Unocal Corp., Ventura, Calif.; small benthic foraminifera identified by H. L. Heitman, Unocal Corp., Ventura, Calif.

<p>Sample Mf1 (sandstone, 11 m above base of measured section) Small benthic foraminifera: <i>Amphistegina</i> sp. <i>Cibicides midwayensis</i> (Plummer) <i>Elphidium</i> sp. <i>Eponides mexicana</i> (Cushman) <i>Lenticulina</i> spp. Micro-gastropod molds Echinoid spines</p>	<p>Sample Mf3 (sandstone, 194 m above base of measured section) Calcareous nannofossils: <i>Calcidiscus formosus</i> (Kamptner) <i>Chiasmolithus solitus</i> (Bramlette and Sullivan) <i>Discoaster barbadiensis</i> Tan Sin Hok <i>Discoaster lodoensis</i> Bramlette and Sullivan <i>Discoasteroides kueperi</i> (Stradner) <i>Helicosphaera seminulum</i> (Bramlette and Sullivan) <i>Neochiastozygus concinnus</i> (Martini) <i>Spinelithus radians</i> Deflandre in Grasse <i>Transversopontis pectinatus</i> (Bramlette and Sullivan) <i>Transversopontis pulcher</i> (Deflandre)</p>
<p>Locality CSUN 1511 (pebble conglomerate, 63 m above base of measured section) Large benthic foraminifera: <i>Pseudophragmina psila?</i> Woodring</p>	<p>Small benthic foraminifera: <i>Anomalina dorri aragonensis</i> Nuttall <i>Bulimina denticulata</i> Cushman and Parker <i>Cibicides midwayensis</i> (Plummer) <i>Gaudryina jacksonensis coalingensis</i> (Cushman and Hanna)</p>
<p>Locality CSUN 1512 (pebble conglomerate, 169 m above base of measured section) Large benthic foraminifera: <i>Pseudophragmina psila?</i> Woodring</p>	<p><i>Gyroidina orbicularis obliquata</i> Cushman and McMasters <i>Lenticulina</i> spp. <i>Loxostomum applini</i> (Plummer) <i>Marginulina eximia</i> Neugeboren <i>Nodosaria</i> spp. <i>Pseudonodosaria</i> sp. <i>Vaginulinopsis asperuliformis</i> (Nuttall)</p>
<p>Locality CSUN 1524 (sandstone, 0.5 km west of beach outcrops) Large benthic foraminifera: <i>Pseudophragmina psila?</i> Woodring</p>	<p>Planktonic foraminifera: <i>Acarinina</i> sp. <i>Subbotina eocaena</i> (Gumbel)</p>
<p>Sample Mf2 (sandy siltstone, 66 m above base of measured section) Small benthic foraminifera: <i>Amphistegina</i> sp. <i>Cibicides midwayensis</i> (Plummer) <i>Lenticulina</i> sp. <i>Vaginulinopsis mexicana</i> var. B? of Laiming Planktonic foraminifera: <i>Acarinina</i> sp.</p>	<p>Abundant recrystallized radiolarians</p>

brachiopods, an intergrown mass of possible boring bivalve tubes, several gastropods and bivalves, fragments of a nautiloid, a cidaroid echinoid spine, fragments of a spatangoid echinoid, and an echinoid.

Micropaleontology

Three microfossil samples were collected from the Crescent Formation. Samples Mf1 and Mf2 from near the base of the measured section (Fig. 3) yielded a few poorly preserved benthic foraminifers and one species of planktonic foraminifer (Table 2). Sample Mf3 from the top of the Crescent Formation (Fig. 3) yielded 10 species of calcareous nannofossils, 9 species of benthic foraminifers, 2 species of planktonic foraminifers, and abundant recrystallized radiolarians (Table 2).

The large benthic foraminifer *Pseudophragmina psila?* Woodring was found at macrofossil localities CSUN 1511, 1512, and 1524.

Previous Paleontologic Investigations of the Crescent Formation

Macrofossils previously reported in published literature about the Crescent Formation are listed in Table 3. Nearly all of the reports deal with the Crescent Bay area along the north shore of the Olympic Peninsula. One of

the more detailed reports is by Weaver and Palmer (1922), who described, named, and illustrated five species of gastropods and two species of bivalves from a single locality (Univ. of Washington locality 358) on the east side of Tongue Point, just east of Crescent Bay. This area is approximately 80 km northwest of Pulali Point.

Vokes (1937) listed an additional eight species of gastropods (Table 3) from the general area of Observatory Point, a few kilometers east of Crescent Bay (Fig. 1). He did not give any detailed locality information, nor did he illustrate these species. Thus, the presence of all these taxa in the Crescent Formation is not proven. Marinovich (1977) confirmed the presence of the gastropods *Eocernina hannibali* and *Pachycrommium clarki* from the Crescent Formation in Clallam County, Washington.

Another detailed report on macrofossils in the Crescent Formation is by Durham (1942), who described, named, and illustrated six species of colonial corals (Table 3) from the Observatory Point area. Most of these species were collected at a single locality (Univ. of California, Museum of Paleontology (Berkeley) locality A-3206). He also reported the colonial coral *Archohelia clarki* and the solitary coral *Turbinolia quaylei* from locality A-3280 about 13 km southeast of Crescent Bay. He assigned the locality to the Crescent Formation, but the locality plots within the over-

Table 3. Macrofossils previously reported in published literature dealing with the Crescent Formation. All are from the Crescent Bay to Observatory Point area, Clallam County, except for *Nayadina (Exputens) Ilajasensis*, which is from about 5 km north of Pulali Point (Squires, 1992). Data are from Arnold and Hannibal (1913), Weaver and Palmer (1922), Vokes (1937), Durham (1942, 1950), Weaver (1943), Miller and Downs (1950), Hickman (1976), Marincovich (1977), and Squires (1989). * Presence in the Crescent Formation cannot be confirmed; specimens not illustrated and repository and specimen numbers not given

Corals:

Astrepora sanjuanensis Durham
Colpophyllia reagani Durham
Lepidophyllastrea vaughani Durham
Madracis crescentensis Durham
Madracis stewarti Durham
Montipora schencki Durham

Brachiopod:

Terebratulina tejonensis Stanton

Gastropods:

**Calyptraea diegoana* (Conrad)
Calorebama dilleri kirbyi (Clark)
 **Crommium andersoni* (Dickerson)
Eocernina hannibali (Dickerson)
Eratotrivia crescentensis Weaver and Palmer
Galeodea crescentensis Weaver and Palmer
 **Gyrineum californicum* (Gabb)
Ficopsis remondii crescentensis Weaver and Palmer
Harpa? crescentensis Weaver and Palmer
Keilostoma sp.
 **Loxotrema turritum* Gabb
 **Nerita* sp.
 **Neverita (Neverita) globosa* Gabb

Gastropods: (Continued)

Pachycrommium clarki (Stewart)
Pleurotomaria sp.
Solariella crescentensis Weaver and Palmer
Turritella uvasana subsp.

Bivalves:

**Acanthocardia (Schedocardia) brewerii* (Gabb)
 **Acutostrea idriaensis* (Gabb)
 **Brachidontes (Brachidontes) cowlitzensis* (Weaver and Palmer)
 **Callista (Microcallista) conradiana* (Gabb)
Corbula (Caryocorbula) hornii Gabb
Glycymeris crescentensis Weaver and Palmer
Glycymeris fresnoensis Dickerson
 **Macrocallista* sp.
Nayadina (Exputens) Ilajasensis (Clark)
Pitar quadratus (Gabb)
 **Septifer dichotomus* Gabb
 **Spondylus* sp.
Venericardia hornii Gabb
Venericardia (Leuroactis) crescentensis Weaver and Palmer

Nautiloid:

Aturia sp.

lying Aldwell Formation on the geologic map of Brown and others (1960). Investigations by one of us (Goedert, unpub. data) confirm that locality A-3280 is in the Aldwell Formation.

In terms of micropaleontologic investigations of the Crescent Formation, Pardee (1921) was the first to report the presence of foraminifers. Berthiaume (1938) and Rau (1964, table 1) reported the large benthic foraminifers *Pseudophragmina psila* and *Actinocyclus aster* from a locality near Observatory Point. Other Crescent Formation localities for which benthic foraminifer studies have been made are the Doty-Minot Peak area (Pease and Hoover, 1957), the Satsop River valley (Rau, 1966), the Wynoochee River valley (Rau, 1967), and the Crescent Bay-Lake Crescent area (Rau, 1964). Except for the last-mentioned area, which is in the northern Olympic Peninsula, these areas are in southwestern Washington.

Garrison (1967) reported on the discovery of calcareous nannofossil taxa in the Crescent Formation. Worsley and Crecelius (1972) later made a more extensive study of these fossils.

Depositional Environment

The depositional environment of the Crescent Formation at Pulali Point encompassed both shallow-marine conditions caused by basalt extrusions and deeper water

conditions caused by intermittent subsidence and/or sea-level rises.

Shallow-marine conditions are indicated by the macrofossils, almost all of which were found interspersed with the clasts of the pebble-conglomerate beds. These clasts were mostly derived by high-energy erosion of the underlying basalt. The macrofossils, however, do not show much evidence of these high-energy processes. Some of the gastropods have retained delicate spines, ribs, and, in some specimens, the long anterior canals. Although some of the shells are broken, they do not show significant abrasion. The bivalve remains are nearly all single valves, most of which are unbroken and unabraded. Even the delicate, thin valves of the *Pododesmus*-like bivalve are intact. The condition of the macrofossils, therefore, indicates that the distance of any post-mortem transport was slight.

