AN ABSTRACT OF THE THESIS OF

Phillip Jay Rarey for the degree of Master of Science in Geology presented on November 7, 1985 .

Title: Geology of the Hamlet-North Fork of the Nehalem River Area, Southern Clatsop and Northernmost Tillamook Counties, Northwest Oregon

Abstract Approved: ______________________
(Alan R. Niem)

The middle to late Eocene tholeiitic Tillamook Volcanics compose the oldest rock unit in the Hamlet-North Fork of the Nehalem River area. Geochemical plots and field relationships indicate that these rocks were produced in an extensional tectonic setting in the developing forearc and formed an extensive tholeiitic oceanic island. The volcanics consist of a thick sequence of normally and reversely polarized subaerial basalt and basaltic andesite flows in the Hamlet-North Fork of the Nehalem River area. The "Gray's River area" Goble Volcanics in southwest Washington are chemically and stratigraphically correlative to the Tillamook Volcanics. Cessation of Tillamook volcanism resulted in thermal subsidence and transgression of the overlying Hamlet formation.

Upper Narizian (middle to upper Eocene) nearshore fossiliferous basaltic boulder-pebble conglomerates and basaltic sandstones of the Roy Creek member of the Hamlet formation (informal) were deposited along a rocky basaltic coastline over the subsiding volcanic "island". Scanning electron microscopy shows that radial pore-filling chloritic cement has significantly reduced porosity in Roy Creek member sandstones.

Micaceous and carbonaceous silty mudstones and rare thin basaltic turbidite sandstones of the Sweet Home Creek member of the Hamlet formation (informal) were deposited on the outer shelf to upper slope above the Roy Creek member as the basin continued to deepen. The Sweet Home Creek member contains abundant bathyal benthic foraminifera assignable to the upper Narizian stage. Calcareous nannofossils collected from the unit have been assigned to subzone CP-14a which is in agreement with foraminifera data. The upper part of the Sweet Home Creek member is in part a deep marine correlative to shelf arkosic sandstones of the Cowltiz Formation which pinches out into the Sweet Home Creek member in eastern Clatsop County. Much of the detritus in the Sweet Home Creek member was derived from plutonic and metamorphic sources in contrast to the locally derived Roy Creek member.

Calc-alkaline Cole Mountain basalt (informal) intrudes and overlies the Sweet Home Creek member. Cole Mountain basalt was formed in a compressional tectonic environment and emplaced on the outer continental shelf as shallow intrusions and submarine flows. The unit is chemically and petrographically distinct from the Tillamook Volcanics and chemically similar to and stratigraphically correlative to the type Goble Volcanics (e.g. low TiO_2 and low P_2O_5).

Unconformably overlying the Cole Mountain basalt and the Sweet Home Creek member is the bathyal, Refugian (upper Eocene), Jewell member of the Keasey Formation. It consists of three parts: a basal glauconitic sandstone-siltstone, a laminated tuffaceous sandstone unit with rare small arkosic sandstone channels and occasional clastic dikes, and an upper laminated to bioturbated tuffaceous silt-mudstone. Arkosic sandstones were derived from an ancesteral Columbia River system whereas abundant tuffaceous detritus was derived locally from the Cascade arc.

The Refugian lower Smuggler Cove formation (informal) gradationally overlies the Jewell member and consists of bioturbated, tuffaceous, bathyal mudstones. Outer shelf, very fine-grained tuffaceous sandstones of the David Douglas tongue (informal) of the Pittsburg Bluff Formation and deeper marine correlative outer shelf to upper slope glauconitic sandstones of the middle Smuggler Cove formation overlie the lower Smuggler Cove formation. The upper Smuggler Cove formation consists of uppermost Refugian to Zemmorian bathyal, bioturbated, fossiliferous, well-indurated tuffaceous siltstone. Laminated carbonaceous mudstones and thin (<1/2 m) arkosic sandstone beds of the ball park unit in the Smuggler Cove formation overlie and interfinger with (?) the upper Smuggler Cove formation. The ball park unit is late Zemorrian (Oligocene) or Saucesian (Early Miocene) in age. Fluvial-deltaic to shallow marine sandstones and conglomerates of the lower to middle Miocene Angora Peak member of the Astoria Formation unconformably overlies the Smuggler Cove formation.

Numerous middle to upper Miocene basalts and gabbros intrude the sedimentary rocks in the thesis area. The intrusive rocks are chemically, magnetically, petrographically, and chronologically correlative to the Grande Ronde Basalt, Frenchman Springs Member, and Pomona Member of the Columbia River Basalt Group on the Columbia Plateau. The Grande Ronde Basalt intrusives have been divided into three chemical-magnetostratigraphic units in the thesis area and correlated to subaerial Columbia River Basalt flows located approximately 35 km to the northeast. The intrusive rocks are thought to have formed by invasion of voluminous subaerial flows into soft, semiconsolidated marine sediments as first envisioned by Beeson et al. (1979).

Uplift of the Coast Range forearc ridge from late Miocene to present has resulted in subaerial erosion and exposure of rock units. Thin alluvial gravels and sands were deposited in the southeastern corner of the thesis area during the Quaternary.

Structure in the thesis area is dominated by a series of east-west trending high angle faults and a younger series of conjugate northeast-and northwest-trending high angle oblique slip faults. Proton precession magnetometer traverses confirm the presence of the faults. The structure may have been produced by partial coupling of the forearc region with the subducting Farallon plate.

The thesis area has been actively explored for hydrocarbons. Geologic mapping, however, shows that significant sandstone reservoirs are not present in the subsurface and, therefore, the area has low potential of hydrocarbon production. Mudstones in the thesis area average approximately 0.9-1.1% total organic carbon with vitrinite reflectance values ranging from 0.53% Ro (unbaked) to 0.72% Ro (baked). Therefore, the mudstones are a marginal to poor source of thermogenic gas but a possible source of methane gas.

GEOLOGY OF THE HAMLET-NORTH FORK OF THE NEHALEM RIVER AREA, SOUTHERN CLATSOP AND NORTHERNMOST TILLAMOOK COUNTIES, NORTHWEST OREGON

by

Phillip Jay Rarey

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

GEOLOGY OF THE HAMLET-NORTH FORK OF THE NEHALEM RIVER AREA, SOUTHERN CLATSOP AND NORTHERNMOST TILLAMOOK COUNTIES, NORTHWEST OREGON

INTRODUCTION

Purpose

This study is part of a continuing geological investigation of the Tertiary strata in northwest Oregon. Since 1972 sixteen graduate students at Oregon State University, under the guidance of Dr. Alan R. Niem, have been mapping, describing, and interpreting the geology of Clatsop and northernmost Tillamook counties (fig. 1). This study along with the theses in progress of Mumford and Safley will complete the detailed mapping in Clatsop County (scale 1:15,840 to 1:31,680).

The primary purposes of this thesis are: 1) to produce a geologic map (scale 1:24,000) of the Hamlet-North Fork of the Nehalem River area; 2) to determine the age, depositional environments, facies relationships, provenances, and diagenetic histories of the sedimentary units in the area; 3) to physically, petrographically, and chemically describe the volcanic units in the area and to speculate on their origin and extent; 4) to delineate the lateral extent of the gas-producing Cowlitz Formation using both surface and subsurface information; 5) to evaluate the hydrocarbon potential of the area in light of recent discoveries of commercial gas at nearby Mist, Oregon; 6) to better correlate the units in the area with the formalized stratigraphy of northwest Oregon and southwest Washington; 7) to speculate on the intrusive history of the middle Miocene basalts in the area and determine their relationship to the Columbia River Basalt Group; 8) to interpret the geologic history of the area; and 9) to evaluate the chronostratigraphic significance of Eocene benthic foraminifera zones used in the Pacific Northwest by comparison to calcareous nannoplankton zones.

Location and Accessibility

The thesis area consists of a 166-square kilometer (64-square mile) block located in south-central Clatsop County and extreme north-central Tillamook County, approximately 87 kilometers northwest of Portland and 32 kilometers south of Astoria (fig. 1). The area includes parts of Saddle Mountain and Cannon Beach 15 minute quadrangles.

Access to the area is generally very good. Oregon state highway 53 is located near the western boundary and U.S. highway 26 crosses the northern portion of the thesis area. Numerous logging roads provide public entry into the interior of the area. In addition, the many creeks and rivers provide foot access. The majority of the area is located on major corporation timberland (e.g. Boise Cascade Co. and Longview Fibre) and state-owned timberland and, therefore, smaller private ownership does not present an access problem.

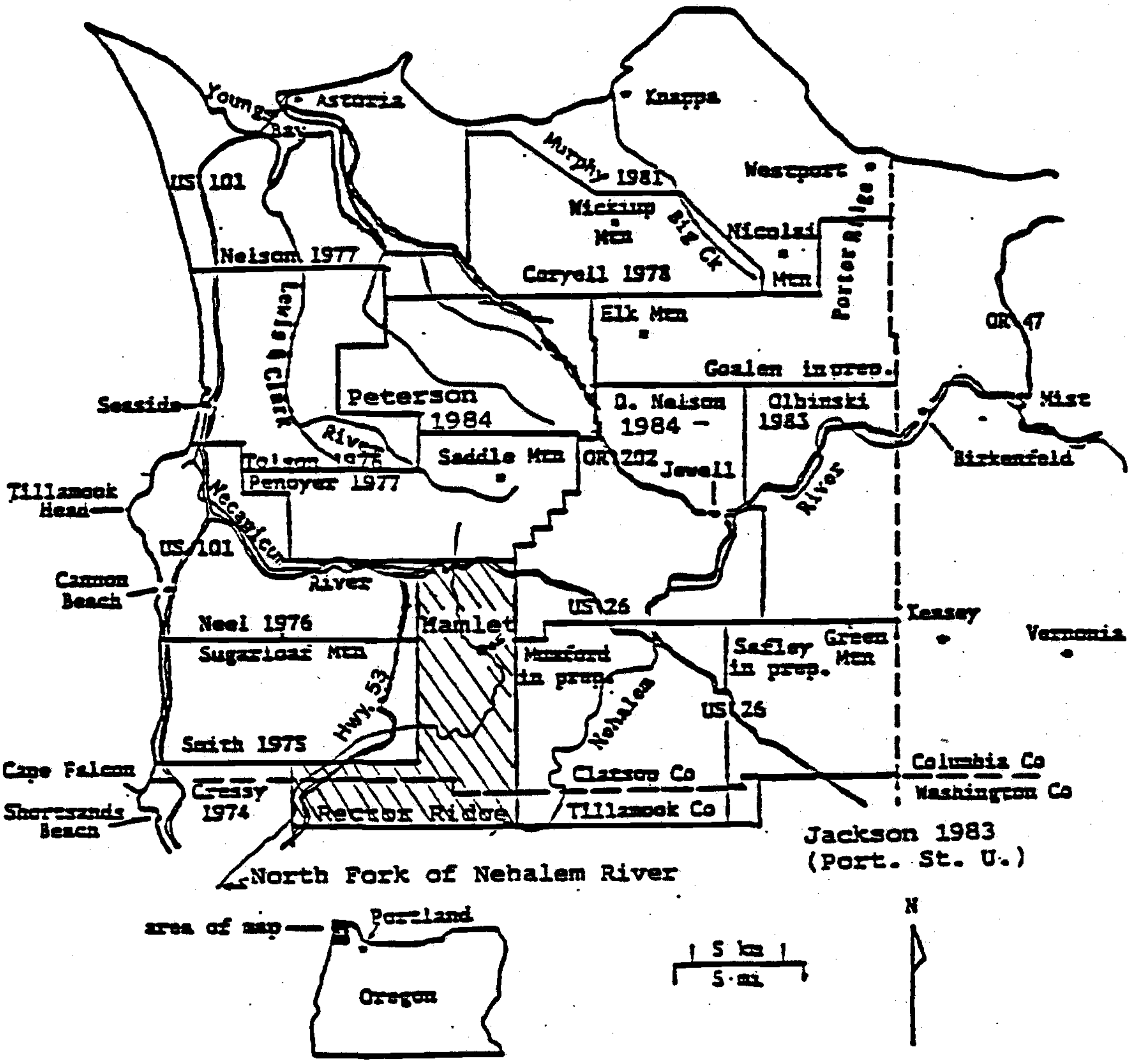


Fig. 1: Map showing the location of the thesis area (shaded) and the location of O.S.U. M.S. study areas in Clatsop County (modified from Peterson, 1984).

The area is sparsely populated with the small settlement of Hamlet being the only town in the area. Hamlet was established as a post office in 1905 with farming and lumber as the main industries. The early development and subsequent depopulation of the community is reflected in the presence of the Hamlet schoolhouse which was built around 1908 and forced to close in 1933 due to lack of students (Miller, 1958).

Much of the area is densely forested but extensive road cuts, quarries, clear-cutting, and creeks provide ample rock exposures. The North Fork of the Nehalem River and Sweet Home Creek both contain numerous exposures. Harrison and Eaton (1920) describe the vegitation in the thesis area as "impenetrable" but with persistence natural cliff and slope exposures can be located. In addition, an almost completely overgrown 1920's to 1950's logging road system provides occasional exposures. The road system shows up as faint traces on Forest Service aerial photographs.

Elevations within the area range from 3 m to 739 m above sea level. Moderate relief (10-50% slope) prevails throughout most of the area except in the extreme southern part where slopes of about 100% are dominant (plate I). Prominent topographic features include Gods Valley, North Fork of the Nehalem River Valley, Cole Mountain, Rector Ridge, and several unnamed peaks (fig. 2). High relief is generally restricted to areas underlain by volcanic rocks whereas low relief areas are generally underlain by Tertiary sedimentary rocks.

Fig. 2. View looking east towards the southern part of the thesis area. The North Fork of the Nehalem River Valley (N) is in the foreground and Rector Ridge (R) is in the background.

Climate and Vegetation

The climate of northwest Oregon is generally cool and damp with a mean annual temperature of 11o C (52o F) at Seaside (15 km northwest of the study area) and a mean annual precipitation of approximately 300 cm (120 in.) in the southeastern corner of the study area (N.O.A.A., 1974). The Tillamook Volcanic highlands, directly south of the thesis area, is the wettest region in Oregon. The four summer months spent in the field were unusually cool with rain being common and persistant. Thirty days were spent in the field during June and July of 1983 in which light persistent rainfall occurred every day.

The native vegetation in the study area is a spruceceder-hemlock forest (U.S. Department of the Interior National Atlas, 1970) but extenisve clear-cutting and large fires have removed most of the old-growth forest. Dougless Fir and alder now dominate with undergrowth consisting of abundant ferns and blackberry bushes. Deer, elk, and rare black bear are present in the study area.

Previous Work

Only reconnaissance geologic work had previously been done within the boundaries of the thesis area, but numerous reports on the Tertiary geology of the region have been published. Diller (1896) stated that the first significant geologic study of the Pacific Northwest was by Dana in 1849. J. D. Dana, while accompanying the Wilkes exploration expedition, collected molluscan fossils at Astoria which Conrad (1849) considered to be Miocene in age. Dana climbed "the volcanic peak" of Saddle Mountain which is located 5 km to the north of the study area. Diller (1896) conducted a geological reconnaissance of northwest Oregon and indentified a sequence of Eocene volcanic rocks with overlying Eocene to Miocene sedimentary rocks in Clatsop County. He described Eocene basalts, volcanic sandstones, and mudstones along the Nehalem River, 3 km east of the study area. Washburne (1940) reported on the geology and oil prospects of northwest Oregon. He described the Coast Range of Oregon as a "broad, low geanticline of Tertiary formations broken by many igneous intrusions". Numerous localities in northwest Oregon were described but are within the thesis area. Harrison and Eaton (1920) conducted another oil and gas investigation of western Oregon and briefly discussed the geologic history of the region. They did not venture into the thesis area.

Detailed description of rock units in the region was begun by Hertlein and Crickmay (1925) who described and named the Pittsburg Bluff Formation. The underlying Keasey Formation was named by Schenck (1927). The first geologic map (scale 1:143,000) including the thesis area was by Warren et. al. (1945). They mapped Eocene volcanics, undifferentiated Tertiary sedimentary rocks, and Miocene volcanics within the thesis area. None of their numerous fossil localities are in the thesis area and no structure was mapped.

The Tertiary stratigraphy of the upper Nehalem River basin was formalized by Warren and Norbisrath (1946). They named the Eocene Tillamook Volcanics, named the Keasey Formation, and extended the Eocene Cowlitz Formation into northwest Oregon from the type section in southwest Washington. Snavely and Vokes (1949) described and named the Nestucca Formation, which is age-equivalent to the Cowlitz Formation, south of the study area. Deacon (1953) proposed the name Rocky Point Formation for the strata mapped as Cowlitz Formation and lower Keasey Formation by Warren and Norbisrath (1946). Deacon (1953) believed that the Eocene sedimentary rocks in northwest Oregon are lithologically distinct from the type section Cowlitz Formation but subsequent workers (e.g. Van Atta, 1971; Wells and Peck, 1961) have referred to this unit as Cowlitz Formation. Wells and Peck (1961) compiled a geologic map of Oregon west of the 121st meridian (scale 1:500,000) in which Tillamook Volcanics, Keasey Formation, undifferentiated upper Eocene sedimentary rocks, undifferentiated upper Eocene-lower Oligocene tuffaceous siltstone, and mafic Miocene intrusion were outlined in the thesis area.

More recently Van Atta (1971) and Newton and Van Atta (1976) have described the Tertiary stratigraphy in the upper Nehalem River basin east of the thesis area. Beaulieu (1973) produced the first and only large scale (1:62,500) geologic map that included the thesis area. The map was part of an environmental geology study of Clatsop and Tillamook counties where engineering and environmental features were stressed over stratigraphic and structural features. The reconnaissance mapping by Beaulieu (1973) in the thesis area is similar to that of Wells and Peck (1961) except that no Eocene sedimentary rocks were mapped (see fig. 3). The reconnaissance nature of this engineering geology project is exemplified by the fact that my field work differentiated sedimentary rocks (fig. 4) in areas that Bealeau (1973) had mapped as Eocene volcanic rocks

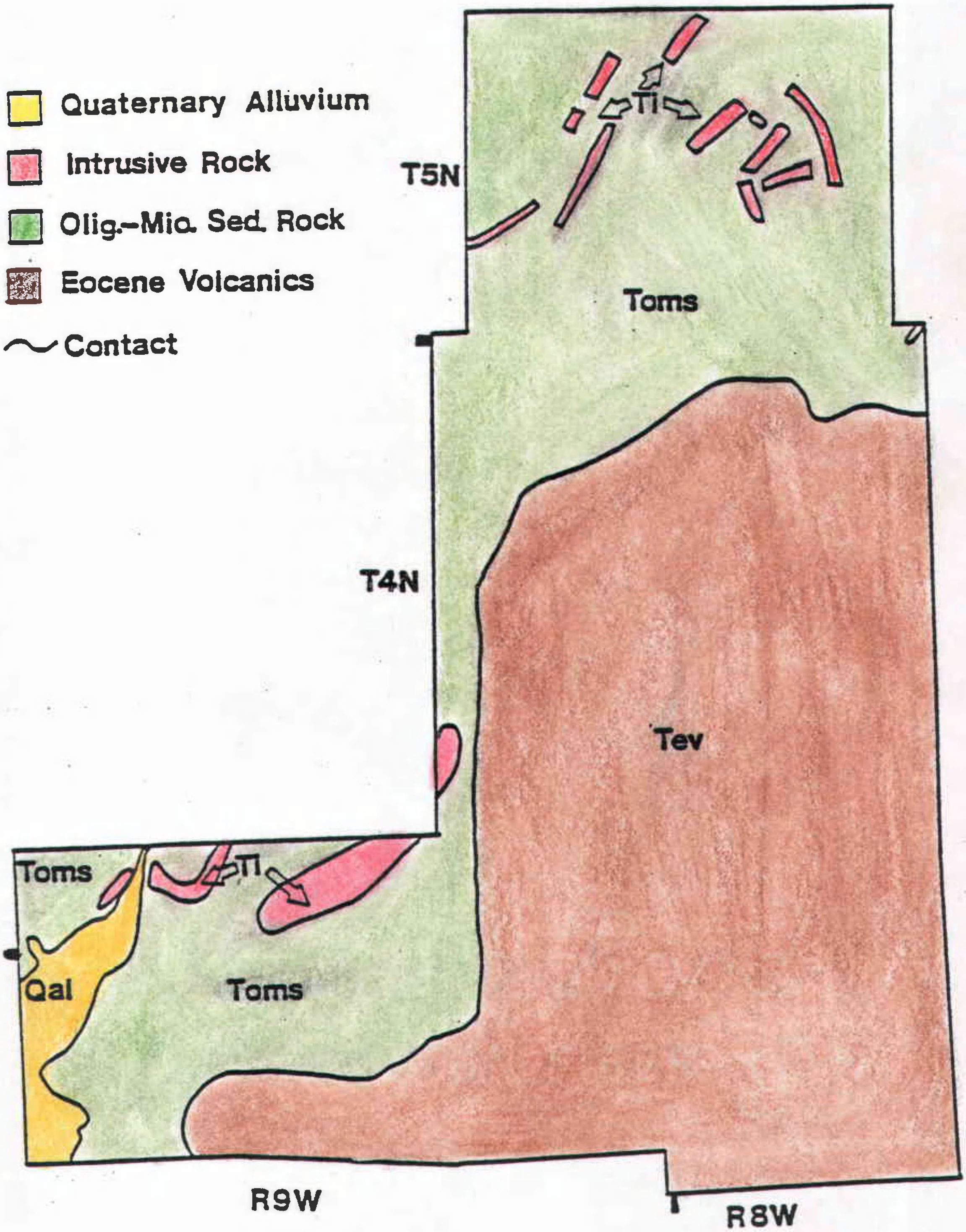


Fig. 3: Previous geologic interpretation of the thesis area (from Beaulieu, 1973).

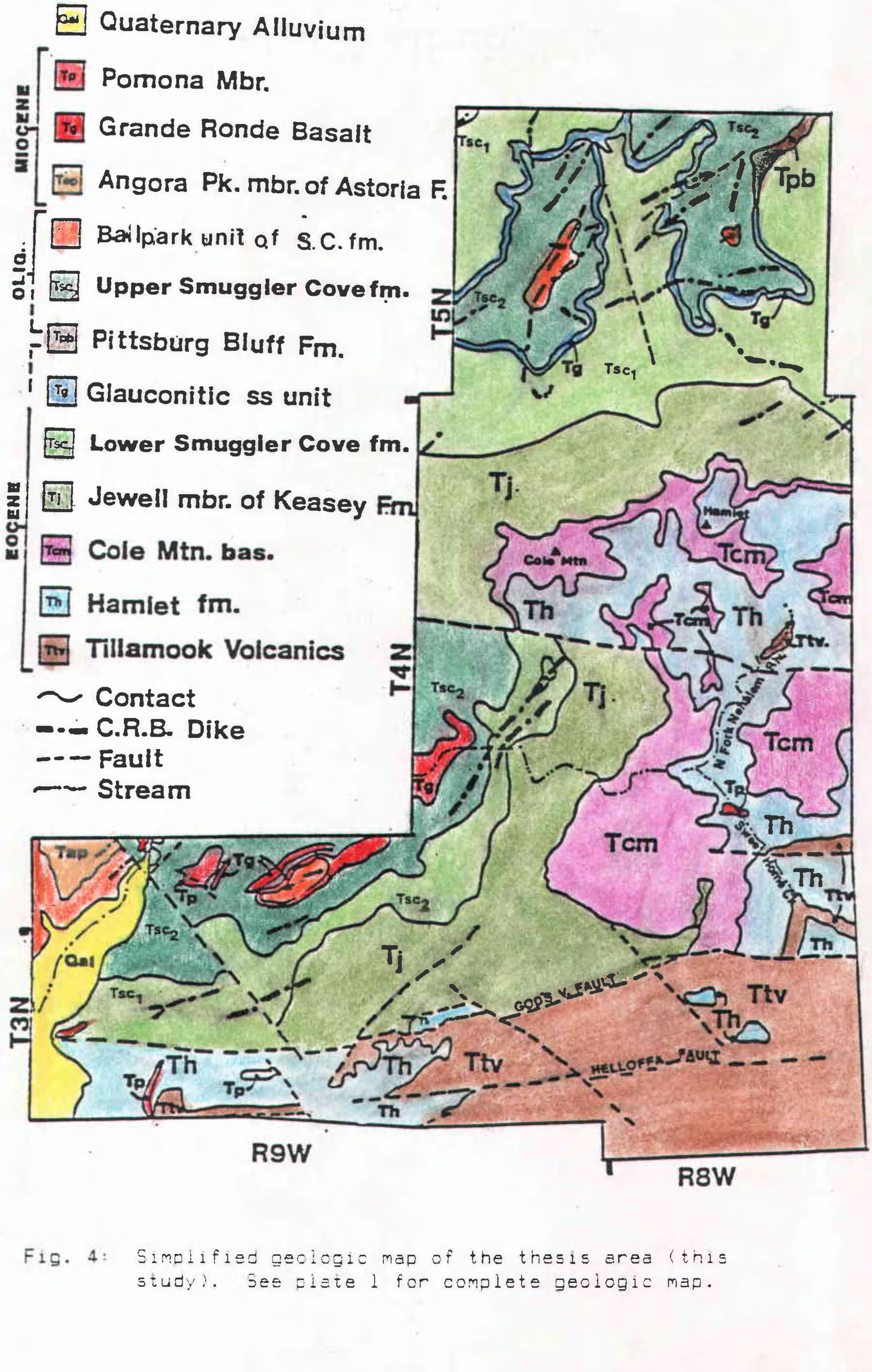


Fig. 4: Simplified geologic map of the thesis area (this study). See plate 1 for complete geologic map.

(compare figs 3 and 4). Snavely et. al. (1973) described the middle Miocene basaltic intrusions and flows of western Oregon but none of his chemical analyses were from within the thesis area. Snavely and Wagner (1963, 1964), Baldwin (1981), and Niem and Niem (1984) have described the region in various sketches and overviews of the geology and geologic history of northwest Oregon.

Graduate students at Oregon State University, under the guidance of Dr. Alan R. Niem, have recently mapped in detail and defined new Tertiary rock units in Clatsop County while graduate students at Portland State University have been working under the guidance of Drs. Robert Van Atta and Richard Thoms in adjacent Columbia and Tillamook counties (fig. 1). Cooper (1981), as part of a PhD. investigation on the Astoria Formation, mapped a small corner (1 square mile) of the thesis area as lower to middle Miocene Angora Peak member of the Astoria Formation and undifferentiated Oligocene sedimentary rocks. Cressy (1974), Smith (1975), Neel (1976), Penoyer (1977), and Nelson (1985) have mapped adjacent to the thesis area.

Mumford (in prep.) is currently finishing mapping directly east of the thesis area.

Wells et. al. (1983) compiled a geologic map of the west half of the Vancouver Sheet (scale 1:250,000) in which preliminary mapping from this study was incorporated. Armentrout et al. (1983) have made stratigraphic and chronologic correlations for western Oregon and western Washington as part of the COSUNA project. Dr. Alan R. Niem and Wendy Niem at Oregon State University are currently involved in an oil and gas investigation report in Clatsop County for the Oregon Department of Geology and Mineral Industries.

Methods of Investigation

Field Methods

Four months of field work were conducted during the summer of 1982 and early summer of 1983. In addition, brief excursions were made to the field area at various times between 1982 and 1984. Reconnaissance investigations were done in surrounding thesis areas, Columbia County, and in southwest Washington. Mapping was accomplished using 1977 Oregon State Department of Forestry aerial photographs at a scale of 1:63,000 and enlarged (1:24,000) parts of Cannon Beach (1955) and Saddle Mountain (1955) U.S. Geological Survey 15-minute quadrangle maps. Lineaments interpreted on high-altitude Side Looking Airborne Radar 1983 imagery, Landsat imagery, and aerial photographs were field checked for possible structural significance.

Attitudes of rock units and orientation of structural features were measured with a Brunton compass. A survey altimeter was used to more precisely locate outcrops. During a part of the field work a portable fluxgate magnetometer was used to determine magnetic polarity of volcanic units following the methods of Doell and Cox (1964). A Unimag proton precession magnetometer was used to locate buried sedimentary-basalt contacts in poorly exposed areas. A Geological Society of America rock-color chart (1970) and a grain size chart augmented the description of rock units. Field terminology of Miocene basalt units was based on the work of Beeson et al. (1973) and Peterson (1984).

Approximately 400 rock samples were collected for further laboratory work. Plant, invertebrate, vertebrate, and trace fossils were collected for more precise, identification by specialists (see appendices). Pebble counts were made at several localities in the Roy Creek member of the Hamlet Formation.

Laboratory methods.

Laboratory analysis of rock samples collected in the field consisted of the following: sieve analysis, heavy mineral separation, thin-section analysis, preparation of fossils for identification, X-ray diffraction of zeolites, scanning electron microscopy, preparation of samples for hydrocarbon maturation and porosity determinations, preparation of basalt samples for major oxide analysis, determination of magnetic polarity of basalts, and description of well cuttings. In addition, electric logs and seismic sections were interpreted for the nearby Diamond Shamrock 11-28 exploration well. A well log was constructed (plate 3).

Size analysis was performed on 25 sandstone and fine-grained conglomerate samples using a minimum diameter (sieve) method as standardized by Royse (1970). Weakly cemented samples were disaggregated with a mortar and rubber pestle. Well-cemented samples were treated with a dilute solution (10%) of hydrochloric acid and kerosene. The silt and clay fraction was removed by washing. This fine material was not analyzed for size distribution due to the high percentage of diagenetic matrix which was determined from thin-section and scanning electron microscope investigations. The sand-sized material was examined under a binocular microscope to insure complete disaggregation. Folk's medium diameter, sorting, skewness, and kurtosis coefficients were calculated from cumulative weight percent curves. These statistical parameters were then plotted on graphs to aid in the interpretation of depositional environments.

Heavy minerals were separated from the 3ø and 4ø (very fine sand) fractions of previously disaggragated sandstones with the use of tetrabromomethane (specific gravity 2.92). The heavy fractions of 52 splits (from 29 localities) were mounted on slides with Piccolyte for petrographic identification. The light fraction from 11 samples was also mounted on slides and briefly examined to check mineral identification from thin sections.

Forty-two sedimentary and 85 basalt thin-sections were prepared and studied. Modal composition of all samples was visually estimated then representative samples were selected for point counting (average approximately 300 points per slide) using a mechanical stage (appendices 8 and 9). Rock billets were stained for plagioclase and potassium feldspar following the methods of Laniz et al. (1964).

Foraminifera, diatoms, calcareous nannoplankton, and molluscs were separated from mudstones and prepared for identification. Ninety-one mudstones were disaggregated using a kerosene treatment described by Peterson (1984). Foraminifera were picked from disaggregated mudstones and mounted on slides for identification by Dr. Kristin A. McDougall of the U.S. Geological Survey and Dr. Weldon W. Rau of the Washington State Department of Natural Resources. Thirty-seven samples contained significant foraminifera representing over 150 species (appendix 1). One hundred and fifty-six smear slides of mudstones were prepared and examined for diatoms, calcareous nannoplankton, and radiolarians. Sixty-nine of these slides contained calcareous nannofossils and four contained significant unaltered diatoms. The slides with the best assemblages were sent to Dr. Dave Bukry (calcareous nannofossils) and Dr. John Barron (diatoms) of the U.S. Geological Survey for identification (appendix 1). Radiolarian assemblages were poor and no attempt was made to further identify them.

Molluscan fossils collected from 18 localities were sent to Dr. Ellen J. Moore of the U.S. Geological Survey for age and paleoecologic information (appendix 1).

X-ray diffraction of zeolite minerals in amygdules was performed on selected volcanic rock samples. Scanning electron microscopy and energy dispersive X-ray analysis of sedimentary rock samples were performed by Al Soeldner of the Department of Botany at Oregon State University.

Six representative samples were sent to Terry Mitchell and Jill Schloefer of Amoco Production Company in Denver, Colorado, for source rock and permeability determinations (appendix 13). Tim England of the University of British Columbia made vitrinite reflectance measurements of a "coaly" sample from the Northrup Creek formation (locality 66) (appendix 13).

Analysis of basalt samples included determination of magnetic polarity on over 250 samples with a fluxgate magnetometer (appendix 7). In addition, 56 samples were prepared for major oxide analysis which was performed by Dr. Peter Hooper of Washington State

University using x-ray flourescence (appendix 4) Preparation included breaking basalt samples and carefully selecting fresh chips which were ultrasonically cleaned. The samples were checked for alteration by thin-section petrography. Altered samples were recollected or discarded. INAA trace element analysis of Grande Ronde Basalt sample 40 was performed by Amy Hoover of Oregon State university. Kris McElwee of Oregon State University attempted a K-Ar date for a Cole Mountain basalt sample (locality 614) but extensive alteration resulted in unreliable dates.

Cuttings provided by Diamond Shamrock Corporation from the CZ-11-28 well, located 3 km west of the study area, were examined under a binocular microscope and a lithologic log was constructed (plate 3). Selected samples were analyzed for fossils, geochemistry, heavy minerals, and modal composition as previously outlined. Well logs and seismic sections in the area were examined to aid in structural and stratigraphic interpretation. One sample of ball park unit sandstone was treated with hydrogen peroxide to estimate organic content.

REGIONAL GEOLOGY

Snavely and Wagner (1964) interpreted the structure of the northern Oregon Coast Range as a north plunging "anticlinorium" with the oldest rocks, the Eocene Siletz River and Tillamook Volcanics exposed in the center (Fig. 5). A sequence of late middle Eocene to middle Miocene sedimentary rocks and middle Miocene volcanic rocks dip from 10o to 40o to the north, east, and west away from the uplifted volcanic core (fig. 5). The structural arch ("anticlinorium") is cut by many northwest-and northeast-trending faults which commonly show strike-slip displacement (Wells *et al.*, 1983).

The early to middle Eocene Siletz River Volcanics consist of a lower unit of low potassium, tholeiitic, submarine pillow basalts and breccias interbedded with minor siltstones. The upper, thinner unit is a differentiated, shallow marine to subaerial, alkalic basalt (Snavely, *et al.*, 1968). The Roseburg Formation in southern Oregon and the Crescent Formation in western Washington are similar, age-equivalent units. Snavely *et al.* (1968) have estimated the thickness of the Siletz River Volcanics to be between 10,000 and 20,000 feet. Seismic data of Berg *et al.* (1966) indicate a crustal thickness of 15 to 20 kilometers. The thickness is intermediate between normal continental and oceanic crust and is suggestive of an anomalously thick oceanic crust due to the presence of oceanic seamounts (Berg *et al.*, 1966). Loeschke (1979) and Duncan (1982) suggest a similar intraplate or mid-ocean ridge origin on the basis of rare-earth and trace elements. Simpson and Cox (1977), based on

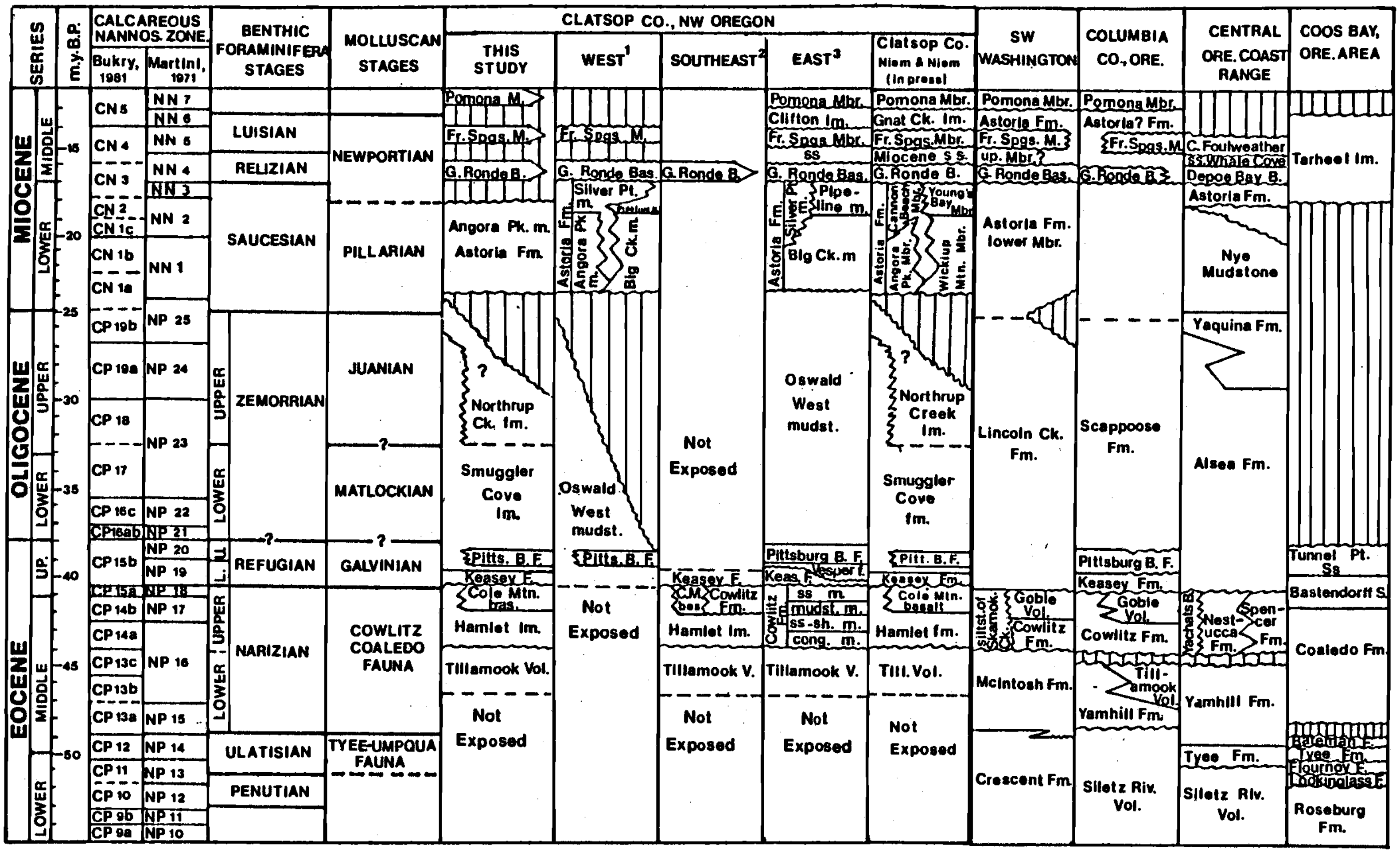


Fig. 5: Correlation of Tertiary strata in western Oregon and southwestern Washington. Data from Armentrout et al. (1983) unless otherwise noted. 1Composited from Peterson (1984), Neel (1976), and Cressy (1974). 2Composited from Mumford (in prep.) and Safley (in prep.). 3Composited from Olbinski (1983), Murphy (1981).

paleomagnetic data, reported up to 75o of clockwise rotation for the Siletz River Volcanics relative to the stable North American craton. The Siletz River Volcanics oceanic crust was accreted to North America at about 50 Ma resulting in a westward jump of the subduction zone (Wells et al., 1984).

Overlying the Siletz River Volcanics are middle Eocene deltaic deep marine fan turbidites and slope siltstones of the Tyee and Yamhill formations respectively (Wells et al., 1983; Chen et al., 1985; Heller et al. 1985). The sediments in these units were deposited in a developing deep forearc basin with the thickest accumulation occurring in the southern and central parts of the present Oregon Coast Range. In northwest Oregon these deep marine sedimentary units are overlain by and interfinger with the middle to late Eocene Tillamook Volcanics (Wells et al., 1983). Wells et al. (1983) and Cameron (1980) divided the Tillamook Volcanics into a lower submarine basalt facies and an upper subaerial basalt facies.

The Tillamook Volcanics, the oldest rock unit exposed in the thesis area, are unconformably overlain by more than 2,000 meters of late Eocene to middle Miocene tuffaceous siltstones, arkosic and basaltic sandstones, and minor boulder conglomerates. These sedimentary units are intruded and overlain by middle Miocene basalts. The oldest of these units is the upper Narizian (late middle Eocene) Cowlitz Formation (includes Hamlet formation of this study) and the time equivalent Nestucca Formation. The Cowlitz Formation, at the type section in southwest Washington, consists of deltaic micaceous and arkosic sandstones, subbituminous coals, shallow water sandstones, and minor deep marine mudstones (Yett, 1979; Wells, 1981). Similar lithologies occur in northwest Oregon but coals are nearly absent and conglomerates as well as turbidites are present (Warren and Norbisrath, 1946; Van Atta, 1971; Olbinski, 1983). Henriksen (1956) appended several hundred meters of deep marine, middle Eocene mudstones and turbidites (Stillwater Creek Member) to the base of the Cowlitz Formation as defined by Weaver (1937). Subsequent workers (e.g. Wells, 1981) have referred to this lower unit as McIntosh Formation, which is age-equivalent to the Tyee and Yamhill formations. Wells (1981) restricted the Cowlitz Formation to Weaver's (1937) definition of shallow marine to deltaic arkosic sandstones and coal, that is, to the Olequa Creek member of Henriksen (1956). In 1979, commercial quantities of natural gas were discovered at Mist, Oregon, in a Cowlitz Formation sandstone reservoir (Newton, 1979).

In the upper Nehalem River area of northwest Oregon (includes Mist) the Cowlitz Formation has been separated into several informal members (Olbinski, 1983; Nelson, 1985). These members are: a basal basaltic boulder conglomerate which unconformably overlies the Tillamook Volcanics, a lower arkosic and basaltic sandstone, a thin turbidite unit, a thin mudstone, and an upper arkosic sandstone. The total thickness of the Cowlitz Formation in this area is approximately 300 meters (Niem and Van Atta, 1973; Olbinski, 1983). Most of the Cowlitz Formation was deposited in a shallow marine environment (Henriksen, 1956; Van Atta, 1971; Timmons, 1981; Olbinski, 1983; Jackson, 1983; Nelson, 1985).

Southwest of the upper Nehalem River area, near Tillamook, Oregon, Snavely and Vokes (1949) described and named the upper

Eocene Nestucca Formation. The Nestucca Formation was originally divided into three members but the lower member has subsequently been referred to as Yamhill Formation by Snavely et al. (1969). Therefore, the Nestucca Formation is now restricted to the upper Narizian and is age-equivalent to the Cowlitz Formation but consists primarily of deep water tuffaceous mudstones.

Therefore, to the northeast of the thesis area, upper Narizian strata have been mapped as Cowlitz Formation whereas to the southwest of the thesis area, age-equivalent strata have been mapped as Nestucca Formation. In the subsurface of Clatsop County these late Narizian strata have been called Yamhill Formation (Bruer et al. 1984). A purpose of this report is to define the extent and facies relationships of these formations and to establish a nomenclature for the upper Narizian sedimentary rocks in the thesis area.

Interstratified with and overlying the Cowlitz Formation are the upper Eocene Goble Volcanics (Wilkenson et al., 1946; Henrickson, 1956; Livingston, 1966). At the type area near Goble, Oregon, they consist of subaerial and submarine basalt flows with minor pyroclastic rocks and have a total thickness of more than 1525 m (Wilkenson et al., 1946). In a similar stratigraphic position upper Eocene Cascade Head volcanics (informal) are interstratified with the Nestucca Formation (Barnes, 1981).

In the upper Nehalem River area tuffaceous siltstones of the Refugian (late Eocene) Keasey Formation unconformably overlie the Cowlitz Formation and the Goble Volcanics (Niem and Van Atta, 1973). These bathyal siltstones were deposited in a forearc basin and received abundant volcanic detritus from the developing calc-alkaline

Cascade arc to the east. Van Atta (1971) divided the Keasey Formation, in Columbia County, into three informal members: a basal thin, pebbly, volcanic sandstone; a thick middle member of structureless, fossiliferous, tuffaceous siltstone; and an upper thin sequence of interbedded siltstone and fine-grained sandstone. In adjacent Clatsop County, Nelson (1985) divided the formation into three, slighty different, informal members: the lowermost unit, the Jewell member, is a well-bedded to laminated tuffaceous mudstone with common clastic dikes; the middle unit, the Vesper Church member (Vesper Church formation of Olbinski, 1983) is a thick sequence of thinly interbedded arkosic turbidites and siltstone; the upper unit consists of massive, tuffaceous siltstones. The total thickness of the Keasey Formation ranges from 0 to 1,500 m (Nelson, 1985; Armentrout *et al.*, 1983).

Niem and Niem (in press) have revised the nomenclature of the informal units in Clatsop County on their 1:100,000 geologic map in order to avoid previous confusing use of stratigraphic nomenclature. The Oswald West mudstone is now known as the Smuggler Cove formation, the Vesper Church formation is now known as the Sager Creek formation and the upper Keasey Formation mudstone is now included in the Smuggler Cove formation.

To the southwest, in Tillamook County, Wells *et al.* (1983) have mapped late Eocene to Oligocene (Refugian) undifferentiated marine sedimentary rocks. Snavely *et al.* (1975) described and named the Refugian to Zemorrian (late Eocene to Oligocene) bathyal Alsea Formation which crops out in an arcuate belt between Yachats and Siletz Bay (west-central Oregon Coast Range). The Alsea Formation consists primarily of massive tuffaceous siltstones with the lower portion of the formation being age equivalent to the Keasey Formation. The thickness of the Alsea Formation ranges from 50 to 1100 m (Armentrout et al., 1983).

The Pittsburg Bluff Formation has been mapped in Washington, Columbia, and eastern Clatsop counties. In Columbia County the formation is thought to be unconformable upon the Keasey Formation (Kadri, 1982; Armentrout et al., 1983) but in Clatsop County it is thought to be conformable upon Oswald West mudstone (Smuggler Cove formation) (Peterson, 1984). Armentrout et al., (1983) considered the Pittsburg Bluff Formation to be late Refugian (late Eocene) in age. Using an older time scale Moore (1976) considered the formation to be middle Oligocene in age. The formation ranges from 0 to 275 m in thickness (Armentrout et al., 1983).