Animals that were attached to the substrate are common in the pebble-conglomerate beds and include the rhynchonellid *Hemithiris reagani*, a colonial coral, the serpulid worm *Rotularia (R.) tejonense*, the *Pododesmus*-like bivalve, and the large *Ostrea?* sp. Modern rhynchonellids are limited to the low intertidal and subtidal zones of only certain rocky shores (Richardson, 1981). Most colonial corals are hermatypic; they are restricted to shallow waters by the light requirements of their symbiotic algae and flourish in depths less than 50 m (Britton and Morton,

1989). *Pododesmus*-like bivalves and ostreids live today along the Pacific coast of California and Mexico on rocks or shells in the intertidal zone and offshore in shallow subtidal depths (Keen, 1971).

Mobile shallow-burrowing species are also common in the pebble-conglomerate beds and include all the gastropods, the bivalve *Venericardia hornii* s.s., and the scaphopod *Dentalium* sp. Deeper burrowing taxa like the spatangoid echinoid are rare.

The macrofossils in the Crescent Formation at Pulali Point are also ones that are found in shallow-marine (neritic) deposits of Eocene age in many places on the Pacific coast of North America (Givens, 1974; Squires, 1984, 1987). Squires (1984) tabulated the bathymetry of extant molluscan genera found in the Eocene Lajas Formation, Simi Valley, California. Some of these genera are the same as those found interspersed with the clasts of the pebble-conglomerate beds of the Crescent Formation at Pulali Point. These genera are *Dentalium*, *Polinices* (*Euspira*), *Scaphander*, *Turritella*, *Brachidontes*, *Corbula* (*Caryocorbula*), and *Nemocardium*. On the basis of the tabulated data by Squires (1984), the extant genera in the Crescent pebble-conglomerate beds would most commonly occur today in seas between 20 and 94 m deep. Additional extant genera in these Crescent deposits also support this depth range. *Parvamussium* lives in water depths between 18 and 632 m (Grau, 1959). *Polinices* (*Polinices*) lives in waters between the intertidal zone and 333 m, and *Pitar* lives today in waters between 25 and 185 m deep (Keen, 1971).

Many extinct taxa of macrofossils in the Crescent pebble-conglomerate beds area are also indicative of shallow subtidal depths. These species are *Calorebama dilleri lineata*, *Cryptochorda* (*Cryptochorda*) *californica*, *Cylichnina tantilla*, *Pachycrommium clarki*, and *Tejonina moragai*. They are present in shallow-subtidal deposits of the Eocene Lajas Formation, Simi Valley, California (Squires, 1984). Most are also present in shallow-subtidal deposits of the Eocene Juncal Formation, Whitaker Peak, southern California (Squires, 1987).

Specimens of the large benthic foraminifer *Pseudophragmina* in the Pulali Point sandstone beds directly overlying the pebble conglomerates indicate shallow-marine conditions. Elsewhere in lower to middle Eocene strata along the Pacific coast of North America, specimens of this genus have been found in nearshore to offshore, normal-salinity shelfal environments (Squires, 1984; Squires and Demetron, 1992).

There are three basalt units at Pulali Point, and we interpret the extrusion of each to have caused marine waters to have become shallow enough so that storm waves and tides could erode the basalts and produce rubble, which was then transported seaward into shallow subtidal depths. The macroinvertebrates inhabited this rubble. The total thickness of the lowermost basalt unit is not known, so it

cannot be determined how much basalt accumulated before being affected by storm waves and tides. During the extrusion of the middle basalt unit, about 30 m of basalt accumulated before being affected by erosion; and during the extrusion of the upper basalt unit, 92 m of basalt accumulated before being affected by erosion. Between the extrusions of the basalt units, there had to have been subsidence or a sea-level rise, or both, to account for the presence of outer neritic to bathyal benthic foraminifers in the overlying sedimentary deposits. Subsidence was probably the dominant factor because of the apparently rapid alternation of shoaling and subtidal conditions, but, as will be mentioned under "Paleoclimate and Paleobiogeography", an early Eocene global sea-level rise accounted for some of the mollusks immigrating into the northeast Pacific Ocean during deposition of the Pulali Point Crescent Formation.

Benthic foraminifers in samples Mf1 and Mf2 (Table 2) from siltstones near the base of the section (Fig. 3) indicate outer neritic to upper bathyal depths (H. L. Heitman, Unocal Corp., written commun., 1991). The outer neritic depth interpretation is favored because elements of the shallow-marine-influenced, undifferentiated early Eocene B-2 to B-4 Zones of Laming (1940) are recognized in these samples. These zones are not recognizable where persistent deep-water conditions prevailed, as they did for the benthic foraminifers in sample Mf3 (Table 2) from muddy siltstone at the top of the Crescent Formation (Fig. 3). Benthic foraminifers from sample Mf3 indicate middle bathyal depths (H. L. Heitman, Unocal Corp., written commun., 1991). This sample also contained abundant radiolarians, indicating deep-water conditions.

Macrofossils in the thick sandstone in the uppermost part of the Crescent Formation at locality CSUN 1514 (near Mf3) are represented only by a mass of possible boring-bivalve tubes (which may have originally been in a piece of driftwood), a single crab specimen that possibly floated to the site after death, a poorly preserved ostreid, and an echinoid.

As a whole, the macrofauna in each of the Crescent Formation Pulali Point conglomerate beds indicates a shallow subtidal environment in waters of about 50 m depth. The macroinvertebrates lived among the basalt rubble that was transported by storm waves seaward into the subtidal waters. Most of the macrofaunal components were mobile forms, but some of the species attached to the rubble. Subsidence or sea-level rise caused deepening of the marine environment and simultaneous deposition of sands and silts, which are essentially barren of macrofauna but rich in microfauna indicative of outer neritic to bathyal depths. Deep-water conditions persisted after the last basalt extrusion event on the basis of the benthic foraminifera assemblage at the top of the Crescent Formation at Pulali Point.

A paleoenvironment similar to that inferred for the Crescent Formation at Pulali Point was reported by Rau

(1964, p. G14) for a portion of the upper Crescent Formation in the northern part of the Olympic Peninsula.

Age

The Crescent Formation at Pulali Point is late early Eocene in age on the basis of its calcareous nannofossils, benthic foraminifers, and macrofossils.

Sample Mf3 from just below the unconformity at the top of the Crescent Formation (Fig. 3) contained the most age-diagnostic microfauna. M. V. Filewicz (Unocal Corp., written commun., 1991) assigned the calcareous nannofossils of this sample to the CP10–CP11 Zones (undifferentiated) of Okada and Bukry (1980). H. L. Heitman (Unocal Corp., written commun., 1991) assigned the benthic foraminifera of this microfossil sample to the Penutian Stage. The middle bathyal paleoenvironmental determination for this sample also suggests a “Penutian” (persistent deep water) character for this sample (H. L. Heitman, oral commun., 1992). These zones straddle the boundary between the molluscan “Capay Stage” and the “Domengine Stage” (Fig. 5).

Samples Mf1 and Mf2, near the base and in the lower part of the exposures, were barren of calcareous nannofossils, but they yielded a few, poorly preserved, small benthic foraminifers and one species of planktonic foraminifer (Table 2). The paucity and poor preservation of the foraminifers in samples Mf1 and Mf2 resulted in only approximate age determinations. H. L. Heitman (Unocal Corp., written commun., 1991) assigned the benthic foraminifers in these samples to the undifferentiated (shallow-marine influenced) B-2 to B-4 Zones of Laiming (1940), which would be approximately equivalent to the CP10 to CP11 Zones of Okada and Bukry (1980) (Fig. 5). The ages of samples Mf1, Mf2, and Mf3, therefore, are compatible.

Macrofossil locality CSUN 1511 in the lower part of the Crescent Formation exposures yielded the most diverse molluscan assemblage. The two most age-diagnostic species are the gastropods *Calorebama dilleri lineata* and *Cryptochorda (Cryptochorda) californica*. They are known only from the Pacific coast of North America provincial molluscan “Capay Stage” through “Domengine Stage” (Squires, 1984, 1989). These two species, however, do not help in further refining the age of the Crescent Formation at Pulali Point.

The age assignment for the Crescent Formation at Pulali Point has some important implications for biostratigraphy. The bivalve *Venericardia hornii* s.s., which was found at locality CSUN 1510, was previously assigned to the upper Eocene “Tejon Stage” (Givens, 1974). This time-stratigraphic assignment is incorrect because of the lack of precise information about the location of the type locality for the species and because some workers have mistakenly identified specimens as *V. hornii* s.s. Much of the confusion as to identification probably stemmed from

Gabb's (1869) emendation of his original description of the species, in which he combined more than one species (Verastegui, 1953). The specimen of *V. hornii* s.s. from locality CSUN 1510 was compared to the lectotype of *V. hornii* s.s. and found to be conspecific. Gabb (1864, pl. 24, fig. 157) provided an enhanced line drawing of the lectotype; Stewart (1930, pl. 11, fig. 11) and Verastegui (1953, pl. 18, fig. 1) showed photographs of the lectotype. The specimen of *V. hornii* s.s. at locality CSUN 1510 documents a lower Eocene occurrence of this species and confirms the report of Arnold and Hannibal (1913) that this species is present in the Crescent Formation.

The brachiopod *Hemithiris reagani*, which was found at localities CSUN 1511 and 1512, was previously reported to be from upper Eocene(?) (Weaver, 1942) or Oligocene (Hertlein and Grant, 1944) strata in western Washington. These early reports were based on imprecise stratigraphic information. *Hemithiris reagani* can now be shown to occur near the boundary between the “Capay Stage” and “Domengine Stage”.

The crab *Glyphithyreus weaveri* found at locality CSUN 1514 is fairly age diagnostic. It is known from the “Capay Stage” through “Domengine Stage” (Squires, 1984). The specimen of this crab in the Crescent Formation is one of the oldest crabs in the fossil record of Washington. Only crab remains from the Cretaceous of the San Juan Islands noted by R. E. Berglund (Bainbridge Island, written commun., 1991) are known to be older.

A sample of unweathered basalt from near the top of the thin basalt just below microfossil sample Mf1 near the base of the measured section at Pulali Point (Fig. 3) yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ age of 50.5 ± 1.6 Ma (R. S. Babcock, Western Washington Univ., and R. A. Duncan, Oregon State Univ., written commun., 1991). The age of this basalt is equivalent to the middle Eocene CP12 Zone of Okada and Bukry (1980) and is at odds with the biostratigraphic control. As discussed under “Stratigraphy”, this basalt may be a sill. If so, the age discrepancy would be explained.

Correlation

The interbedded basalt units and fossiliferous sedimentary units in the Crescent Formation at Pulali Point are similar to some outcrops of the Crescent Formation elsewhere in western Washington. One area is near the type section of the Crescent Formation along the east side of Crescent Bay to the Observatory Point area (Fig. 2). The strata in both areas also have some temporal affinities. Shared species are the macrofossils *Pachycrommium clarki* and *Venericardia hornii* (Tables 1, 3), but they are not useful for precise temporal correlation. *Pachycrommium clarki* ranges throughout the entire Eocene, and the geologic range of *V. hornii* needs much study. The large benthic foraminifer *Pseudophragmina psila* is present at Observatory Point (Berthiaume, 1938; Rau, 1964, table 1) but is only questionably present at Pulali Point.

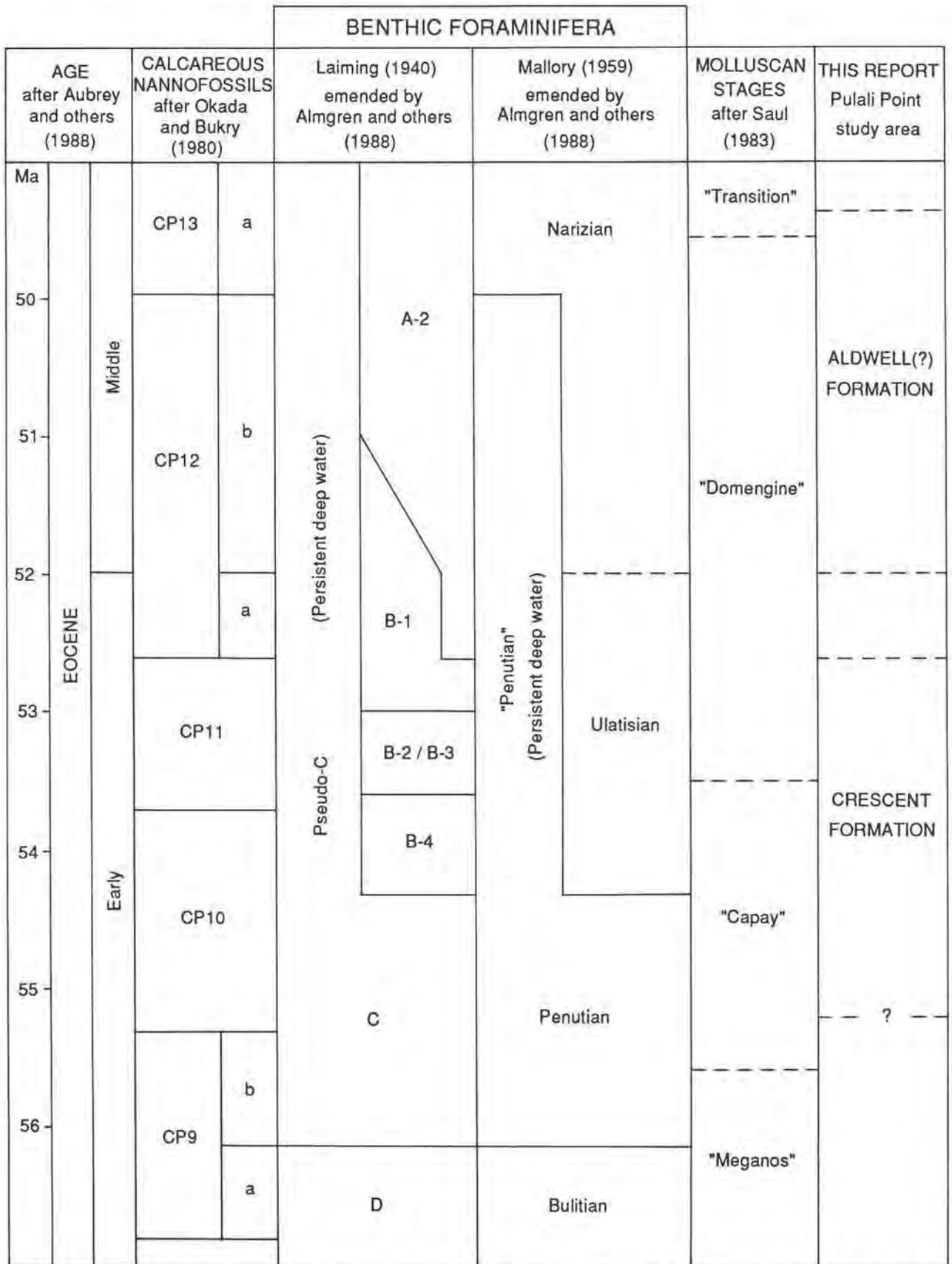


Figure 5. Correlation of the Crescent Formation and Aldwell(?) Formation at Pulali Point with epochs, subepochs, calcareous nannofossil zones, and benthic foraminiferal and molluscan stages for the Pacific coast of North America (modified from Almgren and others, 1988, fig. 2).

Another area that has fossiliferous basaltic sandstones at the top of the Crescent Formation similar to those at Pulali Point is the Satsop River area, southern Olympic Peninsula. Rau (1966) reported on the Satsop River outcrops and showed that, as at Pulali Point, the benthic foraminiferal assemblage indicates an age distinctly older than that of the sedimentary rocks that lie immediately above. Benthic foraminifers found in both areas are *Gaudryina jacksonensis coalingensis* and *Vaginulinopsis asperuliformis*.

In addition, Pease and Hoover (1957) reported marine interbedded volcanic and sedimentary rocks similar to those found at Pulali Point in the upper part of the Crescent(?) Formation on the southeast side of the Doty Hills, southwestern Washington.

With continued detailed mapping near Pulali Point, it is likely that other outcrops of interbedded basalt flows and fossiliferous sedimentary units of the Crescent Formation will be found. One promising area is about 5 km north of Pulali Point, along the west shore of Quilcene Bay, where boulder-size pieces of sedimentary rock are in a modern landslide at the base of a steep cliff (Squires, 1992). The boulder-sized pieces of rock consist of sandstone that encloses abundant brachiopods and some mollusks. Some of these fossils are in a distinctive white, calcareous, medium-grained sandstone very similar in lithology to some of the sandstone boulders in the middle part of the Aldwell(?) Formation found at locality CSUN 1516 at Pulali Point. As will be discussed under "Depositional Environment" of the Aldwell(?) Formation, these sandstone boulders are most likely derived from a Crescent Formation source. Temporal equivalence between the boulder-size pieces of rock along the west shore of Quilcene Bay and the Crescent Formation at Pulali Point is strongly indicated by the joint presence of *Hemithiris reagani*, *Terebratulina unguicula weaveri*, the *Pododesmus*-like bivalve, and the large *Ostrea* sp.

Elsewhere on the Pacific coast of the United States, there are rock units that have temporal affinities with the Crescent Formation at Pulali Point. One of these is the Siletz River Volcanics, north of Corvallis, western Oregon (Baldwin, 1964). *Terebratulina unguicula weaveri* is the only species the Crescent and Siletz River units have in common.

Another rock unit that has temporal affinity with the Crescent Formation at Pulali Point is the Kings Valley Siltstone Member of the upper part of the Siletz River Volcanics, which crops out in the Marys Peak area west of Corvallis in western Oregon. A few of the mollusks listed by Baldwin (1955) for this member are also present in the Crescent Formation at Pulali Point. In addition, the large benthic foraminifera *Pseudophragmina psila* is present in the Marys Peak area (Baldwin, 1955) and is questionably present at Pulali Point.

The Lookingglass Formation, southwestern Oregon, also has temporal affinity with the Crescent Formation at Pulali Point. According to Miles (1981), the lower Eocene Lookingglass Formation includes the often-cited Glide section molluscan fauna that was studied by Turner (1938). Nine molluscan species reported by Turner (1938) from that section are also present in the Crescent Formation at Pulali Point. The crab *Glyphithyreus weaveri* [= *Plagiolophus weaveri*] reported by Orr and Kooser (1971) and Berglund and Feldmann (1989) and the benthic foraminifers *Eponides mexicana* and *Gaudryina jacksonensis coalingensis* reported by Thoms (1975, fig. 8) from this formation are also present in the Crescent Formation at Pulali Point.