Van Atta (1971) and Kadri (1982) divided the Pittsburg Bluff Formation in Columbia County into two units. The lower unit consists of structureless to thin-bedded, bioturbated, arkosic and tuffaceous sandstone and siltstone. This unit may be in part equivalent to the Vesper Chuch formation of Olbinski (1983). The upper unit consists of local basalt conglomerate, arkosic and tuffaceous sandstones, glauconitic sandstones, tuffaceous siltstones, and minor coal beds (Van Atta, 1971; Niem and Van Atta, 1973). Moore (1976) interpreted an intertidal to inner continental shelf depositional environment for the Pittsburg Bluff Formation near the type section in Columbia County.

Olbinski (1983) divided the Pittsburg Bluff Formation in Clatsop County into two informal members. The lower member is predominantly a fine-grained tuffaceous sandstone but contains glauconitic sandy siltstone at the base. The upper member has a limited aerial extent and is composed of silty mudstone. These units were deposited in an open marine, inner to outer continental shelf environment (Olbinski, 1983; Peterson, 1984).

The informal name, Oswald West mudstones (changed to Smuggler Cove formation by Niem and Niem, in press) was introduced by Niem and Van Atta (1973) and Cressy (1974) for a 1,600 foot deep marine, predominantly mudstone unit that occurs along the seacliffs at Short Sands Beach in western Clatsop County. The mudstones in the type area are Zemorrian to Saucesian (Oligocene to early Miocene) in age but subsequent mapping to the north and east (eg. Smith, 1975; Neel, 1976; Nelson, 1978) has extended the lower part of the unit to include Refugian (late Eocene) mudstones. Therefore, the unit is both overlying and laterally equivalent to the Pittsburg Bluff Formation. The thesis area is located in a position where Oswald West mudstones (Smuggler Cove formation), Pittsburg Bluff Formation, and Keasey Formation are thought to interfinger.

Overlying the Pittsburg Bluff Formation in Columbia County is a sequence of tuffaceous sandstones and mudstones. Warren and Norbisrath (1946) proposed the name Scappoose Formation for this unit which they considered to be lithologically similar to the Pittsburg Bluff Formation but contained a different fauna. They concluded that the formation was Oligocene in age. However, Kelty (1981) and Van Atta and Kelty (1985) found middle Miocene Columbia River Basalt cobbles near what was thought to be the base of the formation suggesting that at least a portion of the unit is post middle Miocene in age. The Scappoose Formation is also overlain by middle Miocene Columbia River Basalt flows suggesting that a portion of the unit is younger than middle Miocene. This implies that the presently defined formation crosses a significant unconformity.

The Saucesian (lower to middle Miocene) Astoria Formation unconformably overlies the Smuggler Cove formation in western Clatsop County (Cressy, 1974; Niem and Van Atta, 1973). In this area the formation has been divided into several lithologically distinct informal members (Cooper, 1981). The Angora Peak sandstone member was informally porposed by Niem and Van Atta (1973) and Cressy (1974) for a 1000-foot thick unit of shallow marine sandstone, minor fluvial conglomerate, laminated micaceous and carbonaceous siltstone, and rare coal seams. The type section of the member is located in the extreme southwest corner of Clatsop County where it has been interpreted to be a wave-dominated deltaic unit (Cressy, 1974; Cooper, 1981; Niem, 1976). In northwest Clatsop County the Big Creek sandstone member, a shallow marine unit, and the Pipeline member, a submarine sandstone channel or canyon head deposit, have been mapped and described (Cooper, 1981; Nelson, 1978; Coryell, 1978). The Silver Point member is a deep-water mudstone and turbidite unit which overlies and interfingers with the other members of the Astoria Formation (Cooper, 1981; Smith, 1975). Niem and Niem (in press) have suggested that all of the informal members of the Astoria Formation, with the exception of the Angora Peak member, be given new names (see Astoria Formation section). This was done because most of the old unit names had been previously used in other parts of the United States.

Middle Miocene basalts intrude and overlie late Eocene-middle Miocene sedimentary units in northwest Oregon and southwest Washington. Snavely et al. (1973) interpreted these "coastal basalts" to be petrologic and age equivalents of the "plateau derived" Columbia River Basalt Group in eastern Oregon and Washington. The numerous dikes and sills prompted Snavely et al. (1973) to postulate a local source for the "coastal basalts" which they divided, on a petrologic basis, into the Depoe Bay basalt, Cape Foulweather basalt, and the basalt at Pack Sack Lookout. More recently Beeson et al. (1979) have suggested a plateau derived origin for the "coastal basalts". In this model voluminous subaerial basalt flows erupted in western Idaho, eastern Washington, and eastern Oregon then flowed via an ancesteral Columbia River gorge through the Willamette Valley and into the marine environment. Upon entering the marine environment they formed large breccia and pillow basalt piles; some of the denser lavas invaded the soft, semiconsolidated Miocene to Eocene sediments forming invasive dikes and sills.

Major uplift of the Washington and Oregon Coast Range and subsequent erosion of rock units began in the early Miocene and was well underway by the end of the Miocene (Pavlis and Bruhn, 1983). The uplift of the Coast Range forearc ridge has been interpreted by Pavlis and Bruhn (1983) to be a result of deep-seated flow beneath the ridge. In this model the forearc ridge formed when subduction accretion expanded the arc-trench gap to approximately 300 km creating a region capable of ductile deformation some 50 km from the trench-slope break.

Early workers in northwest Oregon considered the structure to be relatively simple (eg. Warren et al., 1945; Van Atta, 1971). Olbinski (1983) and Nelson (1985) have recently mapped northeast of the thesis area and have shown that the structure is relatively complex. They have mapped a series of northwest- and northeast-trending structural features which include minor folds and abundant faults with conjugate (right-lateral and left-lateral) oblique-slip displacement. East-west high-angle faults and thrust faults have also been mapped in northwest Oregon (Olbinski, 1983; Peterson, 1984). Several episodes of faulting are interpreted to have occurred including an early episode (late Eocene) of east-west faulting followed by Miocene north-south compression which produced the conjugate fault system (Olbinski, 1983; Peterson, 1984; Nelson, 1985).

The geologic history of northwest Oregon can be summarized by several major events. During the middle Eocene, oceanic crust of the Siletz River Volcanics and equivalent units was accreted to the North American Continent (McElwee and Duncan, 1984; Wells et al., 1984). This accretion event resulted in a westward shift of the subduction zone and by late Eocene the western Cascade arc was located near its present position and the modern subduction event is considered to have begun (Pavlis and Bruhn, 1983; Wells et al., 1984). Thick Eocene deltaic and turbidite fan sequences of sedimentary units were deposited in this newly developed forearc basin that expanded westward during the growth of the subduction complex (Snavely et al., 1968; Heller and Ryberg, 1983). Intermittent "forearc" volcanism during the Eocene produced the Tillamook Volcanics and the Goble Volcanics. A thick sequence of late Eocene to middle Miocene sediments was deposited in the forearc. Several major transgressions and regressions are recorded in this sedimentary sequence (Niem and Niem, 1984). Flood basalts of the Columbia River Basalt Group were erupted on the Columbia Plateau, flowed down an ancesteral Columbia River and invaded the semiconsolidated marine sediments in northwest Oregon. Uplift and erosion began in the middle Miocene, possibly a result of deep seated flow. Wells and Coe (1985) and Peterson (1984) suggest that much of the Miocene structure in the region is related to the oblique subduction of the Farallon plate beneath the Pacific plate which produced north-south compression.

REGIONAL STRATIGRAPHIC PROBLEMS

Much of the thesis area is located within a region where the late middle Eocene-Oligocene stratigraphic nomenclature has not been formalized. In the upper Nehalem River area, east of the thesis area, a number of workers have helped to develop a formalized stratigraphy (e.g. Schenck, 1927; Warren et al., 1945; Wells and Peck, 1961). Many of the sedimentary units in the upper Nehalem River area (Clatsop County, Oregon) are shallow water deposits with fairly distinct lithologies. To the west, time-equivalent deeper water mudstones dominate the section, making formational distinctions more difficult (fig. 6). In the Newport to Tillamook area, 20 to 100 km south of the thesis area, a formalized nomenclature has been worked out for similar, fine-grained middle Eocene-Oligocene sedimentary rocks (Snavely and Vokes, 1949; Snavely et al., 1968; Wells et al., 1983).

The stratigraphic nomenclature used in this report incorporates terminology from the upper Nehalem River area with new stratigraphic nomenclature (figs. 5 and 6). It is felt that the presence of lithologically distinct units in the thesis area warrents the use of new nomenclature. The Eocene Hamlet formation and the Eocene Cole Mountain basalt have been proposed in this study. The Hamlet formation has been subdivided into the Roy Creek member and the overlying Sweet Home Creek member. The remainder of the nomenclature used in this study is from other workers. Smuggler Cove formation has been subdivided into an upper unit and a lower unit. These mudstones are fine-grained, deep marine equivalents to the uppermost

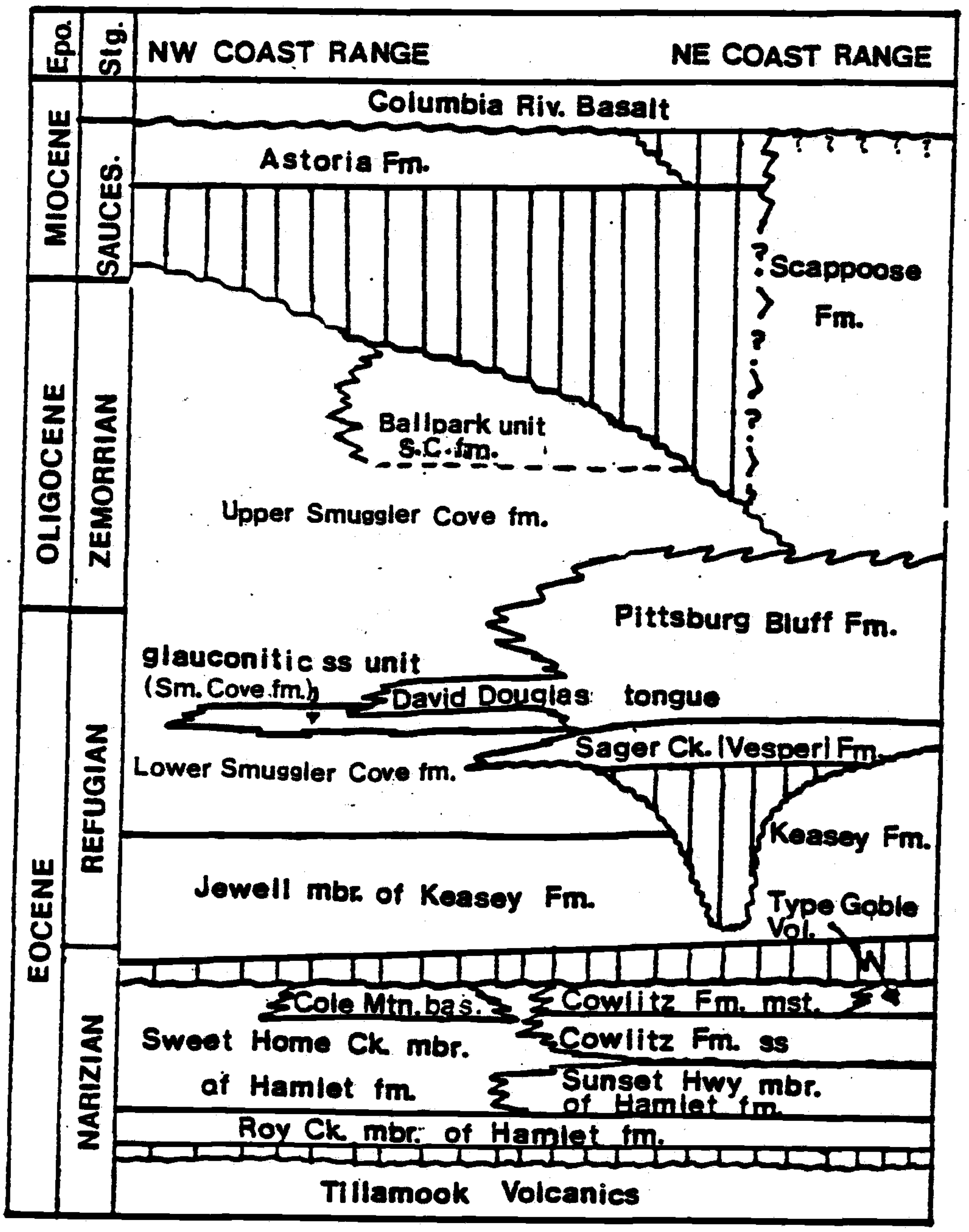


Fig. 6: Correlation of northwestern and northeastern Oregon Coast Range stratigraphy. The shallow-marine units of the east pinch-out into deeper-marine mudstones in the west.

Keasey Formation, Sager Creek formation (Vesper formation of Olbinski, 1983), Pittsburg Bluff Formation, and the Scappoose Formation (fig. 6).

BIOSTRATIGRAPHIC AND CHRONOSTRATIGRAPHIC NOMENCLATURE

The biostratigraphic terminology used in this report is based on the work of Armentrout (1981), Bukry (1981), McDougall (1980), and Armentrout et al. (1983) (fig. 5). The correlation of Oregon and Washington foraminifera and molluscan stages to each other and to oceanic calcareous nannofossil zones appears to be fairly good (Armentrout, 1981). Within the thesis area molluscan, diatom, foraminifera, and calcareous nannofossil ages are consistant with one another. There are, however, significant problems in correlating Oregon and Washington chronostratigraphic units to global chronostratigraphic units.

Armentrout (1981) defined a new geologic time scale for the Cenozoic strata of Oregon and Washington on the basis of new paleontologic data, new radiometric data, and a synthesis of redefined provincial biostratigraphic frameworks. The major changes proposed by Armentrout (1981) are: to move the Narizian foraminifera stage from the late Eocene to the late middle Eocene; to move the Refugian foraminifera stage from the late Eocene-early Oligocene to the late Eocene; and to have the Zemorrian foraminifera stage occupy the entire Oligocene. Armentrout (1981) places the Eocene-Oligocene boundary at 32 Ma whereas Hardenbol and Berggren (1978) place the boundary at 37 Ma. Subsequently, however, Armentrout et al. (1983) have placed the boundry at 38 Ma. This new boundary date invalidates some of the changes in the geologic time scale of Oregon and Washington proposed by Armentrout (1981). It does not, however, affect the correlation between molluscan, foraminifera, and nannofossil stages.

The time scale used in this report is that of Armentrout et al. (1983) because at present it has a wide distribution and is part of the COSUNA (Correlation of Stratigraphic Units in North America) project. In this time scale the Refugian foraminifera stage is still restricted to the late Eocene with a questioned upper boundary at the base of the Oligocene. Moore (1976), based on molluscan fossils, considered the basal Pittsburg Bluff Formation to be "middle" Oligocene, in age but foraminifera collected from this unit indicate a Refugian age. Prothero and Armentrout (1985) have recently suggested that the Refugian stage extend into the Oligocene, thereby modifying the time scale of Armentrout et al. (1983).

It has been shown that the correlation of Oregon and Washington chronostratigraphic units to global chronostratigraphic units has undergone significant revisions over the years. For this reason it is not possible to correlate the stratigraphy in northwest Oregon using global chronostratigraphic units. For example, most of the Pittsburg Bluff Formation has been assigned to the Refugian foraminifera stage but, depending on which time scale was in vogue, has been referred to as Oligocene in age (e.g. Moore, 1976) age and as late Eocene in age (e.g. Armentrout et al., 1983). For this reason the local stage assignment of a unit will be stressed rather than the absolute age or the global chronostratigraphic age of a unit.

McDougall (1980) has shown that many of the foraminifera zones and subzones used in southwest Washington and northwest Oregon are ecologically controlled and time transgressive. Because of this McDougall (1980) used upper and lower subdivisions of the Narizian and Refugian stages rather than the more numerous zones of previous workers (fig. 7). In general, there is good agreement between workers on the foraminifera stage assignment of strata. In many cases contradictory stage assignments are the result of poor microfossil assemblages. Microfossil assemblages (foraminifera, calcareous nannofossils, diatoms) collected from the study area are more complete than any previous assemblages collected from surficial outcrops in Clatsop County making stage assignments very reliable. There appears to be a problem with the exact position of the Narizian-Refugian boundary. The basal part of the Jewell member of the Keasey Formation is located near the Narizian-Refugian boundary. Good foraminiferal assemblages from the same outcrop of this unit have been assigned to both the Narizian and the Refugian by different micropaleontologists (Niem, pers. comm., 1984). There is also some disagreement on the division of the upper and lower Refugian stage. A comparison of McDougall (1975 and 1981), Newton and Van Atta (1976), and Bruer et al., (1984) shows disagreement on the exact position of this boundary. Therefore, it may not be possible to correlate the upper Refugian stage of different workers. In general, there is good agreement on the upper and lower Narizian stages making it possible to correlate assignments of different workers.

Radiometric and biostratigraphic ages from northwest Oregon are often contradictory. McElwee (pers. comm., 1984) has obtained a number of radiometric dates from the uppermost part of the subaerial Tillamook Volcanics indicating that they are as young as 37 Ma. Foraminifera and calcareous nannofossils collected from bathyal

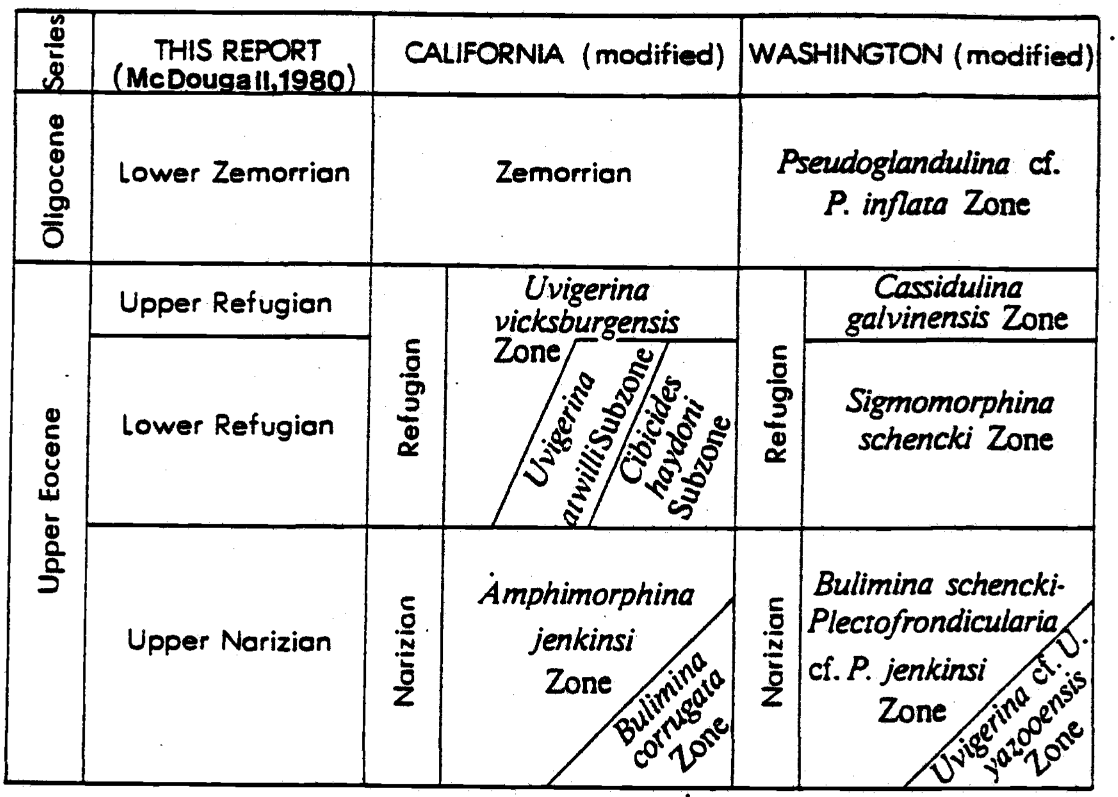


Fig. 7: Correlation of the late Eocene zones and stages as modified by McDougall (1980). The biostratigraphic nomenclature used in this report is that of McDougall (1980)(figure from McDougall, 1980).

mudstones which overlie the volcanics have been assigned to the upper Narizian and subzone CP-14a. Using the global Tertiary time scale of Armentrout et al. (1983) these biostratigraphic assignments indicate absolute ages of 44 to 41 Ma. The time scale revisions of Prothero and Armentrout (1985) would change these ages to approximately 41 to 39 Ma. Caicareous nannofossil subzones have been "accurately" correlated to the geomagnetic time scale and to the absolute time scale through the Deep Sea Drilling Project (Burky, 1981). This suggests that the dates of McElwee are slightly young.

TILLAMOOK VOLCANICS

Nomenclature and Distribution

The middle to upper Eocene Tillamook Volcanics were named by Warren and Norbisrath (1946) and Warren _et al._ (1945) for a thick sequences of middle Eocene basaltic flows and minor tuffs which occur in northwest Oregon. Subsequent workers (_e.g._ Deacon, 1953; Wells and Peck, 1961; Van Atta, 1971) have accepted this nomenclature and mapped Tillamook Volcanics in northwest Oregon (fig 23).

Snavely _et al_. (1970) divided the Tillamook Volcanics into three units. The lower unit consists of pillow basalts, tuffs, and breccias interbedded with minor foraminifera-bearing siltstones. The middle unit is about 670 m thick and consists of tuffaceous siltstone with subordinate sandstone, basaltic tuff, breccia, and pillow basalts. The uppermost unit consists of more than 1400 m of subaerial tholeiitic to alkalic basalt flows and associated basaltic sedimentary interbeds. More recently, Wells _et al_. (1983) have divided the Tillamook Volcanics into two units, a subaerial basalt unit and a submarine basalt unit. The submarine basalt unit is equivalent to the upper part of the middle member of Snavely _et al_. (1970) and the subaerial basalt unit is equivalent to the upper member of Snavely _et al_. (1970). The lower member and the lower part of the middle member of Snavely _et al_. (1970) have been mapped as Siletz River Volcanics and Yamhill Formation respectively (Soper, 1974; Wells _et al_., 1983).

In the thesis area only the upper, subaerial basalt unit of

Wells et al. (1983) is present where approximately 29 square kilometers (11 square miles) of Tillamook Volcanics were mapped (fig. 4, plate I). The unit is restricted to the southern portion of the map area except for a small uplifted block in the east-central part of the thesis area (plate 1). Approximately 600 m of subaerial basalt flows are exposed in the southeast corner of the thesis area.

The Tillamook Volcanics typically form high relief areas with steep canyons where slopes of 100% are common. Owing to the greater erosional resistance of this unit it is typically much better exposed than the overlying sedimentary units. The best exposures of the unit occur along an unnamed logging road on Rector Ridge (secs. 6 and 7, T3N R8W) and along the Southern Pacific Railroad cuts in the extreme southeast corner of the thesis area. The upper contact of the unit is well exposed in several quarries in the southwest part of the thesis area (localities 339, 362, 398, and 366). In addition, numerous natural cliff exposures occur on the south side of Rector Ridge (sec. 4-9, T3N R8W) and good stream exposures occur in Helloffa, Bastard, and Snark creeks in the southeast corner of the map area. The location of exposures within the thesis area are shown on plate 1 and in appendix 15. These can be referred to for additional locations of Tillamook Volcanics exposures.

Lithology

The Tillamook Volcanics in the study area consist primariy of subaerial labradorite and augite phyric basalt flows with minor basaltic andesites and a few reddish soil horizons. The flows have both normal and reversed polarities (appendix 7). They range from 2-13 meters in thickness and average about 5 meters. Individual flows may be sheet like or highly lenticular suggesting deposition on both low relief plains and as intracanyon flows. Individual flows can be traced for up to 1/2 kilometer but owing to the great number of flow units (more than 100 flow units are estimated to occur in the thesis area), the incomplete exposure, the similar lithology, and the lenticular nature of some flow units it was not possible to develop a flow stratigraphy. The most complete section of flows occurs along an unnamed logging road in sections 6 and 7, T3N R8W.

Fresh samples of Tillamook Volcanics basalt are dark gray (N 3) to medium dark gray (N 4) and are typically sparsely phyric. However, abundantly phyric (> 30% phenocrysts) basalts were observed at locality 645c in the thesis area and have been observed by Mumford (in prep.). Phenocrysts are plagioclase and, less commonly, greenish clinopyroxene with total abundances ranging from less than 1% to 35% and averaging about 5%. Phenocrysts average about 2 mm in length but range from 1mm to 1 cm. More rarely, the basalt is aphyric to microphyric. Flow interiors appear crystalline in hand sample with glass content increasing in the upper and lower vesiculated and brecciated parts of the flow unit.

More weathered basalt flows vary in color from light brown (5YR 6/4) to a dark yellowish orange (10YR 6/6) and contain iron oxides and clays. Plagioclase phenocrysts commonly alter to a white clay and clinophroxenes alter to a darker colored clay. The groundmass is more resistant to weathering than the phenocrysts.

All of the flows in the thesis area appear to be either basalt or basaltic andesite. The flows that chemically classify as basaltic andesites are lithologically similar to those that chemically classify as basalts and the two types cannot be easily distinguished in hand sample. None of the flows in the area have the physical or mineralogical characteristics of classical andesites.

Flows typically consist of a well developed, commonly altered, basal breccia zone which may be vessicular; a middle zone with irregular, blocky, or columnar jointing; and an upper highly vesicular to amygdaloidal zone (fig. 8). Amygdule fillings commonly consist of chloritic clay, chalcedony, calcite, and zeolites. The zeolites commonly have a fibrous radiating habit suggestive of thomsonite. A vesicle-filling zeolite from locality 408 is thomsonite based on the X-ray diffraction pattern (powder diffractometer X-ray file) (fig. 9). Walker (1960) has shown that thomsonite is a common constituent of Tertiary tholeiitic lavas which have not been deeply buried (fig. 9). Since the mineral in sample 408 appears to be identical to many other zeolites in the thesis area it is assumed that thomsonite is one of the more common vesicle-filling zeolites in the upper portion of the Tillamook Volcanics. Walker (1960) has found that chabazite is commonly associated with thomsonite but chabazite was not identified in the thesis area. Snavely et al. (1968) have noted a wide variety of zeolites in the more deeply buried lower to middle Eocene Siletz River Volcanics which is consistant with zonal distribution amygdule minerals proposed by Walker (1960) (fig. 8).

Some flows are separated by a 10 cm to 2 meter thick zone of dark reddish brown (10YR 3/4) clay (e.g. localities 685b, and

Fig. 8. Subaerial flow in upper part of Tillamook Volcanics. Note columnar jointing and basal breccia zone. Moin Kadri for scale (locality 339, SW 1/4 SW 1/4 sec. 8, T3N, R9W).

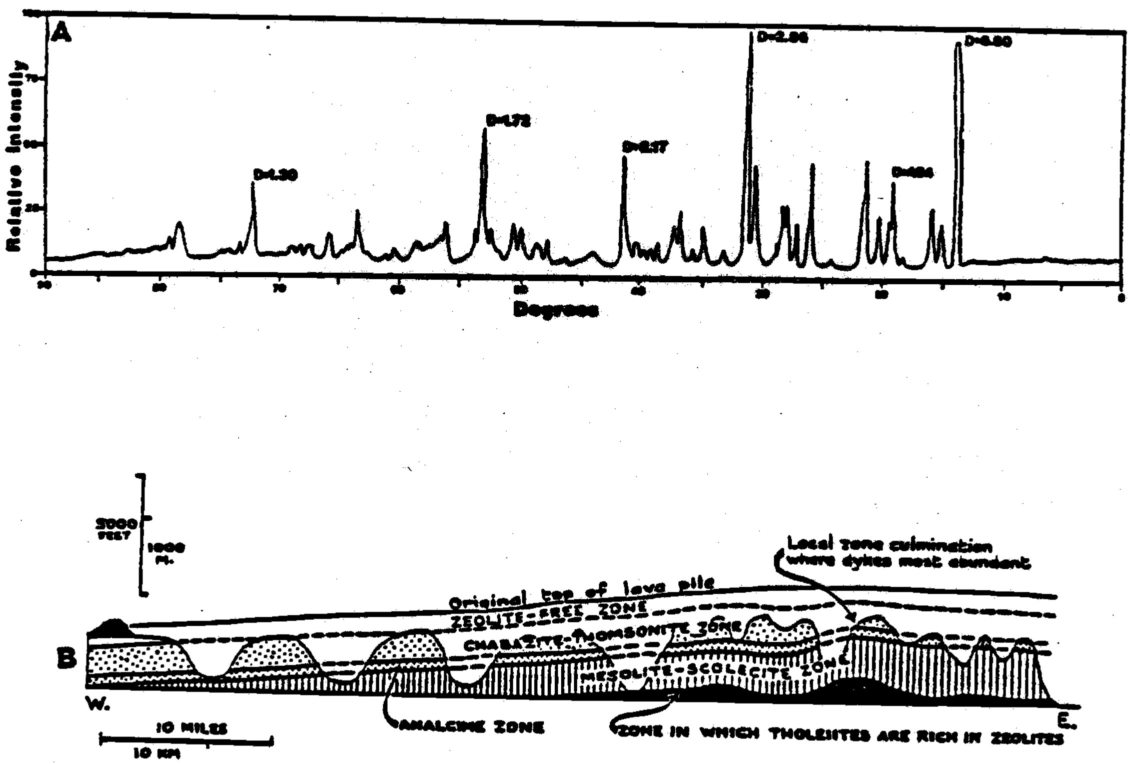


Fig. 9: Diffractometer tracing of vesicle-filling thomonsite in the Tillamook Volcanics (A)(sample 408). Diagnostic peaks are labelled. The zonal distribution of zeolite minerals in Tertiary tholeiitic volcanic rocks from New Zealand is shown in B (from Walker, 1960).

MS-643). This clay typically contains minor amounts of highly weathered volcanic fragments, root traces, and may contain poorly preserved carbonaceous plant debris. The reddish clay units are commonly found between fresh basalt flows and, therefore, are not a product of recent weathering. The clay units are interpreted as baked paleosols.

Jackson (1983) reported several minor basalt conglomerate and basaltic sandstone interbeds in the upper Tillamook Volcanics which were interpreted as both fluvial and debris flow deposits. Fluvial sandstone and conglomerate interbeds were not found in the thesis area. However, rare basaltic debris flow deposits do occur in the thesis area (e.g. NW 1/4 sec. 7, T3N R8W). They consist of poorly sorted, angular, matrix supported basalt clasts in a volcanic clay-sand matrix and are usually less than 3 meters thick. They are of limited lateral extent. The clay-sand matrix of these deposits distinguishes them from flow breccias and altered flow breccias. Olbinski (1983) and Nelson (1985) have mapped debris flow deposits in the Green Mountain area.

Scattered dikes are present in the Tillamook Volcanics of the thesis area. A one-meter thick, nearly vertical basalt dike is exposed along the Southern Pacific Railroad cut (locality 648). The dike contains sparse plagioclase phenocrysts, is dark gray in color (N 3), and has composition similar to Tillamook Volcanic flows. It is normally polarized and is surrounded by reversely polarized basalt flows. Several intrusions up to 1/2 meter wide are present in the SE 1/4 sec. 7, T3N R8W. These small intrusions are also lithologically similar to flows in the area.

A sequence of north- to northwest-trending basalt dikes is exposed in a quarry located in the southwest corner of the thesis area (locality 362, T3N R9W SE1/4 sec. 8). These 1/2 to 3 meter wide dikes intrude a highly vessicular, scoriaceous unit and are apparently truncated by basaltic pebble conglomerates of the basal Hamlet formation (fig. 10). A more complete discussion on the relationship of these dikes to the sedimentary strata is presented in the Hamlet formation section. Olbinski (1983) described a similar quarry some 25 kilometers northeast of the study area. He described a reddish, oxidized, tightly cemented scoria with some basalt dikes which he interpreted as a cinder cone. The reddish scoriaceous unit in this study area is at least 5 m thick, moderately well sorted, clast supported, massive, and contains 3 to 5 cm angular scoriaceous clasts of all the same lithology suggesting an origin other than by debris flow. The unit may be related to cinder cone deposition but true cinder cones are typically unable to support a column of magma except at the base (McBirney, 1963). The presence of abundant dikes suggests that the deposit is not a true cinder cone or that the dikes are younger and unrelated to the scoriaceous unit. In some areas of the exposure the scoria appear to be welded and, therefore, may represent some type of spatter cone deposit, perhaps related to phreatic eruption. Regardless of precise origin the deposit does represent a local vent.

Other workers have described rare dikes in the Tillamook Volcanics (Cameron, 1980; Jackson, 1983; Nelson, 1985; Olbinski, 1983). Wells et al. (1983) have described basaltic to dacitic intrusions in the Tillamook Volcanics. Wells (1984 pers. comm.)

Fig. 10. Uppermost Tillamook Volcanics consisting of columnar jointed basaltic dikes and sills intruding an eroded scoriaceous spatter cone? deposit (locality 362). The overlying Roy Creek member of the Hamlet formation is visible in the upper right-hand corner.

has mapped numerous northwest-trending dikes in the lower submarine facies of the Tillamook volcanics.

Petrography

Thirty-eight surface and subsurface samples were thin-sectioned for petrographic analysis. Most samples come from the central part of flow units where fresh samples were most easily obtained. An attempt was made to sample representative flows at various stratigraphic intervals. More closely spaced sampling was done along a logging road near Bastard Creek (plate 1). Eighteen samples were point counted (200 - 500 points) and visual estimates of mineral abundances were performed on the remaining samples (appendix 8).

The Tillamook Volcanics flows and dikes are typically sparsely (< 1/2% to 24% phenocrysts) glomeroporphyritic to porphyritic and occasionally microporphyritic. Phenocrysts are plagioclase, augite, opaque minerals, and in one sample (locality 398) oxyhornblende (fig. 11). The phenocrysts are set in a pilotaxitic intergranular groundmass composed of plagioclase microlites, clinopyroxene, and opaque minerals.

Plagioclase phenocrysts and microphenocrysts range in size from 0.5-7 mm and average 1-2 mm. They are typically euhedral to subhedral but may show partially resorbed crystal boundaries and comprise from less than 1% to 22% of thin sectioned samples. The albite twinned plagioclase is labradorite (An 58 to An 68). Normal zoning is present in some phenocrysts in which cores are An 65-68 and rims are An 54-60. Plagioclase compositions were determined with a

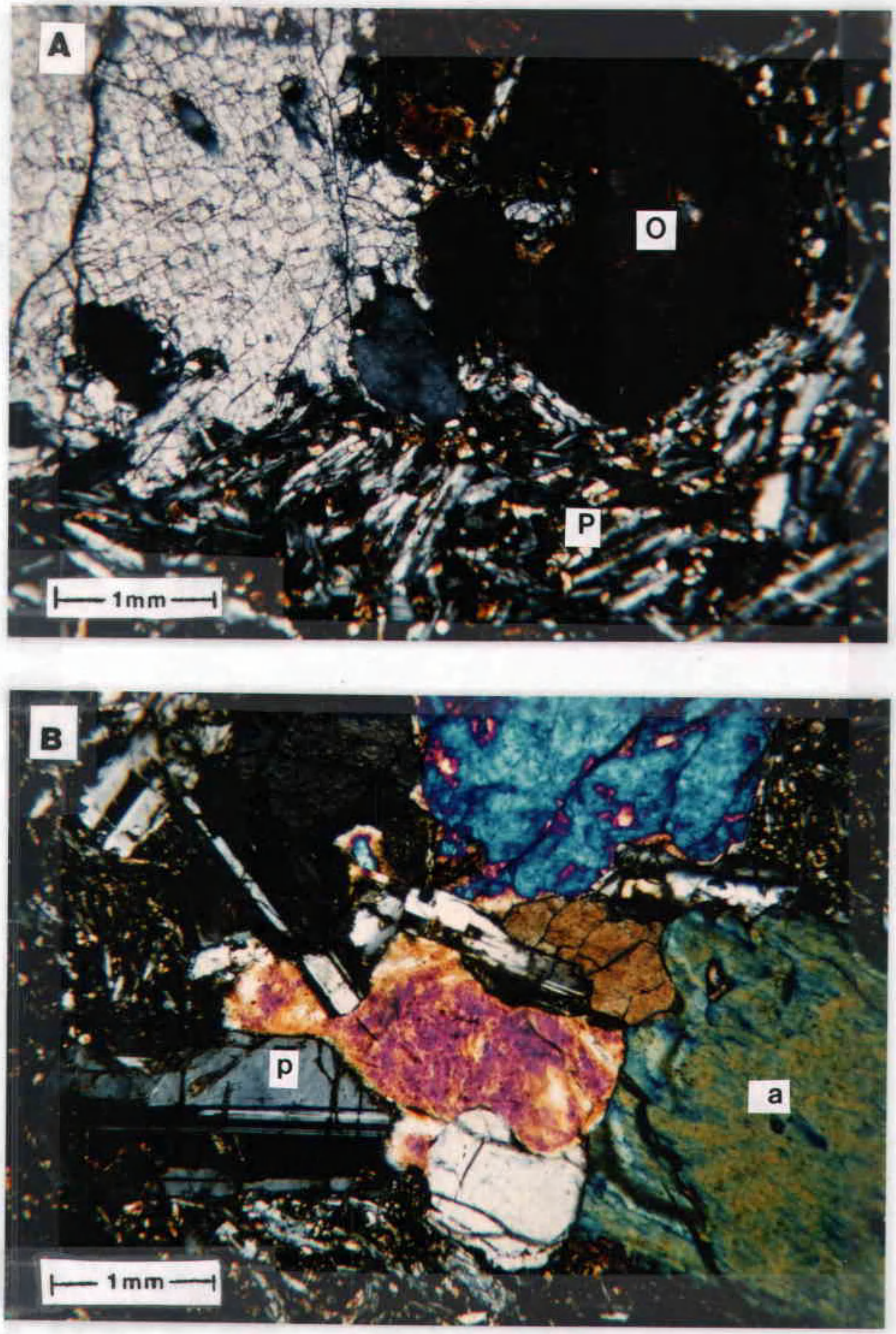


Fig. 11. Photomicrographs of Tillamook Volcanics glomerophenocrysts of augite (a) and plagioclase (p)(crossed nicols). Note oxyhornblende (O) and pilotaxitic groundmass (P) in A (sample 398). Augite and labradorite occur in a pilotaxitic groundmass in B (sample 423).

petrographic microscope using Michael Levy and A-normal methods. Albite twinning and combined albite-carlsbad twinning are common.

Clinopyroxene phenocrysts are less abundant than plagioclase phenocrysts; they compose 0-4% of thin sectioned samples. They are typically euhedral to subhedral, commonly twinned, and relatively small (0.8-2 mm). Augite is the most common variety of clinopyroxene. It is colorless to pale green or pale brown, has extinction angles up to 45o and a 2Vz of approximately 55o. Chemical analyses of Tillamook Volcanics in the thesis area have relatively high TiO2 values (up to 3.5%) suggesting that some of the augite could be titaniferous augite. The light brown color in plane polarized light indicates that some augite titanium rich augite but the lack of hourglass zoning and the lack of purple pleochroism suggest that they are not true titaniferous augite (Kerr, 1979). One sample (locality 375) contains clinopyroxene phenocrysts that are probably pigeonite. Maximum extinction angles of 40o and a 2V2 of 30o are observed in this sample. Augite typically alters to green fibrous chloritic clays and in several samples pseudomorphs of calcite are present.

Opaque phenocrysts occur in six samples (localities 672, 673, 907, 645a, 645b, and 646) where they form less than 1% of the rock. They typically occur in phenocrystrich rocks in association with glomerophenocrysts. Many of the opaque phenocrysts contain leucoxene as an alteration product suggesting that most are ilmenite. Iron oxide alteration is more rarely present indicating that magnetite phenocrysts are also present. Olivine was not observed in any of the thin sections or in outcrop.

The groundmass of Tillamook Volcanic samples is typically intergranular and is faintly to strongly pilotaxitic (fig. 12). Plagioclase, clinopyroxene, and opaque minerals comprise the vast majority of the groundmass. The plagioclase is labradorite (An 50 to An 61), comprises from 30% to 62% of the total rock, and is typically lath-shaped and albite twinned with lengths ranging between 0.1 and 0.5 mm. Clinopyroxene is primarily augite which is anhedral to subhedral, less than 0.1 mm in length, and forms 22 to 38% of the rock. Opaque minerals are mostly subhedral to anhedral ilimenite and magnetite which range in size from less than 0.1 to 0.2 mm and form 8 to 18% of the rock. Basaltic glass is very rare in samples from flow interiors where it forms less than 1% of the total mineralogy. Minor apatite occurs in several samples (e.g. localities 398 and 907). Groundmass plagioclase typically alters to calcite and to chloritic clays. Alteration products of augite include calcite and chloritic clays. Ilmenite and magnetite alter to leucoxene and iron oxide respectively.

Three samples (localities 398, 907 and 674) have SiO2 values which range from 53 to 56% and, therefore, using the chemical classification scheme of Cox et al. (1979) classify as basaltic andesites (fig. 13). Petrographically they are similar to basalts in the thesis area but tend to have few phenocrysts (1-2%) and slightly more sodic groundmass plagioclase (An 50 to An 53).

The Tillamook Volcanics in the thesis area are petrographically similar to the Tillamook Volcanics examined by Jackson (1983) some 30 km to the east of the thesis area and by Mumford (in prep.) directly

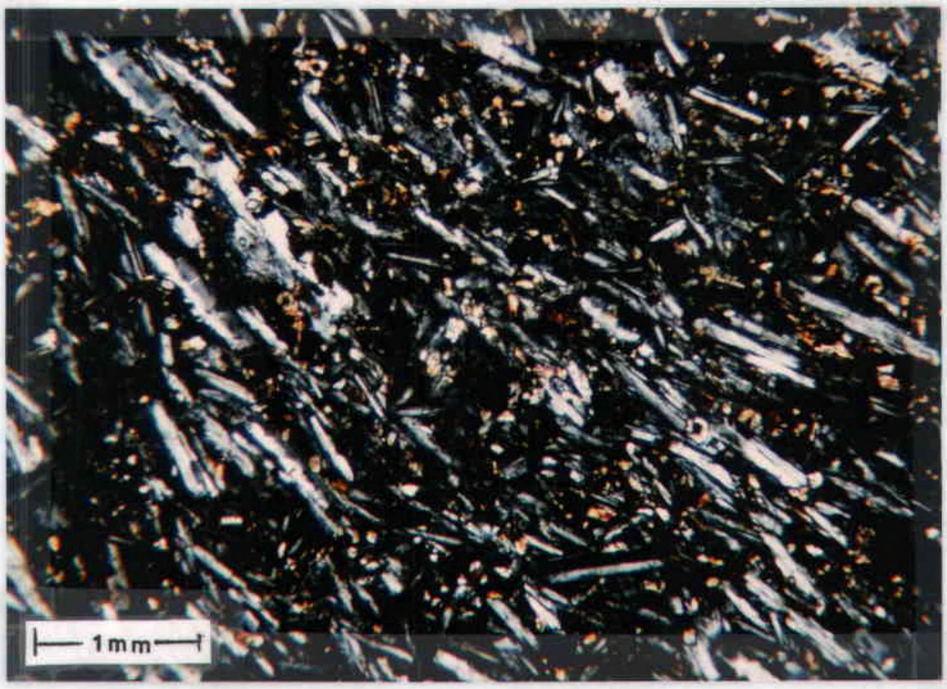


Fig. 12. Photomicrograph of sample 674 showing pilotaxitic texture typical of Tillamook Volcanics. Groundmass consists of aligned plagioclase microlites with interstitial augite and opaque minerals (crossed nicols).

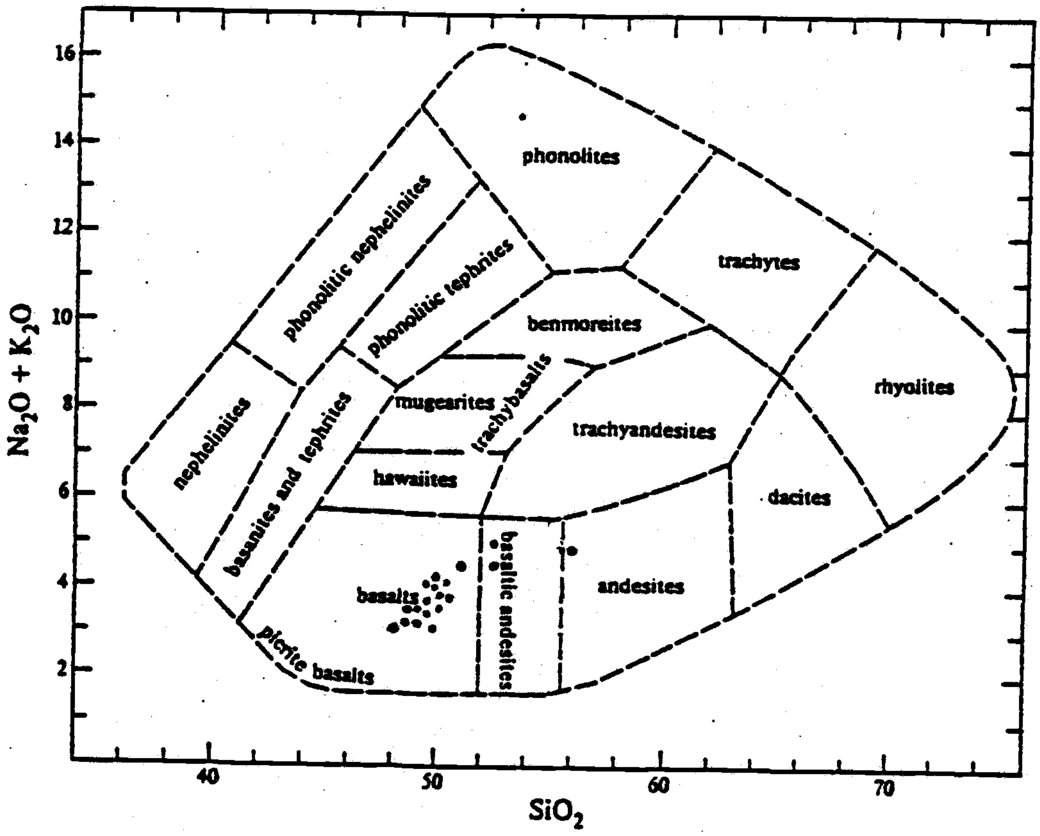


Fig. 13: Chemical classification scheme of Cox *et al.* (1979) for volcanic rocks. Tillamook Volcanics analyses from the thesis area are plotted (●).

east of the thesis area. They are also similar to subaerial flows examined by Cameron (1980) which occur near the base of the Tillamook Volcanics south of the thesis area. In the Green Mountain area the Tillamook Volcanics are dominated by basaltic andesites and andesites which are petrographically similar to rocks in the thesis area but contain less clinopyroxene and more sodic plagioclase (Olbinski, 1983; Nelson, 1985; Safley, in prep.). Therefore, on a regional basis, the Tillamook Volcanics show relatively little petrographic variability. An exception to this may be the dacitic intrusions reported in the uppermost Tillamook Volcanics by Wells et al. (1983).

The Tillamook Volcanics are petrographically distinct from other volcanic units in the thesis area. The overlying late Eocene Cole Mountain basalts (informally proposed in this study) have an intersertal texture, contain less clinopyroxene (0 - 20%), contain fewer opaque minerals, lack a pilotaxitic texture, and contain significant amounts of altered glass (10 to 50%). The fresher middle Miocene Columbia River Basalts are aphyric to very sparsely porphyritic, contain fewer opaque minerals, and have intersertial to ophitic textures. Outside of the thesis area the middle Eocene Crescent Formation and the middle Eocene Siletz River Volcanics may contain olivine, are commonly extensively zeolitized, and may be glass rich (Wolfe and McKee, 1972; Snavely et al., 1968).

In summary, Tillamook Volcanics are typically glomeroporphyritic, to porphyritic (<1 to 24% phenocrysts) with phenocrysts of plagioclase, augite, and rarely opaque minerals. The groundmass is intergranular, usually pilotaxitic with aligned labradorite microlites and interstitial augite and opaque minerals (fig. 12). Samples from the thesis area are petrographically similar to other Tillamook Volcanics in the region and distinct from other basaltic units in the thesis area.

Contact Relationships

The subaerial Tillamook Volcanics in the thesis area are disconformably overlain by nearshore deposits of the Roy Creek member of the Hamlet formation (informally proposed in this study). Previous workers have noted a similar relationship between Tillamook Volcanics and overlying sedimentary units (Jackson, 1983; Olbinski, 1983; Nelson, 1985; Warren and Norbisrath, 1946). Flows at the top of the Tillamook Volcanics have approximately the same attitude as the overlying Roy Creek member of the Hamlet formation and flows at the upper contact can be traced for up to 1/2 kilometer suggesting a disconformable or possibly slightly angular relationship between the units. The unconformity is evidenced by the absence of interfingering volcanic and sedimentary units, by an erosional contact, and by the presence of a basal conglomerate.

The basal contact of the Tillamook Volcanics is not exposed in the thesis area. Cameron (1980) and Wells et al. (1983) state that the lower contact is conformable upon the lower Narizian Yamhill Formation and equivalent units.

Age

A sample from the upper part of the Tillamook Volcanics in

Clatsop County yielded a whole rock K/Ar age of 40.1 + 1.2 Ma after acid treatment (Leda Beth Pickthorn in Niem and Niem, in press). Other K/Ar ages reported from Clatsop County samples range from 37.1 + 0.4 Ma to 42.4 + 0.5 Ma (McElwee in Nelson, 1985). The 37 Ma age is inconsistant with biostratigraphic data. Late Narizian foraminiferal assemblages and subzone CP 14a and 14b calcareous nannofossil assemblages have been collected from the Hamlet formation which disconformably overlies the Tillamook Volcanics. The youngest proposed Refugian-Narizian boundary is 37 Ma (Prothero and Armentrout, 1985). The calcareous nannofossil subzones are approximately 2 m.y. in duration. The presence of two nannofossil subzones above the Tillamook Volcanics indicates that the Tillamook Volcanics are older than 39 Ma. Therefore, the 37 Ma age is probably too young. This young date may be the result of clay alteration. Pickthorn (pers. comm., 1984) suggested that clay alteration in the Tillamook Volcanics can result in slightly young dates.

Whole rock K/Ar dates from the lower part of the Tillamook volcanics in Tillamook County range from 43.2 + 0.9 Ma to 46.0 + 0.9 Ma (Magill et al., 1980). Foraminifera collected from the underlying Yamhill Formation have been assigned to the Ulatizian and lower Narizian (middle Eocene) stages. Therefore, the Tillamook Volcanics range in age from approximately 46 Ma to 39 Ma (middle to late? Eocene). It is, however, felt that an age range of 44 Ma to 40 Ma is most likely.

Magnetostratigraphy

A number of fluxgate magnetometer readings were taken to determine magnetic polarity of flows in the Tillamook Volcanics (appendix 7). These rocks are moderately weathered, middle Eocene in age, and have been rotated approximately 45o (Magill et al., 1981; Nelson, 1985). These factors contribute to uncertain fluxgate magnetometer readings. Orientation of fluxgate samples included a correction for tectonic rotation and structural deformation. Nevertheless, a more accurate magnetostratigraphy could be worked out using a spinner magnetometer to magnetically clean samples.

Approximately 600 meters of Tillamook Volcanics are exposed in the thesis area. The upper 30 to 60 meters appears to be normally magnetized and the basal 150 meters appears to be reversely magnetized (Plate 1). The middle part may contain a reversely magnetized zone overlying another normal zone. Samples from the middle part of the Tillamook Volcanics show a section of alternating reversely and normally polarized flows which are apparently underlain by a fairly thick normally polarized section. The section of alternating polarity could have originally been a reversely magnetized section where slightly altered flows have been remagnetized in the earth's present magnetic field. Secular variations in the magnetic field could also have resulted in the alternating polarities.

The presence of fairly thick sections of normally and reversely polarized flows suggests that the fluxgate readings are of some value and that the Tillamook Volcanics in the thesis area consist of at least one normal and one reverse section. Structural and magnetic complications make other inferences from fluxgate data highly

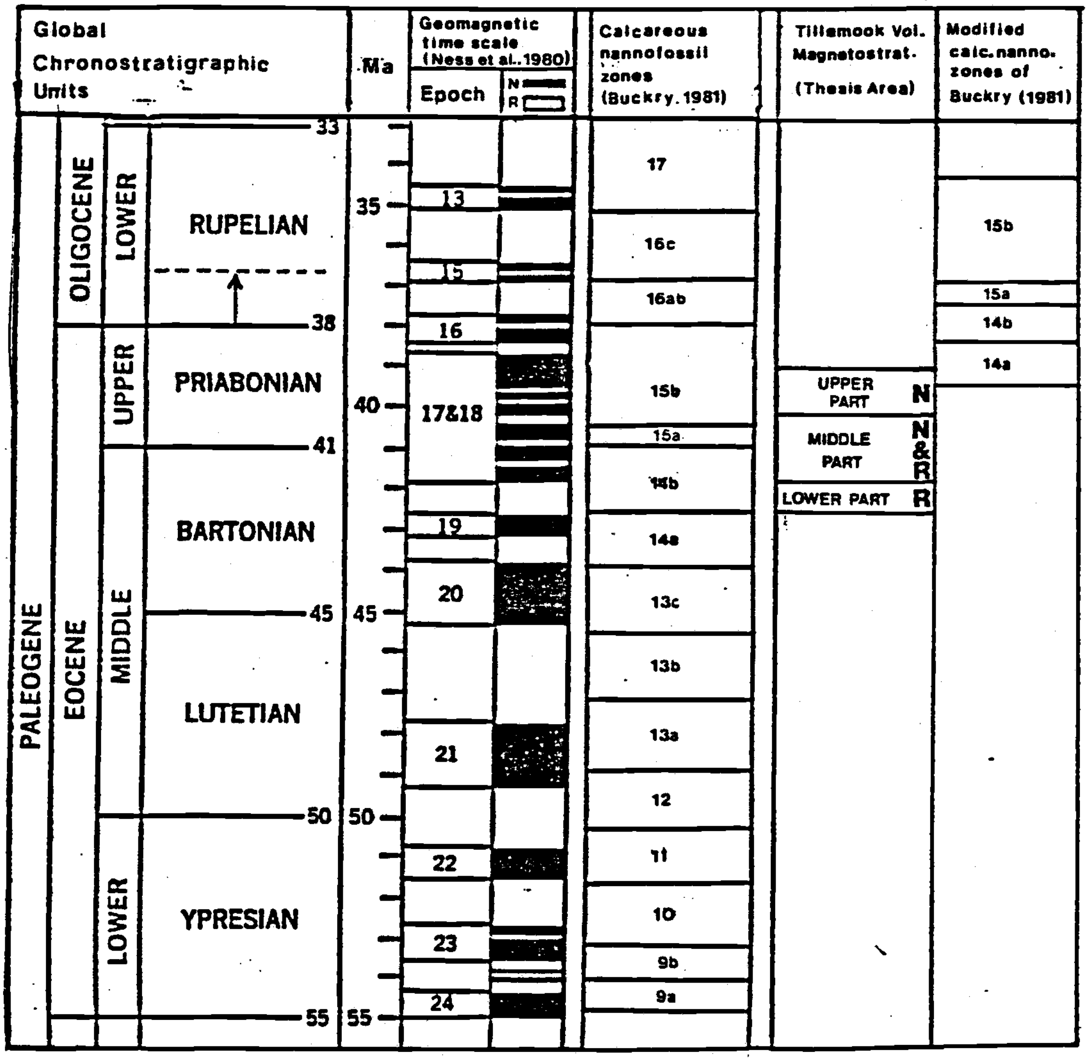


Fig. 14: Paleomagnetic time scale of Ness et al. (1980) (A) compared to possible magnetic stratigraphy of the Tillamook Volcanics in the thesis area (C). Correlation of absolute time scale is from Armentrout et al. (1983). Note the discrepency between radiometric age determinations of the Tillamook Volcanics (min. 39 Ma) vs. biostratigraphic determinations of absolute age (approx. 43 ma). In column D calc. nanno. subzones have been repositionsed relative to the absolute time scale so that subzone 14a (age of Hamlet fm.) overlies Tillamook Volcanics. This repositioning relative to absolute age is roughly consistant with new time scale refinements by Prothero and Armentrout (1985).

tenuous.

If the 39 Ma minimum age is accepted for the Tillamook Volcanics in the thesis area then the basalt flows may correlate to magetic epochs 17-20 of Ness et al. (1980) (fig. 14). Considerably more work would need to be done before the flows in the thesis area could be confidently tied into the magnetic time scale.

Geochemistry

Nineteen Tillamook Volcanics samples were analyzed for major oxide chemistry using X-ray fluorescence by Dr. Peter Hooper of Washington State University (appendix 4). Sample locations are shown on plate 1. One of the samples is from a Tillamook Volcanics clast in the overlying basal conglomerate of the Roy Creek member (locality 424) and one sample is from the bottom Diamond Shamrock CZ 11-28 exploration well located 3 km west of the thesis area (sample CZ-5). A large sledgehammer was used to obtain fresh samples from flow interiors. These samples were examined in thin section and if significant alteration was present the samples were recollected or discarded. Approximately 10 grams of unaltered ultrasonically cleaned basalt chips (< 1 cm3) from each sample were sent away for analysis.

The Tillamook Volcanics in the thesis area have SiO_2 values ranging from 48.5% to 56.2% with all but four samples having values between 48.5% and 50.7%. Total alkalies (K_2O + Na_2O) range from 3.1% to 5.4% and average about 3.7%. On the SiO_2 vs. total alkalies plot of Cox et al. (1979) 16 of the samples classify as normal basalts, 2 classify as basaltic andesites (localities 398 and 807), and one classifies as a low-silica andesite (locality 674) (fig. 13). The fields of Cox et al. (1979) are only approximate and show where the different rock types usually plot. The chemical boundary between basalts, basaltic andesites, and andesites has been variously defined. Cox et al. (1979) place the boundaries at 52% and 56% SiO_2 but other workers place the boundaries at 54% and 58% SiO_2 (Best, 1981). The sample with 56.2% SiO_2 does not have the petrographic features of classical andesites and will be called a basaltic andesite as will the samples with 53% SiO_2. Typical percentage of other major oxides for basalts are: CaO 8-12%, MgO 4-12%, $FeO+Fe_2O_3$ >10%, Al_2O_3 10-17%, and typical K_2O/Na_2O values are <0.4% (Cox et al., 1979). The basalts in the thesis area fall within these ranges (appendix 4) and the basaltic andesites have slightly less CaO and MgO suggesting a more silicic composition.

Normative analyses of Tillamook Volcanics samples are shown in appendix 6. The presence of normative quartz (4-13%) and hypersthene (7-12%) and the absence of normative olivine and nephaline classifies these samples as quartz tholeiites (Yoder and Tilly, 1962). Subsequent workers (eg. McDonald and Katsura, 1964) have used this normative classification scheme in naming rock series. Recent workers in the Tillamook Volcanics (Jackson, 1983; Olbinski, 1983) have used the total alkalies ($K_2O + Na_2O$) vs. SiO_2 plot of McDonald and Katsura (1964) to distinguish rock series. This classification scheme, however, can be misleading as the tholeiitic-alkalic boundary on this plot is merely a division of Hawaiian alkalic and tholeiitic rocks and was not meant to be used as a world-wide definition of rock series (McDonald and Katsura, 1964).

Furthermore, no alkalic rocks with SiO_2 values greater than 49.5% were used to define this boundary and since most Tillamook Volcanics samples have greater than 49% SiO_2 it is recommended that either a normative classification scheme or a more diagnostic chemical classification be used.

Irvine and Baragar (1971) devised a chemical classification scheme for volcanic rocks. In this classification scheme rocks are first classified as either alkaline or subalkaline on the basis of normative composition or by a plot of total alkalies (K_2O + Na_2O) vs. SiO_2. The total alkalies plot is the same one used by McDonald and Katsura (1964) except that the dividing line between alkaline and subalkaline rocks has been adjusted (see fig. 15). The Tillamook Volcanics samples from the thesis area classify as subalkaline on the total alkalies plot of Irvine and Baragar (1971) (fig. 15). Middlemost (1975) used a plot of K_2O vs. SiO_2 to separate alkaline and subalkaline rocks. The Tillamook Volcanics within the thesis area classify as subalkaline on this diagram also (fig. 16). Subalkaline rocks are divided into the tholeiitic and clac-alkaline suites. Irvine and Baragar (1971) used an AFM diagram (ternary plot of total alkalies, total iron, and MgO) to distinguish these two suites. Tillamook Volcanics classify as tholeiitic on the diagram (fig. 17). Miyashiro (1974) used a plot of FeO*/MgO vs. SiO_2 to distinguish between the tholeiitic suite and the calc-alkaline suite. The Tillamook Volcanics plot well within the tholeiitic field of this diagram as well (fig. 18). In conclusion, the Tillamook Volcanics are tholeiitic in composition.

Major oxide abundances for the Tillamook Volcanics and for

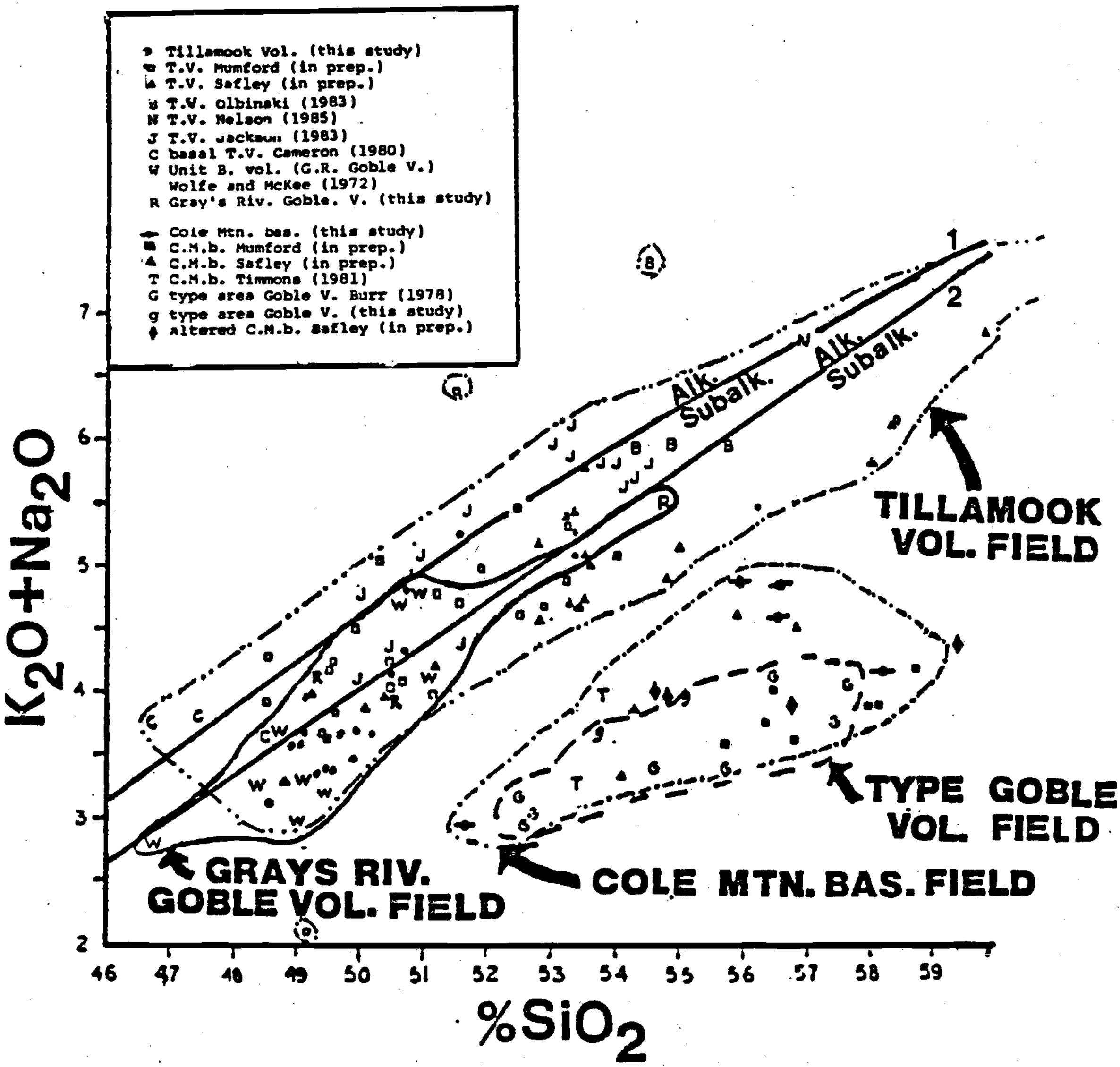


Fig. 15: SiO2 vs. total alkalies plot of Tillamook Volcanics and other Eocene volcanic units in the region. The upper line (1) is the alkaline-subalkaline dividing line of Irvine and Baragar (1971) and the lower line (2) is that of McDonald and Katsura (1964). Tillamook Volcanics samples from the thesis area (●) plot within the subalkaline field of Irvine and Baragar (1971) and alkaline-subalkaline field of McDonald and Katsura (1964).

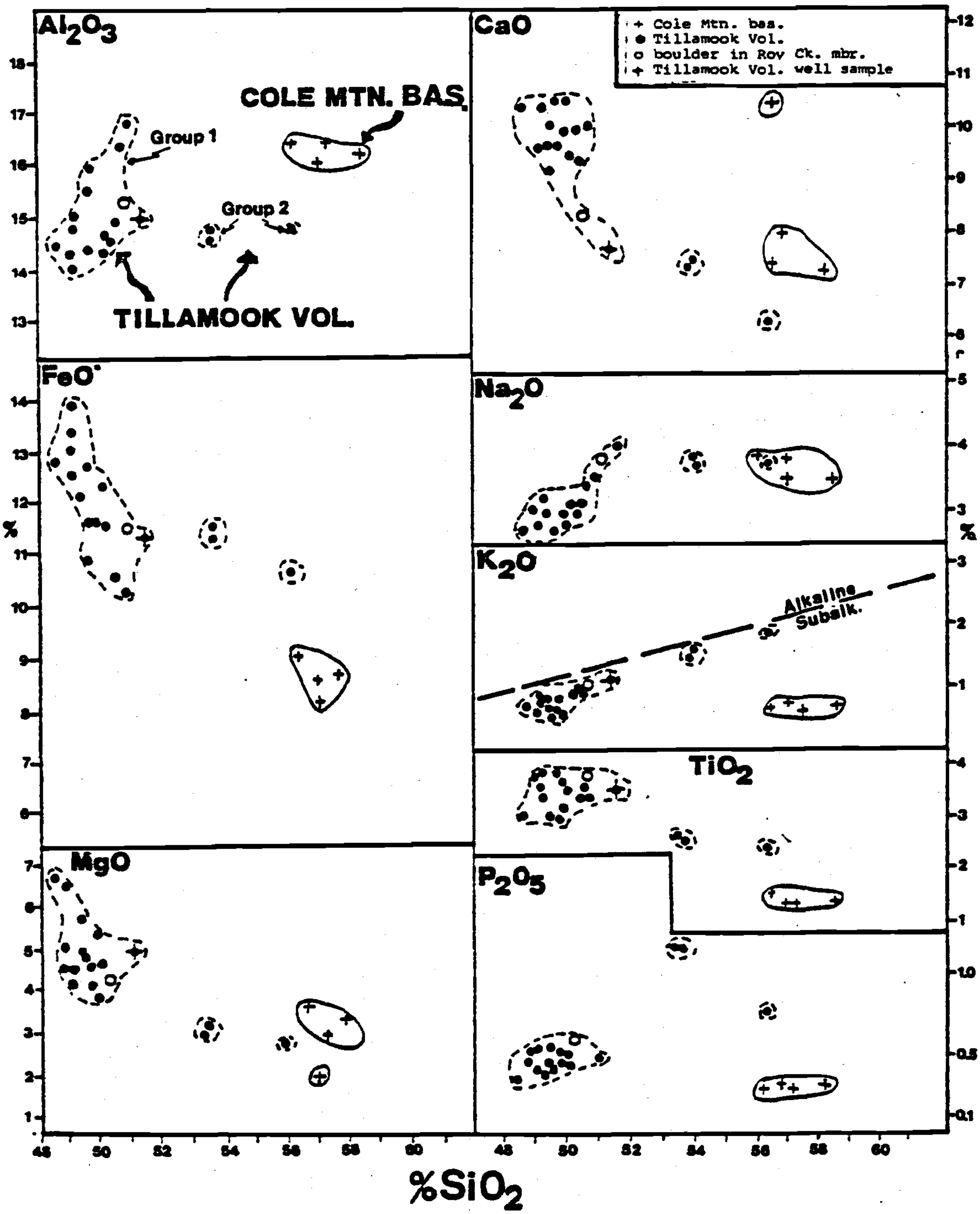


Fig. 16: Silica variation diagram for Eocene basalt samples from the thesis area. These rocks plot within the subalkaline field of Middlemost (1975)(see K2O plot and alkaline-subalkaline line). Note the different groupings of Tillamook Volcanics samples and the distinct cluster of Cole Mtn. basalt samples.

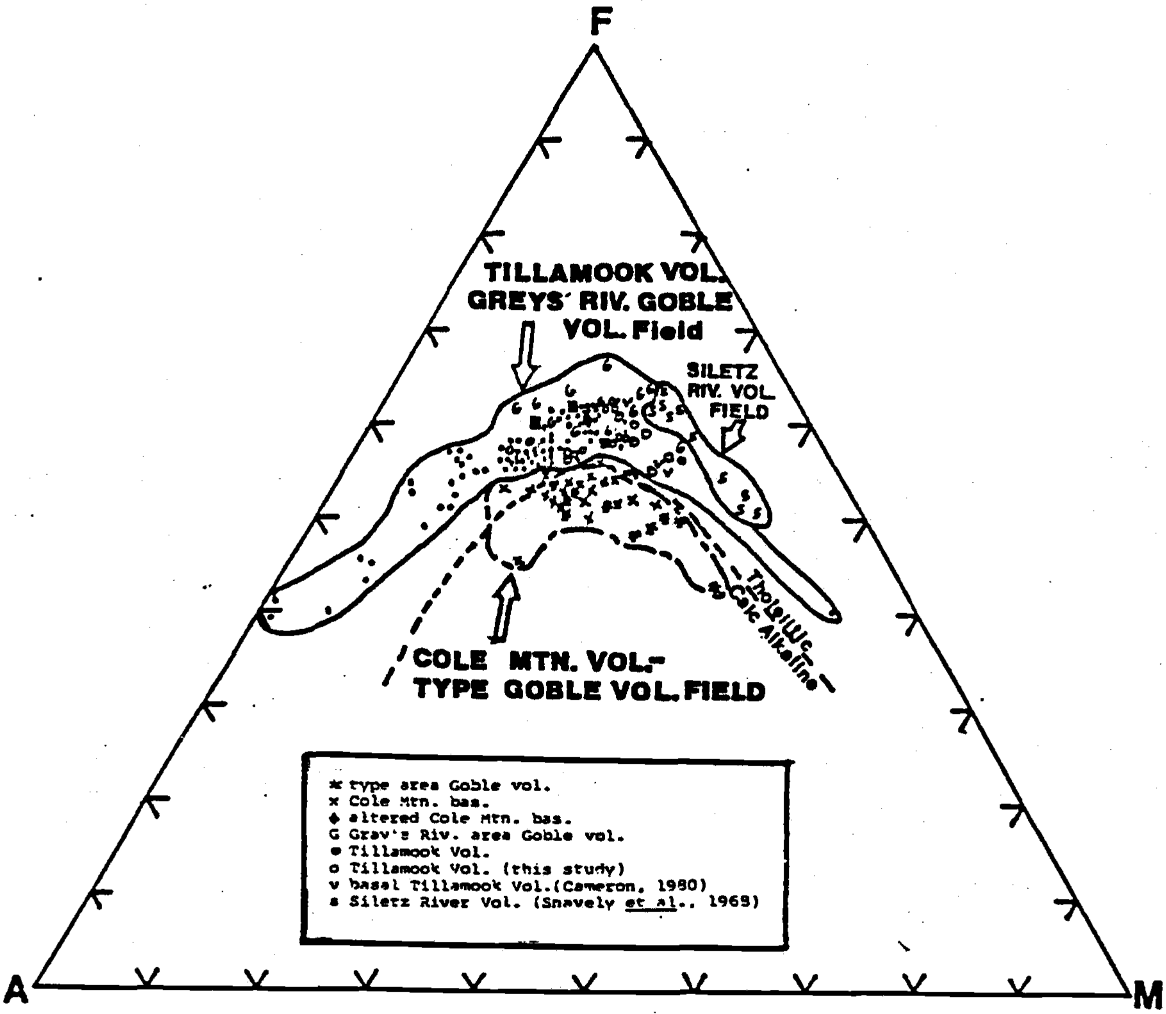


Fig. 17: AFM (total alkalies-FeO*-MgO) diagram for Eocene volcanic units in the region. The Tillamook Volcanics plot within the tholeiitic field of Irvine and Baragar (1971) whereas most Cole Mtn. basalt samples plot within the calc-alkaline field. Note that the Goble Volcanics in the Grays River area plot within the Tillamook Volcanics field and that the Goble Volcanics at the type area plot within the Cole Mtn. basalt field.

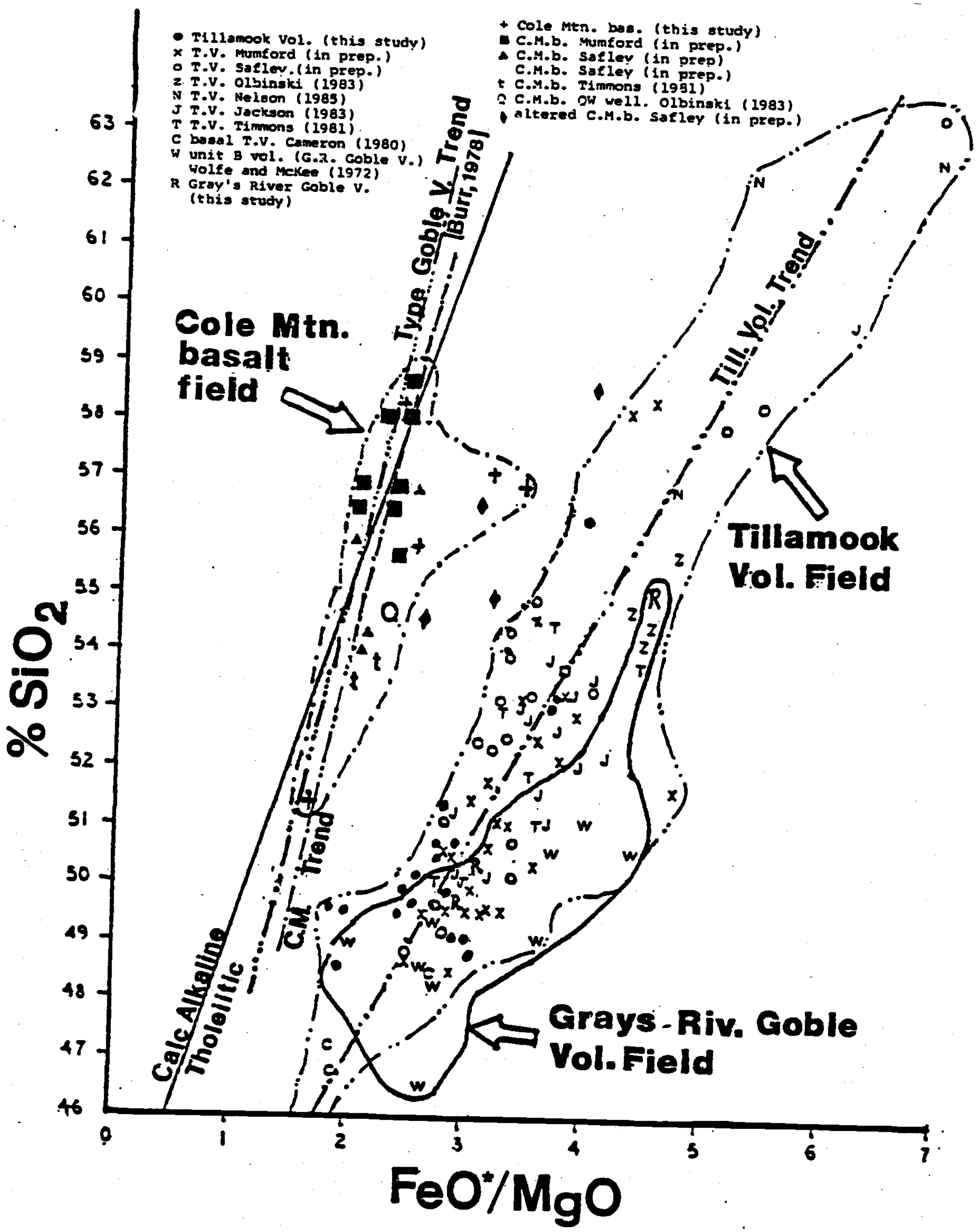


Fig. 18: "Iron enrichment" plot of Miyashiro (1974) showing that the Tillamook Volcanics plot well within the tholeiitic field whereas the Cole Mtn. basalt has a calc-alkaline trend. Note the location of the two Goble Volcanics fields.

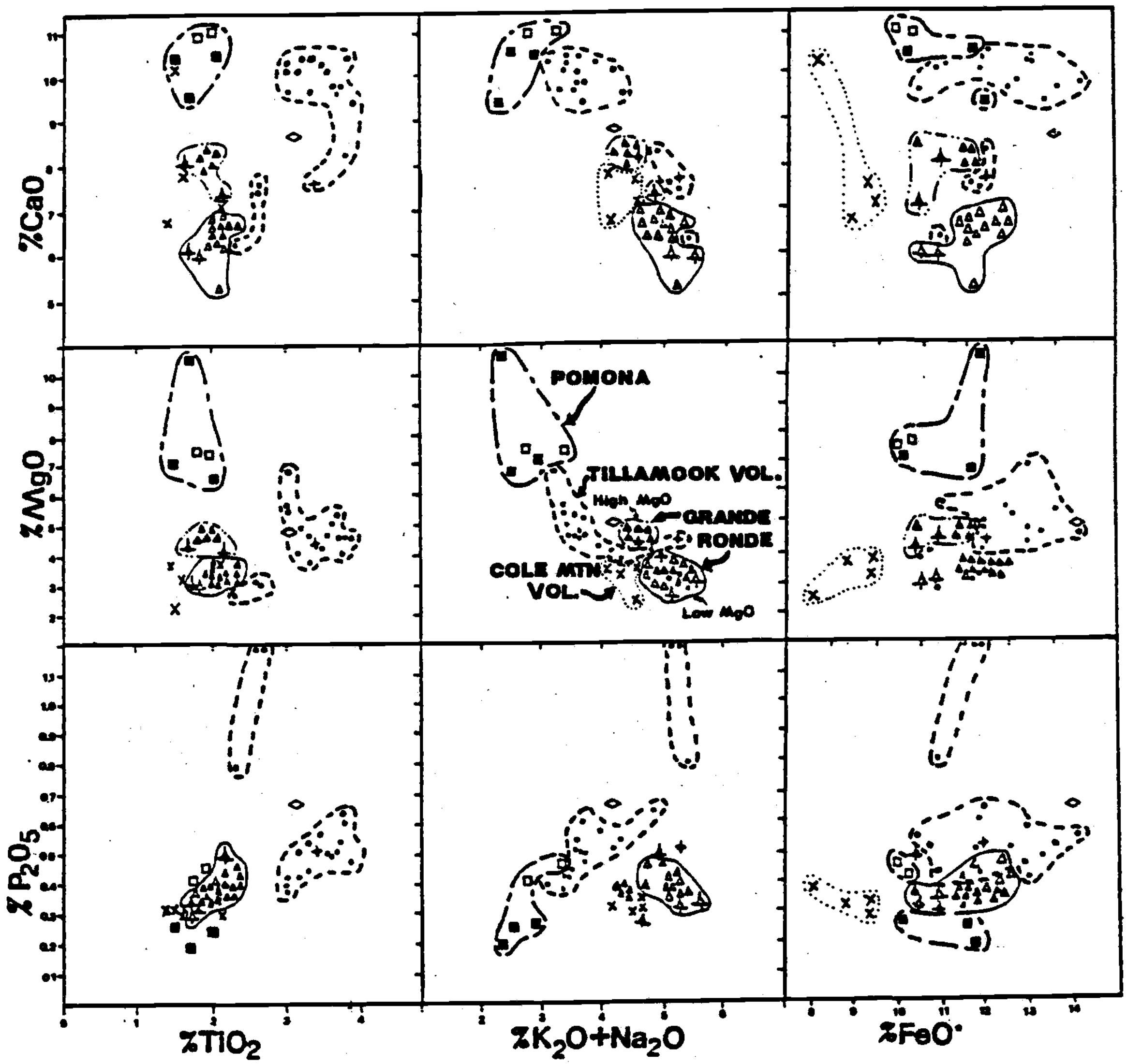


Fig. 19: Geochemical cross plot of both Eocene and Miocene volcanic rocks within the thesis area. Fields are drawn where fairly distinct groupings occur. Tillamook Volcanics (•), Cole Mtn. basalt (✕), and Columbia River Basalt Group (◻■▲♣) were plotted. The Columbia River Basalt Group samples were divided into low MgO Grande Ronde Basalt (△), high MgO Grande Ronde Basalt (▲), Frenchman Springs Mbr. (◇), aphyric Pomona Mbr. (◻), and gabbroic Pomona Mbr. (■). Well samples are flagged (♣).

other volcanic units in the thesis area were plotted on a number of diagrams in an attempt to differentiate geochemically the units. A Harker variation diagram, where SiO_2 is plotted against the other major oxides, and an unnamed diagram where TiO_2, total alkalies, and total iron are plotted against P_2O_5, MgO, and CaO, were used (figs. 18 & 19).

These diagrams show that the Tillamook Volcanics within the thesis area can be divided into two distinct geochemical groups. Group I contains 18 samples which form a distinct cluster on all the plots and have SiO_2 values between 48.5% and 50.7%. This group contains all the samples that are chemicaly classified as basalts. Group II contains the three samples that classify as basaltic andesites (localities 398, 907, and 874). These samples come from the uppermost (398 and 907) and from the upper middle (874) parts of the Tillamook Volcanics in the thesis area. Group II samples have higher SiO_2, P_2O_5, K_2O, Na_2O and lower MgO, CaO, TiO_2 values than Group I samples.

Both Tillamook Volcanics groups are geochemically distinct from other volcanic units in the thesis area (figs. 18 & 19). SiO_2 vs. K_2O, SiO_2 vs. TiO_2, SiO_2 vs. P_2O_5, and other plots using TiO_2 and P_2O_5 best separate the units. The late Eocene Cole Mountain basalt, informally named in this report, has previously been mapped as Tillamook Volcanics and undifferentiated sedimentary rocks (Beaulieu, 1973; Wells and Peck, 1961; Warren <u>et al.</u>, 1945). Cole Mountain basalt intrudes and overlies the Hamlet formation basaltic conglomerates, basaltic sandstones, and mudstones which in turn overlie the Tillamook volcanics. In addition to being stratigraphically distinct from the Tillamook Volcanics the younger Cole Mountain basalt shows no overlap on 16 of the 17 geochemical plots. The Cole Mountain basalts are consistantly lower in total iron, total alkalies, TiO_2, P_2O_5 and higher in SiO_2 (fig. 19). In addition, they tend to be lower in CaO, MgO, and MnO (fig. 19, appendix 4). The middle Miocene Columbia River Basalt Group is best differentiated from the Tillamook Volcanics on a P_2O_5 vs. TiO_2 diagram where the Tillamook Volcanics have higher TiO_2 and P_2O_5 (fig. 19). On the remainder of the plots there is generally a good separation between the the different units with exceptions being Frenchman Spring Basalt, in which there is some overlap with Tillamook Volcanics group I, and Grande Ronde Basalt, which occasionally overlaps with Tillamook Volcanics group II.

Geochemistry of Tillamook Volcanics flows was compared to stratigraphic position in an attempt to define a chemical stratigraphy. There were, however, no distinct differences or trends observed over the 600 m section in the thesis area. For example, a sample from the base of the section (locality 645) has a chemistry similar to flow at the top of the section (localities 339 and 672). The limited number of samples in conjunction with extensive faulting, "intracanyon" flows, and vegetative cover contribute to the difficulty in defining a chemical stratigraphy.

Several samples were taken at or near the upper, unconformable, contact with the overlying Hamlet formation and analyzed for major oxide chemistry (localities 339, 398, 362, 366, and 907). The chemistry, petrography, magnetic polarity, and outcrop characteristics of samples 398 and 907 are identical suggesting that they are the same flow. They are located in the southwest part of the thesis area and are approximately 1 km apart. Petrographic, stratigraphic, and physical characteristics of flows at localities 672 and 673, which are laterally several hundred meters apart, suggest that they are the same flow. In addition, localities M585 and M250 probably represent the same flow. This suggests that individual flows can be traced laterally for moderate distances.

The only stratigraphic difference noted over the 600 m section of Tillamook Volcanics in the thesis area is the tendency for baked, oxidized soil horizons to be thicker and more abudant near the upper contact. This may suggest a less frequent outpouring of flows towards the end of Tillamook volcanism. As previously mentioned, there may be a difference in magnetic polarity from the base of the section to the top.

Chemistry and petrography of flows agree very well. Samples with abundant augite and more calcic plagioclase have higher percentage of MgO and CaO (appendices 4 and 8). Normative plagioclase composition averages about An 50 with petrographically determined values ranging from An 50 to An 68. Olivine is not present in thin section and none of the samples contain normative olivine. Normative opaque minerals (magnetite and ilmenite) range from 12% to 15% and compare favorably with values of 10% to 18% determined by point counting thin sections. Modal analysis shows that quartz and hypersthene are not present and the occurance of normative amounts of these minerals emphasizes the fact that normative analyses are equilibrium assemblages which do not necessarily occur in nature.

Regional Correlation

Clatsop, Tillamook, and Columbia Counties.

Jackson (1983) concluded that it was not possible to distinguish between the Tillamook Volcanics and the Goble Volcanics using major oxide geochemistry in nearby Columbia and Tillamook counties. Data from this study suggests that it is possible. The addition of over 100 major oxide analyses and detailed mapping of several hundred square miles (this study, Olbinski, 1983; Nelson, 1985; Mumford, in prep.; Safley, in prep.) have made it possible to make the regional stratigraphic correlations presented in this report. Rarey (1984), using data from this thesis, first reported the chemical and stratigraphic correlations presented in the following.

Mumford (in prep.) has done major oxide analysis on a number of samples from the Tillamook Volcanics and the Cole Mountain basalt in an area adjacent to the eastern boundary of the thesis area. These analyses were plotted on a Harker silica variation diagram and compared to analyses from the thesis area (fig. 20). The data from Mumford (in prep.) plots within or along trend with the fields extablished from the thesis area. The chemical difference between the Cole Mountain basalts and the Tillamook Volcanics is still very apparent in the diagram. It is also apparent that Tillamook Volcanics groups I and II from the thesis area represent artificial boundaries and that a continuum in chemical composition exists between the two groups.

Olbinski (1983), Nelson (1985), and Safley (in prep.)

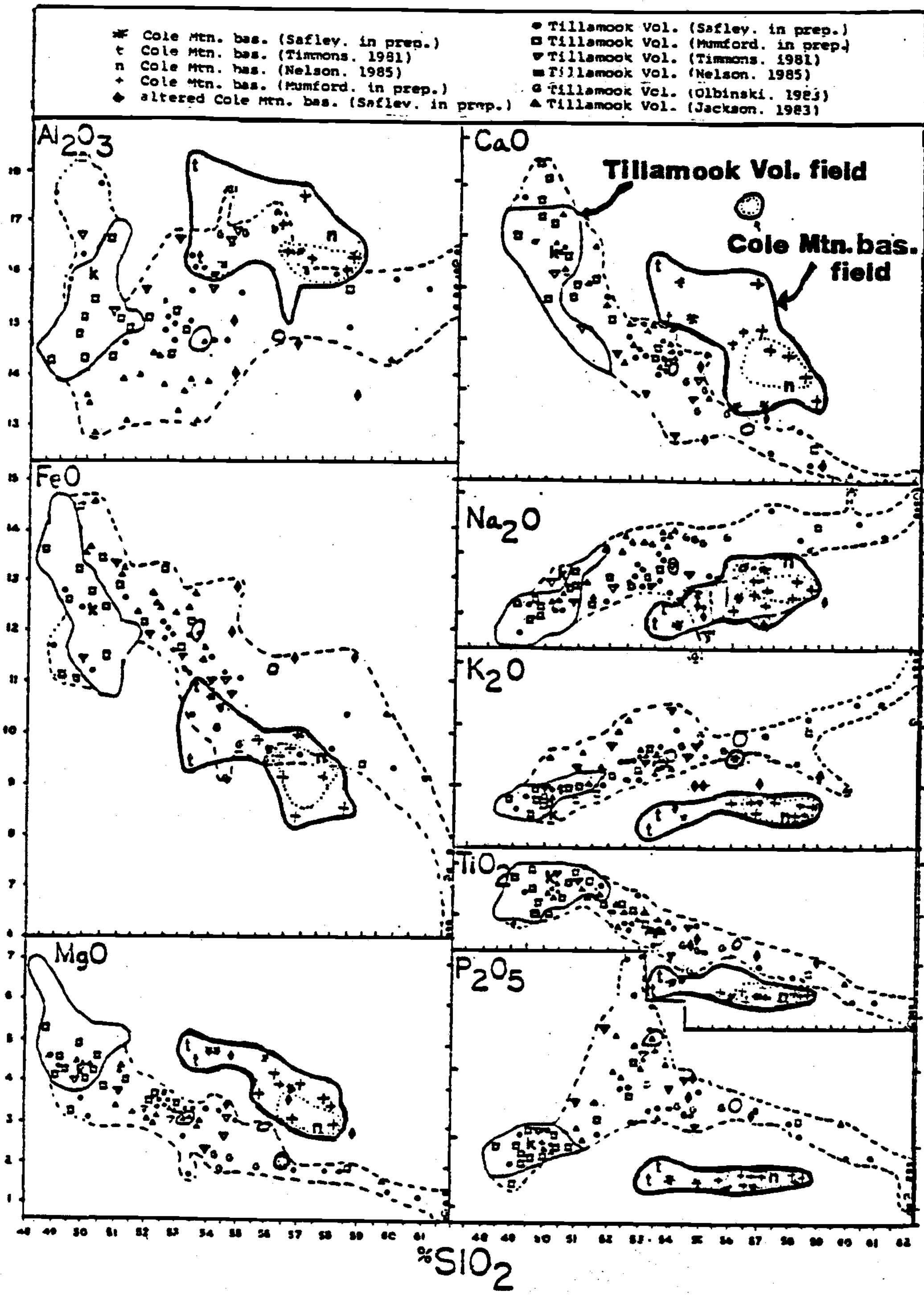


Fig. 20: Harker silica variation diagram for Tillamook Volcanics and Cole Mtn. basalt samples outside of the thesis area. The Tillamook Vol. field (←--→). and the Cole Mtn. bas. field (←—→) for samples from the thesis area are shown in fig. 13.

have worked in eastern Clatsop County on an isolated volcanic outlier near Green Mountain (fig. 21). The volcanic rocks in this area were previously mapped as Goble Volcanics (Wells and Peck, 1961; Newton and Van Atta, 1974). Near the type section along the Columbia River in northeastern Columbia County, the Goble Volcanics overlie and interfinger with the Cowlitz Formation which in turn overlies Tillamook Volcanics (Wilkenson <u>et al</u>., 1945; Warren and Norbisrath 1946; Henrikson, 1956). Safley (in prep.), Mumford (in prep.), Niem and Niem (1985), Nelson (1985), and Olbinski (1983) have mapped the Green Mountain outlier (fig. 21) as Tillamook Volcanics suggesting that it is an upthrown basement block rather than the younger upper Eocene Goble Volcanics. Timmons (1981) and Van Atta (1971) mapped a series of basaltic to andesitic flows in Columbia County as Goble Volcanics. As with the Green Mountain area these flows appear to be upthrown blocks of Tillamook Volcanics (reconnaissance this study). Jackson (1983) reported a number of chemical analyses from the main outcrop area of the Tillamook Volcanics (fig. 21) in northeastern Tillamook County. This area is clearly part of the main Tillamook Volcanics sequence.