The rock unit in California that has the greatest temporal affinity with the Crescent Formation at Pulali Point is the Llajas Formation in Simi Valley, southern California. Nine of the molluscan species and the crab *Glyphithyreus weaveri* in the Llajas Formation (Squires, 1984) are also present in the Crescent at Pulali Point.

Paleoclimate and Paleobiogeography

As shown in a review by Squires (1987), early Eocene time was the warmest interval of the Cenozoic, and tropical to subtropical conditions were widespread. Addicott (1970) reported that warm-water conditions existed at that time as far north as the Gulf of Alaska. Durham (1942, 1950) concluded that during "Capay" time, tropical macrofaunas inhabited areas as far north as the northern shore of the Olympic Peninsula. He based his conclusions on the presence of reef corals and large benthic foraminifers in the Crescent Formation at Crescent Bay. Furthermore, he concluded that the Crescent assemblage lived in a tropical environment similar to that now at 20° latitude on the Pacific coast and that the 18.5°C isotherm must have been some distance north of the Olympic Peninsula. In addition, he reported that all known macrofaunas of early Eocene age in Oregon, California, and Baja California Sur, Mexico, substantiate the tropical character of such assemblages along the Pacific coast of North America.

The early Eocene was a time of major influx of Old World Tethyan macroinvertebrates into the Pacific coast of North America via a seaway through Central America (Clark and Vokes, 1936; Givens, 1979; Squires, 1984, 1987; Squires and Demetron, 1992). Arrival of the Tethyan mollusks in the Pacific coast region was also coincident with a global sea-level rise (Squires, 1987). Two of the genera used (Squires, 1987) to document the timing of this influx of immigrants into the Pacific coast region, the gastropods *Ectinochilus* and *Pachycrommium*, are also present in the Crescent Formation at Pulali Point.

Pulali Point is now the northern limit of the geographic distribution for nine of the identifiable species or subspecies in the Crescent Formation there (Table 4).

Table 4. Macrofossil species or subspecies whose geographic distribution is now extended to the Crescent Formation at Pulali Point

<u>Taxon</u>	<u>Previous known range</u>	<u>Taxon</u>	<u>Previous known range</u>
Gastropods:		Gastropods: (Continued)	
<i>Calorebama dilleri lineata</i> (Gabb)	Southern California through northern California (Squires, 1989)	<i>Tejonina moragai</i> (Stewart)	Southwestern to northwestern Oregon (Snively and Baldwin, 1948; Marinovich, 1977)
<i>Cryptochorda (C.) californica</i> (Cooper)	Southern California through southwestern Oregon (Squires, 1984)	<i>Turritella uvasana hendoni</i> s.s. Merriam	Southwestern Oregon (Turner, 1938)
<i>Cyllichnina tantilla</i> (Anderson and Hanna)	Baja California Sur, Mexico, through western Washington (Squires and Demetron, 1992)	Bivalve:	
<i>Ectinochilus (Macilentos) macilentus oregonensis</i> Turner	Northwestern Oregon (Snively and Baldwin, 1948)	<i>Nemocardium linteum</i> (Conrad)	Baja California Sur, Mexico, through northwestern Oregon (Snively and Baldwin, 1948; Squires and Demetron, 1992)
<i>Scaphander (Mirascapha) costatus</i> (Gabb)	Baja California Sur, Mexico, through western Washington (Squires and Demetron, 1992)	Crab:	
		<i>Glyphithyreus weaveri</i> (Rathbun)	Southern California through southwestern Oregon (Squires, 1984)

ALDWELL(?) FORMATION AT PULALI POINT**Stratigraphy**

At 194 m above the base of the measured section at Pulali Point (Fig. 3), there is an angular unconformity and an abrupt change in lithology (Fig. 6). The Crescent Formation beds below the contact strike N64°W and dip 53 degrees northeast; the overlying beds strike N55°W and dip 67 degrees northeast. The 72-m-thick section above this unconformity is entirely sedimentary and composed of siltstone (55 percent), silty sandstone (including some allochthonous blocks of sandstone) (36 percent), and boul-

der conglomerate (9 percent). The contacts between these various lithologies are gradational.

The boulder conglomerate is a single massive bed, 6.5 m thick, at the base of this part of the section (Fig. 7). It differs from the Crescent Formation conglomerates because it has larger clasts (≤ 0.5 m across), is clast supported, and contains reworked fossiliferous concretions that consist of very well indurated siltstone. The clasts in the boulder conglomerate bed consist of about 75 percent basalt and about 25 percent reworked concretions. Locally this conglomerate is almost all basalt clasts or nearly 50 percent reworked concretions.



Figure 6. The unconformable contact (shown by inked line) between the Crescent Formation and the overlying Aldwell(?) Formation at Pulali Point. Hammer is 40 cm in length.

Some of the reworked concretions in the basal conglomerate contain brachiopods and crabs. A single nautiloid specimen is the only macrofossil from this conglomerate that was not enclosed in a concretion. It is an internal mold of a complete specimen of *Eutrephoceras* sp. (Pl. 2, figs. 8–9), and it was found in sandy matrix between boulders. The specimen is filled with very well indurated siltstone like that of the reworked concretions in the conglomerate. It is, therefore, most likely the erosional core of a former concretion.

The silty sandstone contains, in its middle part, some matrix-supported allochthonous blocks of macrofossil-bearing sandstone. The blocks are as much as 2 m across and randomly oriented in the silty sandstone. Locally, be-

tween the blocks are carbonaceous debris and contorted bedding. The blocks consist of sandstone with layers of mollusks and brachiopods, sandstone with trace fossils, calcareous shale with wood fragments and a lucinid bivalve, and a distinctive white, calcareous, medium-grained sandstone that contains fragments of the bivalve *Nayadina (Exputens) llajasensis*. A single shark tooth was found with mollusks in one of the blocks.

Also in the middle part of the silty sandstone are reworked concretions of very well indurated siltstone. Some are in the sandstone blocks, and others are in the matrix between the blocks. Some of these concretions contain crabs. Danner (1966, p. 426) mentioned these fossil-bearing concretions but did not recognize that they are reworked.

At the top of the silty sandstone is a 0.3-m-thick pebble conglomerate (locality CSUN 1517) composed of reworked limy concretions, reworked pieces of nodules, and clasts of calcareous siltstone and sandstone. None contains fossils. In the silty matrix, however, there are single valves of *Corbula* cf. *C. (Caryocorbula) hornii*. For another 0.5 m above this conglomerate are discontinuous pebble conglomerates that fine upward into micaceous sandstone.

The siltstone near the top of the measured section is gray, very finely bedded, and, locally, black and argillaceous. It is thicker, more carbonaceous, less fractured, and less indurated than the Crescent Formation siltstone. There are abundant small pieces of carbonaceous debris on the bedding planes. At locality CSUN 1518 are some delicate, flattened specimens of gastropods(?) about 5 mm in length and delicate valves of the "mud pecten" *Delectopecten* cf. *D. vancouverensis sanjuanensis*. Some of the *Delectopecten* specimens are articulated. A few bedding planes also have numerous fish scales, as well as some glauconite.

Overlying the post-Crescent unit at Pulali Point is an undetermined thickness of glacially derived Pleistocene gravels.

Macropaleontology

About 40 specimens of macrofossils were collected from four localities in the post-Crescent unit at Pulali Point (Fig. 2). Preservation of the specimens ranges from fair to poor. About half the macrofossils were collected at two localities (CSUN 1515 and 1516). Locality CSUN 1515 is in the boulder conglomerate at the base of the sequence;



Figure 7. The boulder conglomerate at the base of the Aldwell(?) Formation at Pulali Point. Hammer is 30 cm in length.

the other is in the overlying silty sandstone with allochthonous blocks of sandstone. Squires (1992) mentioned the presence of the bivalve *Nayadina (Exputens) llajasensis* in allochthonous blocks of sandstone in this unit at locality CSUN 1516. Excluding crabs and a lobster, a total of nine taxa (Table 5) were collected from these two localities. Only five of these could be identified to genus or species/subspecies: two brachiopods, one bivalve, a coiled nautiloid, and a shark tooth (Plate 2). Other fossils

Table 5. Macrofossils from reworked concretions and allochthonous blocks of sandstone in the Aldwell(?) Formation at Pulali Point

Locality CSUN 1515 (in reworked concretions in basal conglomerate)

Brachiopod:

Terebratulina unguicula weaveri Hertlein and Grant

Nautiloid: (in a sedimentary clast)

Eutrephoceras sp.

Crabs

Locality CSUN 1516 (in allochthonous blocks of sandstone, about 18 m above base of formation)

Calcareous algae?

Wood fragments

Brachiopod:

Eogryphus n. sp.

Bivalves:

Nayadina (Exputens) llajasensis (Clark)

lucinid

pitarid

Crabs (in reworked concretions)

Lobster (in reworked concretion)

Shark tooth:

Striatolamia macrota (Agassiz)

too poorly preserved for generic identification are calcareous algae(?), wood fragments, and bivalves.

Fossil crabs are fairly common in the reworked concretions at locality CSUN 1516. Specimens include at least eight species of crabs and one species of lobster. Several of the crabs, as well as the lobster, are new species (R. E. Berglund, Bainbridge Island, oral commun., 1991). None of the crabs or the lobster is described or illustrated in this report because other workers are studying them.

The other macrofossils collected from this sequence are from localities CSUN 1517 and 1518 in the middle and upper parts of the unit. The only identifiable fossils at locality CSUN 1517 are single valves of *Corbula* cf. *C. (Caryocorbula) hornii*, which were found in the matrix between the clasts. A fairly diverse assemblage of mollusks was found at locality CSUN 1518, where carbonaceous debris is common. Ten taxa were collected from these two localities (Table 6), but only three could be identified to genus or species/subspecies: two bivalves and a spatangoid echinoid (Plate 3). Other forms too poorly preserved for generic identification are minute gastropods, small, flattened gastropods(?), small bivalves, and fish scales.

Micropaleontology

Numerous benthic foraminifers were found in sample Mf4 (Fig. 3), a mix of material from just below and just above the 0.3-m-thick conglomerate composed mostly of limy sedimentary clasts, between 26 to 34 m above the contact with the Crescent Formation. Microfossils from this sample at Pulali Point are listed in Table 7.

Depositional Environment

The depositional environment of the post-Crescent sequence at Pulali Point was in deep water near or on a submarine fan. Bouldery proximal deposits grade upward into finer grained distal deposits.

Table 6. Macrofossils found in place in the Aldwell(?) Formation at Pulali Point

Locality CSUN 1517 (in 0.3-m-thick conglomerate, 32 m above base of formation)	
Minute gastropods	
Bivalve:	
	<i>Corbula</i> cf. <i>C. (Caryocorbula) hornii</i> Gabb
Locality CSUN 1518 (siltstone, about 52 m above base of formation)	
Carbonaceous debris	
Gastropods? (small, flattened)	
Bivalve:	
	<i>Delectopecten</i> cf. <i>D. vancouverensis sanjuanensis</i> (Clark and Arnold)
	mytilid
	pitariid
	thracid?
Spatangoid echinoid:	
	<i>Schizaster</i> cf. <i>S. diabloensis</i> Kew
Fish scales	

The basalt-boulder conglomerate at the base of this sequence at Pulali Point is similar to proximal-turbidite conglomerates described by Cameron (1980) from the lower Tertiary Hesquiat Formation, western Vancouver Island, British Columbia. The Hesquiat Formation boulder conglomerates are characterized by massive structure, low clay content, and reworked fossils in clasts, and they are overlain by siltstones with few macrofossils but with abundant carbonaceous debris. The basal conglomerate at Pulali Point also has a major scour at its base and a clast-supported fabric. These two features have been observed by Hein (1984) in deep-sea gravel channels in Cambrian-Ordovician deposits in Quebec.

The silty sandstone overlying the basal conglomerate is thought to be a deep-sea deposit on the basis of benthic foraminifers in sample Mf4. According to W. W. Rau (Washington Division of Geology and Earth Resources, written commun., 1990), most of the benthic foraminiferal assemblage from this locality indicates cold water at bathyal depths (perhaps 1,500 to 2,000 m), but a minor (reworked?) component of the assemblage indicates near-shore, warm-water conditions. The allochthonous, 2-m-long blocks of sandstone in the middle of the silty sandstone were transported into deep water most likely by means of a submarine slump or mudflow. Evidence for this transport mechanism includes the large size of the blocks, their random orientation, their matrix support, and the presence of contorted bedding between some of the blocks.

Table 7. Benthic foraminifera from the Aldwell(?) Formation at Pulali Point. Foraminifera identified by W. W. Rau, Washington Division of Geology and Earth Resources

Sample Mf4 (siltstone, between 26 to 34 m above contact with Crescent Formation).	
	<i>Alabamina wilcoxensis californica</i> Mallory
	<i>Bulimina corrugata</i> Cushman and Siegfus
	<i>Cassidulina globosa</i> Hantke
	<i>Chilostomella</i> sp.
	<i>Cibicides</i> cf. <i>C. hodgei</i> Cushman and Schenck
	<i>Cibicides</i> cf. <i>C. natlandi</i> Beck
	<i>Cibicides pseudoungerianus evolutus</i> Cushman and Hobson
	<i>Dentalina</i> spp.
	cf. <i>Eponides</i> sp.
	<i>Globigerina</i> spp.
	<i>Gyroidina simiensis</i> Cushman and McMasters
	<i>Lenticulina inornatus</i> d'Orbigny
	<i>Lenticulina</i> cf. <i>L. welchi</i> Church
	<i>Nodosaria latejugata</i> Gumbel
	<i>Nodosaria longiscata</i> d'Orbigny
	<i>Nodosaria velascoensis</i> Cushman
	<i>Plectofrondicularia packardi packardi</i> Cushman and Schenck
	<i>Plectofrondicularia vaughani</i> Cushman
	<i>Praeglobbulimina</i> spp.
	<i>Quinqueloculina</i> spp.
	<i>Uvigerina garzaensis</i> Cushman and Siegfus
	<i>Vaginulinopsis</i> cf. <i>V. asperuliformis</i> (Nuttall)

The valves of *Corbula* cf. *C. (Caryocorbula) hornii* found in the 0.3-m-thick pebble conglomerate (near where Mf4 was taken) are judged to be indigenous to the unit because the valves were found in matrix between concretions and other sedimentary clasts. *Corbula (Caryocorbula)* lives today mostly among rock rubble in shallow waters, but some species can be found in water as much as 823 m deep (Abbott, 1974).

Multiple provenances are indicated for the out-of-place material in the basal conglomerate and overlying silty sandstone in the upper part of the section at Pulali Point. The basalt boulders in the basal conglomerate were most likely derived, in large part, from similar basalt in the underlying Crescent Formation at Pulali Point. The lithologies of the reworked concretions in the basal conglomerate and silty sandstone and the allochthonous blocks of sandstone in the silty sandstone are not found in the Crescent Formation at Pulali Point. A Crescent Formation source for some of the macrofossils does seem likely, however, because the brachiopod *Terebratulina unguicula weaveri* was found in reworked concretions in the basal bed of the post-Crescent unit and in sandstone at locality CSUN 1524 in the Crescent Formation 0.5 km west of the beach-cliff outcrops of that unit at Pulali Point. In addition, the macrofossils in the allochthonous blocks of sandstone in the silty sandstone are taxa that would have lived in the shallow-marine environment that existed during the deposition of much of the Crescent Formation sedimentary rocks at Pulali Point. For example, the bivalve *Nayadina (Exputens) llajasensis* lived in nearshore environments where a firm substrate was available (Squires, 1990). Erosion of a concretionary sandstone bed formerly present at the top of the Crescent Formation at Pulali Point could have yielded the reworked concretions and allochthonous blocks of sandstone that became incorporated in the deep-water deposits of the upper sequence in the Pulali Point section.

Some of the crabs in the reworked concretions in the basal conglomerate and in the overlying silty sandstone are shallow-marine taxa, and some are deep-marine taxa (R. E. Berglund, Bainbridge Island, oral commun., 1991). This mixture of shallow- and deep-marine crabs is most likely the result of different provenances for the reworked concretions. A detailed analysis of the crab-bearing concretions is needed to resolve how the mixing took place; such studies are under way by other workers.

The basal conglomerate and upper section siltstone at Pulali Point are also similar to submarine-fan conglomerates and interbedded siltstones described by Squires (1988) for the lower part of the upper Eocene Hoko River Formation, northwestern Olympic Peninsula. In addition, nautiloid specimens and similar crab-bearing concretions are present in basalt conglomerates in both of these formations. The fossil crabs from conglomerates of the Hoko River Formation are also a mixture of shallow- and deep-water taxa (Feldmann and others, 1991).

The "mud pectens" in the siltstone in the upper part of the post-Crescent sequence are articulated, and this indicates no post-mortem transport of these very delicate shells. Hickman (1984) established that "mud-pecten" communities represent one of the more common indicators of Cenozoic and modern deep-water siltstone/claystone deposits along the eastern Pacific margin, and Hickman and Nesbitt (1980) described a modern low-diversity "mud-pecten" community from the Gulf of Alaska in waters consistently below 200 m.

The upper sequence at the Pulali Point study area, therefore, accumulated in bathyal depths. The basal basalt-boulder conglomerate represents a turbidite deposit in the proximal part of a submarine fan, the silty sandstone with allochthonous blocks of sandstone represents a submarine mudflow, and the siltstone represents quiet-water deposits in the distal part of the submarine fan.

Age

The post-Crescent sequence at Pulali Point is middle Eocene in age, on the basis of both benthic foraminifers and macrofossils. Sample Mf4 near the middle of the sequence contained the most age-diagnostic fossils. Most of the benthic foraminiferal assemblage (Table 7) from this sample indicates a middle Eocene age (Narizian Stage as used by Mallory, 1959, and applied by Rau, 1981), but according to W. W. Rau (Washington Division of Geology and Earth Resources, written commun., 1990), a minor reworked(?) component of the assemblage indicates a slightly older age (Ulatisian Stage as used by Mallory, 1959). The Narizian Stage as used by Mallory (1959) differs little in its chronologic position from the Narizian Stage as used by Almgren and others (1988). If the macro- and microfossil-based age of the post-Crescent unit at Pulali Point is about 52 Ma, equivalent to the beginning of the Narizian Stage as used by Almgren and others (1988) (Fig. 5), and if the macro- and microfossil-based age of the underlying Crescent Formation is at least 52.6 Ma, then there is a hiatus of about 0.6 million years between the two units at this location.