The chemical analyses from the above areas were plotted on a Harker variation diagram and compared to the Tillamook Volcanics chemical fields defined by this study (fig. 20). All of these analyses plot in, near, or along trend with the Tillamook Volcanics fields. Therefore, in addition to detailed mapping by Safley (in prep.), the major oxide chemistry suggests that the Green Mountain outlier and the subaerial basaltic flow outliers mapped by Timmons (1981) are Tillamook Volcanics. The flows in the Green Mountain

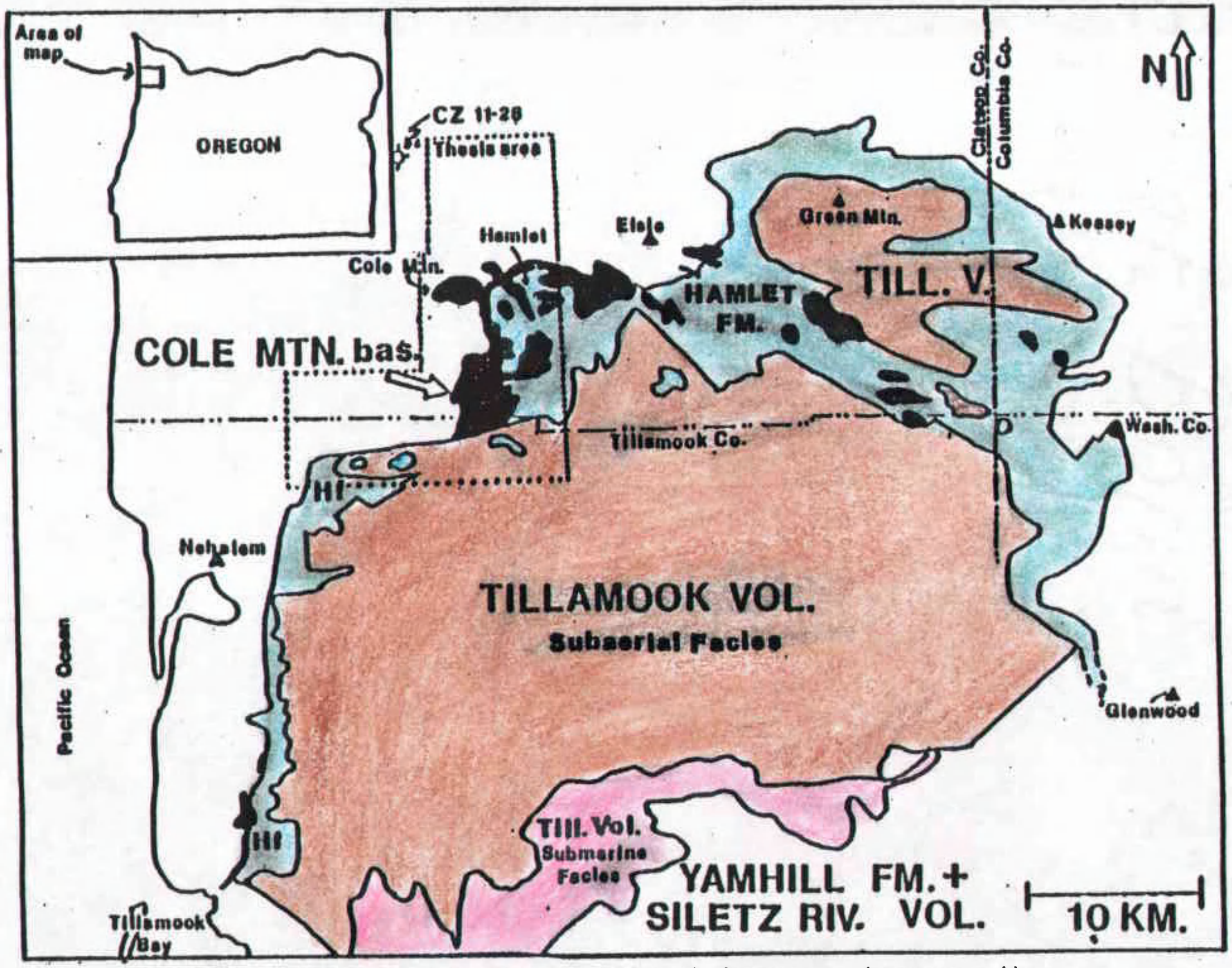


Fig. 21: Geologic map of a part of northwest Oregon emphasizing the distribution of the Tillamook Volcanics, the Cole Mtn. basalt, and the Hamlet formation. Some of the area mapped as Hamlet formation also contains Cowlitz Formation sandstones. Strata dip north, east, and west away from the Tillamook-Siletz River volcanic high. Map from Wells et al. (1983), this study, Mumford (in prep.), and Safely (in prep.).

outlier do, however, tend to be more silicic than flows elsewhere in the Tillamook Volcanics suggesting that that they are an upper more differentiated part of the volcanic sequence. The distinct trend on the Harker variation diagram is interpreted as an overall differentiation trend and will be discussed in a subsequent section.

Several intrusions of Cole Mountain basalt were analyzed for major element chemistry by Safley (in prep.) and one Cole Mountain basalt sample was analyzed by Nelson (1985). Timmons (1981) mapped three intrusions in southern Columbia County as Goble Volcanics. One of these localities (10-18-1) is not an intrusion and was included with the other Tillamook Volcanics flow samples in figure 20. These Cole Mountain basalts intrude upper Narizian mudstones and sandstones of the Hamlet and Cowlitz formations which overlie Tillamook Volcanics. Reconnaissance work shows that the two intrusions are equivalent to the Cole Mountain basalt mapped in the thesis area. The above Cole Mountain basalt analyses plot within or near the Cole Mountain basalt chemical field established by this study (fig. 20). Therefore, with a data base of over 100 chemical analyses it can be demonstrated that the Cole Mountain basalt forms a distinct geochemical group on all of the plots with only minor overlap of Tillamook Volcanics fields. K_2O vs. SiO_2 and P_2O_5 vs. SiO_2 appear to be the best plots for differentiating Tillamook Volcanics from Cole Mountain basalt. Both units show a fairly wide range of SiO_2 values (e.g. Tillamook Volcanics 48%-62% SiO_2 and Cole Mountain basalt 54%-59% SiO_2) but when other oxide abundances are compared at similar SiO_2 values differences are apparent. At similar SiO_2 values Cole Mountain basalt is lower in P_2O_5, TiO_2, K_2O, Na_2O, total iron and higher in CaO, MgO, and Al_2O_3 (figs. 15-20). This strongly suggests that the two units are not genetically related.

Safley (in prep.) has mapped several thick intrusions in the area near Military Creek, south of Green Mountain. These basalts are significantly more altered than any of the Cole Mountain basalt in the thesis area and have been labled altered Cole Mountain basalt on the geochemical plots of figures 15, 17, 18, and 20. They contain abundant authogenic clay and pyrite. Safley (in prep.) made four thin sections of samples from these intrusions. Three thin sectioned samples are coarse grained and gabbroic; much coarser than any Cole Mountain basalt in the thesis area. One sample appears to have been glassy and vesicular but very extensive clay and iron oxide alteration has obscured the original texture. In all of the thin sectioned samples most or all of the augite and much of the plagioclase has been altered to clay. Chemical analyses of these four thin sectioned samples show a chemistry that is somewhat intermediate between Cole Mountain basalt and Tillamook Volcanics. On figure 15 the samples plot well within the Cole Mountain basalt field but on figure 18 the samples plot outside of both the Tillamook Volcanics and the Cole Mountain basalt fields. On other plots (figs. 17 and 20) the samples plot variously in the Tillamook Volcanics and Cole Mountain basalt fields. The stratigraphic position and lithology of the samples indicates that they are Cole Mountain basalt. It is felt that the very extensive alteration of these samples significantly changed the chemistry and resulted in their plotting outside of established fields. The fact that three of the samples are gabbroic indicates that differentiation during slow cooling may also have affected the chemical composition of these rocks.

In addition to geochemical evidence, petrographic and stratigraphic data show that the Tillamook Volcanics and the Cole Mountain basalt are not correlative. The petrographic difference between the two units was discussed in a previous section. The Tillamook Volcanics are unconformably overlain by nearshore basal basaltic conglomerate and sandstone deposits of the Roy Creek member of the upper Narizian Hamlet formation (informal) which are, in turn, overlain by a deepening sequence of neritic to bathyal mudstones of the Sweet Home Crrek member (informal). Minor submarine flows and hyaloclastites of the Cole Mountain basalt interfinger with and overlie the upper part of the Sweet Home Creek member of the Hamlet formation and numerous intrusions of Cole Mountain basalt occur within the Sweet Home Creek member. Many assemblages of upper Narizian microfossils were collected from directly beneath the Cole Mountain volcanics (e.g. localities 548 and 558) and Refugian faunas were collected directly above the Cole Mountain basalt in the Keasey Formation (e.g.localities 659 and 535). The above precludes the possibility that the Cole Mountain basalts are subaerial Tillamook Volcanics flows that reached a marine environment. Therefore, it can be stated with much confidence that the two geochemical groups in figure 20 represent two different igneous events which are separated in time.

Northwest Oregon and southwest Washington. The previous discussion has shown that some volcanic units (e.g. Green Mountain area) previously mapped as Goble Volcanics are stratigraphically and chemically correlative to the Tillamook Volcanics. It has also been shown that a younger, chemically distinct basaltic sequence (Cole Mountain basalt) is present in southern Clatsop and southern Columbia counties. The following discussion will focus on the stratigraphic relationships of middle to late Eocene volcanic sequences in southwest Washington and northwest Oregon and their stratigraphic relationship to the Tillamook Volcanics in the thesis area. These units include the Siletz River Volcanics, the Crescent Formation, the Tillamook Volcanics, the Goble Volcanics, and the unit B basalt of Wolfe and Mckee (1972). The major element chemistry of these units, as reported by several workers, will then be compared to the chemical fields outlined in this study.

The Siletz River Volcanics of western Oregon and the Crescent Formation of western Washington are correlative lower to middle Eocene oceanic "seamount" units that were accreted to the North American continental margin during the middle Eocene (Snavely et al., 1968; Wells et al., 1984; Wolfe and McKee, 1972). There has been considerable confusion between the nomenclature of the Tillamook Volcanics and the Siletz River Volcanics. Snavely et al. (1970) informally divided the Tillamook Volcanics into three units which included a basal basalt unit which is correlative to the Siletz River Volcanics, a middle mudstone unit which is correlative to the Yamhill Formation, and an upper largely subaerial basalt unit. Soper (1974) mapped and described Siletz River Volcanics and Yamhill Formation in the southern portion of the Timber quadrangle, (Washington County) northwest Oregon. These units are lithologically similar to and traceable into the type areas of the Siletz River Volcanics and Yamhill Formation but are located in an area where Snavely et al. (1970) and Warren et al. (1945) proposed Tillamook Volcanics nomenclature. Therefore, Soper (1974) restricted the Tillamook Volcanics to the upper member of Snavely et al. (1970). Al-Azzaby (1980) and Schlicker and Deacon (1967) mapped "upper" Tillamook Volcanics overlain by Yamhill Formation in the Gaston-Yamhill area (Washington and Yamhill counties). These "upper" Tillamook Volcanics are equivalent to the upper Siletz River Volcanics of Snavely et al. (1968) and the lower Tillamook Volcanics member of Snavely (1970). This has created the misconception that uppermost Tillamook Volcanics are overlain by Yamhill Formation. Wells et al. (1983) restricted the term Tillamook Volcanics to the upper Tillamook Volcanics member of Snavely et al. (1970) with the lower and middle members mapped as Siletz River Volcanics and Yamhill Formation respectively. The nomenclature of Wells et al. (1983) will be used in this report.

In summary, the Siletz River Volcanics are stratigraphically separated from the Tillamook Volcanics and, therefore, are not correlative to the volcanics in the thesis area. In addition, the Siletz River Volcanics and the correlative Crescent Formation are stratigraphically separated from the upper Narizian unit B basalt and Goble Volcanics by the Ulatisian to lower Narizian (middle Eocene) Yamhill and McIntosh formations (Wells, 1981; Wells et al., 1983; Wolfe and McKee, 1972). The Siletz River Volcanics and the Crescent Formation have a major element chemistry that is slightly different from the Tillamook Volcanics (fig. 17, appendix 5). The Siletz River Volcanics and Crescent Formation tend to be lower in SiO_2, P_2O_5, K_2O, and TiO_2 and higher in CaO and MgO than the Tillamook volcanics but do plot roughly along the Tillamook Volcanics trend (fig. 17, appendix 5).

Figure 22 shows the stratigraphic position of middle to upper Eocene units in southwest Washington and northwest Oregon and figure 23 shows the locations of areas described in the following section. The type section of the Goble Volcanics is located along the Columbia River near the town of Goble, Oregon where it is thought to overlie upper Narizian sedimentary rocks and is overlain by Refugian sedimentary rocks (Wilkinson et al., 1945). Similar stratigraphic relationships occur for Goble Volcanics mapped by Henrikson (1956) and Livngston (1966) in the Longview-Vader area, southwest Washington. Wells (1981) mapped Goble Volcanics farther to the west in the upper Grays River area of southwest Washington. In this area, however, the Goble Volcanics are overlain by the upper Narizian siltstones of Skamokowa Creek instead of Refugian sedimentary rocks. The Goble Volcanics are underlain by Narizian rocks here but it is not known if they are upper or lower Narizian. In the lower Grays River area, directly to the west of the area mapped by Wells (1981) Wolfe and McKee (1972) mapped unit B basalt which they thought to be correlative to the Goble Volcanics.

Unit B basalts are petrographically and lithologically identical to the Tillamook Volcanics in the thesis area. They are overlain by upper Narizian basaltic conglomerates and sandstones that grade upward into siltstones and are similar to the Roy Creek and Sweet

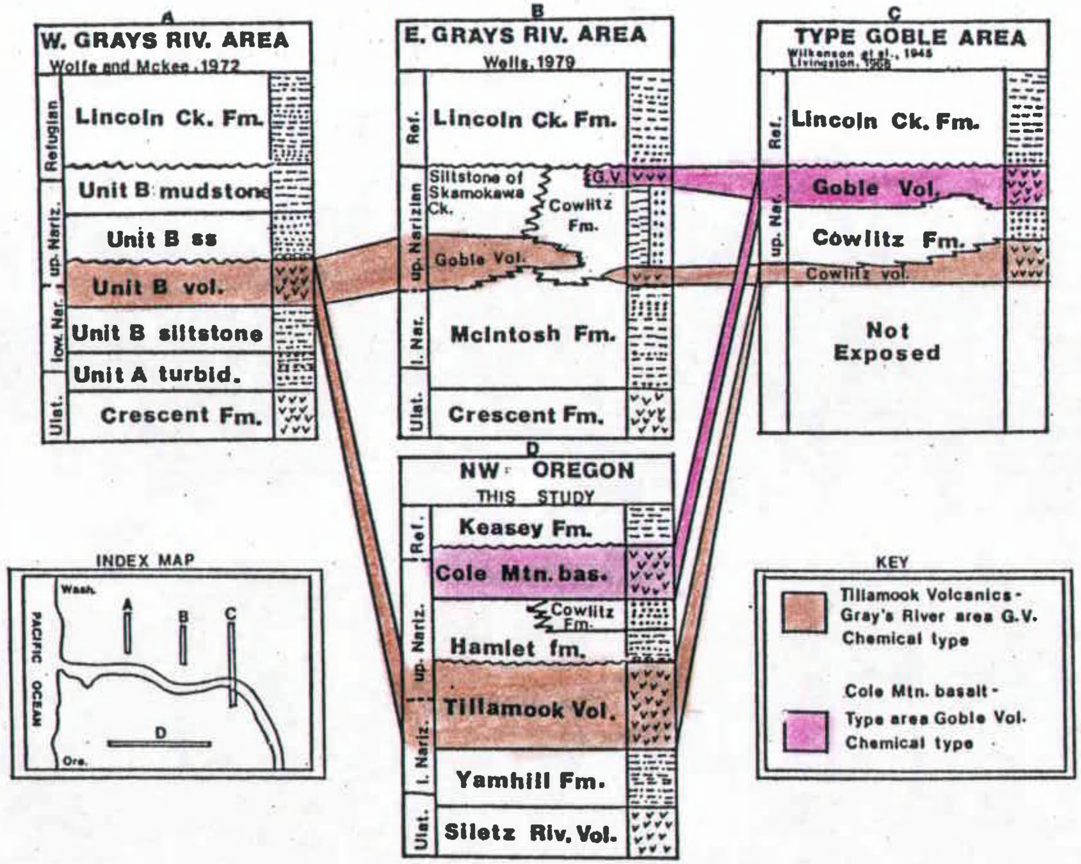


Fig. 22: Generalized stratigraphic columns from southwest Washington (top) and northwest Oregon (below) emphasizing the correlation of Eocene volcanic units. Note that the Unit B volcanics (Grays River area Goble Volcanics) and Tillamook Volcanics appear to be stratigraphically correlative. Also, the type area Goble Volcanic and the Cole Mtn. basalt appear to be correlative.

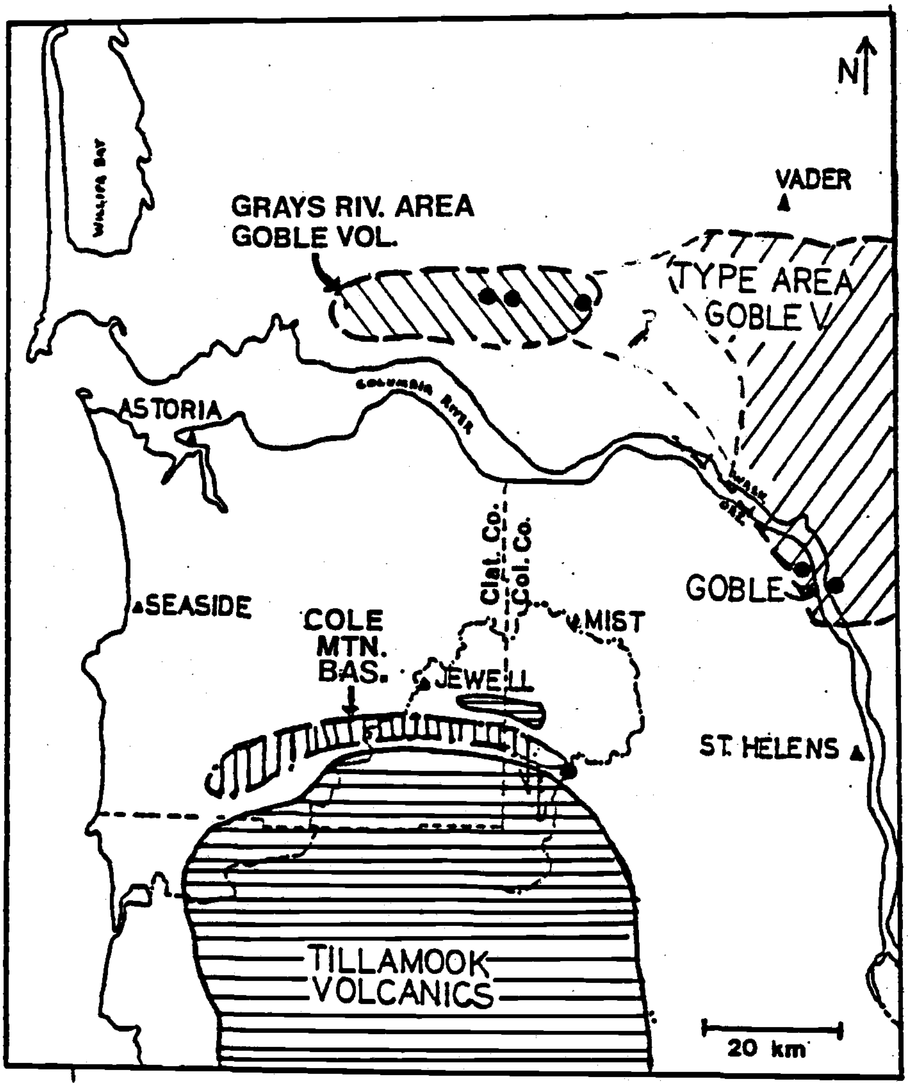


Fig. 23: Sketch map showing the approximate outcrop distribution of Eocene volcanic rocks in northwest Oregon and southwest Washington. The volcanic rocks of the middle Eocene Crescent Fomation in southwest Washington are not shown. The locations of geochemical samples from outside the thesis area are shown (•).

Home Creek members overlying the Tillamook Volcanics in the thesis area (fig. 22). Late Eocene gastropods, which are characteristic to the Cowlitz Formation, are present in the strata that overlie unit B basalt (Wolfe and McKee, 1972). Sedimentary rocks directly underlying unit B basalt are Ulatisian and lower Narizian. No upper Narizian faunas were collected from these rocks (Wolfe and McKee, 1972). The above stratigraphic data suggest that the Tillamook Volcanics are correlative to the "Grays River area" Goble Volcanics and that the Cole Mountain basalt is correlative to the type area Goble volcanics (fig. 22). The term Grays River area Goble Volcanics is informally used in this report for unit B basalt mapped by Wolfe and McKee (1972) and Goble Volcanics mapped by Wells (1981) in the vicinity of Grays River, southwest Washington. To further test the above correlations major element chemistries of the Grays River area Goble Volcanics and the type area Goble Volcanics were plotted on figure 24 and compared to the chemical fields of the Tillamook Volcanics and the Cole Mountain basalt.

To supplement the geochemical data of previous workers (Burr, 1978; Wolfe and McKee, 1972) 5 samples were collected from key locations in the "Goble Volcanics" and analyzed for major element chemistry (fig. 23, appendix 4). The Grays River area Goble Volcanics plot within or near the Tillamook Volcanics field whereas the type area Goble Volcanics plot within or near the Cole Mountain basalt field (fig. 24). Also plotted on figure 20 are two analyses of Cole Mountain basalt? sills. One is from the 4,600' interval of the Quintana Watzek well (sample QW-4560) in eastern Clatsop County (map area of Olbinski, 1983) and the other (sample RCC-1) is from a

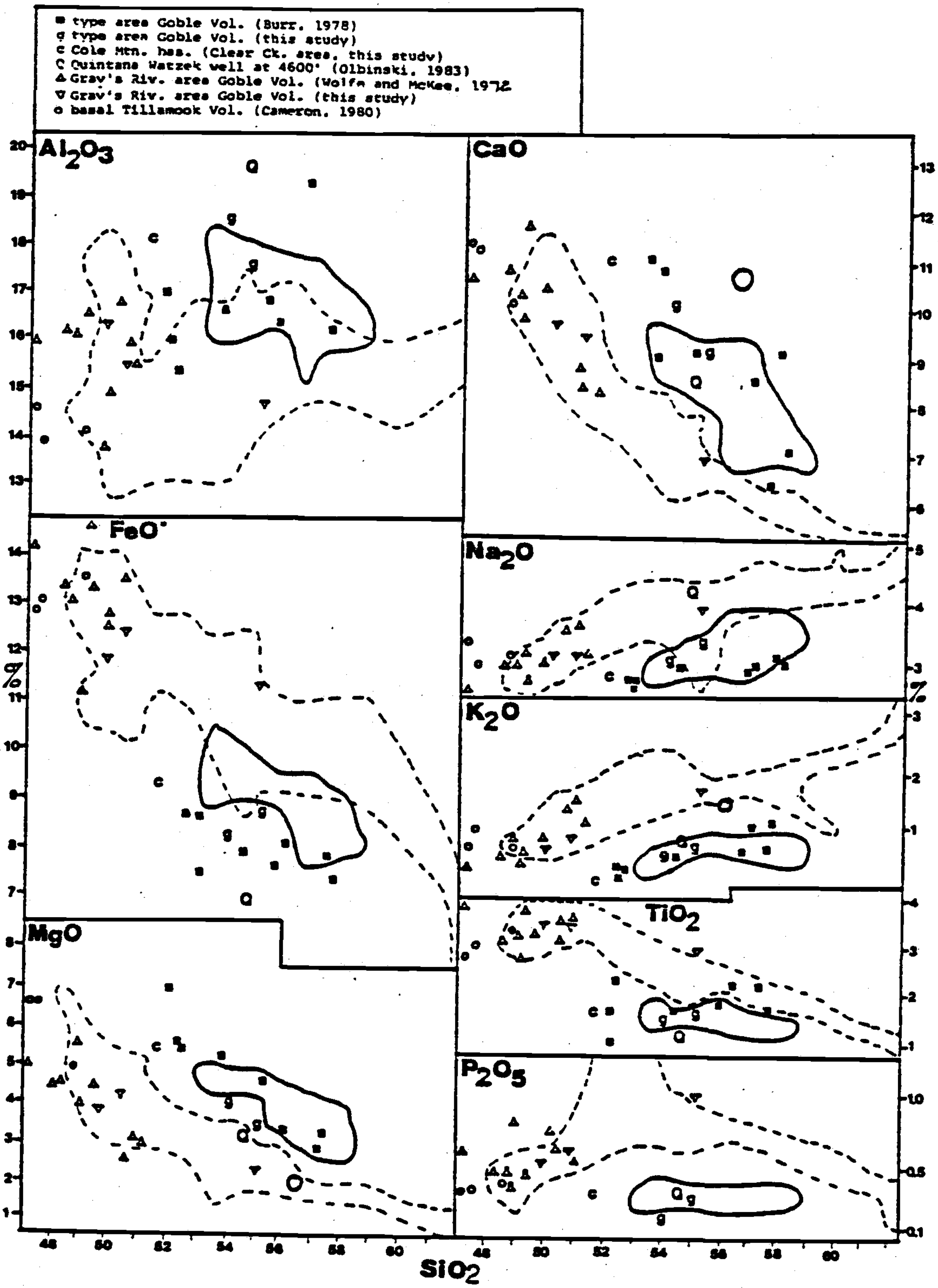


Fig. 24: Silica variation diagram for samples from the Grays River area (Unit B) Goble Volcanics of Wolfe and McKee (1972) and Wells (1983), the type area Goble Volcanics, the basal Tillamook Volcancs, and isolated Cole Mtn. basalt? intrusions. The upper Tillamook Volcanics field (---) and the Cole Mtn. bas. field (—) from fig. 13 are shown.

sill in northern Washington County, Oregon (map area of Jackson, 1983). These two samples plot within or near the Cole Mountain volcanics field of figure 24. These chemical data in conjunction with stratigraphic data indicate that the above samples are Cole Mountain basalt.

Olbinski (1983) and Martin et al. (in press) considered the sill in the Quintana Watzek well to be Grande Ronde Basalt based primarily on a gabbroic texture. The fact that the sill has a distinct chemistry from any other Grande Ronde basalt analyzed, even from sills of similar thickness, was attributed to deuteric alteration and contamination of the well sample by mudstone. It is felt that the very strong chemical similarity of this sample to Cole Mountain basalt (fig. 24, appendix 5), the petrografic similarity to gabbroic Cole Mountain basalt intrusions described by Safley (in prep), and the stratigraphic position of the sill at the upper contact of the Narizian Cowlitz formation suggest that the sill is more likely Cole Mountain basalt than Grande Ronde Basalt.

Three analyses from the basal portion of the Tillamook Volcanics (data from Cameron, 1980) were also plotted on figure 24. These samples plot at the mafic end of the Tillamook volcanics trend and are chemically somewhat intermediate between the upper part of the Tillamook Volcanics and the Siletz River Volcanics. The chemical analyses from Cameron (1980) were run through a different lab than analyses from the thesis area but it is felt that the data are at least comparable.

Figure 25 compares the total chemical fields of middle to upper Eocene subalkaline volcanic rocks in northwest Oregon and

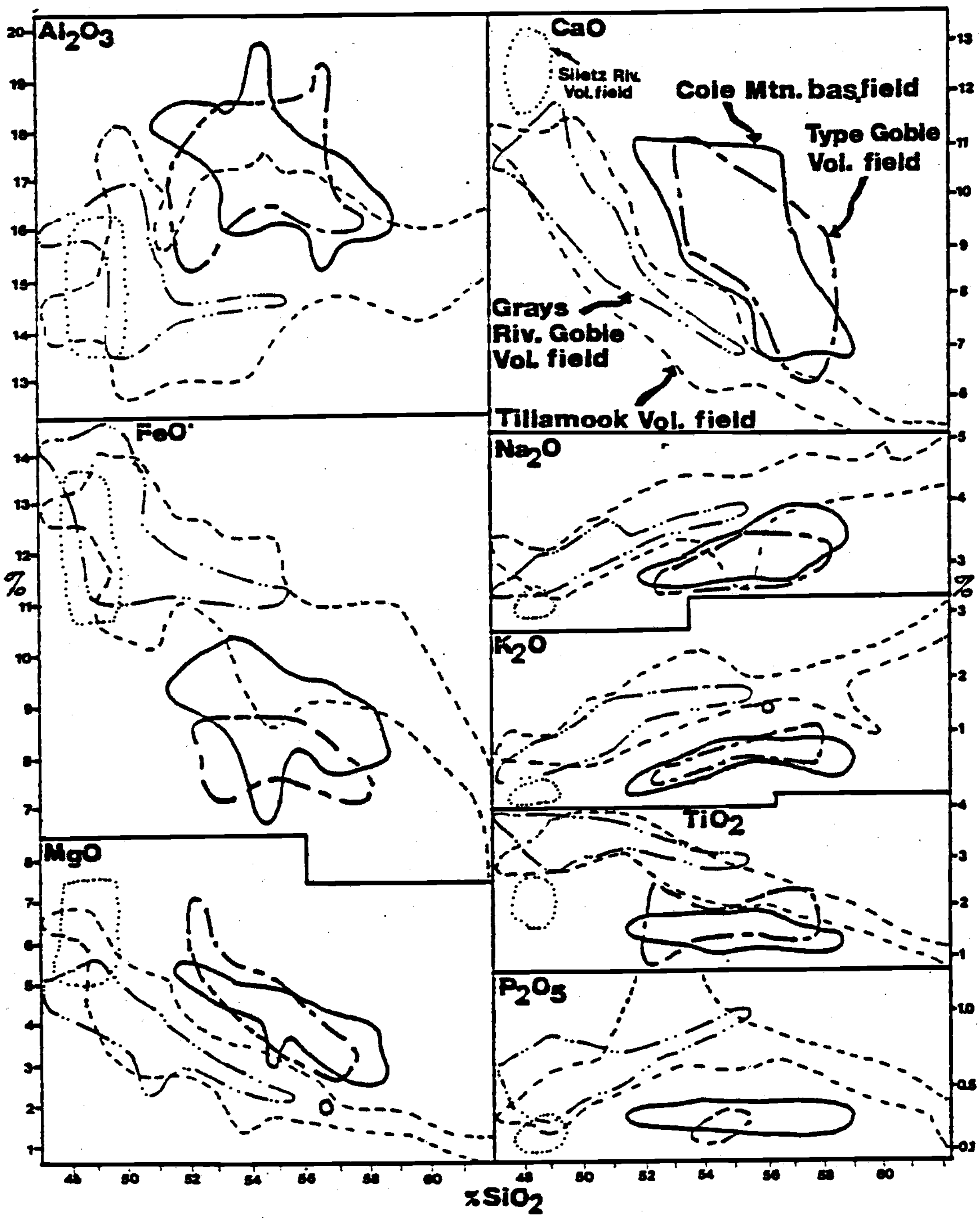


Fig. 25: Silica variation diagram showing the chemical fields of Eocene volcanic units in northwest Oregon and southwest Washington. Note the similarities between the Grays River area Goble Volcanics field and the Tillamook Volcanics field as well as the nearly identical fields of the type Goble Volcanics and the Cole Mtn. basalt.

southwest Washington. The chemical fields of the Cole Mountain basalt and the type area Goble Volcanics are virtually identical and the Grays River area Goble Volcanics field occurs within the mafic end of the Tillamook Volcanics field. The Siletz River Volcanics field plots on trend with the Tillamook Volcanics field but occupies a more mafic position.

The major element analyses of middle to late Eocene volcanic rocks were also plotted on an AFM diagram, a diagram of FeO*/MgO vs. SiO2, and a total alkalies vs. SiO2 diagram (figs. 15, 17, and 18). On all of these diagrams the Tillamook Volcanics and Grays River area Goble Vocancis of Wolfe and McKee (1972) and Wells (1981) plot together forming a distinct group from the Cole Mountain basalt and type area Goble Volcanics which also plot together. Table 1 shows the average chemical composition of the previously mentioned volcanic units (appendices 4 and 5 give standard deviations and individual analyses of these units). The average chemical composition of the Cole Mountain basalt is very similar to that of the type area Goble Volcanics and the average chemical composition of the Tillamook Volcanics is similar to that of the Grays River area Goble Volcanics, especially when compared at similar SiO2 values. For example, the Tillamook Volcanics in the thesis area have a chemical composition that is nearly identical to the average composition of the Grays River area Goble Volcanics (table 1).

A number samples from the type area Goble Volcanics and from eastern parts of the Grays River area Goble volcanics have recently been analyzed for major oxides (Phillips, pers. comm., 1985). These samples plot in or near the respective fields outlined in this study

UNIT	LOCATION AND SOURCE OF DATA[1]	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	No. of Samp.
UPPER TILLAMOOK VOLCANICS	S.-central Clatsop Co. (This study)	50.48	14.96	3.28	5.86	6.72	0.21	9.31	4.55	0.94	3.11	0.59	19
	S.-cent. Clat. Co. (Mumford, in prep.)	51.37	15.27	3.18	5.62	6.44	0.21	8.69	4.00	1.11	3.40	0.71	25
	SE Clatsop Co. (Safley, in prep.)	55.11	15.62	2.42	4.96	5.68	0.19	7.11	2.72	1.65	3.76	0.78	25
	N. Wash. Co. (Jackson, 1983)	52.56	13.76	2.98	5.83	6.70	0.24	8.39	3.32	1.40	3.94	0.85	16
	E.-cent. Clat. Co. (T)(N)(O)+	55.35	16.25	2.18	4.59	5.65	0.20	6.55	2.52	1.87	3.98	0.67	16
	AVERAGE OF UPPER TILLAMOOK VOL.*	53.0	15.2	2.8	5.4	6.2	0.21	8.0	3.4	1.4	3.6	0.72	101
BASAL T.V.	AVG. OF BASAL TILL. VOL.(Cameron)	47.5	14.2	2.9	6.5	7.0	0.21	10.9	6.0	0.81	3.0	0.33	3
GRAY'S RIVER "GOBLE VOLCANICS"	Gray's River Area (Wolfe and McKee)	49.3	15.7	3.4	5.3	8.0	0.24	9.8	4.2	0.66	3.0	0.57	9
	E. Gray's River Area (This study)	51.73	15.49	3.12	5.82	6.67	0.19	8.57	3.48	1.03	3.23	0.66	3
	AVERAGE OF G.R. "GOBLE VOL."*	50.5	15.6	3.3	5.6	7.3	0.22	9.2	3.8	0.85	3.1	0.62	12
TYPE AREA GOBLE VOLCANICS	Type area Goble Vol. (Burr, 1974)	54.92	16.71	1.96	3.93	4.55	0.10	9.10	4.85	0.65	2.85	--	8
	Type area Goble Vol. (This study)	54.52	17.85	1.21	4.17	4.76	0.15	9.44	3.85	0.59	3.27	0.19	2
	AVG. OF TYPE AREA GOBLE VOLCANICS*	54.7	17.3	1.6	4.1	4.7	0.13	9.3	4.4	0.62	3.1	0.19	10
COLE MOUNTAIN basalts	S.-central Clatsop Co. (This study)	56.81	16.21	1.67	4.38	5.02	0.15	7.94	3.15	0.80	3.58	0.31	4
	S.-cent. Clat. Co.(Mumford, in prep.)	57.15	16.30	1.47	4.27	4.89	0.15	7.89	3.76	0.60	2.85	0.30	8
	SE Clatsop Co. (Safley, in prep.)	55.28	16.28	1.55	4.75	5.45	0.15	7.69	4.48	0.85	3.28	0.26	4
	N. Wash. Co. (This study)	51.44	17.95	1.33	4.51	5.17	0.14	10.83	5.25	0.16	2.94	0.28	1
	E.-cent. Clat. Co. (T) (N) (O)+	54.88	17.83	1.42	4.28	4.90	0.15	8.24	3.77	0.55	3.69	0.30	4
	AVERAGE OF COUGAR MTN. VOLCANICS*	55.1	16.9	1.5	4.4	5.1	0.15	8.5	4.1	0.59	3.3	0.29	21
alt.C.M.b.	AVERAGE OF alt. Cole M.b.(Safley)	56.2	14.3	2.3	5.6	6.4	0.17	6.4	3.6	1.0	3.0	0.90	4
CRESCENT VOLCANICS SILETZ R.V	Gray's River Area (Wolfe and McKee)	49.0	15.2	2.0	5.2	6.8	0.26	12.7	6.1	0.22	2.6	0.26	3
	Western Wash. (Snavely *et al.*, 1968)	48.5	14.6	2.2	4.3	8.0	0.21	11.8	7.2	0.22	2.6	0.26	10
	Western Ore. (Snavely *et al.*, 1968)	48.6	14.6	2.3	4.8	8.2	0.22	11.6	6.7	0.15	2.5	0.25	8
	AVG. OF CRESCENT AND SILETZ RIV. V.	48.6	14.8	2.2	4.8	7.7	0.23	12.0	6.4	0.19	2.5	0.27	21

[1]Map locations shown in figs. 1 and +(T)=Timmons,1981 (N)=Nelson,1985 (O)=Olbinski,1983 *Avg. of above means

Table 1: Average chemical composition of Eocene volcanic units in northwest Oregon and southwest Washington.

(Phillips and Rarey, in prep.). Phillips and Kaler (1985) and Phillips and Rarey (in prep.) have suggested that the Cowlitz volcanics of Livingston (1966) (located in the vicinity of Longview, southwest Washington) are chemically similar to the Grays River area Goble Volcanics and should be included in that unit.

Miyashiro (1974) has shown that volcanic sequences tend to show distinct differentiation trends on major element diagrams. This is also apparent in this study. The fact that the Tillamook Volcanics-Grays River area Goble Volcanics and the Cole Mountain basalt-type area Goble Volcanics plot as separate trends indicates that they are not closely related. In addition, the Tillamook Volcanics-Grays River area Goble volcanics are tholeiitic whereas the Cole Mountain volcanics-type area Goble Volcanics are largely calc-alkaline. In the following section it will be shown that the two groups of volcanic rocks were, most likely, formed in different plate tectonic settings.

Trace element geochemistry supports interpretations made from major element data. Timmons (1981) reported rare earth element (REE) abundances from several volcanic rocks in northwest Oregon. The analyses come from 2 intrusions (Quartz Creek and Clear Creek) and 6 flows. One sample that Timmons (1981) considered to be an intrusion is not (locality 10-81-1) and it will be included in the flow data. Timmons (1981) refered to all of these rocks as Goble Volcanics but reconnaissance work has shown that the flows are upfaulted blocks of uppermost Tillamook Volcanics and that the intrusions are correlative to Cole Mountain basalt (this study, Safley, in prep.). He also reported REE abundances for basalts near the base of the Tillamook Volcanics in the study area of Cameron (1980). For unkown reasons Timmons (1981) normalized his analyses to a Columbia River Basalt standard (BCR-1). The REE plot from his work is shown in figure 26 and is used only to contrast the different units. The Cole Mountain basalts have consistantly lower REE abundances than the uppermost Tillamook Volcanics showing that they are not an upper more differentiated sequence of Tillamook Volcanics but are instead a distinct volcanic unit. The lowermost Tillamook Volcanics are depleted in light REE indicating that they are less fractionated than uppermost Tillamook Volcanics. McElwee (pers. comm., 1985) noted similar trace element characteristics for Eocene basalts in northwest Oregon. The fractionation trend from base to top is also suggested by major oxide abundances and will be discussed in more detail in the following section.

Martin et al. (in press) and Niem and Niem (in press) using the chemical fields outlined in this study, have reported Tillamook Volcanics-Grays River area Goble Volcanics chemical type basalt flows beneath upper Narizian strata in exploration wells in northern Clatsop County. This area is located midway between outcrop areas of Tillamook Volcanics and Grays River area Goble volcanics and serves to substantiate the correlation of the two units and suggests that the units are physically continuous.

In conclusion, it has been demonstrated that the Tillamook Volcanics in northwestern Oregon are chemically and stratigraphically correlative to the Goble Volcanics in the Grays River area of southwest Washington. It has also been shown that the Cole Mountain basalts are chemically and stratigraphically correlative to the type

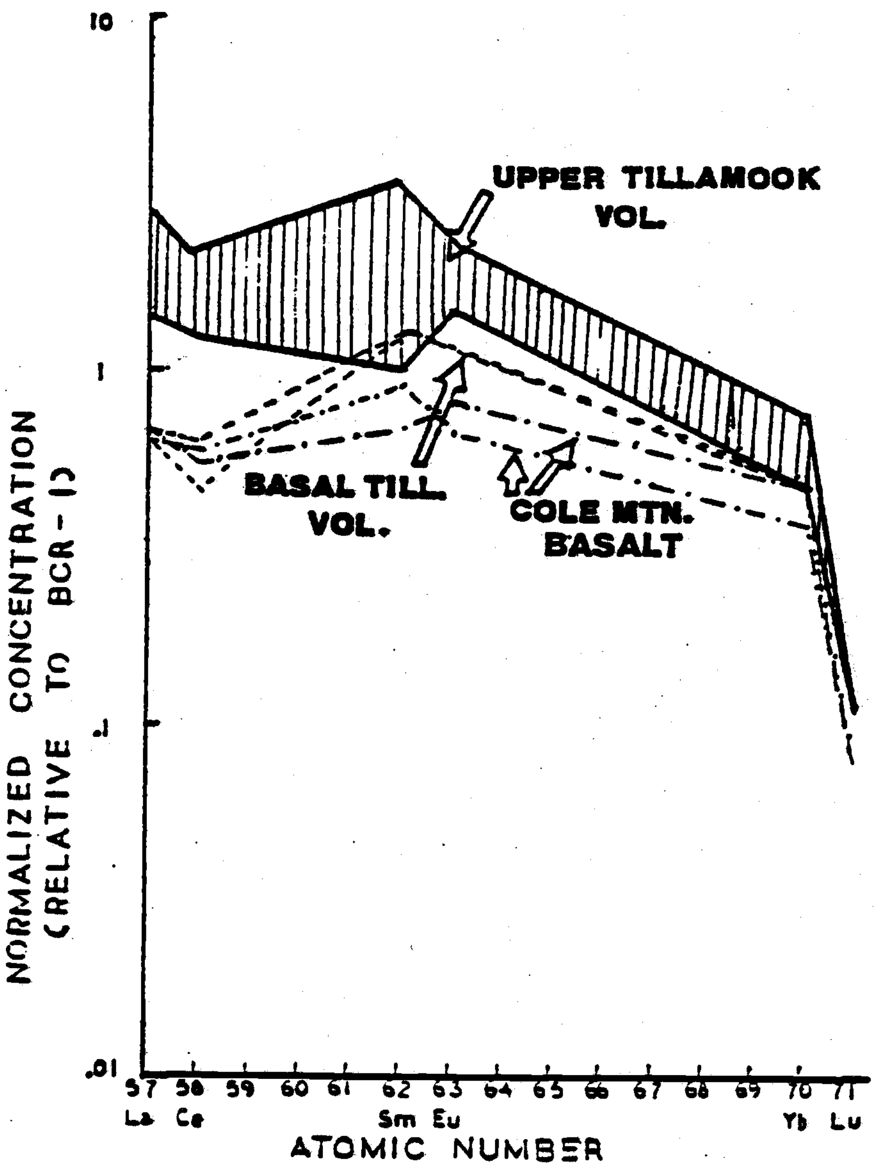


Fig. 26: Rare earth element abundances for the Tillamook Volcanics and the Cole Mtn. basalt. Note that the Cole Mtn. basalt are depleted in REE relative to the Tillamook Volcanics (data from Timmons, 1981; and Jackson, 1983).

area Goble Volcanics and distinct from the Tillamook Volcanics and Greys River area Goble Volcanics. It has been shown in this report that the Tillamook Volcanics and Cole Mountain volcanics represent two distinct igneous episodes separated in time. This implies that the Grays River area Goble Volcanics and the type area Goble Volcanics also represent two distinct igneous events. Wells (1981), however, has continuously mapped Goble Volcanics from the type area to the Grays River area. This could be explained by: 1) a vertical and lateral stacking of volcanic episodes without intermediate sedimentary rocks; 2) simultaneous eruption of two major source areas with one in the west (Grays River area) and one in the east (type Goble area); 3) coincidental chemical correlations; or 4) misleading geologic mapping. Explanations 1 and 2 seem unlikely because of stratigraphic data indicating that the type area Goble Volcanics are slightly younger than the Grays River area Goble volcanics. Chemical differences between the two areas are very distinct. This strongly suggests that the chemical correlations are real. Therefore, explanation 3 is probably not adequate. It is felt that somewhat misleading geologic mapping (explanation 4) has resulted in the continuous mapping of Goble Volcanics in southwest Washington. This will be discussed in the following section.

Cowlitz Fm., Goble Vol., Tillamook Volcanics Relationships.

Until the recent use of major element geochemical analysis in northwest Oregon and southwest Washington the Goble Volcanics have been an overextended and misused term with all Narizian aged basaltic rocks being included. The Cowlitz Formation nomenclature has undergone significant changes since it was first propsed by Weaver (1912). It is felt that the somewhat loose terminology has resulted in misleading geologic mapping. Sample RG-3 was collected from near the base of the Grays River area Goble Volcanics in the Elochoman River (NW1/4 sec. 24). Directly beneath this sample locality Cowlitz Formation sandstones were mapped by Wells (1981). If these sandstones are age equivalent to the Cowlitz Formation sandstones in northwest Oregon and to the upper part of the Cowlitz Formation at the type section (Olequa Creek) then the Grays River area Goble Volclanics cannot be correlative to the Tillamook Volcanics. Reconnaissance work from this study suggests that the sandstones beneath sample RG-3 are correlative to the upper McIntosh Formation sandstones of Wells (1981) and are significantly older that the type section Cowlitz Formation and the Cowlitz Formation in northwest Oregon. If this is the case then it is quite possible that the Grays River area Goble Volcanics are correlative to the Tillamook Volcanics. It is suggested that the boundary between the Grays River area Goble Volcanics and the type section Goble Volcanics is located to the east of the Elochoman River, probably several kilometers west of Longview Washington. This boundary may be in the form of a fault or an unconformity but most likely represents a simple stratigraphic separation.

In this report it has been suggested that the Goble Volcanics in southwest Washington consist of two stratigraphically and chemically distinct volcanic units. Bill Phillips of the Washington division of natural resources has recently tested this hypothesis by obtaining a number of chemical analyses from both the Grays River area Goble

Volcanics and the type area Goble Volcanics. His data strongly supports the conclusions of Rarey (1984) and of this report that the Goble Volcanics in southwest Washiington consist of two distinct units. Additional detailed biostratigraphic work should be done on the sedimentary rocks directly beneath the Grays River area Goble Volcanics (e.g. on samples from the Elochoman River) to determine the precise age of these rocks. McElwee (personal communication, 1984) has obtained several K-Ar dates from the Goble Volcanics which suggest that the Grays River area rocks are older than those at the type section but overlap does occur. K-Ar dates from the Grays River area Goble volcanics range from 41 to 43 Ma whereas K-Ar dates from the type area Goble Volcanics range from 32-42 Ma (Beck and Burr, 1979; McElwee pers. comm., 1985). Several K-Ar dates from the Tillamook Volcanics contradict biostratigraphic data. For example, K-Ar dates of 36 Ma have been obtained from the top of the Tillamook Volcanics and Narizian faunas have been collected above the Tillamook Volcanics resulting in an age discrepency of at least several Ma depending on which time scale is used (Nelson, 1985). Therefore, the accuracy of K-Ar dating appears to be insufficient to differentiate the subunits of the Goble Volcanics.

The correlations presented in this report are significant for a number of reasons. First, the subdivision of the Goble Volcanics and the recognition of the Cole Mountain volcanics may help to better understand the early development of the western Cascade Arc. Secondly, a paleomagnetic study of the Cole Mountain basalt would serve to evaluate the tectonic models suggested by Beck and Burr (1979) for the type area Goble Volcanics. Finally, the correlation of volcanic units in this area is of importance to the petroleum industry (i.e. wheather or not there are arkosic reservoir sandstones beneath the Grays River area Goble Volcanics)

The major element diagrams presented in this report can be used to differentiate volcanic units in northwest Oregon and southwest Washington on the basis of chemistry alone. Figure 15 (plot of total alkalies vs. SiO2) is probably the single best diagram for distinguishing the Tillamook Volcanics-Grays River area Goble Volcanics from the Cole Mountain basalt-type area Goble Volcanics. When a chemical analysis is plotted on several of the major element diagrams presented in this report the sample can be assigned to the correct volcanic unit with an accuracy of greater than 95%. This could be extremely useful in correlating well samples (e.g. see Niem and Niem, in press and Martin et al., in press.). It should be noted, however, that the fields outlined in this study are for quickly cooled rocks. Gabbroic sills that have undergone significant fractionation and deuteric alteration after emplacement will probably give anomalous results on the major element diagrams. The major element fields of alkaline volcanic rocks in northwest Oregon (e.g. Cascade Head volcanics of Barnes, 1981) have not been discussed in this report. The alkaline nature of these rocks would serve to distinguish them from the subalkaline volcanic units in northwest Oregon.

Geologic History and Tectonic Setting

Physical Setting.

The Tillamook Volcanics have been interpreted as a middle Eocene island complex (*e.g*. Cameron, 1980; Jackson, 1983). This is evidenced by the presence of subaerial basaltic flows underlain by interfingering marine sedimentary rocks (*i.e.* Yamhill Formation) and submarine basalts (Wells *et al*., 1983) (fig. 21). Approximately 1,300 square kilometers of Tillamook Volcanics have been mapped at the surface (Wells *et al*., 1983) (fig. 21). The presence of correlative and presumably physically continuous volcanic rocks in the Texaco Clark and Wilson well, the CZ 11-28 well, the Standard Hoagland well, other exploration wells in Columbia County (see Martin *et al.*, in press and Bruer *et al.*, 1984), and in the Grays River area of southwest Washington indicate that the "Tillamook island" covered an area of about 5,000 square kilometers. The absence of Tillamook Volcanics in the middle Eocene strata in the Yamhill and Mt. Hebo quadrangles, in the central Oregon Coast Range, and in the Willopa bay and Vader areas of southwest Washington limits the size of the "island". In the central part of the Tillamook Volcanics outcrop area (fig. 21) more than 1500 meters of basaltic flows are present (Wells *et al.* 1983). The physical dimensions of the Tillamook Volcanics are comparable to moderately large shield volcanoes (McDonald, 1972) (table 2). The wide aerial extent of the Tillamook Volcanics coupled with a relatively low height (thickness) indicate that they may consist of several coalescing shields similar in size to the Icelandic volcanoes.

Table 2: Size of shield volcanoes (Data from this study and from McDonald (1972)

Shield Volcano	Diameter (miles)	Height (miles)
Oraefajokull (Iceland)	15	0.90
Snaefellsjokull (Iceland)	12	0.85
Skjalbreidur (Iceland)	9	0.75
Mauna Loa (subaerial) (Hawaii)	>20	2
Mauna Loa (total)	>40	5
Tillamook Volcanics (this study)	>55	2 max.

Calculations from the regional geologic map of Wells et al. (1983) show that the basal submarine basalt facies of the Tillamook volcanics is over 600 m thick in the west but thins to less than 40 meters in the east (fig. 21). These data and interfingering stratigraphic relationships with the bathyal Yamhill Formation mudstones indicate that the island occupied a continental shelf to upper slope environment and may have, at times, been connected to the North American shore. The relatively thin submarine basalt facies precludes the possibility that the Tillamook Volcanics represent a normal seamount. Seamounts generally have a submarine facies in excess of 2,000 m thick (Best, 1982).

In general, there are relatively few feeder dikes and vents recognized within the thesis area and within the subaerial part of the Tillamook Volcanics in Clatsop, Columbia, and Tillamook Counties (this study, Timmons, 1981; Jackson, 1983; Olbinski, 1983; Nelson, 1985; Mumford, in prep.; Safley, in prep.). A few minor dikes and cinder cones? are present in the Green Mountain area (Olbinski, 1983; Nelson, 1985, Safley, in prep.). Wells (pers. comm., 1984) and Cameron (1980) have mapped extensive systems of northwest-trending feeder dikes in the lower part of the subaerial facies and in the submarine facies of the Tillamook volcanics. The relatively few recognized vent and source areas could be a result of poor exposure, or a volcanic sequence that had a limited number of large, long lasting vent areas. Since the thesis area is located in the uppermost part of the Tillamook Volcanics only the youngest Tillamook Volcanics dikes are present whereas at the base of the unit both younger and older Tillamook Volcanics dikes occur. In any case evidence suggests the presence of relatively few, large vent areas such as are characteristic of shield volcanism. A pipe vessicle at the base of one flow (locality 409) suggested an east to west flow direction but the data are too limited to be of use in determining source direction.

The similar structural attitudes of Tillamook Volcanics flows and the overlying conglomerates, sandstones, and mudstones of the Hamlet formation indicate that the flows originally had shallow dips, probably less than 8 degrees. The mafic composition of the flows indicates that they had a low viscosity and were probably deposited at relatively shallow dips. The fact that debris flows are uncommon in the Tillamook volcanics of the thesis area is also suggestive of a relatively low relief topography. In the Green Mountain area, where the Tillamook Volcanics are more silicic, Olbinski (1983), Nelson (1985) and Safley (in prep.) have described a number of debris flows suggesting that the area had at least moderate relief. The relief may be a result of more viscous silicic flows in that area or may be due to disection of the terrain by streams as volcanism began to wane. The presence of some "intracanyon" flows in the thesis area shows that the topography had been modified by erosion. The above data support a shield volcano origin for the Tillamook Volcanics. The thickness and extent of the Tillamook Volcanics suggests that a number of overlapping shield volcanoes produced the unit. The Tillamook island may have been physically similar to subaerial portions of shield volcanic islands in the Hawaiian chain.

Plant fossils (dogwood, spruce, cedar, tree of heaven, horsetail) from the base of the Tillamook Volcanics indicate a relatively warm and wet climate on the Tillamook island (Cameron, 1980; Jackson, 1983). In warm wet climates soil horizons can develop on basalt flows fairly quickly. The majority of flows in the thesis area are not separated by thick soil horizons suggesting a relatively rapid outpouring of flows.

Discriminant Diagrams.

The detailed tectonic setting of the Tillamook Volcanics has not been established. Several workers have constructed geochemical discriminant diagrams to be used as an aid in determining tectonic setting of volcanic rocks. Analyses from the Tillamook Volcanics in the thesis area and in adjacent areas were plotted on three major element discriminant diagrams (Pearce et al., 1975; Pearce et al., 1977; Mullen, 1983) (fig. 27). Each of the diagrams was constructed for use on rocks which have chemical compositions falling within prescribed limits. The TiO_2-K_2O-P_2O_5 plot of Pearce et al. (1975) is for rocks which have total alkalies less than 20% in a (Fe_2O_3+FeO)--MgO-(Na_2O+K_2O) diagram. The MgO-FeO*-Al_2O_3 diagram of Pearce et al. (1977) is for non-alkaline rocks with 51% to 56% SiO_2 and the MnO-TiO_2-P_2O_5 diagram of Mullen (1983) is for oceanic basaltic rocks

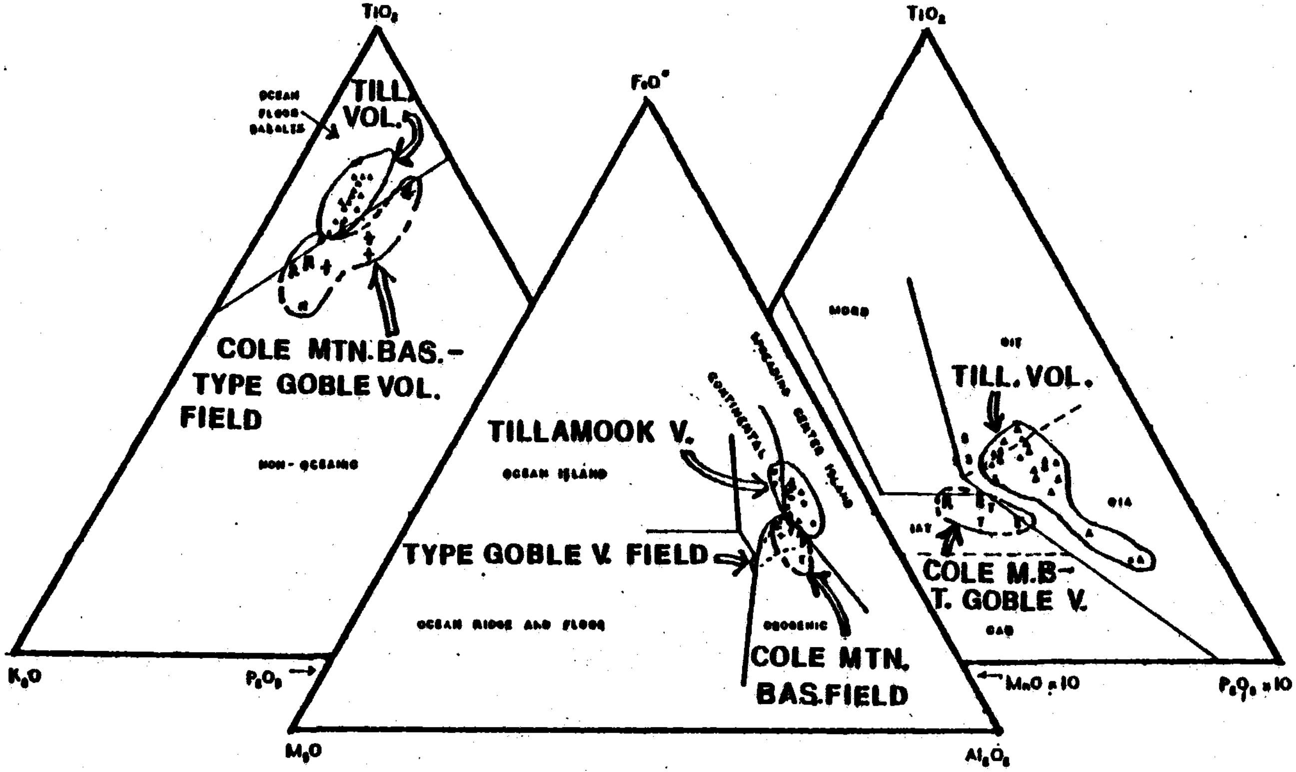


Fig. 27: Tectonic discriminant diagrams from Pearce et al. (1975)(left), Pearce et al. (1977)(center), and Mullen (1983)(right). The Tillamook Volcanics and the Grays River area Goble Volcanics (not shown) plot within oceanic, oceanic island, and spreading center oceanic island fields. These fields represent the same tectonic environment with the spreading center island being the most specific. The Cole Mtn. basalt and the type area Goble Volcanics plot within the island arc (orogenic) fields. Cole Mtn. bas. (+), type area Goble vol. from this study (R), Tillamook Vol. (▲), and Siletz River Vol. (S) samples have been plotted.

with 45% to 54% SiO_2. Several workers have plotted analyses which do not fit the given criteria on discriminant diagrams and have arrived at invalid conclusions. Cameron (1980), for example, concluded that the Tillamook Volcanics had continental affinities based on the Pearce et al. (1977) diagram. However, analyses with less than 51% SiO_2 were used making the conclusions invalid. In this study only "valid" analyses are considered in making tectonc interpretations.

On the TiO_2-K_2O-P_2O_5 diagram of Pearce et al. (1975) all of the Tillamook Volcanics in the thesis area plot as ocean floor basalts (fig.28). For reference, the valid Cole Mountain basalt analyses plot in the non-oceanic field (includes island arc rocks and other volcanic rocks erupted on continental crust). The dividing line in the diagram separated 93% of representative ocean floor and ocean ridge basalt analyses in the oceanic field and >80% of continental basalt analyses into the non-oceanic field (Pearce et al., 1975). The oceanic field was defined by Pierce et al. (1975) with basalt samples from the Mid Atlantic Ridge, Pacific Ocean floor, the East Pacific Rise, and other oceanic localities whereas the non-oceanic field was defined with samples from the Columbia River Basalt Group, the Karroo Basalts of South Africa, and other continental localities.

The MgO-FeO*-Al_2O_3 diagram of Pearce et al. (1977) is for use with non-alkaline rocks. As a quick screening method only analyses which plot in the tholeiitic field of Hawaiian basalts as defined by McDonald and Katsura (1963) were used in constructing this diagram (Pearce et al., 1977). Therefore, only analyses which plot in the tholeiitic field of McDonald and Katsura (1963) and have

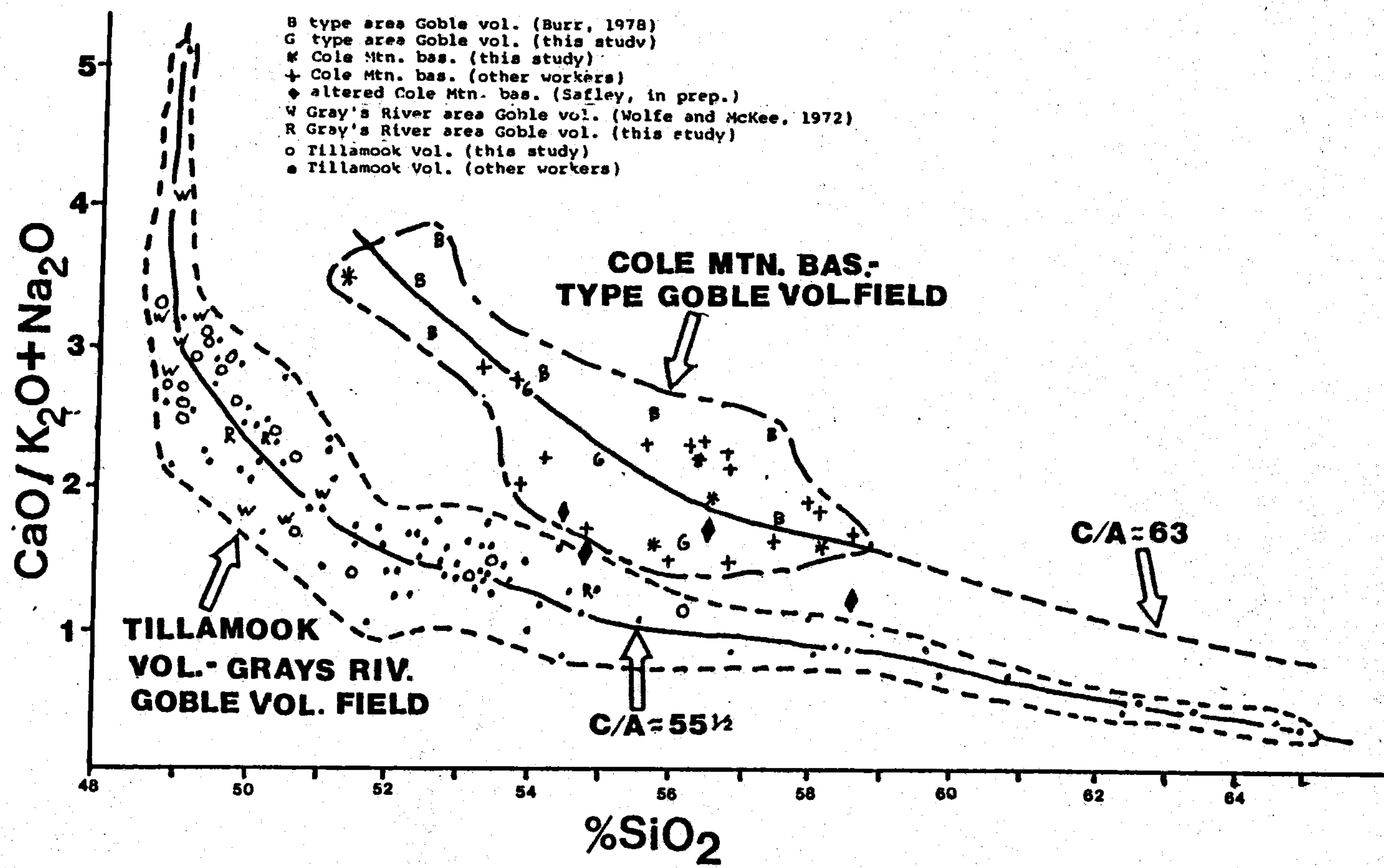


Fig. 28: Variation diagram for CaO/(Na2O+K2O) vs. SiO2 with samples from Eocene volcanic rocks in northwest Oregon and southwest Washington. Petro et al.(1979) used this diagram to graphically estimate the calc-alkali index of plutonic rock suites. The Tillamook Volcanics-Grays River area Goble Volcanics have an index of approx. 55 1/2 indicating that they represent extensional volcanism where as the Cole Mtn. basalt-type area Goble Volcanics have a high index indicative of compressional volcanism.

51% to 56% SiO_2 were used in tectonic interpretations. Of fourteen analyses of Tillamook Volcanics that fit within these chemical restrictions 12 plotted in the spreading center island field and 2 plotted in the continental field. While over 8,000 analyses were used to define the fields in this diagram, relatively few analyses were used to define the spreading center island field. This field is primarily based of analyses of volcanic rocks from Iceland and the Galapagos Islands (Pearce et al., 1977). Of interest is the fact that only one of the great number of analyses from ocean floor and ocean island (non spreading center islands such as the hot spot generated Hawaiian chain) areas plotted in the spreading center island field. This strongly suggests that the Tillamook Volcanics are not normal oceanic islands or oceanic crust. In addition, five valid analyses of Cole Mountain basalt and the field of the type area Goble Volcanics were plotted on this diagram. All of these samples plot in the orogenic field which is defined as rock from island arcs such as the Cascade Arc and subduction related active continental margins (Pearce et al., 1977).

All analyses of the Tillamook Volcanics from the thesis area plot in the oceanic island field on the MnO-TiO_2-P_2O_5 plot diagram of Mullen (1983) (fig. 27). In this field, spreading center island settings are not differentiated from other oceanic island settings. A dashed line separates the oceanic island field into alkalic and tholeiitic subfields. Analyses from the thesis area straddle the boundary as do tholeiitic basalts from the Siletz River Volcanics. This and the fact that other tholeiitic rocks plot in the alkaline field (Mullen, 1983) suggests that the boundary in figure 27 is only an approximate boundary. The two valid Cole Mountain basalt analyses (data from Timmons, 1981) plot in the island arc field. The island arc field in this diagram was in part defined by chemical analyses from the Cascade arc. This indicates that the Tillamook Volcanics are chemically distinct from volcanic rocks of the Cascade arc and that the Cole Mountain basalt is chemically similar to volcanic rocks of the Cascade arc.

Christiansen and Lipman (1972) and Petro et al. (1979) have used a calc-alkali index to distinguish between rocks formed in compressional tectonic settings and those formed in extensional tectonic settings. The calc-alkali index can be estimated from trends on a $CaO/(Na_2O+K_2O)$ vs. SiO_2 diagram. The index is defined as the value of SiO_2 where the curve intercepts at a ratio value of 1.0. The calc-alkali index (C/A) for the Tillamook Volcanics-Grays River area Goble Volcanics is approximately 55 1/2 whereas the calc/alkali index for the Cole Mountain basalt-type area Goble Volcanics is approximately 63 (fig. 28). Christiansen and Lipman (1972) and Petro et al. (1979) concluded that compressional suites have indices that are high (60-64), whereas extensional suites have indexes that are low (50-56). Therefore, the Tillamook Volcanics classify as an extensional suite on the diagram and the Cole Mountain basalt classifies as a compressional suite.

Jackson (1983) used trace elements in an attempt to determine the tectonic setting of the Tillamook Volcanics. He compared REE patterns of Tillamook Volcanics to REE patterns of volcanic rocks from various tectonic settings. Although absolute abundances of REE are quite different he considered the Tillamook Volcanics to be most like the Icelandic volcanics. In addition, the Tillamook Volcanics are petrographically similar to volcanic rocks from Iceland and the Galapogos Islands described by Carmichael et al. (1974).

In summary, it can be stated that the major element discriminant diagrams used in this study show that the Tillamook Volcanics are geochemically and petrogenetically similar to volcanic rocks forming in oceanic spreading center island tectonic settings (extensional) as opposed to compressional tectonic settings (i.e. island arcs). The plots on the discriminant diagrams do not necessarily imply that the Tillamook Volcanics formed in exactly the same tectonic setting as Iceland and the Galapagos Islands (spreading center islands).

Three significant factors can be ascertained from geochemical data of middle to upper Eocene basaltic units in northwest Oregon and southwest Washington: 1) Tillamook Volcanics-Grays River area Goble Volcanics are geochemically distinct from normal oceanic crust, normal hot spot generated seamounts and islands, continental basalts, and orogenic (island arc sequences such as the Cascade arc); 2) Cole Mountain basalt- type area Goble Volcanics samples consistently plot in an orogenic (compressional, island arc) field on the discriminant diagrams; and 3) the Tillamook Volcanics-Grays River area Goble Volcanics plot on trend with the Siletz River Volcanics-Crescent Formation on several diagrams (figs 17 and 25) but tend to plot in the oceanic island field rather than the spreading center island field on the discrimanant diagrams.

Tectonic-Petrogenetic Models.

Interpretation of the geochemical data presented above can be used to speculate on the origin and development of the Tillamook Volcanics-Grays River area Goble Volcanics and the Cole Mountain basalt-type area Goble Volcanics. The lower to middle Eocene Siletz River Volcanics-Crescent Formation oceanic crust was accreted to the North American Continent at about 45 Ma (Wells et al., 1984; McElwee and Duncan, 1984). The middle Eocene Tyee and Yamhill formations were deposited on this oceanic crust and Tillamook volcanism began between 43 and 45 Ma. (Wells et al., 1984; Magill et al., 1981)). The Challis arc of eastern Washington and Idaho was active from about 55-43 ma. with the arc shifting to a western Cascade axis at about 42 ma. This information indicates that the Tillamook Volcanics formed in a forearc setting during a period of reorganization of arc magmatism. The Tillamook Volcanics, however, do not have any geochemical affinites to arc volcanism and are located some 100 km west of the western Cascade arc.

Several petrogenetic-tectonic models have been proposed to account for the presence of Tillamook Volcanics (which include the Grays River area Goble Volcanics based on data from this report) and type area Goble Volcanics (which include Cole Mountain basalt based on data from this report) (Beck and Burr, 1981; Duncan, 1982; McElwee and Duncan, 1984; Wells et al., 1984). The presence of the above volcanic sequences is somewhat enigmatic because of their position in the forearc. The forearc region is usually characterized by an absence of volcanism (Best, 1982). It has been difficult to define the petrogenetic and tectonic setting of the Tillamook Volcanics because a number of major regional events occurred near the time of Tillamook volcanism: 1) accretion of Siletz River

Volcanics-Crescent Formation oceanic crust to the North American Continent at about 44 Ma and corresponding westward jump of the subduction zone (Wells et al., 1984) 2) westward migration of the volcanic arc from a Challis arc position to a Cascade arc position at about 43 Ma (Wells et al., 1984); and 3) demise of the Kula-Pacific-Farallon triple junction on oceanic crust to the west of present day Oregon and Washington between 50 and 43 Ma (Byrne, 1979; Wells et al., 1984).

Duncan (1982) considered the Tillamook Volcanics to be related to the Siletz River Volcanics and the Crescent Formation. In this model a spreading ridge centered hot spot produced an age progressive (lower to middle Eocene) sequence of oceanic islands and seamounts, including the Tillamook Volcanics, which were accreted onto the North American Continent during the middle Eocene. Recent studies, however, indicate that the Siletz River-Crescent Formation terrain was accreted to the North American continent at about 44 Ma prior to eruption of Tillamook Volcanics. Therefore, the model of Duncan (1982) is not considered to be viable.

McElwee and Duncan (1984) suggested that the "Yellowstone" hotspot produced the Siletz River Volcanics-Crescent Formation terrain and then after accretion of the terrain produced the Tillamook Volcanics and the "Goble Volcanics". However, in the surface and subsubsurface of the thesis area all of the above volcanic units are stacked upon one another (with intervening sedimentary strata) and range from approximately 55 Ma to 37 Ma. It appears unlikely that a fixed mantle hotspot would remain at a single location for 18 m.y. producing a thick succession of volcanic rocks. Geochemical data from this report indicate that the Siletz River Volcanics-Crescent Formation were produced in an oceanic island setting (includes hotspot generated seamounts), that the Tillamook Volcanics-Grays River area Goble Volcanics were produced in a spreading center island (extensional) setting, and that the type area Goble Volcanics-Cole Mountain basalts were produced in an orogenic (compressional) setting. The hotspot model of McElwee and Duncan (1984) does not adequately explain these apparent changes in tectonic setting.

Wells _et al._ (1984) suggest that after accretion of the Siletz River-Crescent Formation terrane to North America a marked decrease in the rate of Farallon plate-North American plate convergence between 43 and 28 Ma resulted in a period of extensional volcanism in the Coast Range forearc region producing the Tillamook, "Goble", Cascade Head, and Yachacts volcanics as well as Oligocene intrusive rocks in the central Oregon Coast Range. The above model of Wells _et al._ (1984) considers all of of the forearc volcanism to be extensional and, therefore, fails to explain the compressional affinities of Cole Mountain basalt and type area Goble Volcanics.

A new model is presented in this report that addresses the apparent change from tholeiitic spreading center island type of volcanism to calc-alkaline orogenic type of volcanism in the developing forearc region. As previously demonstrated the Tillamook Volcanics are geochemically quite distinct from island arc rocks and it is highly unlikely that they represent a protoarc. Therefore, oceanic petrogenetic mechanisms must be called upon to produce the Tillamook Volcanics. The northward moving Kula-Farallon spreading ridge was being subducted beneath the North American continent near the present Oregon-Washington border at about 48 Ma (Wells et al., 1984). During initial Tillamook-Grays River area Goble volcanism (approx. 43 Ma.) The Kula-Farallon spreading ridge was becoming extinct and was probably located off the coast of Washington (Wells et al., 1984). It is, however, quite possible that a northwest-trending transform fault offset the spreading ridge and that the offset ridge was being subducted beneath the North American plate in the vicinity of the Washington-Oregon border at about 43 Ma (fig. 29). Wells et al. (1984) state,

> "An orientation for the ridge (Kula-Farallon) can be calculated based on Kula-Pacific and Farallon-Pacific spreading velocities, but there is little controll on the location of the ridge with respect to North America because evidence for a possible transform offset of the ridge has been subducted".

This subducting spreading ridge, possibly in conjunction with a hotspot, may have produced the Tillamook Volcanics-Grays River area Goble Volcanics.

The model presented above would explain the major oxide chemistry of the Tillamook Volcanics. In addition such a model would explain some of the geochemical similarities between the Siletz River Volcanics and the Tillamook Volcanics (e.g. the fact that the two units plot along trend in figures 17 and 25). Duncan (1982) suggested that the Kula-Farallon ridge, the same ridge suggested in this report to have produced the Tillamook Volcanics, may have produced the Siletz River Volcanics and the Crescent

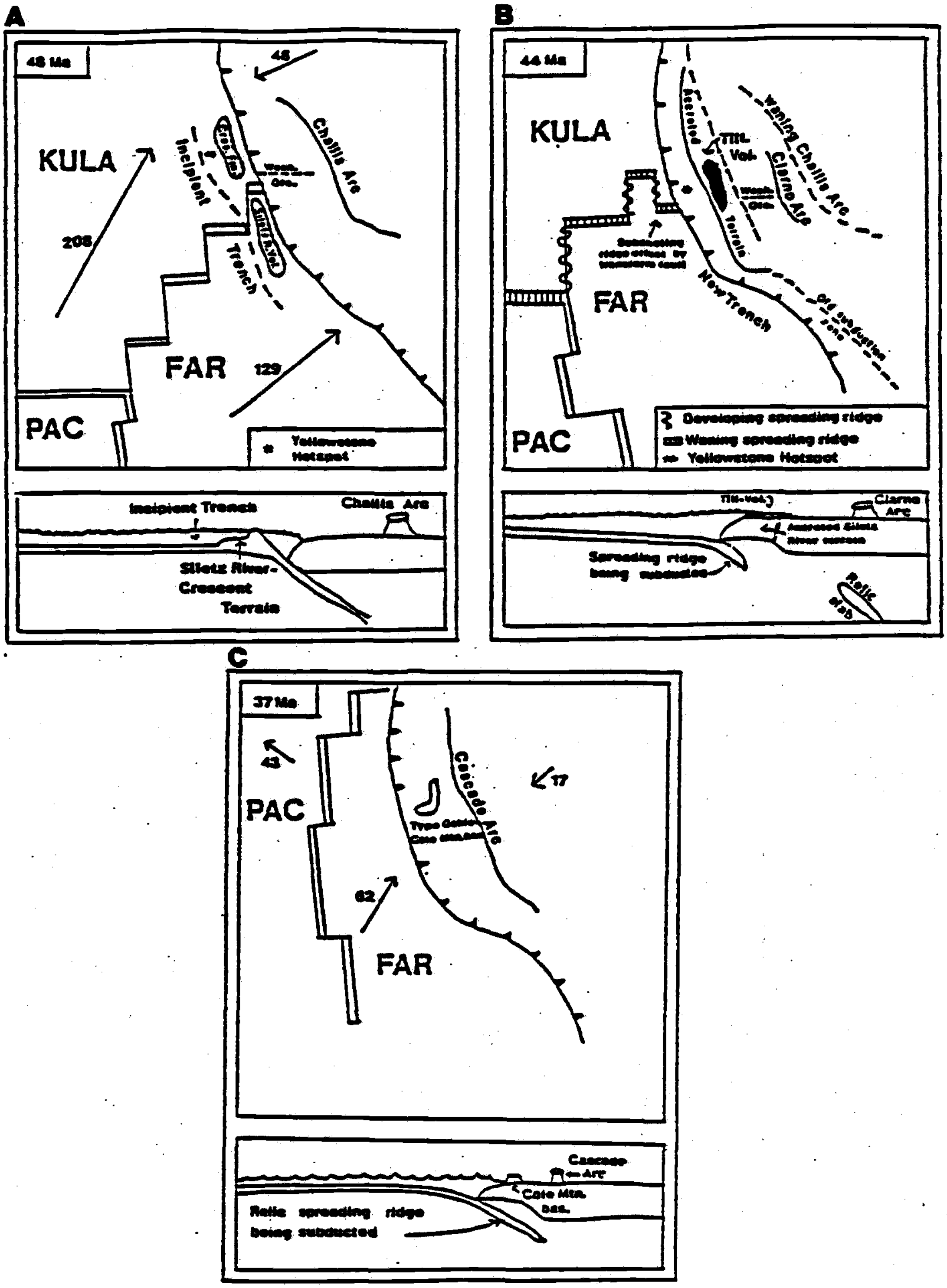


Fig. 29: Tectonic models for formation of the Tillamook Volcanics and the Cole Mountain basalt. A is modified from Wells <u>et al.</u> (1984).

Formation. The fact that the Siletz River Volcanics have oceanic island affinities whereas the Tillamook Volcanics have spreading center oceanic island affinities could be attributed to the centering of the "Yellowstone" hotspot over the ridge during Tillamook time and an absence of the hotspot during Siletz River time. Alternatively, the slight geochemical differences between the units on discriminent diagrams may reflect changes unrelated to tectonic environment.

Cole Mountain basalt-type area Goble Volcanics have been shown in this report to have chemical affinities to orogenic (compressional, island arc) volcanic rocks. Several model are herein suggested for the formation of these volcanic rocks.

Model 1. The Cole Mountain basalt-type area Goble Volcanics could have been produced by continued subduction of remaining portions of the Kula-Pacific ridge. Hurst et al. (1982) suggested that volcanic rocks of the southern California borderland are genetically related to subduction of the East Pacific Rise beneath the North American plate. These rocks include the Conejo, Santa Cruz Island, and Catalina Island volcanic suites. The Santa Cruz volcanic suite consists of basalts to dacites with the basalts and basaltic andesites having a major element chemistry that is very similar to the Cole Mountain basalt-type area Goble Volcanics (table 3). The only significant difference being the more abundant (2%)

Table 3: Chemical comparison of Cole Mountain basalt to the Conejo volcanic suite of southern California

Unit	SiO2	TiO2	Al2O3	FeO*	MnO	MgO	CaO	Na2O	K2O	P2O5
Santa Cruz*	55.5	1.6	15	8.5	0.15	5.2	7.5	3.7	0.7	0.26
Cole Mtn. b.	55.0	1.5	17	9.0	0.15	4.1	8.5	3.3	0.6	0.29
Till. Vol.	53.0	1.5	15	10.5	0.21	3.4	8.0	3.6	1.4	0.72

*Data from Crowe et al. (1976)

Al_2O_3 in the Cole Mountain basalt and the slightly more abundant (1%) MgO in the Santa Cruz volcanic suite. The Conejo, Santa Cruz, and Catalina island suites plot in a similar position to Cole Mountain basalt on AFM and FeO*/MgO vs. FeO* diagrams (figs. 17, 18 and Hurst et al., 1982) and, therefore, classify as "mildly" calk alkaline on the classification scheme of Irvine and Baragar (1971). This indicates that Cole Mountain basalt could have been produced by continued subduction of part of the Kula-Farallon ridge and as the slab continued to descend, deeper partial melting. This may have resulted in a "mixing" of compressional and extensional magmatic processes.

Model 2. Cole Mountain basalt-type area Goble Volcanics may represent a proto Cascade arc. Data from figures 27 and 28 shows that the above units are chemically similar to volcanic rocks generated in island arc settings. It is possible that Cole Mountain basalts are related to early arc magmatism and that migration of the melt up the oceanic slab resulted in the far westward, forearc position of the basalts.

Model 3. Type area Goble volcanism could represent an early, westernmost extension of the Cascade arc and the Cole Mountain basalts may be invasive flows that originated from the type area Goble Volcanics. Beeson et al. (1979) have suggested that subaerial flows can invade semiconsolidated, water saturated marine sediments and form invasive dikes and sills far from the original source areas.

Model 4. Discriminant diagrams are unable to determine the petrogenetic environment of the Cole Mountain basalt-type area

Goble Volcanics. In other words, it is possible that these rocks were not produced in a compressional environment.

There are several problems with the above models. Physical and stratigraphic relationships in the Cole Mountain basalt indicate that they are not invasive but are locally erupted (see Cole Mountain basalt section) making model 3 unlikely. The consistant plotting of Cole Mountain basalt-type area Goble volcanics in the compressional field of several different diagrams (figs. 27 and 28) suggests that model 4 is inadequate. Models 1 and 2 are considered to be the best. More detailed petrologic and tectonic data is needed before more definitive petrogenetic modeling of the volcanic rocks in northwest Oregon and southwest Washington can be accomplished.
One problem with all of the above models is that they do not explain the presence of the Oligocene Yachacts volcanics and Oligocene intrusive rocks in the forearc. These rocks may be unrelated to the Cole Mountain basalt, as is suggested by age differences and physical separation. These rocks may have been produced by a decreased rate of convergence of the North American and Farallon plates as suggested by Wells et al. (1984).

Within the thesis area it is difficult to see any distinct geochemical trends in the Tillamook Volcanics but regionally (e.g. Clatsop and Tillamook counties) trends are apparent (figs. 23, 24, & 25). At the base of the Tillamook Volcanics and to the west the rocks are less evolved. This is evidenced by relatively abundant CaO, MgO, and FeO* in samples from the base of the sequence. In addition, the basal Tillamook Volcanics are depleted in LREE relative to the uppermost Tillamook Volcanics in the Green Mountain area (fig. 22). The major element geochemical trends on figure 25 are interpreted as an overall differentiation trend. These trends are similar to classic fractionation trends and are similar to fractionation trends of St. Helena Island in the south Atlantic (Carmichael <u>et al</u>., 1974). CaO, MgO, FeO*, and TiO_2 decrease with increasing SiO_2 content whereas K_2O and Na_2O increase with SiO_2 enrichment. P_2O_5 content increases, then levels, and then decreases, probably in response to apatite crystallization. Although the geochemical data are consistent with an overall fractional crystallization sequence, the presence of more silicic flows (<u>e.g.</u> basaltic andesite sample 674) interbedded with mafic flows in the thesis area and elsewhere suggests that a variety of differentiation mechanisms were operative. It is possible that several magma chambers were being sequentially filled and then tapped. It is also possible that a single magma chamber was repeatedly replenished from a greater depth.

It is suggested that cessation of Tillamook volcanism in the late middle Eocene (approx. 40 Ma) resulted in thermal subsidence and subsequent transgression of the overlying Hamlet formation. Eustatic sea-level curves of Vail and Mitchum (1979) show that the middle to late Eocene was a time of global regression, therefore implying that the Hamlet formation transgression was tectonically controlled (fig. 30). There is a problem accurately correlating the time scale of Vail and Mitchum (1979) with the time scale used in this report; figure 30 is a best attempt of the correlation. Tillamook Volcanics are not interbedded with the overlying Roy Creek member in the thesis area, which is interpreted to be located near

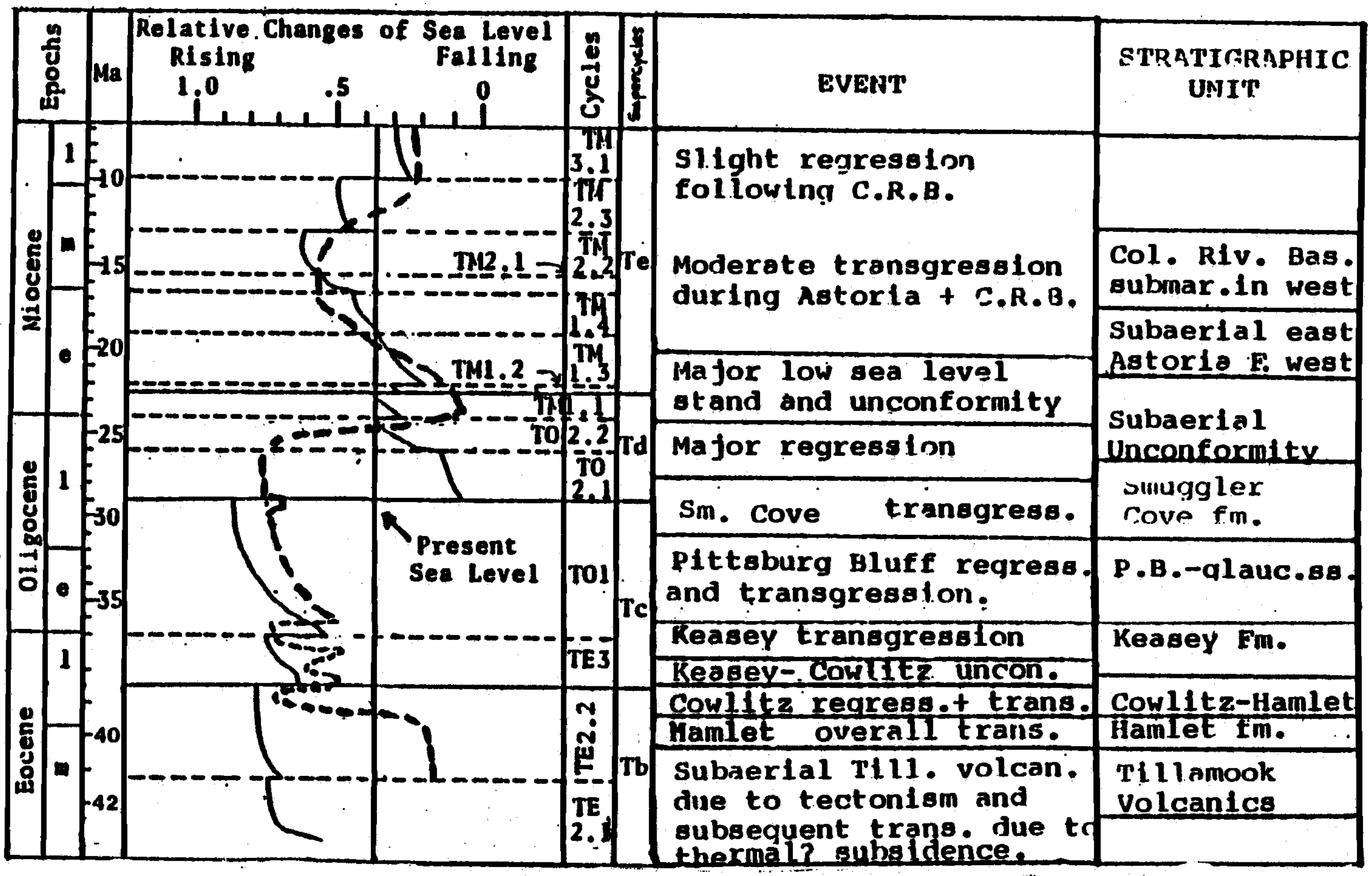


Fig. 30: Comparison of eustatic sea level curves from Vail and Mitchum (1979)(solid line) to an estimated sea level curve for the thesis area (dashed line). Note the large discrepancy in the curves during the late middle Eocene. The right hand part of the diagram lists the stratigraphic units present in the study area and interpreted depositional events.

the center of the "Tillamook Island". Therefore, the cessation of volcanism was quickly followed by erosion and transgression suggesting the possibility of a thermal subsidence model.

In conclusion, the presence of relatively thin and laterally extensive basalt flows, rare pyroclastics, low depositional dips, and the large aerial extent of the Tillamook Volcanics suggest that they formed a broad shield-island complex in a reorganizing forearc. Regional studies (e.g. Wells et al., 1983; Bruer et al., 1984) suggest that on the island margins and at the base submarine volcanics interfingered with marine sediments (e.g. Yamhill Formation). The "Tillamook Island" was physically similar to islands in the Hawaiian chain and geochemically similar to spreading center islands such as Iceland. The Tillamook Volcanics may have been generated in an extensional tectonic setting caused by the subduction of a remanant of the Kula-Farallon plate beneath the North American plate.