The most age-diagnostic macrofossil in place in the younger Eocene sequence at Pulali Point is the spatangoid echinoid *Schizaster* cf. *S. diabloensis*. This fossil was found in siltstone at locality CSUN 1518. The species is not known from strata younger than the "Domengine Stage". This molluscan provincial stage for the North American Pacific coast ranges from the upper lower through lower middle Eocene (Fig. 7) (Saul, 1983; Squires, 1984). The genus *Schizaster* has not been previously reported from the Eocene of Washington, and *S. diabloensis* has been previously known only from southern through central California (Squires, 1984).

The bivalve *Corbula (Caryocorbula) hornii*, which is tentatively identified from locality CSUN 1517, was previously reported as occurring only in the middle through

upper Eocene "Tejon Stage" (Givens, 1974), but Arnold and Hannibal (1913) gave an unconfirmed report of the species from the type section of the Crescent Formation (Table 3). The possible presence of this bivalve in the post-Crescent unit below a "Domengine Stage" echinoid suggests that this species is not confined biostratigraphically to the "Tejon Stage".

The "mud pecten" *Delectopecten vancouverensis sanjuanensis*, which is tentatively identified from locality CSUN 1518, was previously reported as occurring only in the upper Oligocene to lower Miocene Sooke Formation from Vancouver Island, British Columbia (Weaver, 1942). If this species is present in the upper unit at Pulali Point, it would represent the earliest occurrence of this genus, whose geologic range has been previously reported as late Eocene to Recent (Hertlein, 1969).

Fossils from the reworked concretions and allochthonous blocks of sandstone in the post-Crescent sequence indicate that their source rock was Eocene in age. The nautiloid *Eutrephoceras* sp. is poorly preserved but resembles *E. eyerdami* Palmer (1961, pl. 73, figs. 1-6) from the upper middle Eocene Cowlitz Formation, southwestern Washington. *Eutrephoceras eyerdami* is the only species of this genus reported from Washington. The bivalve *Nayadina (Exputens) llajasensis* is known from lower to middle Eocene strata elsewhere on the Pacific coast (Squires, 1990, 1992). The shark *Striatolamia macrota* [= *Eugomphodus macrota* in Welton and Zinsmeister, 1980] is a cosmopolitan species known from the Eocene of California, Oregon, Belgium, the Paris Basin, the Ukraine, central Asia, Kazakhstan, Chile, Seymour Island off Antarctica, and the east coast of North America (Welton and Zinsmeister, 1980; Cappetta, 1987). The species has not previously been reported from Washington.

Correlation

The lithology of the Eocene rocks overlying the Crescent Formation at Pulali Point closely resembles that of both the Aldwell Formation and the Humptulips Formation. The middle to lower upper Eocene Aldwell Formation, named by Brown and others (1960), crops out on the northern part of the Olympic Peninsula. Most of the formation is well-indurated marine siltstone. At the type section near Lake Aldwell (Fig. 1), the formation is about 900 m thick. Massive lenses of unsorted pebbles, cobbles, and boulders of basalt are locally present throughout the siltstone of the Aldwell Formation, and they have been interpreted as having been formed by marine landslides or mudflows (Brown and others, 1960). In places, the basal contact of the formation is marked by beds, 10 to 30 m thick, of cobble and boulder conglomerate derived from the underlying Crescent Formation (Snavelly, 1987).

Brown and others (1960) reported that the lower part of the Aldwell Formation in some places interfingers with volcanic rocks of the Crescent Formation, and the two

formations are therefore partly equivalent in age. McWilliams' (1970) studies, however, suggest that the two formations do not intertongue and are not partly equivalent in age.

Tabor and Cady (1978) showed the Aldwell Formation cropping out west of Leland about 15 km north of Pulali Point. The Aldwell Formation becomes more prevalent northwest from Leland in the direction of Port Angeles. Tabor and Cady (1978) also showed the Aldwell Formation cropping out within 5 km north of Pulali Point. They show a small outcrop along the west shore of Quilcene Bay. Observations by one of us (Goedert, unpub. data), however, indicate that much of this area of outcrop is actually blocks of boulder-sized pieces of Crescent Formation in a modern landslide block.

The upper sequence at Pulali Point resembles the base of Spencer's (1983a) Bolton Peninsula section of bathyal siltstone and mudstone on the Bolton Peninsula just east of Quilcene (Fig. 1). The upper unit at Pulali Point also resembles Spencer's (1983b) Donovan Creek section of bathyal micaceous sandstone and siltstone just north of the Bolton Peninsula. Spencer also reported *Delectopecten* sp. from beds of the Donovan Creek section.

The Humptulips Formation, named by Rau (1984), crops out in the vicinity of the town of Humptulips, northern Grays Harbor County, western Washington (Fig. 1). At the type section near Humptulips, the formation is about 760 m thick and lies unconformably on the Crescent Formation. The Humptulips Formation is mostly siltstone and mudstone. Many beds consist of massive sandy siltstone. Mica is common, and macerated carbonaceous debris is locally common. There are scattered calcareous concretions throughout the formation. Rau (1984, 1986) concluded that the formation formed in bathyal depths between 150 and 2,500 m. Goedert and Squires (1990) reported a localized deep-sea deposit of macrofossiliferous limestone in the Humptulips Formation; this formed in association with a subduction-related methane seep. Squires and Goedert (1991) described two new species of chemosynthetic bivalves that were found in this deposit. Also, at least one locality in the Humptulips Formation contains a thick basal basalt-boulder conglomerate overlain by thin-bedded sandstone and siltstone (Rau, 1966, p. 12).

Rau (1986) mapped the Humptulips as far east as the Wynoochee River valley east of Humptulips, but he noted that the formation also crops out in the Satsop River valley just east of Wynoochee River valley. The Satsop River valley is about 80 km southwest of Pulali Point.

It is difficult to determine whether the upper unit at Pulali Point should be labelled the Aldwell Formation or the Humptulips Formation because the lithologies are so similar. Furthermore, microfaunas similar to those in the upper sequence at Pulali Point are in parts of the Aldwell Formation on the northern flank of the Olympic Peninsula,

in the Humptulips Formation of the south flank of the Olympic Peninsula, and in the McIntosh Formation of southwestern Washington (W. W. Rau, Washington Division of Geology and Earth Resources, written commun., 1990). The name Aldwell(?) Formation is chosen primarily because the known outcrops of the Aldwell Formation are closest to Pulali Point. In order to verify the application of this name, it will be necessary to show that the nearest outcrops of known Aldwell Formation along the west shore of Quilcene Bay are correlative to those at Pulali Point. Work is also needed to determine the stratigraphic relation between the Aldwell Formation and the Humptulips Formation.

Paleoclimate and Paleobiogeography

During middle Eocene time, the widespread tropical to subtropical conditions of the early Eocene continued. In Washington, Durham (1950) found many of the same corals and mollusks in early Eocene faunas as he found in middle Eocene faunas, and he concluded that the assemblages indicate much the same temperature. Fossils of land plants from Republic, Washington, also indicate that subtropical conditions were prevalent there during the middle Eocene (Wolfe and Wehr, 1991).

Old World Tethyan macroinvertebrates continued to immigrate to the Pacific coast of North America via a seaway through Central America, but the influx of taxa was not as extensive as that during the early Eocene (Squires, 1984). The Aldwell(?) Formation macroinvertebrate assemblage is judged not to have been influenced by the Old World Tethyan influx of taxa during the middle Eocene.

SUMMARY

The 194-m-thick section of the upper Crescent Formation in the northeastern Olympic Peninsula at Pulali Point contains fossiliferous marine sedimentary units interbedded with three units of extrusive tholeiite basalts. Each basaltic extrusion caused the local marine waters to become shallow enough so that storm waves could erode the basalts and produce rubble. Storm waves then transported the rubble seaward, where substrate-attached and mobile species of macroinvertebrates were able to inhabit it. The mollusks, brachiopods, and large benthic foraminifers are indicative of intertidal to shallow subtidal conditions, as well as of warm water and normal salinity. Post-mortem transport of the macrofauna was slight.

Sandstones and siltstones that overlie the conglomerates are essentially barren of macrofossils but contain a rich microfauna indicative of outer neritic and bathyal conditions. These indicate that subsidence and/or sea-level rise followed each major episode of basalt extrusion. Persistent deep-water conditions occurred near the top of the Crescent Formation where the microfauna indicates middle bathyal conditions.

The Crescent Formation at Pulali Point is late early Eocene in age on the basis of the contained calcareous nannofossils, benthic foraminifers, and macrofossils. This age is equivalent to the calcareous nannofossil CP10 and CP11 Zones (undifferentiated) and to the benthic foraminiferal Penutian Stage. The CP10 and CP11 Zones straddle the boundary between the molluscan "Capay Stage" and "Domengine Stage".