HAMLET FORMATION

Nomenclature and Distribution

The Hamlet formation is proposed in this report for a thick (200m to 900m) marine sequence of late Narizian (late middle to late Eocene) mudstones and siltstones with subordinate sandstones and basaltic conglomerates occurring in northwest Oregon. In the vicinity of the thesis area these rocks have previously been mapped as undifferentiated Tertiary sedimentary rocks (Warren et al., 1945; Wells and Peck, 1961) and as Tertiary volcanic rocks and Oligocene to Miocene sedimentary rocks (Beaulieu, 1973). Wells *et al*. (1983), using preliminary mapping from this thesis referred the late Narizian strata to the Cowlitz Formation. In eastern Clatsop County, southern Columbia County, and northern Washington County, the strata of the proposed Hamlet formation have previously been mapped as Cowlitz Formation (Warren and Norbisrath, 1946; Wells and Peck , 1961; Van Atta, 1971; Newton and Van Atta, 1976; Jackson, 1983; Wells *et al*., 1983). The distribution of the Hamlet formation on the surface and in the subsurface of Clatsop County is shown by Niem and Niem (in press) and Martin *et al.* (in press).

Cowlitz Fm.-Yamhill Fm. Nomenclature Problem

The Cowlitz Formation was proposed by Weaver (1912) for a 60m section of Eocene (late Narizian) siltstones and sandstones in southwest Washington ("Big Bend locality"). He subsequently expanded the definition to include a 1,300m thick, late Narizian, predominantly shallow marine sandstone section along Oequa Creek, in southwest Washington (Weaver, 1937). Warren and Norbisrath (1946) and Warren *et al.* (1945) extended the Cowlitz Formation into northwest Oregon (mainly Columbia County). They divided the Cowlitz Formation in Oregon into four late Narizian members: 1) a basalt conglomerate; 2) a lower "shale" member; 3) a sandstone member; and 4) an upper "shale" member. Deacon (1953) considered the Oregon rocks to be lithologically distinct from the type area Cowlitz Formation and proposed the name Rocky Point formation for these rocks. Subsequent workers in northwest Oregon have, however, continued to use the Cowlitz nomenclature (*e.g.*, Van Atta 1973; Newton and Van Atta, 1976; Timmons, 1981). Henricksen (1956) added a 1,600 m thick section of upper Narizian to Ulatisian bathyal strata to the base of the type Cowltiz Formation in southwest Washington (Stillwater Creek member). However, in 1981 Wells restricted the Cowlitz Formation in the Willapa Hills of southwest Washington to a sequence of upper Narizian sandstones (essentially the Olequa Creek section of Weaver, 1912) and referred older sedimentary rocks to the McIntosh Formation.

The above summary shows that the Cowlitz Formation nomenclature has undergone many significant changes over the past 70 years. The restriction of the type Cowlitz Formation in southwest Washington by Wells (1981) to a predominantly sandstone unit, as it was originally defined by Weaver in 1937, is rather sensible. It allows the formation to be a lithologically distinct, mappable unit as required by the Stratigraphic Code (1984). It, therefore, follows that the Cowlitz Formation in northwest Oregon should be restricted to an equivalent unit (i.e., sandstone member of Warren and Narbisrath, 1946). This definition of the Cowlitz Formation appears to be accepted by most workers in northwest Oregon (Niem, personal communication, 1984). In addition, Bruer et al. (1984) in their subsurface work show that there is a regional unconformity at the base of the Cowlitz Formation sandstone member of Warren and Norbisrath (1946). Bruer et al. (1984) restricted the definition of the Cowlitz Formation to this sandstone member and the overlying shale member. This is in accordance with the Code of Stratigraphic Nomenclature which says that a formation should not have a major unconformity in it. The revised definition of the Cowlitz Formation leaves the basal conglomerate and lower "shale" members of Warren and Norbisrath (1946) without a formational assignment.

Subsurface workers (e.g., Bruer, 1984) have recently included these upper to possibly lower Narizian units (conglomerate and lower shale members of Warren and Norbisrath, 1946) in the Yamhill Formation. The type section of the Yamhill Formation is located along Mill Creek and the strata are Ulatisian to "upper" Narizian in age (Gaston, 1974). Data from this thesis and from Mumford (in prep.) shows that the microfauna in the "shale" member is different and younger than the microfauna in the type Yamhill Formation (Rau, W. W. and McDougall K. A., pers. comm., 1984). In addition, the "shale" member microfauna is very similar to that found in the Nestucca Formation (Rau, pers. comm., 1984). Wells et al. (1983) have restricted the Yamhill Formation to mudstones which overlie the Siletz River Volcanics and underlie and interfinger with the

Tillamook Volcanics. This unit is equivalent in part to the Tyee Formation and to the type section Yamhill Formation along Mill Creek, Oregon (see fig. 5).

Several workers in the Tualatin Valley region (e.g., AlAzzaby, 1980; Schlicker and Deacon, 1967), however, have mapped "lower" Narizian Yamhill Formation on top of "Tillamook Volcanics" and below the upper (Narizian) Spencer Formation. This mapping relationship may have helped influenced Bruer et al. (1984) to correlate the type Yamhill Formation to the conglomerate and "shale" members of Warren and Norbisrath (1946) in the subsurface of Clatsop and Tillamook counties. The "Tillamook Volcanics" mapped by Schlicker and Deacon (1967) near the type section of the Yamhill Formation, however, are lithologically and chemically identical to nearby outcrops of Siletz River Volcanics and lower Narizian basalt sills (i.e., contain olivine, abundant zeolites, and submarine basalts). There is little doubt that these rocks are the older Siletz River Volcanics and not Tillamook Volcanics. In any case, they are not correlative to the thick sequence of subaerial Tillamook Volcanics in the thesis area.

Hamlet Formation

It is informally proposed in this report that the congomerate and "shale" members of Warren and Norbistrath (1946) in Columbia County be combined with the undifferentiated upper Narizian rocks in the thesis area and southern Clatsop County to form the Hamlet formation. Advantages to this nomenclature are: 1) the Cowlitz Formation in Oregon would be restricted to mappable, predominantly shallow marine micaceous arkosic sandstone unit with a thin mudstone unit overlying the sandstone (upper "shale" member of Warren and Norbisrath, 1946). This stratigraphic sequence is lithologically similar to the type Cowlitz Formation in southwest Washington as first defined by Weaver (1912) and later restricted to by Wells (1981); 2) the lithologically and depositionally distinct sedimentary rocks above the Tillamook Volcanics would be separated from the older sedimentary rocks (e.g., Yamhill formation of Wells et al., 1983 and Tyee Formation) beneath and interfingering with the Tillamook Volcanics. The only major disadvantages of the Hamlet nomenclature arise from the difficulty in distinguishing the Hamlet mudstone from the Yamhill mudstone where the Tillamook Volcanics are absent. This situation appears to occur only in the subsurface of Columbia County (Bruer et al., 1984) and in a small area near the Tualatin Valley. In the subsurface this problem could be alleviated by referring the lower Ulatisian-lower Narizian strata to the McIntosh Formation of Wells (1981) where the Tillamook Volcanics are absent.

Disadvantages of including the basal conglomerate and "shale" members in the Yamhill Formation are numerous: 1) strata younger than the type area would be added to the unit (i.e., new members); 2) lithologies, depositional environments, and faunas not represented in the type section would be added to the formation; 3) the Yamhill Formation would overlie and underlie a 2,000 m thick sequence of subaerial basalts and cross a significant unconformity at the top of the volcanic sequence (Wells et al., 1983; this study; Mumford, in prep.; Safley, in prep.). The volcanic rocks and the associated unconformity cover an area of many hundreds of square kilometers in the surface and subsurface of Clatsop, Columbia, and Tillamook counties (Niem and Niem, in press; this study) and are by no means minor features; 4) the Yamhill Formation would both overlie and be laterally equivalent to lithologically similar mudstones in the upper Narizian Nestucca Formation which has been mapped by Snavely and Vokes (1949) and Snavely et al. (1969, 1976) in the Newport and Tillamook embayments as overlying the Yamhill Formation. In other words, it would have somewhat arbitrary upper and lateral boundaries; and 5) the Yamhill Formation of northwest Oregon and the McIntosh Formation of southwest Washington would be differentiated on a purely geographical basis (the state line) instead of on a geologic basis. The only major advantage of the Yamhill nomenclature is that it tends to simplify subsurface correlations between the Willamette Valley and the Nehalem River Basin (Bruer et al., 1984).

In summary, the Yamhill Formation nomenclature has been rejected for surface geologic work in the Nehalem River Basin. Extension of the Yamhill Formation into this area would serve to obscure important tectonic and depositional events. In addition, the extension of the formation would be in contrast to the "spirit" of the North American Stratigraphic Code (1983). Schematic presentations of the pre-1983 nomenclature, the nomenclature of Bruer et al. (1984), and the nomenclature suggested in this study are shown in figure 31.

Figure 31 shows that Bruer et al. (1984) have distinguished "Cowlitz mudstones" from the underlying Yamhill Formation mudstones on the basic of well log characteristics and microfossil assemblages in the subsurface of northern Clatsop County. Detailed examination of well logs and well cuttings from the same area by Martin et al. (in

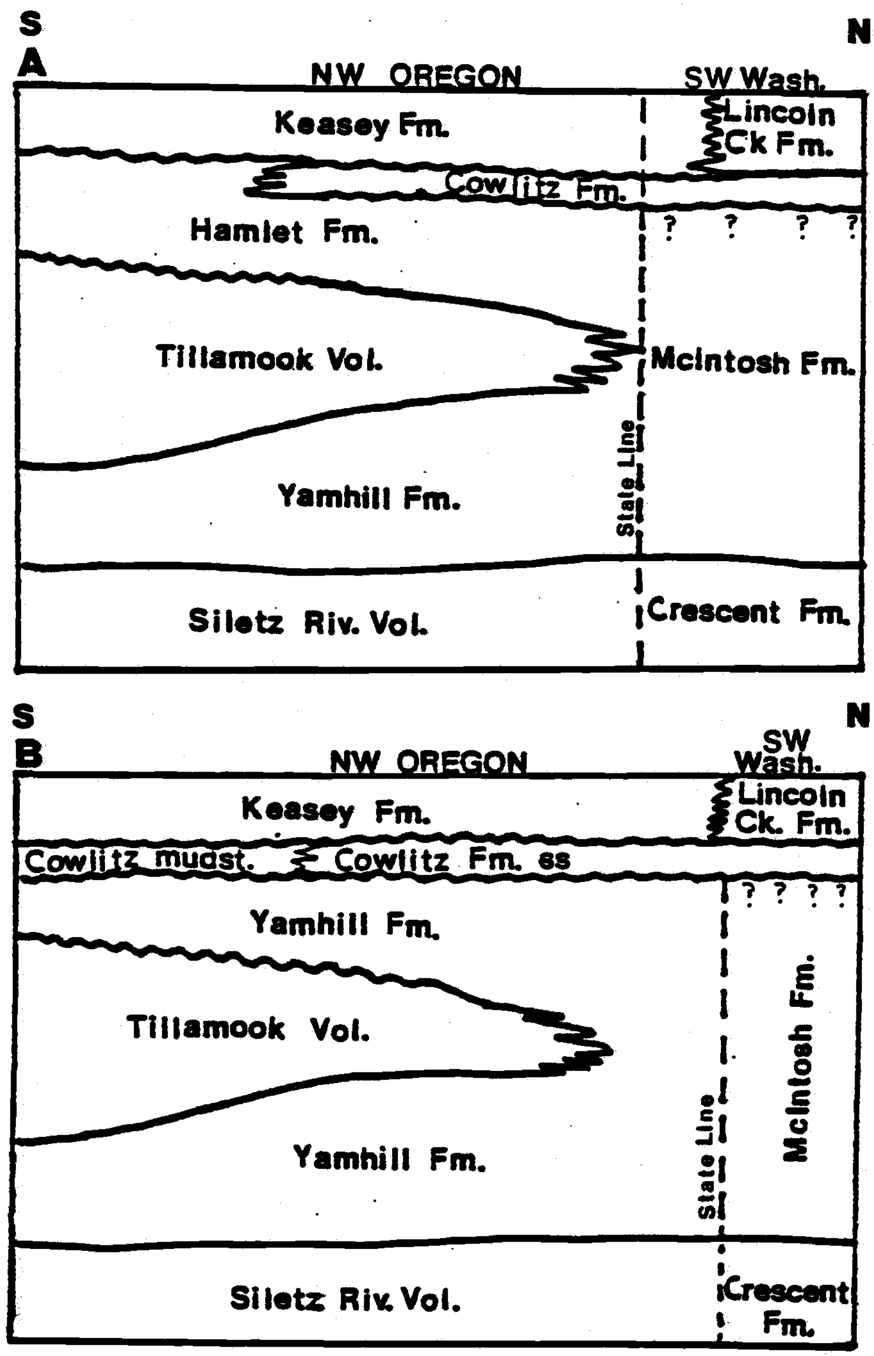


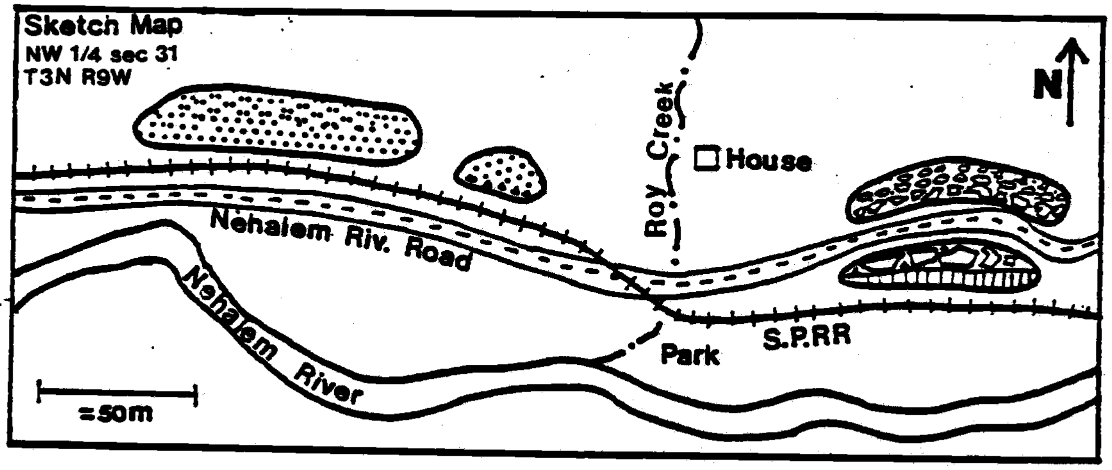
Fig. 31. Schematic diagrams showing the stratigraphic nomenclature proposed in this study (A) and the stratigraphic nomenclature of Bruer et al. (1984)(B). Previous workers included the Hamlet formation of (A) in the Cowlitz Formation.

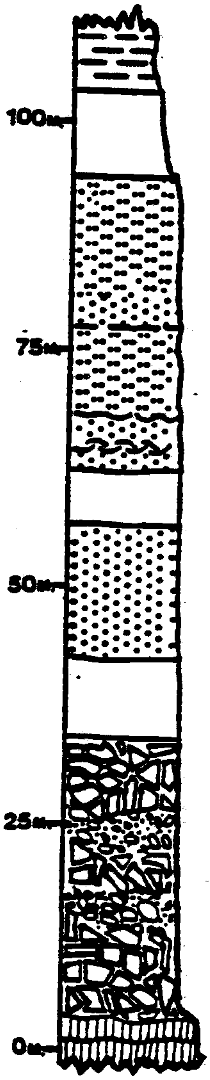
press) has, however, shown that there is little or no lithologic difference between these units. Within the thesis area it is not possible to separate on a litologic basis the "Cowlitz mudstones" from the underlying mudstones outcropping in the Hamlet formation. The "Cowlitz mudstones" in western Clatsop County, therefore, are not a mappable unit on the surface and the term has been discarded. The "Cowlitz mudstones" of Bruer et al. (1984) have been included in the the Hamlet formation mudstones. In addition, south of the thesis area the Hamlet formation is laterally correlative to the mapped extent of the Nestucca Formation and undifferentiated Narizian rock (Wells et al., 1983) not the underlying mapped extent of the Yamhill Formation. The Nestucca Formation has some lithologic similarities to the Hamlet formation (e.g., basal basalt conglomerate and overlying bathyal mudstone) but tends to be distinclty bedded with light colored tuff layers (Snavely and Vokes, 1949; Snavely et al., 1969). Ray Wells of the U.S. Geological Survey is currently mapping south of the thesis area and recommends that the upper Narizian strata in the Nehalem River Basin not be included in the Nestucca Formation (pers. comm., 1984).

The Hamlet formation has been divided into three members to aid in depositional and structural interpretations. The basal unit, the Roy Creek member, consists of 0-125m of basaltic sandstone and conglomerate. Overlying this unit are the Sweet Home Creek and Sunset Highway members which interfinger with one another (plate IV). The Sweet Home Creek member consists primarily of mudstone whereas the Sunset Highway member is dominated by interbedded basaltic and arkosic sandstones (Mumford, in prep.). Both the Roy

Creek and Sweet Home Creek members crop out in the thesis area; the Sunset Highway member generally crops out in the eastern part of Clatsop County, some 10 km to the east of the thesis area (Mumford, in prep.; Niem and Niem, in press). Plate IV shows the stratigraphic relationships of the units in the Hamlet formation.

The Hamlet formation crops out in an arcuate pattern around the Tillamook Volcanics in northern Tillamook, southern Clatsop, southern Columbia, and northern Washington counties (fig. 27). The southern extent of the formation is suggested to be near Tillamook Bay on the coast and near Gales Creek in the Willamette Valley (see fig. 21). Good exposures of the unit occur near Hamlet on several unnamed logging roads (N 1/2 sec. 16, T4N, R8W). The proposed type section of the Roy Creek member is located near Roy Creek on the Southern Pacific Railroad cut, approximately 3 km south of the thesis area in northernmost Tillamook County (fig. 32). The author was referred to these excellent exposures by Dr. Alan R. Niem of Oregon State University and Ray Wells of the U.S. Geological Survey. Figure 32 is a composite section of these exposures with figure 33 showing the lithologies present. The base of the member is defined as the unconformity between the lowermost basaltic conglomerate or sedimentary breccia and the uppermost subaerial flow of the Tillamook Volcanics; the top of the unit is the boundary where basaltic sandstones or conglomerates no longer dominate the section. This boundary is usually sharp occurring over several feet. Within the thesis area the Roy Creek member is overlain by mudstones of the Sweet Home Creek member and in eastern Clatsop County the Roy Creek member is overlain by arkosic sandstone rich rocks of the Sunset





Medium gray, slightly micaceous, faintly laminated mudstones of the Sweet Home Ck. member.

Cover

Dark gray, fine-grained, subrounded, moderately well-sorted, basaltic sandstone.

Thin (8 cm.) bed of calcareous mudstone

Dark gray, fine- to coarse-grained, subrounded to well-rounded, moderately well-sorted, fossiliferous, well indurated, basaltic ss. (see fig. 29 for photograph)

Cover

Dark gray, fine- to medium-grained, subrounded to angular, moderately well-sorted basaltic sandstone.

Cover

Dark gray basaltic breccia plus basaltic boulder to pebble conglomerate. Breccia ranges from 1 meter to 1 cm. in diameter. Conglomerate is rounded and moderately sorted (see fig. 29 for photograph).

Dark gray, sparsely porphyritic, subaerial basalt flows of the Tillamook Volcanics.

Fig. 32. Sketch map and columnar section of the type section Roy Creek member (measurements are approximate).

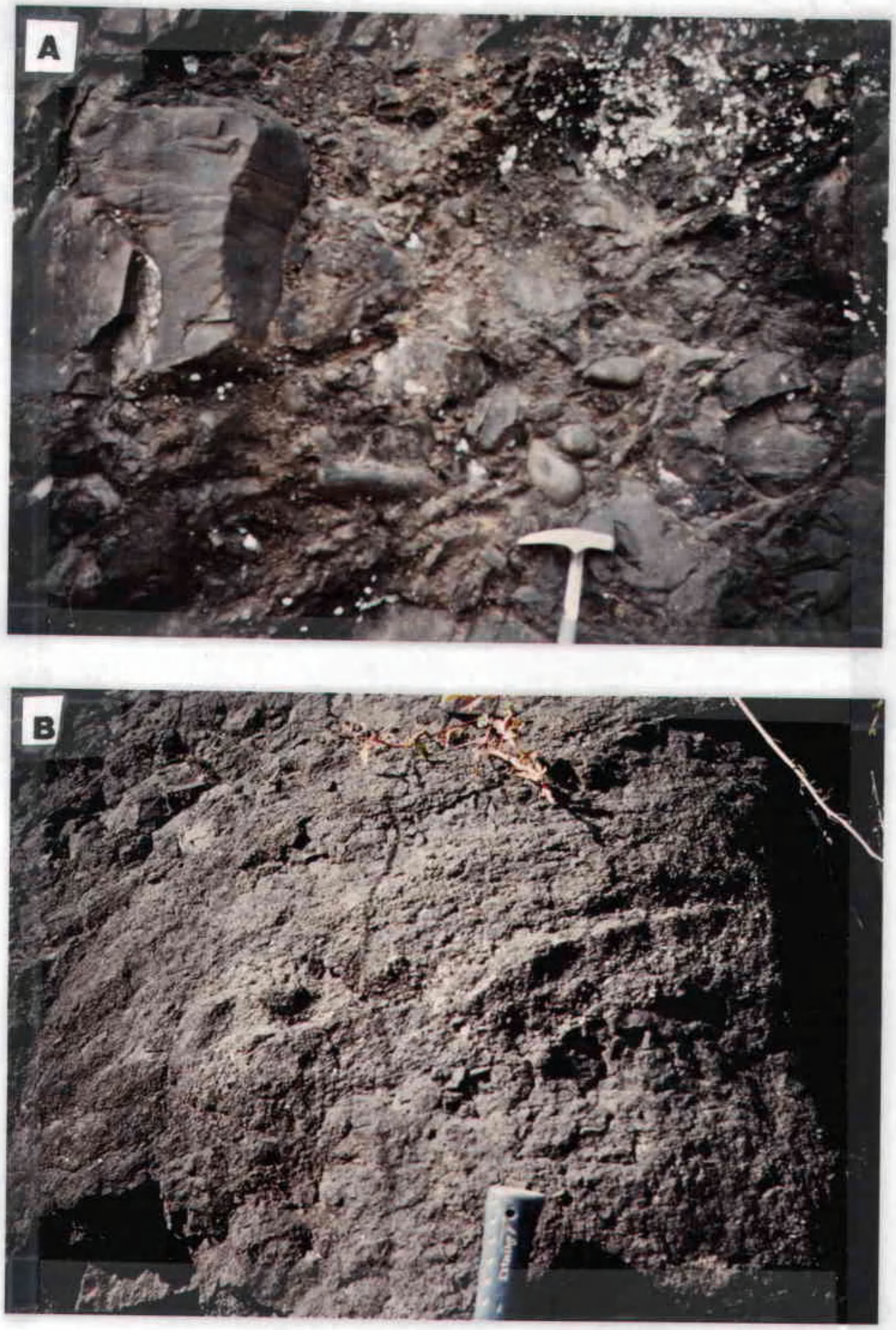


Fig. 33. Basal conglomerate (A) and basaltic sandstones (B) at the type section of the Roy Creek member. Note the abundant shell debris in B.

Highway member (Mumford, in prep.; Safley, in prep; Niem and Niem, in press). The proposed type section of the Sweet Home Creek member is along Sweet Home Creek in the southeastern corner of the thesis area (fig. 34). Exposures here are small but relatively continuous and fresh. The lower Contact of the Sweet Home Creek member is best exposed along Gods Valley Road in the southwestern corner of the thesis area (locality 339, SW1/4 SW1/4 sec. 8, T3N R9W). The upper contact is best exposed along the Nehalem River Road near the confluence of Sweet Home Creek and the North Fork of the Nehalem River (locality 258 NW 1/4 SW 1/4 sec. 20, T4N, R8W). Mumford (in prep.) and Safley (in prep.) have proposed that a section exposed along the Sunset Highway, 2 km east of Elsie, be the type section of the Sunset Highway member.

Within the thesis area the best exposures of the Roy Creek member occur along logging roads on Rector Ridge (localities 419, 424, 425), in Helloff Creek (locality 854), in Sweet Home Creek (localities 630, 631), in small quarries near Rackheap Creek (localities 339, 365, 398), and southeast of Hamlet (localities 248 and 746). Refer to plate I for additional exposures. The outcrop pattern of the unit is restricted to the southern and eastern portions of the map area. The unit is generally well-indurated and erosionally resistant. Thickness in the thesis area ranges from 2 to 100m and averages about 25m.

Most Sweet Home Creek member exposures in the study area occur in stream beds. The best exposures are located in Sweet Home Creek (localities 553, 620, 621, 622, 628, 629) and in the North Fork of the Nehalem River (localities 548, 550, 612). Slighty

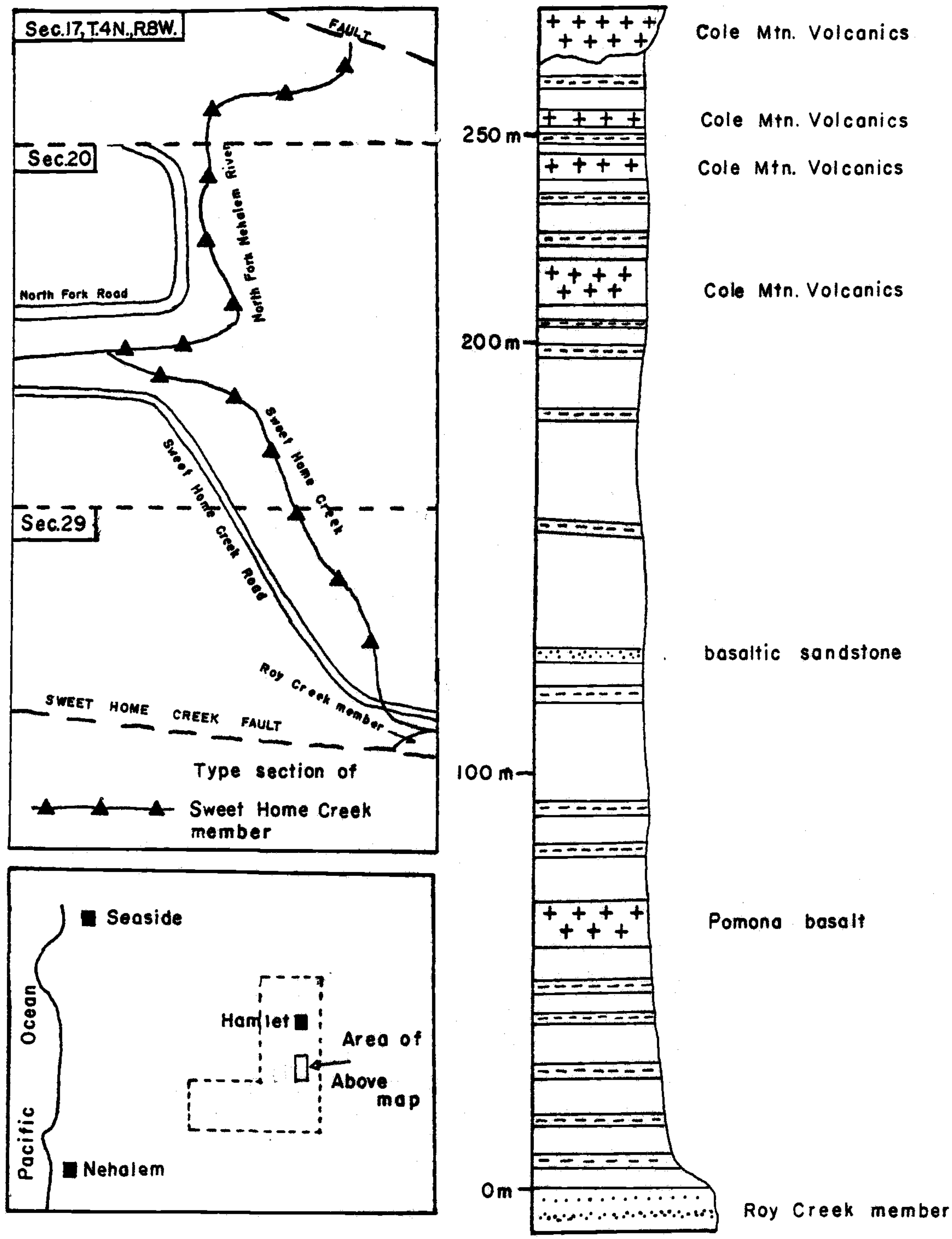


Fig. 34. Proposed type section of the Sweet Home Creek member. Most exposures occur in the bed of Sweet Home Creek.

weathered exposures occur in logging road cuts with the better exposures located near Hamlet (localities 329, 330) and near Rackheap Creek (locality 339). The Sweet Home Creek member crops out in the southern and eastern parts of the thesis area (see plate I) where, due to its low resistance to weathering, forms valleys. Incomplete exposures, the presence of sills, and moderately complex faulting make it difficult to accurately estimate the thickness of the unit. In the Crown Zellerbach 11-28 well, adjacent to the thesis area (plate III), the unit is only 137 m thick. Within the thesis area thicknesses are approximated to range between 130 m and 300 m.

Roy Creek Member

Lithology

The Roy Creek member consists of a basal basaltic boulder to pebble conglomerate, a middle coarse-grained basaltic sandstone, and an upper fine-grained basaltic sandstone (fig. 32). The basal comglomerate consists of clast-supported, rounded, moderately sorted to occasionally poorly sorted basaltic boulders (up to 1 m in diameter) cobbles and pebbles in a basaltic sand-silt matrix. The unit is generally massive but may contain faint horizontal stratification. Clasts tend to be roughly spherical and, therefore, imbrication is not present. The conglomerates typically consist of 60-85% sparsely porphyritic basalt clasts, 3-20% abundantly porphyritic (>10% labradorite and augite phenocrysts) basalt clasts, and 3-75% vesicular basalt clasts. Clasts are dark gray (N 3) to pale yellowish brown (10YR 6/2) and are lithologically identical to flow rocks in the underlying Tillamook Volcanics. Within the thesis area the thickness of the conglomerate ranges from 1-15m and averages about 5m.

A coarse-grained basaltic sandstone overlies and interfingers with the conglomerate. The contact between the two lithofacies is gradational over several meters with the coarse-grained sandstone commonly filling pore spaces between framework clasts in the upper part of the conglomerate. The coarse-grained sandstone lithofacies is massive to horizontally stratified and may contain laterally extensive beds of coarse-grained basaltic sandstone alternating with beds of finer-grained basaltic sandstone (e.g., locality 339). Beds are usually 1/2-2 m thick. The sandstone is grayish olive (10YR 4/2) to dark greenish gray (5GY 4/1) when fresh and weathers to a moderate yellowish brown (10 YR 4/2). This color change is apparently due to oxidation of iron-rich chloritic clays. The sandstone is well to moderately sorted and is composed almost entirely of subrounded basaltic rock fragments. Abraded oyster shell fragments are common at some localities (e.g., 339 and 554) and other unbroken shallow marine mollusks such as *Scurria* (gastropod) are less commonly present (Ellen Moore, personal communication, 1983). Barnacle fragments are present at the type section of the Roy Creek member. Petrographic analysis shows that cement consists of chloritic clays and more rarely calcite. Within the thesis area the coarse-grained sandstone ranges from 1-15 m in thickness and averages about 8 m.

Overlying and interfingering with the coarse-grained basaltic sandstone is a fine-grained basaltic sandstone. This sandstone is typically massive and unfossiliferous but may be horizontally stratified or may contain very faint hummocky cross-stratification (e.g., localities 425 and 656, appendix 16). A few small (1 cm) clay-filled burrows are present locally. On fresh surfaces the sandstone is grayish olive (10YR 5/2) to dark greenish gray (5GY 4/1) and weathered surfaces are a moderate yellowish brown (10YR 4/2). The thick bedded sandstone commonly weathers to large ellipsoids and from a distance may resemble basalt outcrops (fig. 35). The sandstone is usually moderately sorted and is composed of subrounded to subangular basaltic rock fragments and plagioclase. In the lower portion of the lithofacies isolated, rounded pebbles may be present. Thicknesses range from 1-40m and average about 20m.

Regionally the lithology of the Roy Creek member is similar to that in the thesis area. The volcanic clasts in the Green Mountain area are more silicic than those in the thesis area (Olbinski, 1983; Nelson, 1985). This is most likely a result of the more silicic nature of the underlying Tillamook Volcanics in that area. The Roy Creek member in the Green Mountain area also tends to be more poorly sorted, thicker, contains more volcanic breccia, and has more debris flow deposits than in the thesis area (Nelson, 1985; Safley, in prep.). The basal part of the proposed type section also contains a thick section of sedimentary breccia composed of angular basalt clasts (fig. 32).

Fig. 35: Typical exposure of fine-grained basaltic sandstones in the Roy Creek member (locality 248, SW 1/4 NW 1/4 sec 16, T4N, R8W). Note ellipsoidal weathering.

Contact Relations

The Roy Creek member unconformably overlies the Tillamook Volcanics. The unconformable nature of the contact is evidenced by the following: 1) the Tillamook Volcanics and the Roy Creek member do not interfinger in exposed areas; 2) there is a change in environment from subaerial flows to shallow marine conglomerates; 3) the contact between the two units is irregular and erosional; and 4) dikes and flows in the Tillamook Volcanics are truncated by the Roy Creek member (Nelson, 1985). Within the thesis area the lower contact is best exposed along Gods Valley Road at locality 339. Previous workers in the region have noted this unconformable relationship (Olbinski, 1983; Nelson, 1985). The upper contact of the Roy Creek member is conformable and gradational with the overlying mudstones of the Sweet Home Creek member in the thesis area (e.g. locality 339) and with the Sunset Highway member to the east (Mumford, in prep.).

Age and Correlation

The Roy Creek member is late middle Eocene to late Eocene (late Narizian) in age. No age diagnostic fossils were collected from the unit in the thesis area but late Narizian formainiferal assemblages and late middle Eocene (subzone CP-14a) calcareous nannofossil assemblages were collected from directly above the unit in the Sweet Home Creek member (e.g. localites 621, 522, 629). The uppermost part of the Tillamook Volcanics may be as young as 39 Ma (late Narizian) but are thought to be slightly older (approx. 41 Ma) (see Tillamook Volcanics section). This age bracketing and the conformable contact with the Sweet Home Creek member demonstrates a late Narizian age for the Roy Creek member. Molluscan fossils collected from the Roy Creek member in adjacent areas also support a late Narizian age (Warren et al., 1945; Deacon, 1953; Mumford, in prep.).

The Roy Creek member is correlative to and may include part of the upper Narizian Unit B sandstones of Wolfe and McKee (1972) in southwest Washington. Wolfe and McKee (1972) described "local" basaltic sandstones overlying Unit B volcanics, which are thought to be correlative to the Tillamook Volcanics (see Tillamook Volcanics section). Directly south of the thesis area Wells et al. (1983) have mapped unnamed middle to late Eocene basaltic sandstones and conglomerates which, in this report, are considered part of the proposed Roy Creek member. As previously mentioned parts of the proposed Roy Creek member have been mapped as basal Cowlitz Formation (Warren and Norbisrath, 1946; Olbinski, 1983; Nelson, 1985). Regionally the Roy Creek member is correlative to the lower portions of the Nestucca, Coaledo, and Skookumchuck formations in western Oregon and western Washington (Armentrout et al., 1983) (fig. 5).

Petrography

Thirteen thin-sections and five heavy mineral grain mounts from the Roy Creek member were examined with a petrographic microscope (appendix 9). In addition, a basalt clast from the basal conglomerate was analyzed for major oxide chemistry and thin-sectioned (sample 424). This clast is sparsely porphyritic (<1% labradorite phenocrysts) and has an intergranular groundmass composed of flow-aligned labradorite microlites, augite, and opaque minerals (appenidx 8). It is petrographically identical to the Tillamook Volcanics flows in the thesis area. The major element chemistry of the clast is comparable to analyses from the Tillamook Volcanics (appendix 8) and plots within the Tillamook Volcanics chemical field (figs. 15-19).

One pebble conglomerate was thin-sectioned (locality 339). It consists of approximately 60% volcanic rock fragments, 2% labradorite, 1% augite, and <1% opaque minerals. The basaltic rock fragments can be texturally subdivided into 35% pilotaxitic intergranular, 5% pilotaxitic intersertal, and 20% vesicular. The basaltic rock fragments occur as rounded pebbles and as subrounded sand-sized clasts. Labradorite (avg. An 60), augite, and opaque minerals are sand-sized and subrounded to subangular. Sieve analysis shows the sample to be moderately to poorly sorted (see size analysis section).

Thin sections from four coarse-grained basaltic sandstones show a composition of 63-82% basaltic rock fragments, 1-8% labradorite, 1/2-1% augite, <1/2% opaque minerals, and <1/2% quartz (appendix 9). The quartz is morphologically similar to volcanic vesicle filling quartz. Basaltic rock fragments consist of 53-61% pilotaxitic intergranular clasts, 8-15% pilotaxitic intersertal clasts, and 7-10% vesicular clasts. Radial, pore-filling chloritic clays are the most common cement, forming 10-15% of the rock (fig. 36). In weathered samples, the clays may lack a well-developed

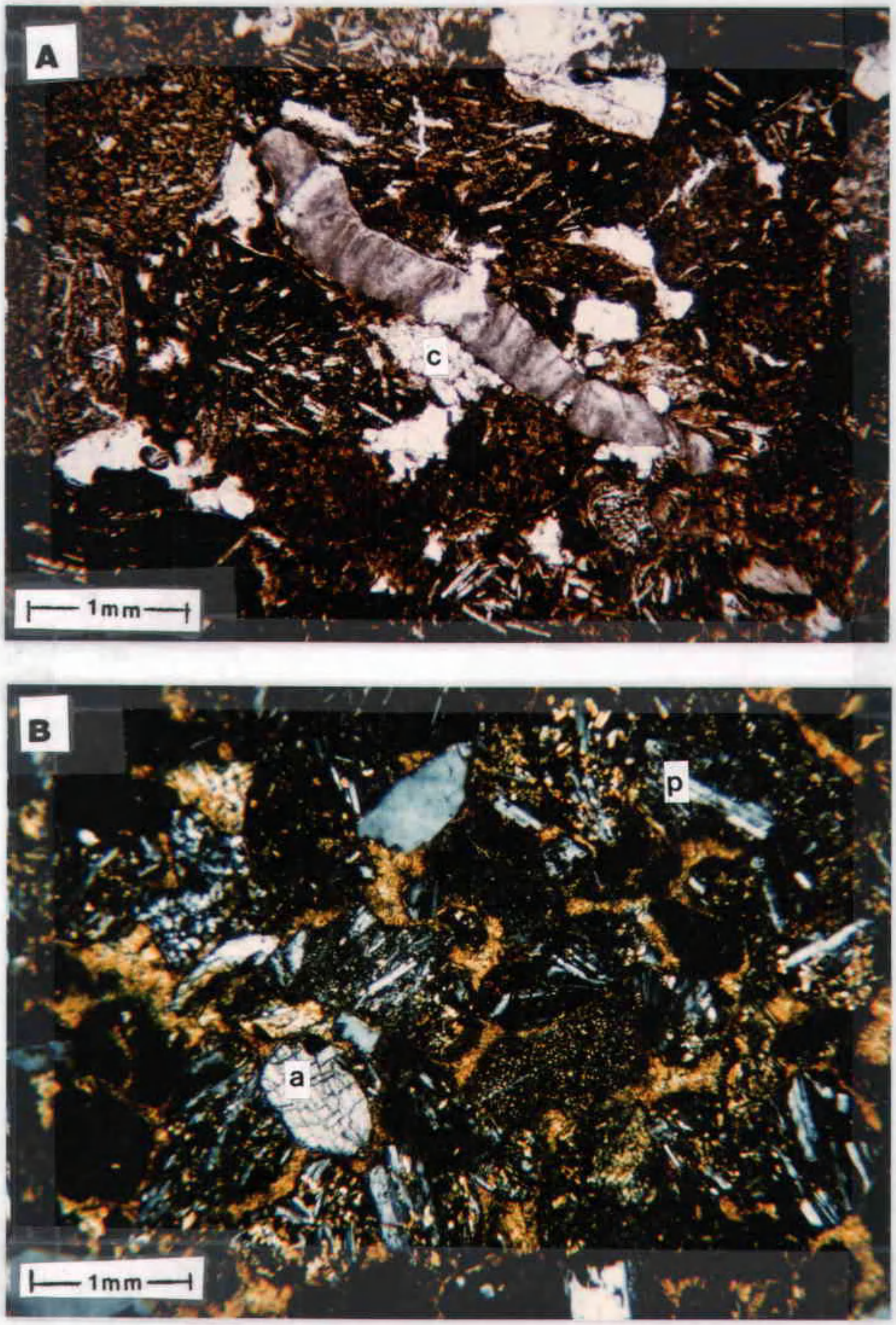


Fig. 36: Photomicrographs of basaltic sandstones in the Roy Creek member. A: Sample 398 showing volcanic rock fragments cemented by sparry calcite (c)(plane polarized light). Note pilotaxitic groundmass of VRF and mollusk fragment. B: Sample 630 showing chloritic porefilling cement (p), an augite clast (a), labradorite clasts, and VRF (crossed nicols).

radial structure. Calcite cement is less common, often associated with fossil fragments, and comprises 0-12% of the samples analyzed (fig. 36). Porosity is usually less than 3% but is very difficult to estimate because of extremely small pore spaces. Labradorite and augite clasts are typically subangular whereas basaltic rock fragments are subrounded to rounded. In thin-section the sandstones appear to be moderately sorted and appear to lack detrital matrix.

Eight fine-grained basaltic sandstones of the upper part of the Roy Creek member were examined by thin-section. They consist of 62-84% basaltic rock fragments, 3-25% plagioclase (An 45-63), 0-1% augite, 1% opaque minerals, and 0.1% quartz. The basaltic rock fragments can be texturally subdivided in to 5-65% pilotaxitic intergranular, 8-18% pilotaxitic intersertal, and 5-15% vesicular. Matrix consists of silt and clay and commonly occurs as helminthoida burrow fills (fig. 37). In surficially weathered samples it is very difficult to distinguish detrital clay matrix from pore-filling chloritic cements. Fresh samples (e.g., 630) contain approximately 15% pore filling chloritic cement and contain less than 3% detrital matrix. Some very fine-grained sandstones near the contact with the Sweet Home Creek member contain abundant detrital clay matrix associated with burrowing (e.g., sample 289). The sandstone is moderately sorted and subrounded to subangular.

In summary, the Roy Creek member is composed entirely or almost entirely of basaltic detritus which is petrographically and geochemically identical to the underlying Tillamook Volcanics. Grain-size has only a slight effect on the composition of the sandstones and the type of cement present. Fine-grained sandstones

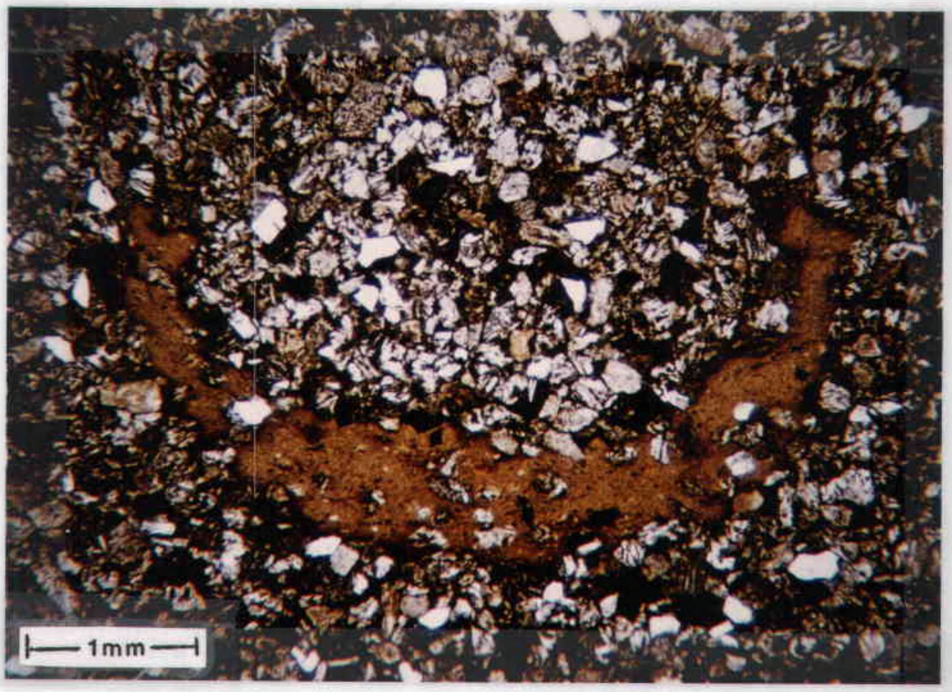


Fig. 37: Photomicrograph of a clay-filled burrow in a fine-grained basaltic sandstone of the Roy Creek member (sample 792). Plane polarized light.

tend to contain more plagioclase clasts and coarse-grained sandstones are more likely to have molluscan fossil fragments and calcite cement. The sandstones have been referred to as basaltic sandstones in the preceding discussions. According to the classification scheme of Folk (1980) the sandstones are litharenites but it is felt that the term basaltic sandstone, or possibly basaltic litharenite, is more descriptive and useful.

Diagenesis

The following diagenetic sequence occurs in the sandstones of the Roy Creek member: 1) development of chloritic clay coats around framework grains and local development of pore-filling calcite cement; 2) compaction of some basaltic rock fragments; 3) precipitation of radial, pore-filling chloritic cement or alteration of volcanic rock fragments to form unoriented microcrystalline clay aggregates; 4) teleogenetic dissolution of calcite cement; and 5) teleogenetic oxidation of iron-rich clays and basaltic rock fragments.

Galloway (1974) suggests that clay coats in lithic sandstones (includes clay rims) form at burial depths between 1,000 and 4,000 feet. Burns and Ethridge (1979), however, found clay coats forming in volcaniclastic sediments at depths of several meters. The clay coats in the Roy Creek member began to form before precipitation of calcite cement and before significant compaction occurred, as evidenced by contact relationships observed in thin section. This suggests that they are very early diagenetic products. Clay coats on basaltic rock fragments are present in all of the samples studied.