At Pulali Point, an angular unconformity separates the Crescent Formation from the overlying Aldwell(?) Formation; the two units are lithologically and paleontologically different. Our work is the first to recognize post-Crescent rocks, herein termed the Aldwell(?) Formation, at Pulali Point. The Aldwell(?) Formation there is 72 m thick. At the base is a proximal-turbidite conglomerate with basalt boulders most likely derived from the Crescent Formation. The overlying silty sandstone is a submarine slump or mudflow deposit that contains allochthonous, 2-m-long blocks of sandstone. Benthic foraminifers in the silty sandstone indicate cold-water conditions at bathyal depths. Some of the allochthonous blocks of sandstone, as well as some reworked concretions in both the basal conglomerate and the slump or mudflow deposit, contain mollusks, brachiopods, and crabs that were probably derived from shallow-marine beds of the Crescent Formation. Some of the crabs in these reworked concretions are deep-marine taxa, indicating an additional source area not yet identified.

Overlying the silty sandstone is siltstone with abundant carbonaceous debris and in-place "mud-pecten" communities. The presence of benthic foraminifers, as well as the pectens, in this part of the Aldwell(?) Formation suggest cold conditions at bathyal depths.

We conclude that the Aldwell(?) Formation basal basalt-boulder conglomerate represents the proximal phase of a submarine-fan complex, the overlying sandy siltstone with allochthonous blocks of sandstone represents a submarine slump or mudflow, and the siltstone in the upper part of the formation represents the distal phase of the submarine-fan complex.

The Aldwell(?) Formation at Pulali Point is middle Eocene in age (Narizian Stage as used by Rau, 1981, and Almgren and others, 1988) on the basis of its benthic foraminifers.

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environment. R. E. Berglund also identified the crab from the Crescent Formation and reviewed an early draft of the manuscript. Tucker collected the Aldwell(?) Formation nautiloid specimen.

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Plate 1. Macrofossils identifiable to genus or species/subspecies in the Crescent Formation at Pulali Point.

- Figures 1–2. Solitary coral ?*Trochocyathus nomlandi* Bentson, 1943, hypotype, LACMIP 11495, loc. CSUN 1511, x 2.3, height 11.5 mm, width 8 mm, front and side views.
- Figures 3–8. Brachiopods. 3–5. *Hemithiris reaganii* Hertlein and Grant, 1944, hypotype, LACMIP 11496, loc. CSUN 1512, x2.5, length 11.5 mm, width 10 mm, thickness 6.8 mm, dorsal, ventral, and anterior views. 6–8. *Terebratulina unguicula weaveri* Hertlein and Grant, 1944, hypotype, LACMIP 11497, loc. CSUN 1524, x2.2, length 12.2 mm, width 10.5 mm, thickness 4.2 mm, dorsal, ventral, and anterior views of internal mold.
- Figures 9–11. *Terebratalia* n. sp.?, loc. CSUN 1512; 9, hypotype, LACMIP 11498, x1.4, length 20.2 mm, width 22.2 mm, thickness 10.8 mm, dorsal view; 10, hypotype, LACMIP 11499, x1.2, length 22.8 mm, width 25.5, ventral view; 11, same specimen as in Figure 9, anterior view.
- Figures 12–13. Serpulid worm *Rotularia (Rotularia) tejonense* (Arnold, 1910), hypotype, LACMIP 11500, loc. CSUN 1512, x4.1, diameter 5.5 mm, thickness 2.7 mm, umbilical and side views.
- Figure 14. Scaphopod *Dentalium* sp., hypotype, LACMIP 11501, loc. CSUN 1511, x1.5, length 29.8 mm, diameter 4 mm, side. view.
- Figures 15–25. Gastropods. 15. *Turritella uvasana hendoni* s.s. Merriam, 1941, hypotype, LACMIP 11502, loc. CSUN 1511, x1.2, height 33 mm, width 10.3 mm, abapertural view. 16. *Ectinochilus (Macilentos) macilentus oregonensis* Turner, 1938, hypotype, LACMIP 11503, loc. CSUN 1511, x1.8, height 19 mm, width 7.7 mm, abapertural view. 17. *Tejonia moragai* (Stewart, 1927), hypotype, LACMIP 11504, loc. CSUN 1511, x1.6, height 20.5 mm, width 15.8 mm, apertural view. 18. *Pachycrommium clarki* (Stewart, 1927), hypotype, LACMIP 11505, loc. CSUN 1511, x1.1, height 32.5 mm, width 24.6 mm, apertural view. 19. *Polinices (Polinices) gesteri* (Dickerson, 1916), hypotype, LACMIP 11506, loc. CSUN 1511, x1.8, height 17.2 mm, width 10.8 mm, apertural view. 20. *Polinices (Euspira) nuciformis* (Gabb, 1864), hypotype, LACMIP 11507, loc. CSUN 1511, x2, height 14.8 mm, width 14 mm, apertural view. 21. ?*Falsifusus marysvillensis* (Merriam and Turner, 1937), hypotype, LACMIP 11508, loc. CSUN 1511, x1.2, height 31.8 mm, width 14.6 mm, apertural view. 22. *Calorebama dilleri lineata* (Gabb, 1864), hypotype, LACMIP 11509, loc. CSUN 1511, x1.9, height 15.5 mm, width 12.5 mm, abapertural view of a specimen missing its spire. 23. *Cryptochorda (Cryptochorda) californica* (Cooper, 1894), hypotype, LACMIP 11510, loc. CSUN 1511, x1.4, height 27.3 mm, width 16.8 mm, apertural view. 24. *Cylichnina tantilla* (Anderson and Hanna, 1925), hypotype LACMIP 11511, loc. CSUN 1511, x2.5, height 10.5 mm, width 4.5 mm, apertural view. 25. *Scaphander (Mirascapha) costatus* (Gabb, 1864), hypotype, LACMIP 11512, loc. CSUN 1511, x1.7, height 16.3 mm, width 9.2 mm, apertural view.
- Figures 26–35. Bivalves. 26. *Brachidontes* sp., hypotype, LACMIP 11513, loc. CSUN 1511, x2.4, length 10.5 mm, height 7.3 mm, partial internal mold of right valve. 27. *Parvamussium* sp., hypotype, LACMIP 11514, loc. CSUN 1512, x11.4, length 2.2 mm, height 2.2 mm, interior of left valve. 28–29. Anomiid (*Pododesmus*-like, new genus?), hypotype, LACMIP 11515, loc. CSUN 1511, x1.6, length 18.1 mm, height 20.9 mm, exterior and interior views of right (attached) valve. 30–31. *Ostrea* sp., hypotype, LACMIP 11516, loc. CSUN 1511, x0.5, length 82.6 mm, height 96.2 mm, exterior and interior views of right valve. 32. *Venericardia hornii* s.s. (Gabb, 1864), hypotype, LACMIP 11517, loc. CSUN 1510, x0.8, length 62.5 mm, height 47.4 mm, internal mold of right valve. 33. *Nemocardium linteum* (Conrad, 1855), hypotype, LACMIP 11518, loc. CSUN 1511, x1.3, length 18.5 mm, height 17.5 mm, internal mold of right? valve. 34. *Pitar* sp., hypotype, LACMIP 11519, loc. CSUN 1511, x2.6, length 10.2 mm, height 8.4 mm, internal mold of right valve. 35. *Corbula* cf. *Corbula (Caryocorbula) dickersoni* Weaver and Palmer, 1922, hypotype, LACMIP 11520, loc. CSUN 1511, x3.5, length 8.3 mm, height 5.4 mm, internal mold of right valve.
- Figure 36. *Teredo?* sp., hypotype, LACMIP 11521, loc. CSUN 1514, x1.3, length 30.5 mm, diameter 12.2 mm, a single tube from a cluster.
- Figure 37. Crab *Glyphithyreus weaveri* (Rathbun, 1926), hypotype, LACMIP 11522, loc. CSUN 1514, x1.2, carapace length 18.6 mm, carapace width 21.6 mm, external mold showing two-thirds of dorsal surface.

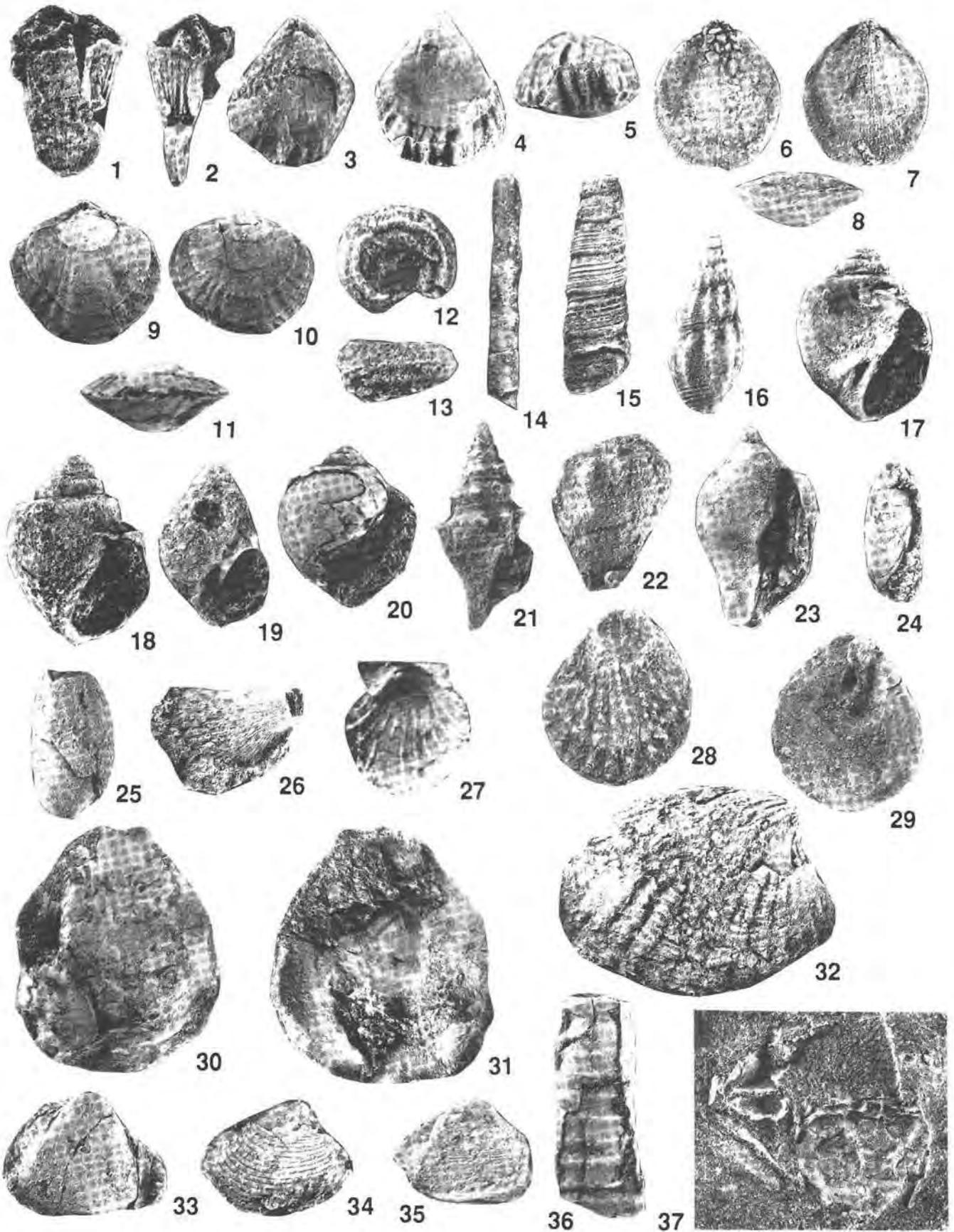


Plate 1

Plate 2. Macrofossils identifiable to genus or species/subspecies in allochthonous blocks of sandstone in the Aldwell(?) Formation at Pulali Point. Crabs and a lobster from reworked concretions are not included.

- Figures 1–6.** Brachiopods. 1–3. *Terebratulina unguicula weaveri* Hertlein and Grant, 1944, hypotype, LACMIP 11523, loc. CSUN 1515, x1.1, length 27.4 mm, width 21.1 mm, thickness 12.9 mm, dorsal, ventral, and anterior views. 4–6. *Eogryphus* n. sp., hypotype, LACMIP 11524, loc. CSUN 1516, x1.1, length 28.1 mm, width 22.1 mm, thickness 17.2 mm, dorsal, ventral, and anterior views.
- Figure 7.** Bivalve *Nayadina (Exputens) llajasensis* (Clark, 1934), hypotype, LACMIP 11525, loc. CSUN 1516, x1.6, length 23.5 mm, height 12.8 mm, internal mold of right valve.
- Figures 8–9.** Nautiloid *Eutrephoceras* sp., hypotype, LACMIP 11526, loc. CSUN 1515, x0.7, diameter 65.9 mm, maximum width 50.5 mm, lateral and ventral views.
- Figures 10–12.** Shark tooth *Striatolamia macrotia* (Agassiz, 1843), hypotype, LACM 132160, loc. CSUN 1516 [=loc. LACM 6080], x1.3, height 28.3 mm, width 12 mm, lingual, distal, and labial views.

Plate 3. Macrofossils identifiable to genus or species/subspecies in place in the Aldwell(?) Formation at Pulali Point.

- Figures 1–2.** Bivalves. 1–2. *Delectopecten* cf. *D. vancouverensis sanjuanensis* (Clark and Arnold, 1923), loc. CSUN 1518; 1, hypotype, LACMIP 11527, x3.8, length 6.9 mm, height 8.2 mm, left valve; 2, hypotype, LACMIP 11528, x3.8, length 7.7 mm, height 8.5 mm, right valve (posterior auricle missing).
- Figures 3–4.** *Corbula* cf. *Corbula (Caryocorbula) hornii* Gabb, 1864, loc. CSUN 1517; 3, hypotype, LACMIP 11529, x2, length 19.7 mm, height 11.6 mm, left valve; 4, hypotype, LACMIP 11530, x1.8, length 21.5 mm, height 14.1 mm, right valve.
- Figure 5.** Spatangoid echinoid *Schizaster* cf. *Schizaster diabloensis* Kew, 1920, hypotype, LACMIP 11531, loc. CSUN 1518, x2.1, length 16.5 mm, width 15.8 mm, dorsal view.

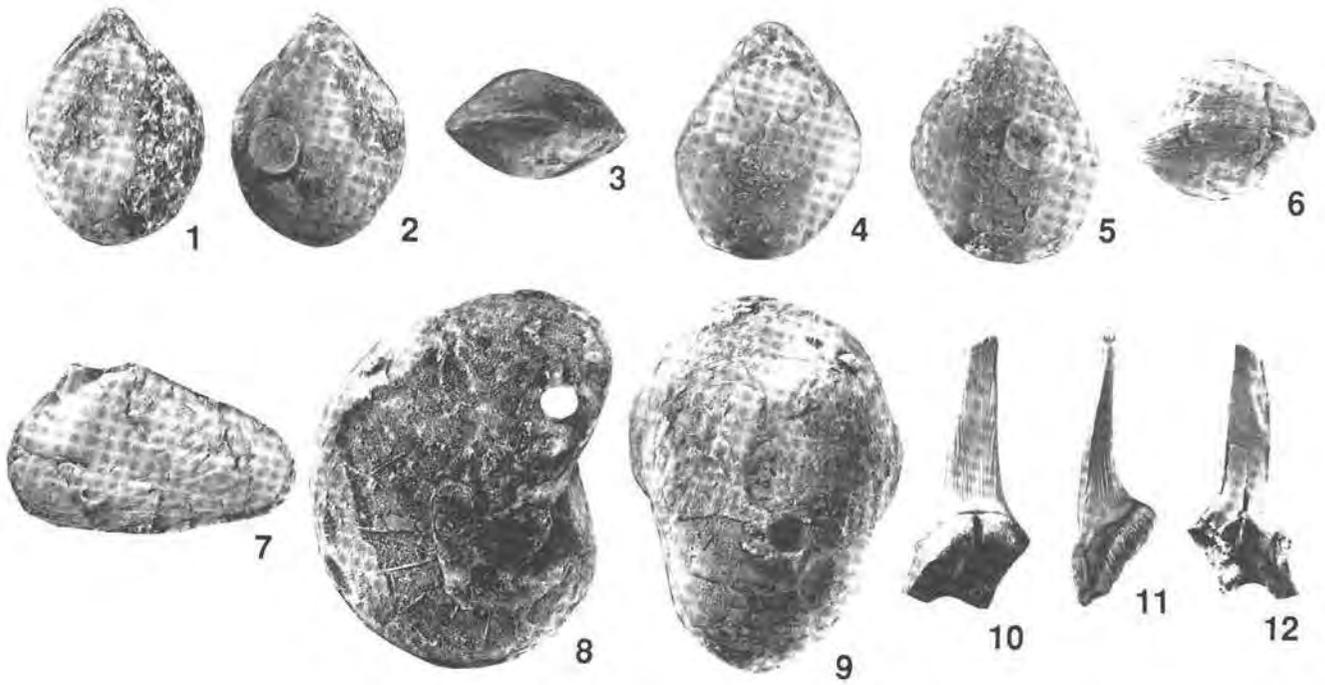


Plate 2

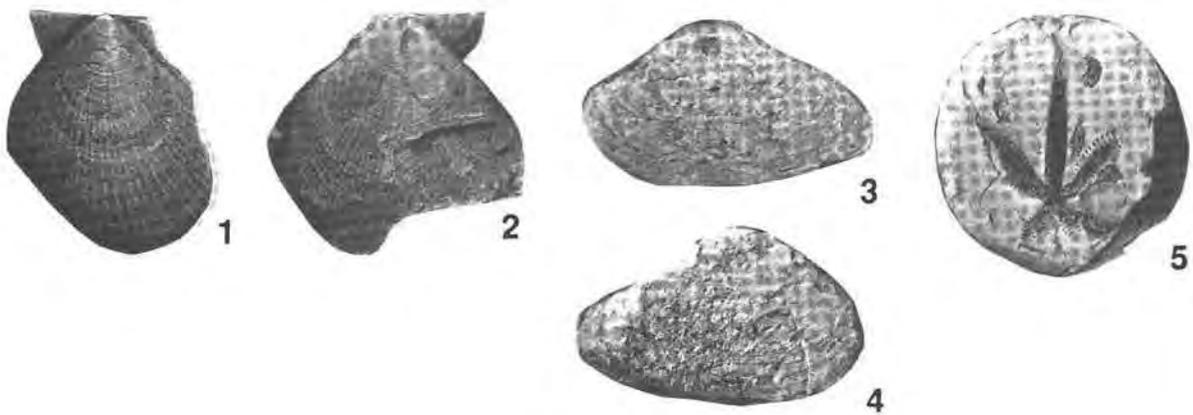


Plate 3