Sparry calcite pore-filling cement formed after the development of clay rims and was only observed in several of the coarser-grained sandstones (e.g., samples 339, 338, 398). Galloway (1979) suggested that the distribution of calcite cement is related to depositional environment. This may account for the restriction of calcite cement to the coarser-grained sandstones. The calcite-cemented sandstones tend to contain abundant mollusk fragments (fig. 36). This suggests that the calcite is derived from shell dissolution of more soluble aragonite that forms molluscan shells or that the diagenetic environment which favored calcite precipitation also favored preservation of shell fragments. In the latter case calcium could easily be derived from alteration of the volcanic detritus. Most of the calcite appears to be early pore fill; that is, it was precipitated prior to development of chloritic cements. In some samples, the paragenetic relationship between the calcite and the chloritic clays is not clear, and it is possible that some of the calcite is "late stage" and was precipitated after the chlorite.

Mechanical crushing and compaction occurs throughout the diagenetic sequence but is most prevalent after the development of clay rims and before the development of chloritic cement. Clay coats are generally compacted between framework grains and chloritic cements tend to fill postcompaction pore spaces. Compaction features are present in all samples but are better developed in some than others. Basaltic rock fragments tend to deform plastically, creating long grain-to-grain contacts whereas plagioclase clasts tend to deform brittly (fig. 38). In some cases sparry calcite cement may

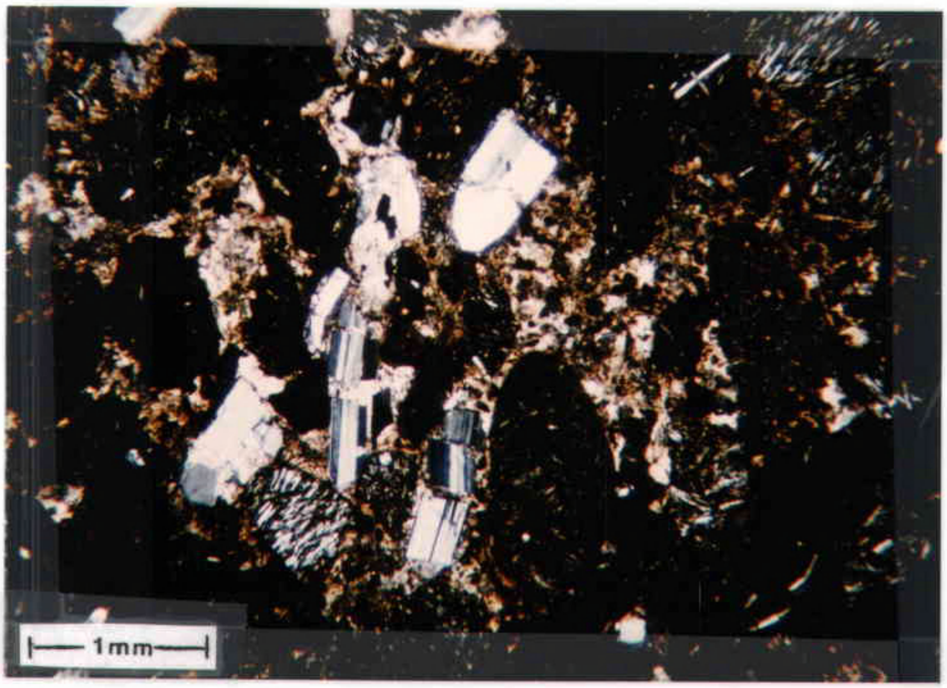


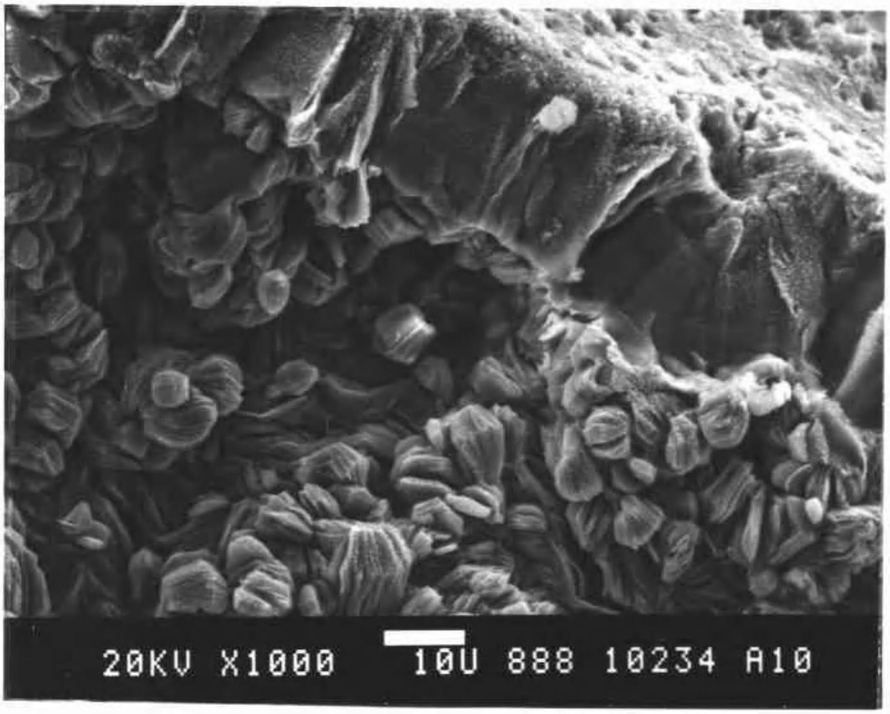
Fig. 38. Photomicrograph of calcite cemented basaltic sandstone in the Roy Creek member (crossed nicols). Note fractured albite twinned labradorite filled with calcite cement (sample 398b).

form after significant compaction of rock fragments and fracturing of plagioclase (fig. 38). The compaction process probably results in a 10-50% loss of primary porosity (Galloway, 1979). None of the Roy Creek member samples contain enough "early" calcite cement to arrest the compaction process. Pseudomatrix was not observed in the sandstones studied.

Greenish birefringent radial pore-filling chloritic cement forms late in the diagenetic sequence. Galloway (1979) suggests that these pore-filling clays form at intermediate burial depths (1,000-3,000 m). Clay coats are usually preserved and form halos around the framework grains, separating them from the chloritic cements (fig. 36). The chloritic cements may fill entire pore spaces but minor primary porosity is locally preserved in the central part of the pore spaces. Galloway (1979) stated that porosity ranges from 1 to 17% after emplacement of the radial pore-filling clays. Porosity in the Roy Creek member averages less than 4%. Radial chloritic cement appears to be restricted to basic volcanic-rich sandstones which retained sufficient porosity for pore fluids to alter the basic volcanic clasts and transport the necessary ions (Burns and Ethridge, 1979). Sufficient porosity appears to occur only in sandstones that were deposited in a high-energy, nearshore environment (Burns and Ethridge, 1979). The Roy Creek member is thought to have been deposited in such an environment. Laumontite has been reported to occur at similar temperature and pressure conditions as pore-filling chloritic cement but the formation of a specific mineral phase during this stage of diagenesis is probably dependant on regional or local variations in pore fluid chemistry (Surdam and Boles, 1979). Burns and Ethridge (1979) noted that radiating chlorite and zeolites are never found in the same samples or in the same part of the stratigraphic section. Therefore, the absence of zeolite cements in the Roy Creek member is not unusual.

Scanning electron microscopy and energy-dispersive x-ray analysis were performed on fresh medium-grained basaltic sandstone (sample 625) to better examine the pore-filling cements and clay coats. Clay coats in this sample are about 25 um thick and are commonly massive but may show a perpendicular alignment to grain boundaries (fig. 37). Pore-filling clays consist of numerous small (5um x 5um) bundles of clay platelets (fig. 39). These clays have some morphologic similarities to kaolinite but are smaller and much thinner. They are most similar to what Welton (1984) describes as authigenic "beehive-structured" chlorite. This structure is typified by sub-circular to slightly hexagonal, very thin clay platelets stacked into small bundles. The EDX spectrum of both the clay rims and the pore-filling clays (fig. 40) is similar to the spectrum of chlorite reported by Welton (1984). This spectrum is significantly different from the spectrum of other clay minerals. In conclusion, the above analyses show that the pore-filling clay is authigenic chlorite.

Unoriented microcrystalline chloritic aggregates in some samples were formed at about the same time as radial pore-filling chlorite. These aggregates are difficult to distinguish from detrital matrix and from surficially altered pore-filling chlorite. Distinguishing features of these aggregates include a transparent



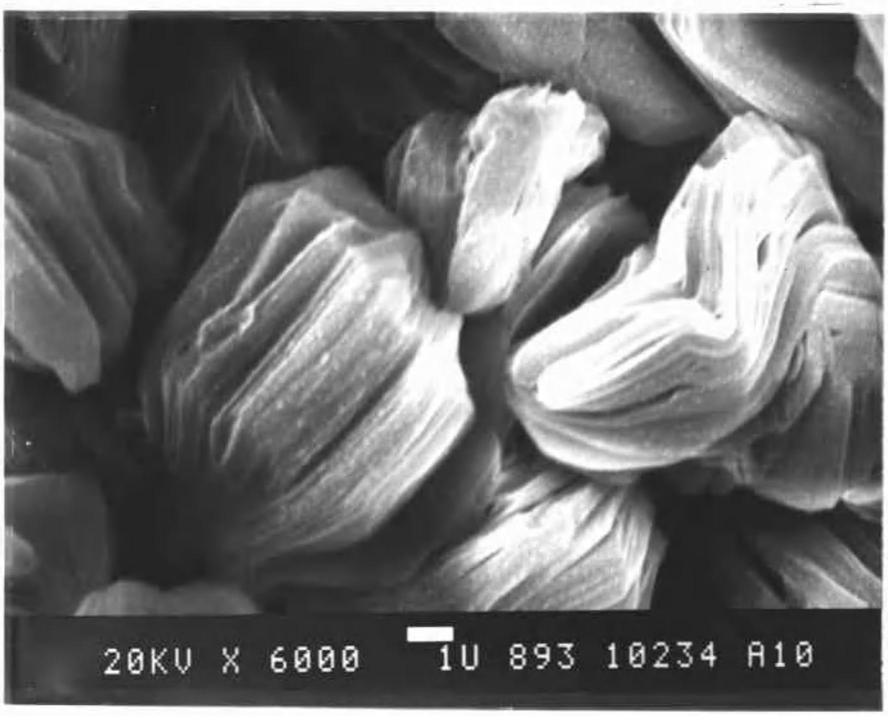


Fig. 39. SEM photograph of pore-filling chloritic clays in basaltic sandstone of the Roy Creek member. Figure B is a closeup of A.

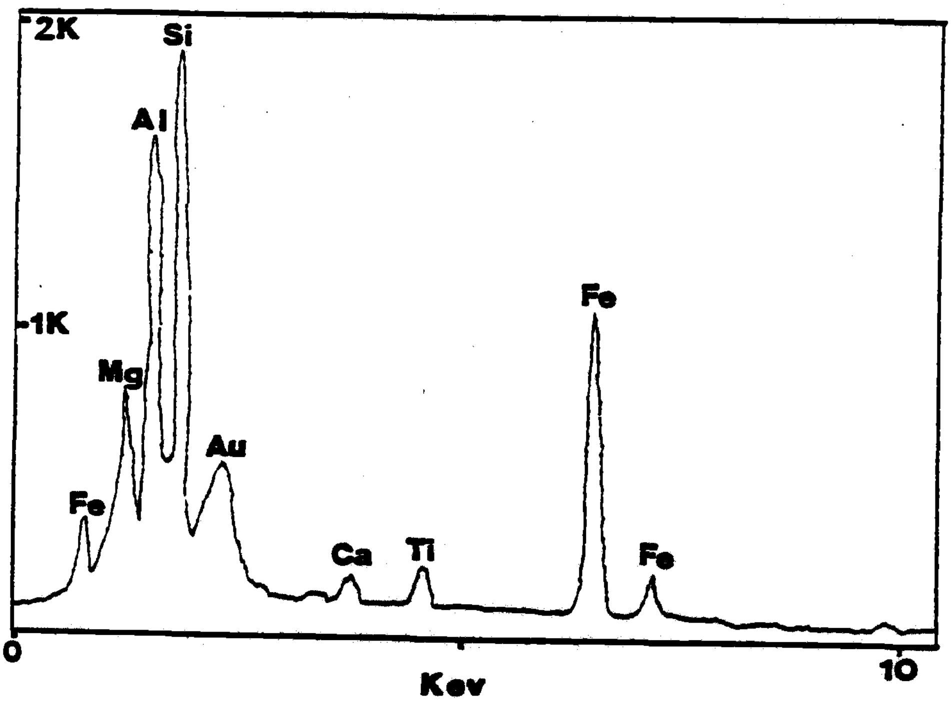


Fig. 40. Energy dispersive X-ray (EDX) pattern of pore filling chloritic clay in the Roy Creek member (sample 625). Note abundant Fe, Mg, Al, and Si, in the analysis of this clay.

nature and lack of murky impurities. This type of aggregate cement is less common than radial, pore-filling chloritic cement.

Replacement fabrics are relatively rare with some plagioclase being replaced by calcite or chlorite. Glassy basaltic rock fragments are commonly partially altered to opaque authogenic clay.

Teleogenetic dissolution of sparry calcite occurs to a very limited extent producing minor secondary porosity. Within several meters of the ground surface the chloritic clays alter to iron oxide (e.g. limonite) resulting in a green to brown color change. This change is observable at a number of localities (e.g., 289, 630, 854). Authigenic pyrite is present in most sandstones, indicating that a reducing diagenetic environment existed prior to surficial oxidation.

The aforementioned diagenetic sequence is best observed in fresh (i.e., stream exposures), moderately well-sorted sandstones (samples 625, 630, 792). Extensive surficial alteration results in complete masking of the diagenetic history (e.g., samples 338, 443). Several samples have undergone moderate surficial alteration and lack well-developed radial, pore-filling chloritic cement (e.g., samples 289, 389, 248). In these samples it is difficult to distinguish matrix from altered pore-filling cement. It is possible that abundant detrital matrix prevented the growth of pore-filling cements in some of these samples.

Previous workers (e.g. Van Atta, 1973; Timmons, 1981; Jackson, 1983) in northwest Oregon have not performed detailed diagenetic studies on the Roy Creek member and equivalent units. Therefore, it is not possible to compare diagenetic features observed in the thesis area to diagenetic features observed elsewhere in the member. The diagenetic history observed in the thesis area is, however, similar to that of the Paleocene to Eocene Umpqua Group in southwest Oregon and to some arc derived sandstones along the Pacific Rim (Burns and Ethridge, 1979; Galloway, 1979). The Roy Creek member differs from the volcanic-rich sandstones in these areas in that authigenic zeolites, authigenic feldspar, and authigenic silica are absent. The absence of these phases in the Roy Creek member is probably a result of shallower burial and/or differing pore fluid chemistries and the overwhelming basaltic composition. The Roy Creek sandstones are unusual in that they are composed entirely of basaltic detritus and, therefore, would tend to have a unique pore fluid chemistry. In particular, the pore fluids would tend to be rich in Fe, Mg, and Ca and poor in Si and Al. Volcanic-rich sandstones from the upper part of the Umpqua Group do, however, have many of the same diagenetic features that are present in the Roy Creek member including clay rims, "early" calcite cement, and radial pore-filling chlorite (Burns and Ethridge, 1979). Figure 41 shows the sequential development of diagenetic features in arc-derived sandstones from the Pacific Rim compared to the diagenetic sequence observed in the Roy Creek member.

Galloway (1979) used diagenetic features to estimate burial depths of arc-derived sandstones. Using his criteria (fig. 41) the Roy Creek member was buried to a depth of between 1,000 and 3,000m. These depths are in agreement with depths estimated from the overlying stratigraphic sequence and from structural data. Surdam and Boles (1979), however, suggested that individual mineral zones

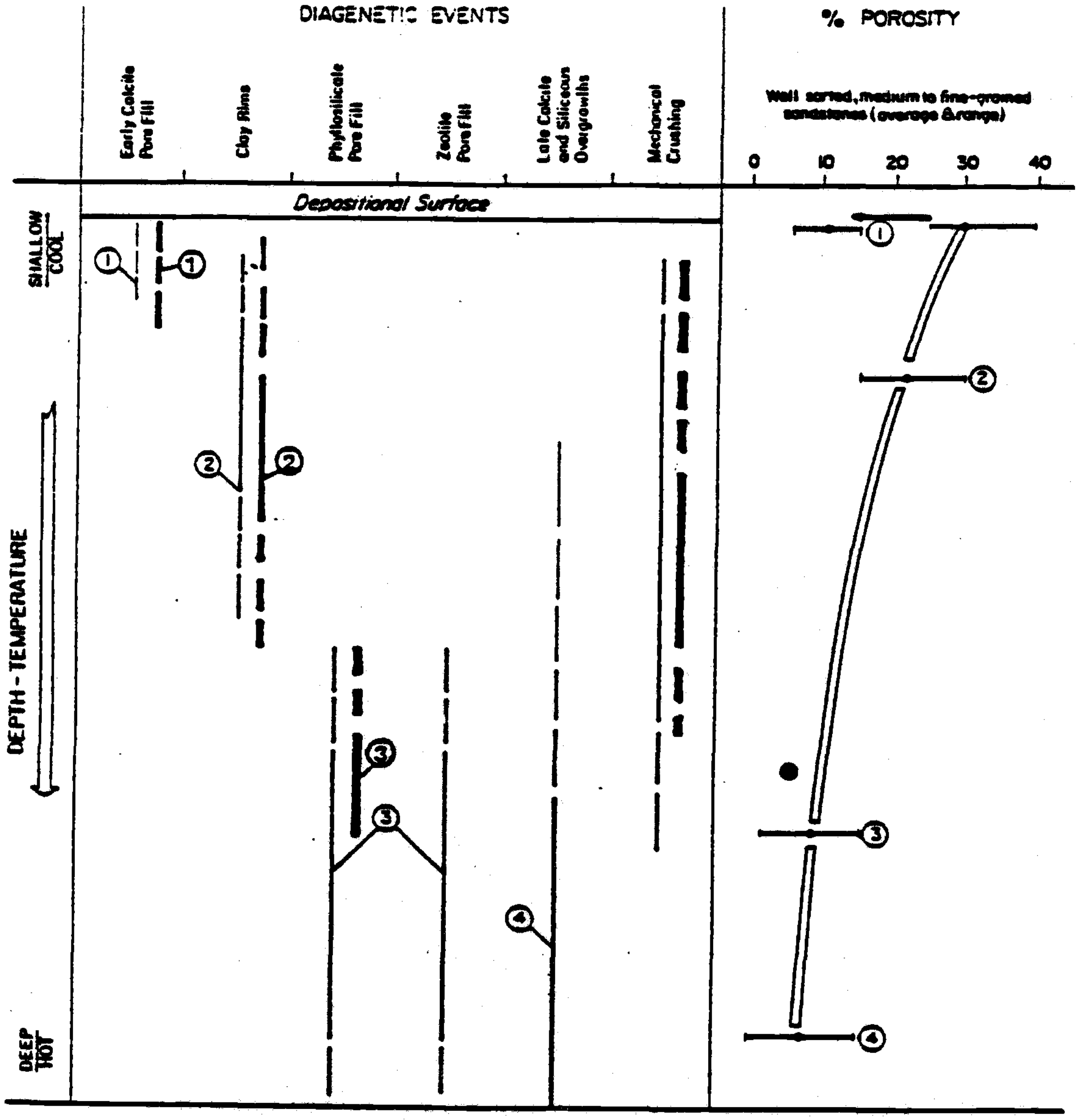


Fig. 41. Comparison of the paragenetic sequence observed in the Roy Creek member (thick lines) to the sequence observed by Galloway (1979) in arc derived sandstones of the Pacific Rim (thin lines). The vertical bars denote interpreted relative depth range of major diagenetic events with stages being numbered. The right hand curve shows successive porosity decrease for sandstones in successive diagenetic stages. Blackened circle represents an estimated average porosity for the Roy Creek member (figure modified from Galloway, 1979).

are as much related to fluid flow and composition as to burial depth and, therefore, the diagenetic sequences and depth ranges of Galloway (1979) should be used only as a generalized paragenetic sequence related to depth and temperature.

Heavy Minerals

Heavy mineral assemblages (specific gravity >2.92) from 5 Roy Creek member localities were examined (appendix 10). Abundances were estimated from both the 3 phiiand 4 phi size fractions. The assemblages consist of augite (8-35%), opaque minerals (30-92%), and other minerals (0-1%). The augite is light green in color and usually subangular (fig. 42). Opaque minerals include pyrite, magnetite, hematite, ilmenite, and leucoxene. Pyrite, hematite, and leucoxene are, most likely, diagenetic products with hematite being an alteration product of detrital magnetite and leucoxene being an alteration product of ilmenite. Pyrite is generally the most abundant heavy mineral and may form up to 60% of the assemblage. Magnetite, ilmenite, and leucoxene occur in roughly equal amounts with hematite being relatively rare. Minor mineral constituents, which are only present in the uppermost portion of the Roy Creek member, include apatite, brown tourmaline, garnet, pink zircon, colorless zircon, epidote, green hornblende, biotite and muscovite. With the exception of very rare apatite and very rare garnet (samples 365, 398) the minor minerals are restricted to one sample (289) from the upper contact of the Roy Creek member. Samples 339 and 419 contain only augite and opaque minerals. The finer 4ϕ size fraction

Fig. 42. Photomicrograph of heavy minerals assemblage from the 3ø size fraction of Roy Creek member sample 365 (plane polarized light). Note the complete dominance by angular light green augite and opaque minerals.

typically contains a wider variety of heavy minerals than the 3ø size fraction.

The heavy mineral assemblage of the Roy Creek member is distinguished from the heavy mineral assemblages of other units in the area by the dominance of augite and opaque minerals as well as by the paucity or absence of other minerals. In addition, the Roy Creek member contains a higher percentage of heavy minerals (avg. 4%) than do other units in the thesis area (avg. 0.3%).

Provenance

Framework grains in the Roy Creek member consist of basaltic rock fragments, plagioclase (An 45-65), augite, ilmenite, magnetite, and very rare quartz. Sample 298, which is located near the upper contact of the unit, is also dominated by volcanic framework grains but contains very minor amounts (<1/2%) of hornblende, biotite, muscovite, epidote, zircon, garnet, tourmaline, and apatite. In addition to volcanic detritus, sample 398 contains very minor (0.1%) garnet. It, too, is located near the upper contact of the unit.

Therefore, all of the clasts in the Roy Creek member, with the exception of sandstones located near the upper contact, can be ascribed to and probably limited to a basic volcanic source area. The basaltic rock fragments in the Roy Creek member are petrographically and geochemically (i.e., sample 424) identical to Tillamook Volcanics flows. In addition, the average composition of the Roy Creek member is identical to the composition of the Tillamook volcanics (Table 2). Phenocrysts (labradorite and augite) in the Tillamook volcanics are sand-sized whereas the groundmass minerals are silt-sized (Appendix 8). Therefore, upon weathering the Tillamook Volcanics would be expected to produce sand-sized "phenocrysts" and sand-sized "groundmass" clasts in addition to other clay-silt-size detritus. Basaltic rock fragments in the Roy Creek member sandstones very rarely contain phenocrysts and there is very little compositional variation between coarse-grained sandstones and fine-grained sandstone. The only difference being a slight tendency for fine-grained sandstones to contain more plagioclase (appendix 8). As a result, Table 2 appears to be a valid comparison of the two units.

Most groundmass of thin-sectioned Tillamook Volcanics samples contains very little glass and has a pilotaxitic intergranular texture. Roy Creek member basaltic rock fragments average about 70% pilotaxitic intergranular texture and 30% pilotaxitic intersertal to glassy vesicular textures. This discrepancy is probably a result of Tillamook Volcanics sampling bias; samples were taken from flow interiors and not from flow margins. Field estimates show that the Tillamook Volcanics are composed of approximately 80% crystalline flow interiors and 20% glassy to vesicular flow margins.

The nearly perfect mineralogical correlation of the Roy Creek member to the Tillamook Volcanics and the stratigraphic relationship (erosional unconformity) of the units shows that the Tillamook Volcanics were the primary source of the Roy Creek member. The absence of detritus from other source areas in the lower to middle

UNIT	GROUNDMASS (Bas. rock frag.)	PLAG. (>0.5mm)	AUGITE (>0.5mm)	OPAQUES (>0.5mm)
ROY CK. MBR.	93%	6%	1%	<0.3%
TILLAMOOK VOL.	92%	6.5%	1.5%	<0.3%
Data based on 50 samples				

Table 4. Average composition of Roy Creek member basaltic sandstones compared to the average composition of the Tillamook Volcanics. Note the nearly identical compositions of the units suggesting that the Roy Creek member was derived from Tillamook Volcanics.

parts of the Roy Creek member indicates that the Tillamook Volcanics were the only source area. In the upper part of the Roy Creek member, the Tillamook Volcanics are still the dominant source area but there was minor admixing from an acid igneous and metamorphic source area as is evidenced by heavy mineral composition (e.g. presence of very minor garnet, epidote, and zircon).

This very minor amount (<1/2%) of non-volcanic detritus is mineralogically similar to micaceous arkosic sandstones in the Sunset Highway member which interfinger with the upper part of the Roy Creek member east of the thesis area (Mumford, in prep.) (Plate IV) . Van Atta (1971) suggested the Mesozoic Idaho and Wallowa batholiths as the source rocks for the middle to late Eocene arkosic sandstones (e.g. Cowlitz Formation) in northwest Oregon. Such a source area is probable for the minor non-volcanic component present in the upper part of the Roy Creek member. A northern Cascades or Klamath source area is also possible based on the limited heavy mineral assemblage.

"Pebble" counts from the basal conglomerate within the thesis area and in adjacent areas (Mumford, in prep.; Safley; in prep.) suggest that the cobbles and boulders were deposited very near the source area. This is indicated by the dominance of different basaltic rock types (e.g. porphyritic, glassy, or aphyric) at different localities with underlying Tillamook Volcanics flows having a similar composition.. Some basaltic boulders are greater than 1 m in diameter and subangular further supporting a very local Tillamook Volcanics source with minimal transportation. Sandstones in the Roy Creek member tend to have a more uniform composition and reflect a relatively broad homogenous Tillamook Volcanics source area. The presence of fairly common andesine in some of the fine-grained sandstones is suggestive of a more silicic, andesitic source area such as the Green Mountain area (Olbinski, 1983; Nelson, 1985; Safley, in prep.).

Modal analyses of the Roy Creek member sandstones were plotted on several of the tectonic provenance differentiation diagrams of Dickinson and Suczek (1979) (fig. 43). In these ternary diagrams framework proportions of several quartz, feldspar, and lithic varieties are plotted against one another to help distinguish key provenance types and tectonic settings. On figure 43a the Roy Creek member sandstones plot on the base of the diagram within the magmatic arc field and mostly within an area where no fields have been delineated. On figure 43b most of the sandstones plot in the recycled orogen field. The recycled orogen provenance is defined as an uplifted terrain of deformed strata from which recycled detritus of sedimentary or metasedimentary origin is especially prominant. Detailed analysis of the Roy Creek member has shown that it was derived almost entirely from basaltic flows of the Tillamook Volcanics in a developing forearc setting. Therefore, the diagrams of Dickinson and Suczek (1979) are not sensitive enough to detect this local forearc volcanic provenance and should only be used as a generalized guide with more detailed analysis always being desirable. Dickinson and Suczek (1979) assume that the total feldspar to total lithic ratio on figure 43 could be used to distinguish magmatic arc provenances from recycled orogen provenances. The feldspar to lithic ratio in sediments derived from volcanic rocks is, however, heavily influenced by the coarseness of

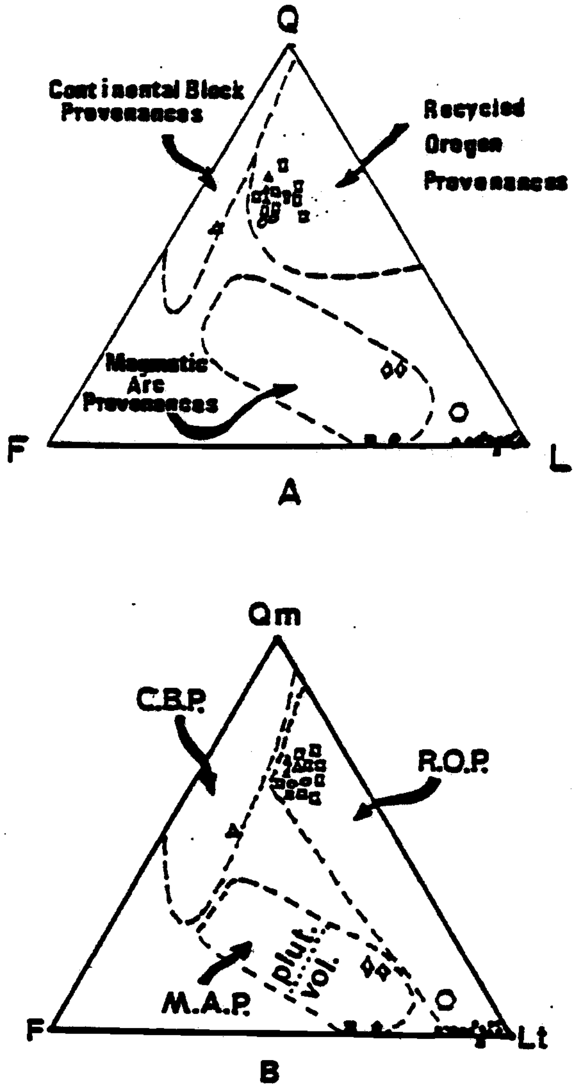


Fig. 43. Tectonic provenance differentiation diagrams from Dickinson and Suczek (1979) with sandstone samples from the thesis area plotted. Roy Creek member samples (•) plot in an undefined field on the QFL (quartz-feldspar-lithic) diagram and most plot within the recycyled orogen provenance on the QmFLt (monocrystalline quartz-feldspar-total lithics) diagram. Also shown are samples from the Sweet Home Creek member (■), the Jewell member (□), the Smuggler Cove mudstones (O), the Pittsburg Bluff Formation (◊), the ball park unit of the Smuggler Cove formation (Δ), and the Angora Peak member of the Astoria Formation (▭).

the volcanic source rock. The Tillamook Volcanics, like many tholeiites, are very fine-grained and contain only a few sand-sized phenocrysts resulting in a low feldspar to lithic ratio. Dickinson and Suczek (1979) assume that magmatic arcs will produce abundant sand-sized plagioclase clasts. It is felt that the magmatic arc provenance should be extended on the diagrams of Dickenson and Suczek to include the area of 85-100% lithics. This would create minor overlap with the recycled orogen provenance on several of the diagrams, which is a more realistic situation.

Grain Size Analysis

Grain size analysis was performed on six basaltic sandstone and conglomerate samples from the Roy Creek member in order to better interpret the depositional environment. Cumulative frequency curves were constructed (fig. 44) and the statistical parameters of Folk and Ward (1957) were calculated (Appendix 11). These samples contain modest amounts of chloritic clay matrix. Thin-section petrography and scanning electron microscopy show that much or all of the clay-sized material is authogenic. Because of this the statistical parameters were calculated both with the clay and without the clay. It is felt that the latter calculations more closely approach the grain-size distribution of the sediments at the time of deposition. In many samples there is very little difference between the values calculated with the chloritic clay and those calculated without the clay (Appendix 11).

The samples analyzed (calculated with clay) have mean grain

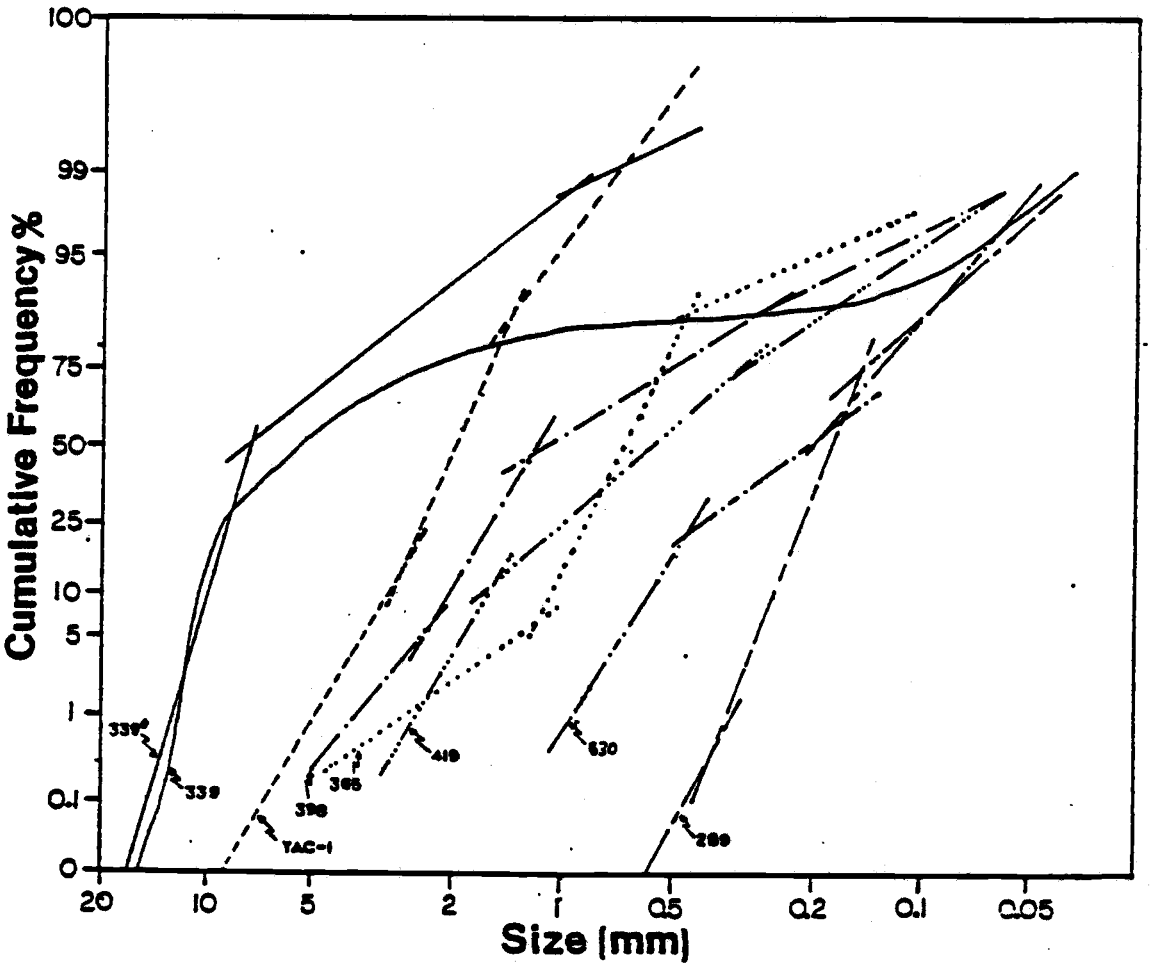


Fig. 44. Cumulative frequency curves for selected sandstone and conglomerate samples from the Roy Creek member. Sample curve 339* was constructed without including matrix.

sizes ranging from fine sandstone to fine gravel (mean -2.9ø to +2.5ø) and are moderately- to poorly-sorted (standard deviation 0.6-0.8) suggesting fairly rapid deposition and burial before much sorting. The clay free samples have inclusive graphic skewnesses that are nearly symmetrical to positively skewed (-0.09 to 0.66). Sample 339 has a very high kurtosis (1.58) which Folk and Ward (1957) consider to be suggestive of bimodality and a mixing of two different sources or populations. A histogram of sample 339 from the southwestern part of the thesis area (fig. 45) shows that the sample has a bimodal grain-size distribution. The fine-grained (very fine sand-size) population of sample 339 consists of subrounded to subangular plagioclase and basaltic rock fragments indicating that the bimodality is not a result of clay diagenesis. Since the Tillamook Volcanics appear to supply detritus of all sizes the bimodality of this sample is most likely the result of mechanical infiltration of overlying finer sands into the pore spaces of a gravel deposit or a result of rapid mixing of two different sorted populations by storm waves.

Grain size analysis of samples from the Roy Creek member was performed to aid in evaluating the depositional environment of the unit. Numerous grain size studies of modern sands and have shown that grain size distribution is partly dependent on the final depositional environment (e.g., Visher, 1969; Friedman and Sanders, 1978; Friedman, 1979). However, as can be seen in the Roy Creek member, the grain size distribution of a sediment is commonly changed significantly by post-depositional processes such as mechanical infiltration and formation of authigenic minerals. In

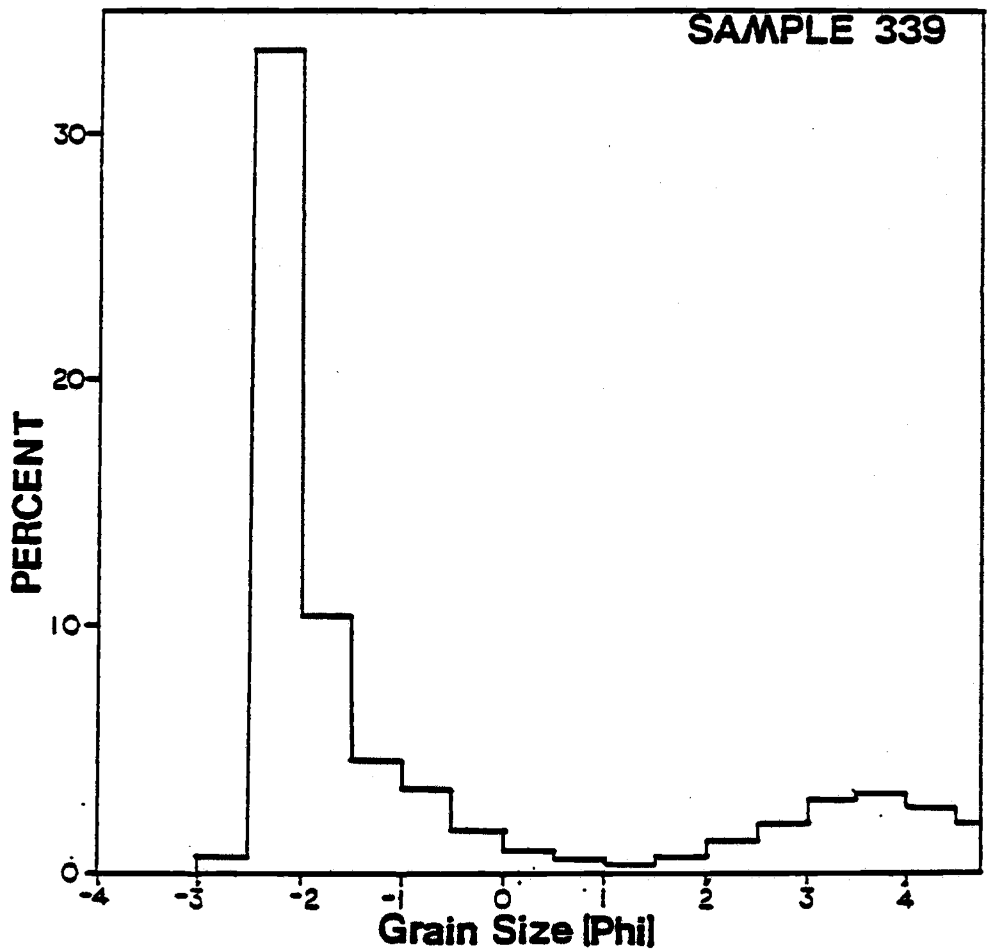


Fig. 45. Histogram of sample 339 from the Roy Creek member showing a distinct bimodality.

this study an attempt has been made to remove post-depositional effects when plotting grain size data on depositional environment differentation diagrams.

The grain size data from the Roy Creek member were plotted on the simple skewness versus simple sorting diagram of Friedman (1979) (fig. 46). All samples (calculated clay free) plot in the "river field" except for sample 365 from the southwestern part of the thesis area which plots in the beach field. Although all of the sandstones sampled contain marine fossils and are clearly not fluvial, the diagram does show that the majority of samples are more poorly sorted than "typical" beach sands. A modern very coarse--grained basaltic beach sand was collected from near Yachats, Oregon (sample yac-1) and plotted along with the data from the Roy Creek member. The Yachats beach sand and gravel is derived from adjacent basalt sea cliffs and, therefore, represents a modern depositional environment similar to that of the Roy Creek member (see following section). The Yachats beach sand plots within the beach field of figure 46 very near sample 365. The Yachats beach sand and the Roy Creek member samples were plotted on the CM diagram of Passega (1957) as were other sandstones from the thesis area (fig. 47). All samples plot in an area where beach and turbidity current sands overlap This indicates that the Roy Creek member is more likely to have been deposited in a beach environment than in a fluvial (tractive current) environment. The plot of figure 47 also shows that Roy Creek member sandstones tend to be coarser than other sandstones in the thesis area.

Emery (1955) studied the grain-size distribution of marine

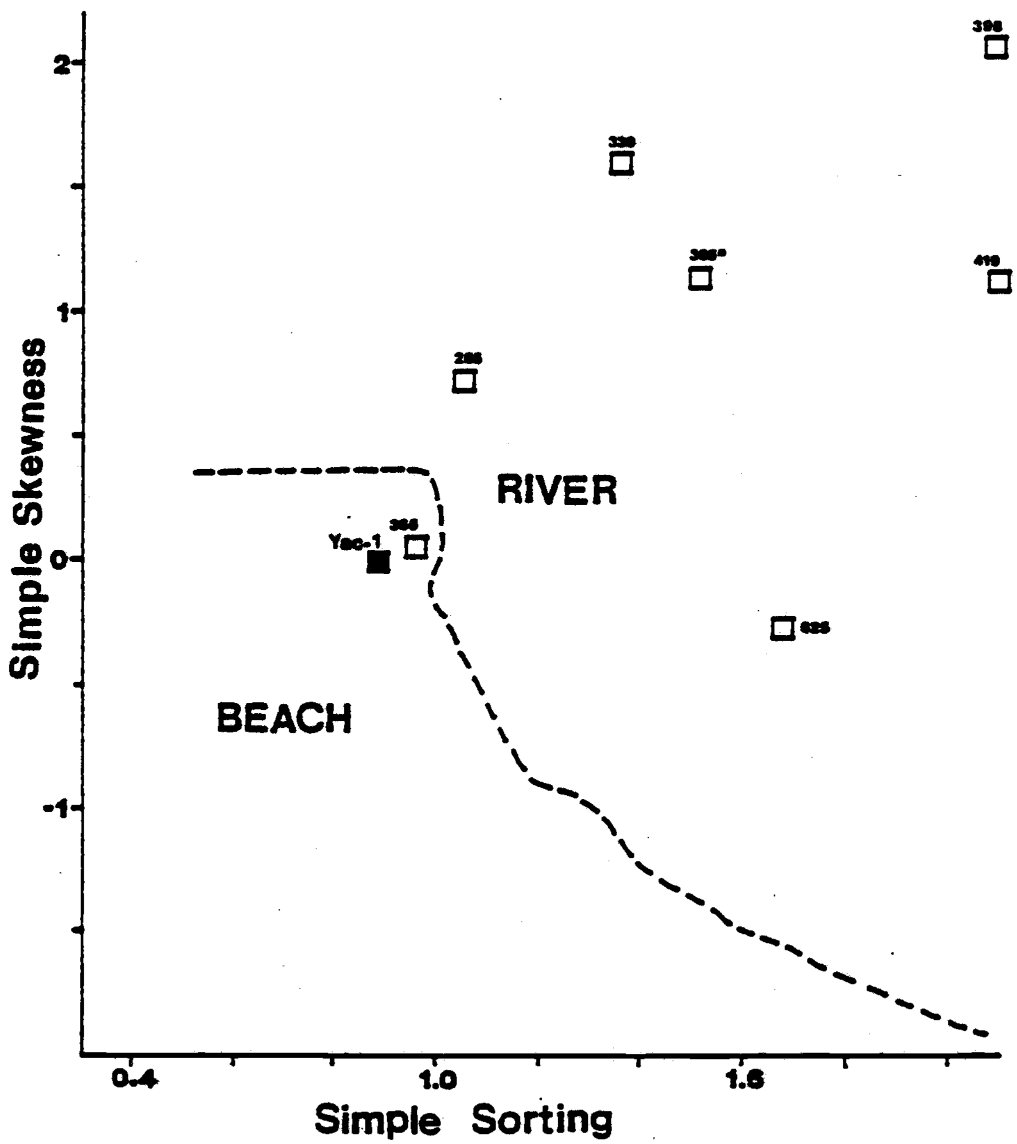


Fig. 46. Simple skewness vs. simple sorting diagram of Friedman (1979) with sandstone samples from the Roy Creek member and from Holocene beach sand at Yachats (Yac-1) plotted. With the exception of sample 339* the samples were calculated without diagenetic matrix.

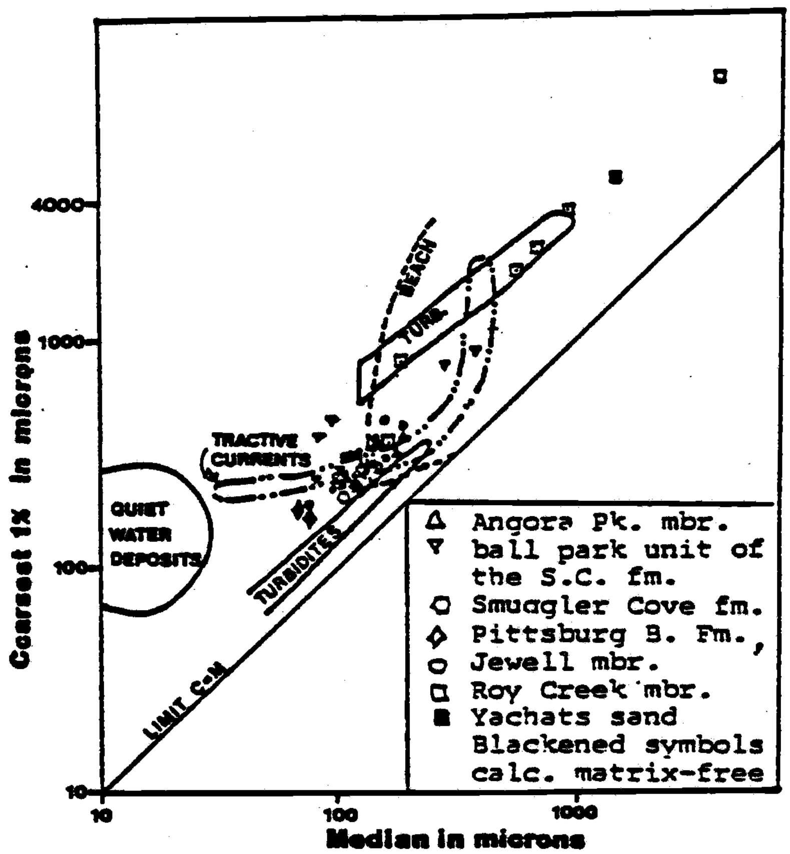


Fig. 47. CM diagram of Passega (1957) with sandstone samples from the thesis area plotted.

beach gravels and very coarse-grained sandstones. These beach deposits had an average Trask sorting coefficient of 1.25 (range of 1.13-2.14) compared to a medium sorting coefficient of 3.18 (range 1.34-5.49) for stream gravels. The median Trask sorting coefficient for the Roy Creek member is 1.6 (range 1.22-1.83) which is within range of beach deposits (appendix 11).

Visher (1969) analyzed log-normal grain size distribution curves and was able to differentiate three modes of grain transport which are suspension, saltation, and surface creep or rolling. These modes are developed as a separate subpopulation on cumulative frequency curves (fig. 44). Most samples in the Roy Creek member have a well-sorted saltation population and contain a moderate amount of detritus in the suspension population. These curves are similar to curves from beach sands but tend to contain more clay- and silt-sized detritus in the suspension mode. The saltation population of the modern Yachats beach sand has a slope similar to the saltation population of the Roy Creek member sandstones. The moderately large suspension populations in conjunction with well-sorted saltation populations may reflect initial deposition of the Roy Creek member in a beach environment with subsequent infiltration and mixing of fine-grained detritus from an offshore setting.

Kulm et al. (1975) have shown that Holocene beach sands and inner shelf sands in Oregon have distinct grain-size distribution. Beach sands are coarser-grained (<2.75ø) and more negatively skewed than inner shelf sands (fig. 48). Coarser-grained sandstones from the lower part of the Roy Creek member plot near the beach field (samples 365, 419) whereas finer-grained sandstones from the upper

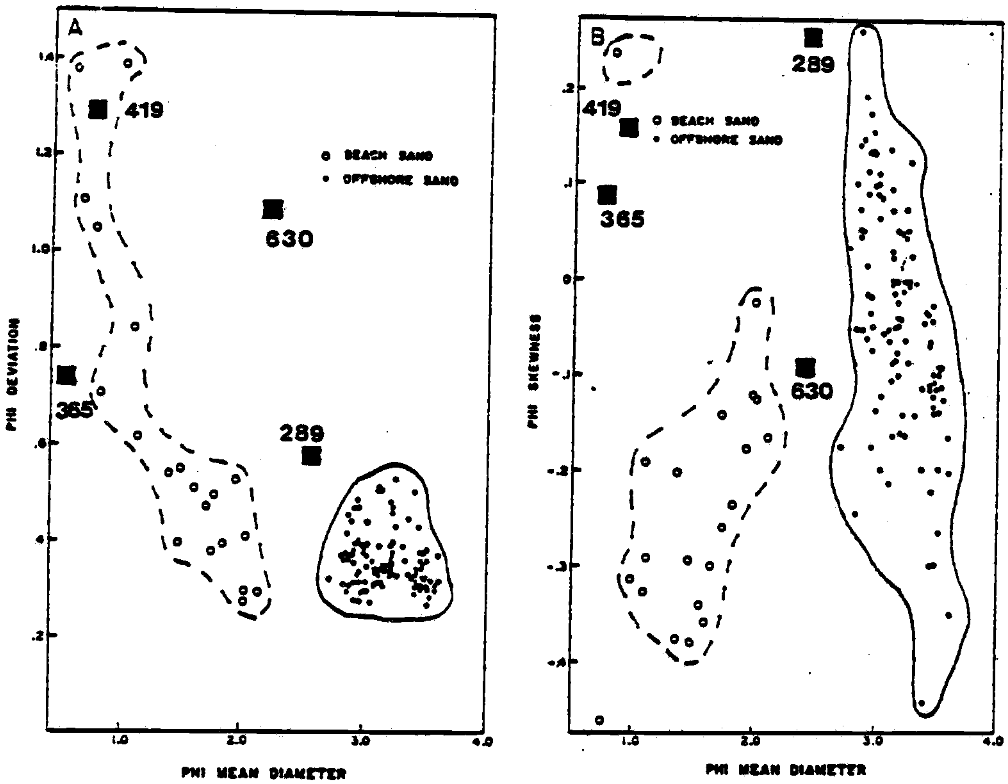


Fig. 48. Textural analysis of the sand fraction of shelf (solid line) and beach (dashed line) sediments in the vicinity of the Rogue River, Oregon (Kulm et al., 1975) compared to textural analysis of samples from the Roy Creek member (■). Samples 339 and 398 were too coarse-grained to plot on this diagram. Samples 419 and 365 have some similarities to the beach samples whereas samples 630 and 289 plot between the beach and shelf samples. The figure was modified from Kulm et al.(1975).

part of the unit plot near the the inner shelf field (sample 289), and between the two fields (sample 630) on the two textural diagrams of Kulm _et al_. (1975) (fig. 48). This data confirms previous observations that some Roy Creek member sandstones have grain size distributions similar to but not identical to "typical" beach deposits. It also shows that the fine-grained sandstones from the upper part of the Roy Creek member have grain size characteristics similar to modern inner shelf sands. The relatively slight variation between modern beach and shelf sands and Roy Creek member sandstones can be ascribed, at least in part, to post depositional processes (clay diagenesis, compaction, and bioturbation) and the distinct basaltic composition of the Roy Creek member.

Depostional Environment

The Roy Creek member consists of three lithofacies, a basal boulder-cobble-pebble conglomerate, a coarse-grained basaltic sandstone, and an overlying fine-grained basaltic sandstone. Throughout most of the study area all three lithofacies are present and relatively thick, but locally (_e.g._, locality 398) the entire member is less than 3 m thick.

Within the thesis area the basal conglomerate is relatively thin (1 m-6 m), moderately to poorly sorted, has laterally extensive beds, contains a few oyster shell fragments (_e.g._, locality 419), and consists primarily of rounded to subrounded basalt cobbles and boulders. Petrographic and chemical data in addition to field relationships show that the clasts were derived from the underlying

Tillamook Volcanics. "Pebble" count data and the presence of large (>1 m) boulders indicates that the basal conglomerate was deposited very near the source area. Regional mapping (e.g., Mumford, in prep.; Safley, in prep.; Jackson, 1983; Wells et al. 1983, Niem and Niem, in press) and reconnaissance work by the author shows the basal conglomerate to be very widespread (>500 km2). The conglomerate erosionally overlies subaerial flows of the Tillamook Volcanics and is gradationally overlain by basaltic sandstones that contain shallow-marine mollusks suggesting at a widespread marine transgression over the Tillamook highlands.

Clifton (1973) demonstrated that beach gravels have different bedding characteristics than fluvial gravels. The continuity of bedding and the lack of large planar cross-beds in the Roy Creek member conglomerate suggest deposition in a nearshore environment rather than in a fluvial environment. The sorting characteristics, bedding style, and thickness of the basal conglomerate is similar to storm produced beach gravels studied by Bluck (1967). Bluck (1967) describes a trench section through a beach in south Wales that consists of two cobble beds separated by a thin sand layer (fig. 49). The interstices between cobbles have been infilled with fine sand and pebbles from above. This style of bedding and infilling is similar to many outcrops in the Roy Creek member basal conglomerate (e.g., localities 339, 746, 854 in the southern part of the thesis area). Leckie and Walker (1982) described conglomeratic beach deposits in the Cretaceous Gates Formation of western Canada which are similar to the Roy Creek member conglomerates. The Cretaceous conglomerates consist of bedded cobble conglomerates with rare

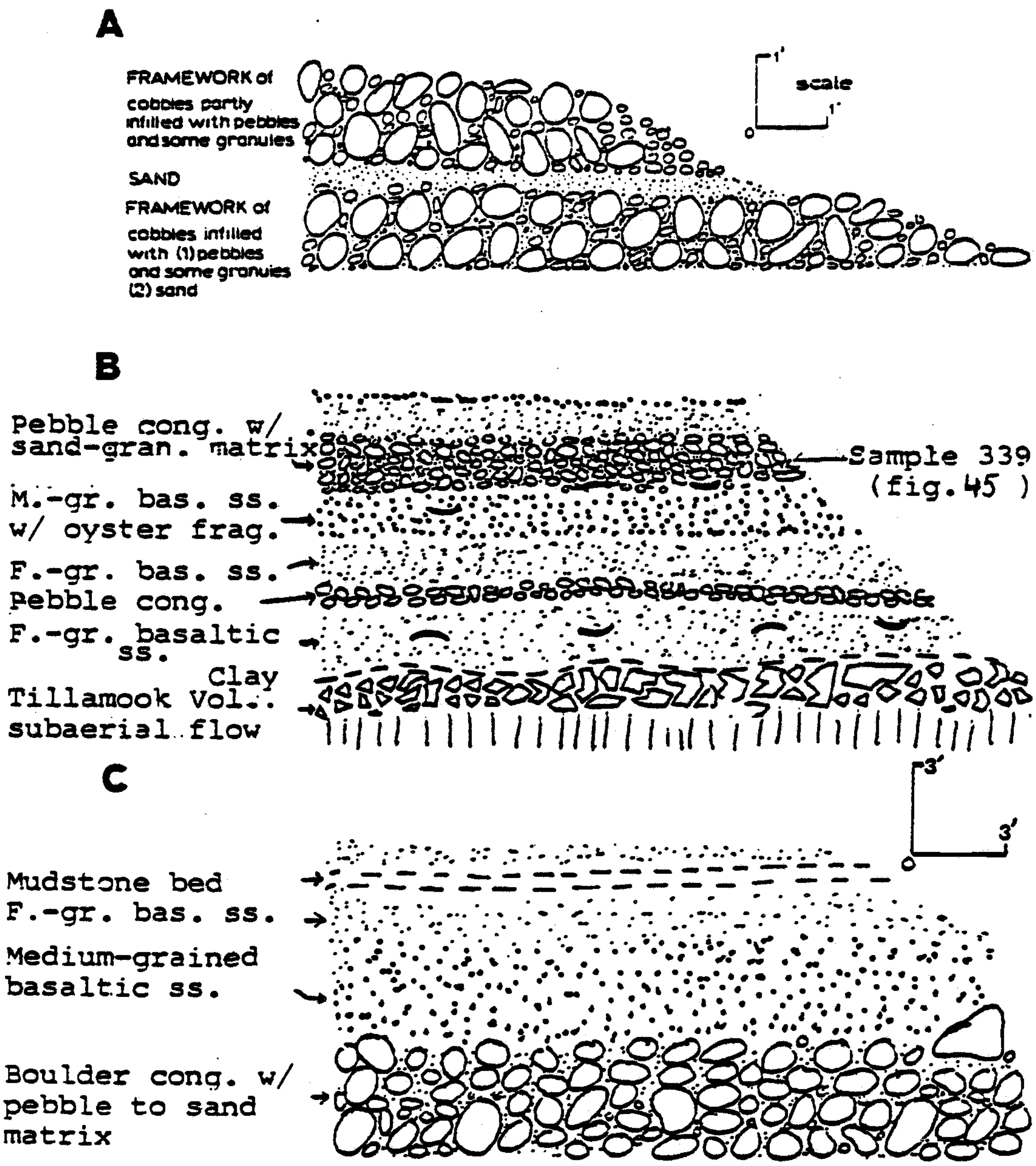


Fig. 49. Comparison of storm beach profile in Wales (A) to nearshore-beach deposits of the Roy Creek member (B & C). B is from locality 339 and C is from locality 717. A is from Bluck (1967).

sandstone layers, are detritral matrix free or have a sandy matrix, and are 4-6 m thick. My observation of the modern beach basaltic sands and gravels around the Yachacts and Cape Falcon basaltic headlands of Oregon show the same kinds of sorting and bedding as seen in the Roy Creek member.

The wide distribution, subrounded to rounded clasts, local source area, stratigraphic position, abraded very shallow marine mollusk fragments (e.g. oyster, barnacle, and gastropod), and similarity to other modern and ancient beach deposits show that the basal conglomerate was probably deposited in a beach environment. The large clast size (large boulders) and an irregular basal contact suggests deposition near large basalt sea cliffs where "sea stacks" were locally present. Irregular to nearly vertical contact between the conglomerates and the Tillamook Volcanics occur at several localities (e.g., 339, 362). At locality 362 (a quarry in the southwestern part of thesis area) pebble congolmerate fills topographic lows between eroded remanents of nearly vertical 1/2m thick Tillamook Volcanics dike ribs (fig. 50). This exposure is interpreted to have originally been a volcanic "spatter" deposit intruded by dikes. During marine transgression the erosionally resistant dikes formed small sea stacks. Nearshore rounded pebble to cobble conglomerates were deposited around the small sea stacks. Similar small Miocene dikes occur as nearshore sea stacks at Cape Foulweather, Oregon (Snavely et al., 1973). In some areas the basal conglomerate is very thin and pebbly and may represent areas of subdued topography where finer detritus accumulated.

Outside the thesis area poorly-sorted angular conglomerates and

Fig. 50. Basalt pebble conglomerate of the Roy Creek member showing a nearly vertical contact with the Tillamook Volcanics (locality 362, SE 1/4 SE 1/4 sec. 8, T3N, R9W). Contact shows no sign of baking or shearing. The basalt is interpreted as a small sea stack (erosional remnant) buried by nearshore conglomerates.

breccias, some in matrix support, locally occur near the base of the Roy Creek member (e.g., near the type section). Other workers (e.g., Safley, in prep.; Nelson, 1985) have interpreted these units as debris flow deposits that may have begun as coastal landslides in basaltic headland areas. In other areas the conglomerate appears to be very thick (>30m) and may represent areas where local streams deposited abundant coarse basaltic clasts in the nearshore environment (Olbinski, 1983; Nelson, 1985).

A coarse-grained basaltic sandstone usually overlies the basal conglomerate and is from 2-15m thick. This coarse-grained sandstone is horizontally bedded to massive, moderately sorted, subrounded to well-rounded, contains shallow marine mollusks (both abraded and nonabraded), and commonly lacks detrital matrix. Several unabraded Scurria sp. gastropods were collected from locality 339 (identification by Ellen Moore of the U.S. Geological Survey). Scurria sp. is usually found in intertidal areas (Ellen Moore, personal communication, 1984). Mumford (in prep.) and Deacon (1953) also collected a number of shallow-marine to intertidal mollusks from this unit in adjacent areas. Barnacle plates are locally abundant in the unit (e.g., at type section). Burns and Ethridge (1979) suggested that authogenic pore filling chloritic cement, as in these coarse sandstones, forms only in "clean washed" nearshore sandstones.

The above data combined with grain-size data from the preceding section indicate that the coarse sandstones were deposited in a high energy wave dominated nearshore environment. In and around modern rocky basaltic headland areas (e.g., Yachats and Tillamook Head, Oregon) beach deposits are rare to absent. Coarse-grained basaltic sands occurr below or near the low tide line where wave energy and agitation is less severe (reconnaissance, this study). A similar depositional environment is suggested for the coarse-grained sandstones in the Roy Creek member. In this model, the basal basalt conglomerate and some of the coarse-grained sandstone would have been deposited as high energy beach gravel deposits. The majority of the overlying coarse-grained basaltic sandstones were probably deposited further offshore between the fairweather wave base and the low tide line. Carson (1972) described modern rocky coast environments which would serve as a good analog for the lower part of the Roy Creek member.

Gradationally overlying the coarse-grained sandstone are 1-40 m of fine-grained basaltic sandstones. These sandstones contain subrounded clasts, range from detrital matrix-rich to detrital matrix-poor, and are locally bioturbated. Some have grain size distributions similar to modern day inner shelf sands and a few contain very faint hummocky cross-stratification (e.g. locality 419) which is thought to form during storms on the inner shelf (Dott and Bourgeosis, 1980). Bedding and laminations occur in moddern inner shelf sands whereas outer shelf sands are typically extensively homogenized by bioturbation (Kulm et al., 1975). The Roy Creek member is only moderately bioturbated which supports an inner shelf to beach depositional environment for the unit. Thick mudstones of the overlying Sweet Home Creek member contain foraminifera indicative of outer shelf to upper slope deposition (McDougall, pers. comm., 1984). The above data strongly indicate that the fine-grained sandstones were deposited in an inner to "middle" shelf environment.

In conclusion, the Roy Creek Member is a fining upward and deepening upward sequence sequence of beach to "middle" shelf basaltic sandstones and conglomerates that reflect transgression over and truncation of the Tillamook Volcanics island. The member is somewhat unique in that it was deposited in a high energy basaltic headland rocky coast environment. The majority of the literature on nearshore environments is from areas of subdued topography with soft substrates. Miller and Orr (in prep.), and Miller (1984) however, have recently described wave cut platform rocky coastline deposits from the Oligocene of Oregon. The lower part of these deposits are very similar in texture and composition to Roy Creek member basaltic conglomerates and sandstones. Traditionally, modern beach deposits have been considered to be texturally and compositionally mature (Folk, 1980). "Beach" deposits in the Roy Creek member are, however, composed almost entirely of unstable volcanic rock fragments and are, therefore, compositionally inmature. Ruxton (1970) showed that beach sands in volcanic arc areas may be composed almost entirely of unstable rock fragments. In addition, moderately sorted coarse-grained basaltic beach sands similar to the Roy Creek member occur on the present Oregon coastline in a forearc setting (e.g., locality Yac-1).

In some areas the Roy Creek member is thin (e.g., locality 398) or may be represented by a lag conglomerate abruptly overlain by bathyal mudstones of the Sweet Home Creek member (e.g., eastern Green Mountain area). Kulm et al. (1975) have described submarine rock outcrops on the outer shelf of Oregon. These regions represent areas where nearshore deposits were not preserved and "basement" rock is overlain by outer shelf mudstones. A similar situation during the Eocene could explain the locally poor preservation of the Roy Creek member. The depositional relationships of the Roy Creek member to other upper Narizian units in northwest Oregon is further described in the Depositional Model for the Hamlet Formation section.

Sweet Home Creek Member

Lithology

The Sweet Home Creek member consist of 120-400 m of bioturbated to faintly laminated, slightly micaceous and carbonaceous mudstones and less common siltstones. A few beds of fine-grained, moderately sorted basaltic sandstone are also present. The mudstones are grayish black (N 2) to dark gray (N 3) when fresh and weather to light brown (5YR 6/4) or moderate yellowish brown (10YR 6/4). Small (5-20 cm) oval calcareous concretions are fairly common throughout the unit. Some gastropod fragments and small pelecypods (*e.g.*, *Delectopecten*) are present (indentification by Ellen Moore of the U.S. Geological Survey). A few large benthic foraminifera such as *Cyclamina* are occasionally seen in hand samples. The trace fossils *Helmenthoida* and *Chondrites* are fairly common.

Mudstones and siltstones of the Sweet Home Creek member contain more mica, more carbonaceous debris, and less tuffaceous detritus than the overlying mudstones in the Jewell member of the Keasey Formation. In addition, the Sweet Home Creek member contains more silt which may occur as thin laminae and the Jewell member contains minor glauconitic sandstones and minor channelized arkosic sandstones with associated clastic dikes. In fresh exposures the two units are easily distinguished but in small weathered exposures the two units appear lithologically similar.

Thin beds (1/2 m thick) of basaltic sandstone occur within the lower part of the Sweet Home Creek member at several localites (339, 604, 616). These beds may be highly weathered and are massive to thinly laminated. Fragmented and abraded Delectopecten? shells occur within the sandstones at locality 339. The sandstone beds appear to be restricted to the lower and middle parts of the Sweet Home Creek member; the basaltic sandstones at locality 339 occur 4 m above the basal contact with the Roy Creek member.

The Sweet Home Creek member is relatively homogenous with no apparent lithologic differences between the upper and lower parts of the unit. Exceptions to this may be the lack of basaltic sandstone beds and the occurrence of several thin beds of very fine-grained, altered, volcanic glass rich beds in the uppermost part of the unit (fig. 51). These volcanic glass rich beds occur between two stratigraphic levels of Cole Mountain basalt at localities 193 and 221. The surrounding mudstones are less micaceous and carbonaceous than other parts of the Sweet Home Creek member but the exposures are lithologically distinct from the overlying Keasey Formation. These two exposures have been assigned to the Sweet Home Creek member and may have been deposited contemporaneously with Goble and Cole Mountain igneous activity.

Fig. 51. Mudstones and thin beds of very fine-grained volcanic glass-rich sandstone in the upper part of the Sweet Home Creek member (locality 221, NW 1/4 SW 1/4 sec. 8, T4N, R8W). Sandstone beds define a small anticline.

Petrography

Three sandstone thin-sections and approximately 30 smear slides were examined petrographically (Appendix 9). Grain mounts were made from the heavy mineral fraction (specific gravity >2.92) of four "siltstones" (Appendix 10). One mudstone sample (625) was examined with a scanning electron microscope. The smear slides were made from mudstones and siltstones and examined for mineralogical content. Because of the fine grain size it was not possible to accurately estimate the relative abundace of minerals present. The mudrocks are primarily composed of clay minerals but also contain significant amounts of quartz, potassium feldspar, plagioclase, biotite, muscovite, pyrite, and organic matter. Minor volcanic glass, apatite, and garnet were observed in several samples.

The majority of the material in the smear slides is fine to medium silt with lesser amounts of clay-sized and sand-sized detritus. Therefore, the majority of the Sweet Home Creek member consists of mudstones (33-67% silt) with true siltstones (>67% silt) being relatively rare. Claystones (>67% clay) were not found. Approximately 40 mudstone samples were disaggregated and sieved for microfossils. Foraminifera comprise from 0-2% of the total rock. Sand-sized silicate minerals form less than 5% of the rock with micas most common. Cemented aggregates of clay and silt account for most of the material in the sieves (4ϕ to 0ϕ). Several workers have used a hydrometer sedimentation technique to determine the size distibution of mudrocks in the region (e.g., Murphy, 1981). However, when this technique is used on mudrocks the resulting size distribution usually reflects the effectiveness of the disaggregation rather than the nature of the original size distribution (Blatt _et al._, 1980). For this reason no attempt was made to use a hydrometer sedimentation technique on the mudrocks of the Sweet Home Creek member.

A small (4 mm) well-preserved fish tooth was recovered from locality 628 in Sweet Home Creek. This tooth is V-shaped and has distinctly serrated edges (fig. 52). It is identical in morphology and size to a _Squalus_ sp. (Dog-fish shark) tooth illustrated by Welton (1972) and has been assigned to that genus. _Squalus_ sp. teeth have been reported from the upper Narizian Cowlitz, Spencer, and Nestucca formations in northwest Oregon (Welton, 1972).

Basaltic sandstone samples 604 and 616 consist of subrounded to subangular, fine-grained basaltic rock fragments and plagioclase (An 47-67) (appendix 9). The basaltic rock fragments are texturally identical to the Tillamook Volcanics. Sample 616 is calcite cemented and identical to the basaltic sandstones in the underlying Roy Creek member. Sample 604 is distinctly laminated and contains more plagioclase (25%) than most Roy Creek member sandstones (fig. 53). Sample 221 was collected from the uppermost part of the Sweet Home Creek member. It is composed of very fine-grained, altered, glassy volcanic rock fragments and clay with trace amounts of augite and green hornblende. This sample is similar to aquagene tuffs described by Wolfe and McKee (1972).

Heavy minerals from the coarse silt (4.5ø) and very fine sand (4.0ø) fraction of 4 siltstone and mudstone samples were examined petrographically. More than 1,000 grams of siltstone were

Fig. 52. Squalus sp.? tooth from locality 628 (NW 1/4 SW 1/4 sec 28, T4N, R8W) in the Sweet Home Creek member. Note the serrated edges.

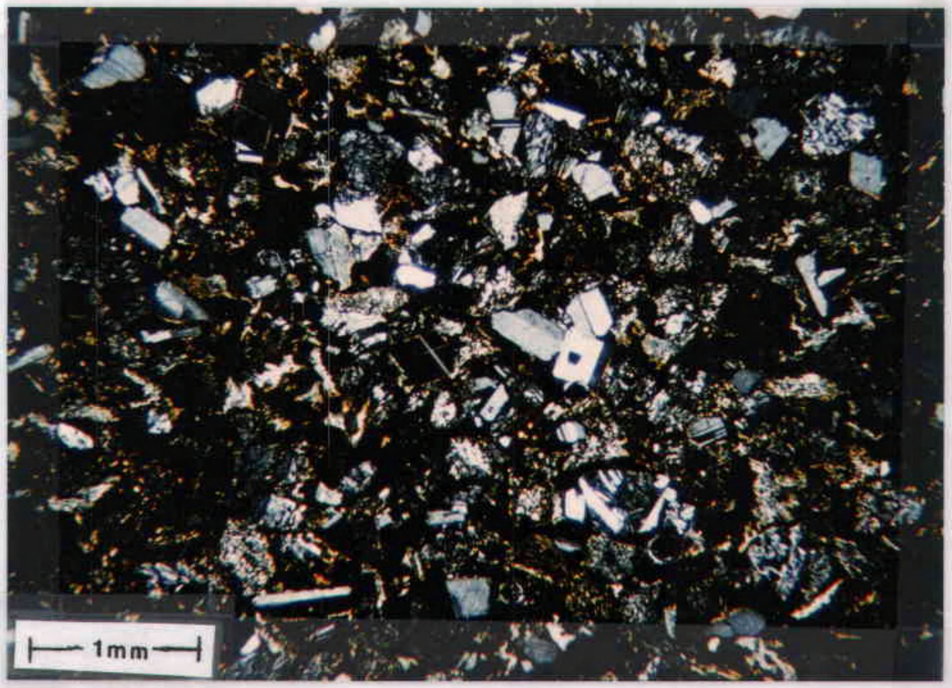


Fig. 53. Photomicrograph of fine-grained basaltic sandstone in the Sweet Home Creek member (sample 604, crossed nicols). Note the abundant labradorite clasts and subrounded volcanic rock fragments.

needed to obtain a significant heavy minerals assemblage in this size range. Pyritized foraminifera and diatoms were the dominant constituent of all samples (fig. 54) (appendix 10). Sample 620, a silty mudstone, also contains a significant amount of augite, biotite, muscovite, epidote, zircon, garnet, apatite, magnetite, and ilmenite (fig. 55). The other samples contain lesser amounts of some of these minerals.

Sample 620, a silty mudstone, was examined with a scanning electron microscope. Clay minerals with a slightly crenulated to flaky morphology are the dominant constituent with silt-sized silicate minerals occurring less commonly. The clays are morphologically similar to smectite clays pictured by Welton (1984). Energy dispersive X-ray (EDX) analysis, which is semiquantitative, was performed over a small area composed of clay minerals and showed the presence of Si, Al, Fe, Ca, K, Mg, and Ti in decreasing abundance. The EDX pattern of these clays is similar to that of iron rich smectites examined by Welton (1984). Van Atta (1971) showed by X-ray diffraction analysis that smectite is the dominant clay in the upper Narizian mudstones of northwest Oregon. Therefore, the morphology and EDX pattern of this sample is suggestive of a dominance by smectite clays but does not exclude the presence of other clays. The very small amount of potassium indicates that illite is not very common and abundant iron indicates that kaolinte is not a dominant constituent. It is, however, possible that a significant amount of chlorite is present.

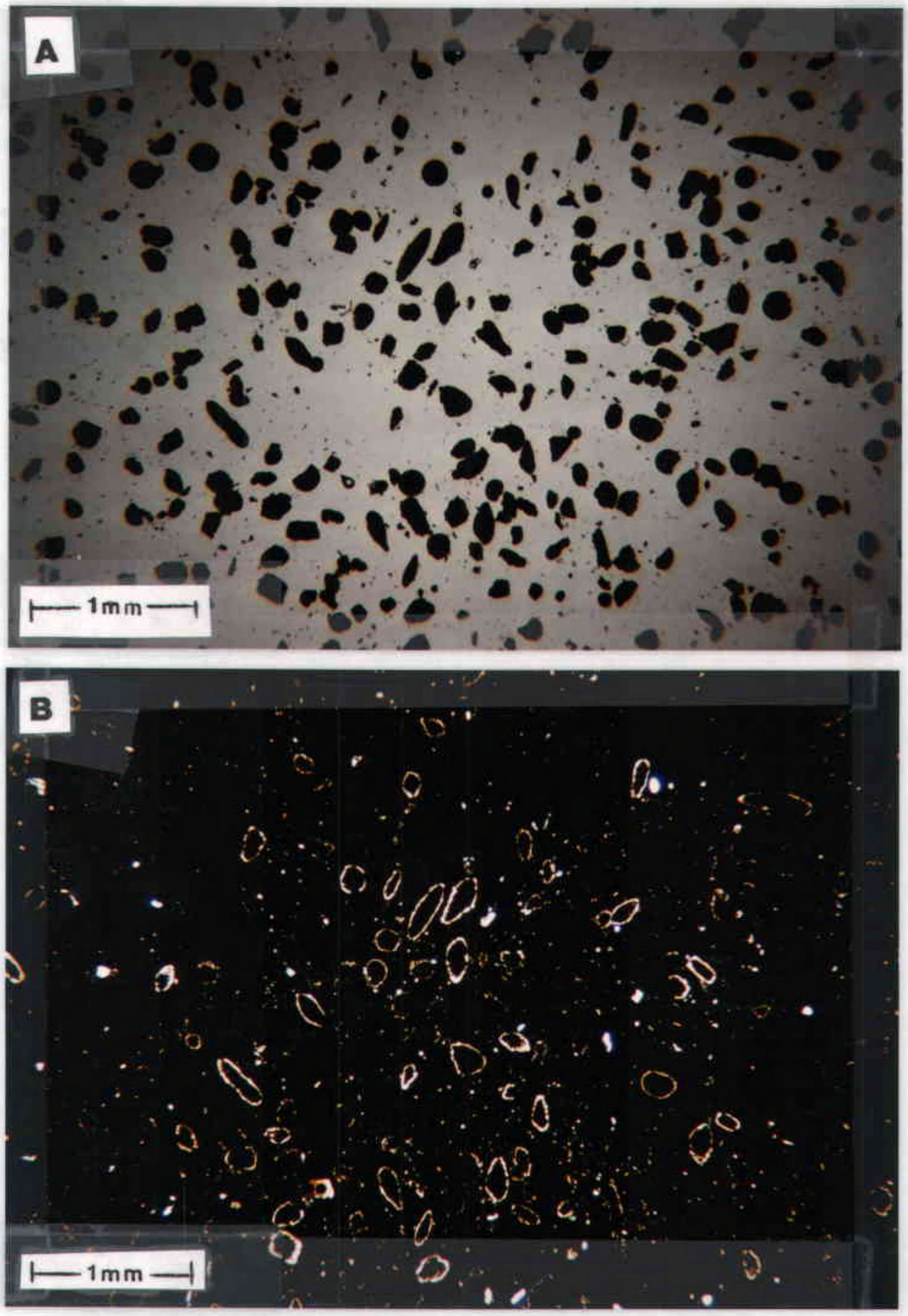


Fig. 54. Heavy mineral assemblage form the Sweet Home member consisting almost entirely of pyritized foraminifera and diatoms (from the 4.5ϕ size fraction of sample 629). Plane polarized light (A) and crossed nicols (B). Note calcite showing the outline of foraminifera in B.

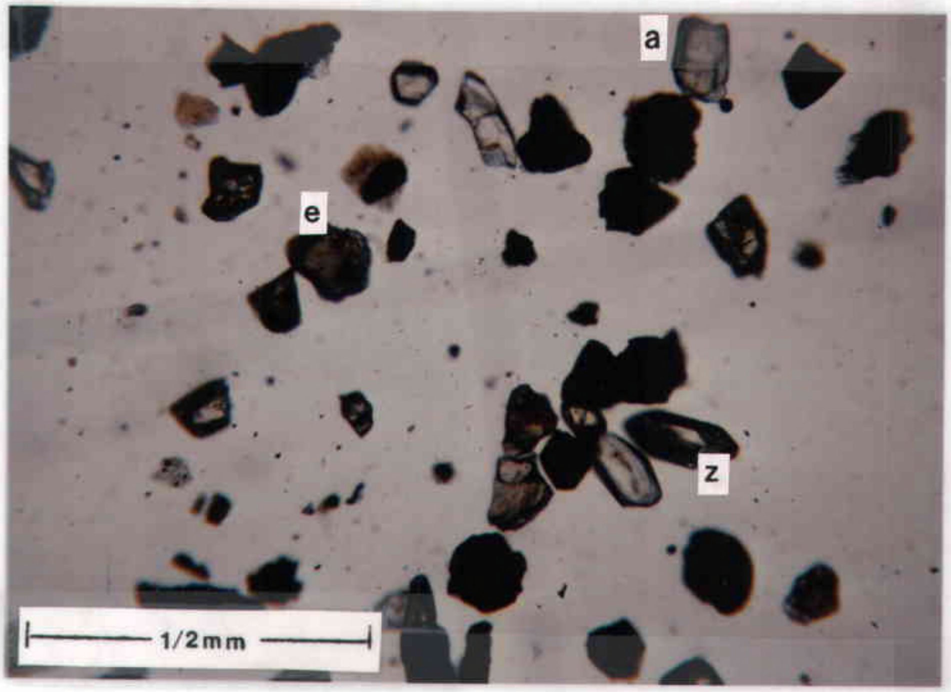


Fig. 55. Heavy mineral assemblage from sample 620 in the Sweet Home Creek member (plane polarized light). Note the abundant euhedral zircon (z), angular epidote (e), and augite (a).

Heavy mineral assemblages and major mineral constituents indicate acid plutonic, metamorphic, and basic volcanic sources for the Sweet Home Creek member. A granitic source is suggested by common euhedral zircon in conjunction with quartz and microcline. Epidote, clinozosite, green-brown tourmaline, and abundant garnet indicate a high-grade metamorphic source. A basic Tillamook Volcanics source is indicated by well-twinned labradorite, basaltic rock fragments, and augite. The absence of rock fragments and limited heavy mineral assemblages make it difficult to precisely determine a source area for these mudrocks. Van Atta (1971), Olbinski (1983) and Nelson (1985) analyzed time-equivalent (upper Narizian) sandstones and siltstones to the east of the thesis area and concluded that the source area consisted of metamorphic, plutonic, and volcanic rocks. He suggested that an ancestral Columbia River draining the Mesozoic Idaho and Wallowa batholiths supplied the arkosic detritus to northwest Oregon. The heavy mineral assemblage from the fluvial, Eocene Herron formation in northeast Oregon (Shorey, 1976) is very similar to that from the Sweet Home Creek member. This shows that the region encompassing the Idaho and Wallowa batholiths could produce the mineralogy seen in the upper Narizian sedimentary rocks of northwest Oregon.

The basaltic sandstone beds in the Sweet Home Creek member were clearly derived from the Tillamook Volcanics. These sandstone beds are composed almost entirely of basaltic rock fragments, which are texturally similar to Tillamook Volcanics flows (e.g. pilotaxitic texture), plagioclase euhdra which are the same size and have the same An content (An 50-65) as the phenocrysts in the Tillamook Volcanics (Appendix 9). Near the top of the Sweet Home Creek member are a few thin beds of fine-grained, glassy volcanic detritus. These may have been locally sourced from the Cole Mountain basalt or could have another volcanic source.

In summary, the Sweet Home Creek member probably received abundant clay to very fine sand-sized metamorphic and plutonic detritus from an ancestral Columbia River with some coarser-grained detritus derived locally from the Tillamook Volcanics. Since much of the unit is composed of clay minerals, it is difficult to determine the relative importance of the two source areas. In any case, the Sweet Home Creek member represents a distinct change in source area from the underlying Roy Creek member which was derived almost entirely from the Tillamook Volcanics.

Contact Relations

The Sweet Home Creek member is conformable upon and slightly gradational with the underlying Roy Creek member. This is evidenced by the following: 1) the upper part of the Roy Creek member and the lower part of the Sweet Home Creek member were deposited in similar environments; 2) the two units have similar structural attitudes (Plate I); 3) there is no significant age difference between the two units; and 4) basaltic sandstones identical to those that form the upper part of the Roy Creek member occur in the Sweet Home Creek member.

The overlying Cole Mountain basalt has features such as pillows and irregular contacts with the Sweet Home Creek member that suggest the units are conformable (e.g. locality 258; see Cole Mtn. basalt section). Workers to the east and north of the thesis area consider the Refugian Keasey Formation to be unconformable upon the upper Narizian Cowlitz Formation (e.g. Kadri, 1982; Bruer et al., 1984). Within the thesis area there is no unequivocal evidence of an unconformity between the Keasey Formation and the Sweet Home Creek member. The two units have similar structural attitudes and there does not appear to be a large age difference between the units. The upper Narizian section in the thesis area is relatively thin compared to the upper Narizian section in the upper Nehalem River Basin (see Plate III). The difference in thickness is due, at least partially, to lower sedimentation rates in a deeper water environment but it is possible that a minor part of the section was removed by an unconformity. The fact that the Keasey Formation does not erode through the Cole Mountain basalt, at least within the thesis area, suggests the absence of a major erosional unconformity. Glauconitic siltstones at the base of the Keasey Formation and a distinct change towards more tuffaceous sedimentation, however, does indicate the presence of a small submarine unconformity or diastem.

Adjacent to the thesis area, in the CZ 11-28 well, dipmeter logs show a small but distinct change in attitudes at the contact of the Keasey and Sweet Home Creek formations (fig. 56). This change in attitudes appears to be the result of a slight angular unconformity rather than a result of faulting. Microfossil data from this well show that the Sweet Home Creek mudstones are time correlative to arkosic sandstones in the Cowlitz Formation (McKeel, unpub. data,

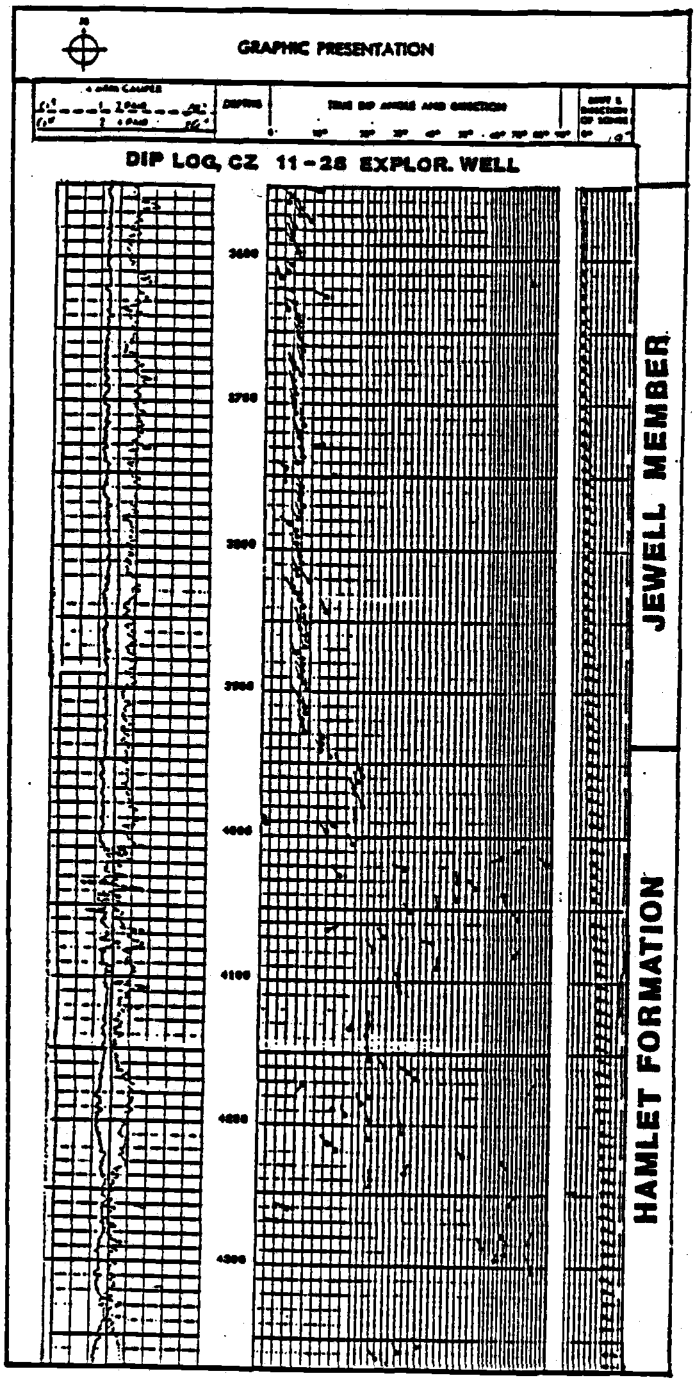


Fig. 56. Dipmeter log of the CZ 11-28 well showing a distinct change in attitude at the Jewell member-Sweet Home Creek member contact.

1983). In summary, there is evidence of an unconformity at the top of the Sweet Home Creek member but this unconformity probably did not result in the removal of significant thickness of the unit.

The upper Narizian Cowlitz Formation in northwest Oregon is thought to be unconformable upon underlying sedimentary rocks (Bruer et al., 1984). Within the thesis area the Sweet Home Creek member is a facies equivalent of the sandstone rich Cowlitz Formation and underlying units (Plate IV). Therefore, an unconformity may occur within the Sweet Home Creek member. There is, however, no evidence of an unconformity within the unit. Similar structural attitudes and lithologies in conjunction with an absence of significant time gaps indicates that the unconformity does not occur in the thesis area.

Age and Correlation

Age-diagnostic microfossils were collected from 12 different surface localities from the base to the top of the unit and 2 well localities (appendices 1 and 2). The majority of the age calls were based on benthic foraminifera, but some localities also contain age diagnostic calcareous nannofossils and diatoms. All foraminiferal assemblages were assigned to the late Narizian (late middle to late Eocene) and are similar to the foraminifera assemblages of the type area Cowlitz Formation and the Nestucca Formation (Rau and McDougall, pers. comm., 1984). The type Yamhill Formation fauna is distinct from and older than the Sweet Home Creek member fauna (Rau, pers. comm., 1984)

Calcareous nannofossils from two surface localities (612, 620) in the upper middle to lower part of the Sweet Home Creek member were assigned to subzone CP-14a and a well sample from the upper part of the unit was assigned to subzone CP-14b (Bukry, pers. comm., 1983). These subzones are correlative to the late Narizian foraminifera stage (fig. 5). Diatoms from locality 558 in the North Fork of the Nehalem River indicate a late middle Eocene to earliest Oligocene age (Barron, pers. comm., 1983).

McDougall (1980) evaluated the chronostratigraphic significance of the late Eocene benthic foraminiferal zonations on the Pacific Coast. She concluded that some of the zones were facies controlled and time transgressive. The occurrence of both late Narizian foraminifera and zone CP-14a calcareous nannofossils in the same outcrop indicates that the late Narizian is a good chronostratigraphic stage. Calcareous nannofossils are planktonic and, therefore, are not likely to be facies controlled.

As part of this thesis, calcareous nannofossils were collected from the original type locality ("Big Bend" locality) of the Cowlitz Formation (sample TC-4). These fossils were assigned to zone CP-14 and are, therefore, age equivalent to those collected from the Sweet Home Creek member. This substantiates the time correlation of the two units based on benthic foraminifera.

The Sweet Home Creek member is time correlative to the following units in northwest Oregon: the Sunset Highway member of the Hamlet formation (Mumford, in prep.) the Nestucca Formation, the Spencer Formation, and the Cowlitz Formation. It is also time correlative to the Cowlitz Formation in southwest Washington and to the Bastendorff and Coledo formations in southwest Oregon (fig. 5). The Sweet Home Creek member appears to be directly correlative to the lower part of the Unit B siltstones of Wolfe and McKee (1973) in southwest Washington. The two units have very similar faunas, lithologies, and appear to be in the same stratigraphic position above correlative volcanic units. The Sweet Home Creek member is younger than most or all of the type area Yamhill Formation.

Depositional Environment

Environmentally diagnostic foraminifera assemblages were collected from 13 widely separated localities in the Sweet Home Creek member (appenidx 2). More than 70 different species were identified allowing for fairly accurate environmental determinations (appendix 1). McDougall (pers. comm., 1983) and Rau (pers. comm., 1983) consider the faunas to be indicative of an outer neritic to middle bathyal (150 m-1,500 m) depositional environment. The two paleontologists, when examining identical faunas from the same locality, often disagree on environmental assignments. The most common discrepancy is that benthic foraminifera assemblages which McDougall considers to be upper bathyal are considered middle bathyal by Rau. This indicates that micropaleontologists have some disagreement on precise subdivision of the bathyal environment. In any case, benthic foraminifera from the Sweet Home Creek member in the thesis area indicate "middle" to upper bathyal deposition. McKeel in Martin et al. (in press) reported "lower" bathyal foraminifera from the Sweet Home Creek member in wells to the north of the thesis area.

Dougless and Heitman (1979) were only able to recognize two distinct formaninfera biofacies on the present California slope. These were an upper slope assemblage and a lower slope assemblage. In addition, they found that few species are truly isobathyal and that subtle environmental changes (e.g., water temperature) can strongly affect the faunal makeup. In conclusion, it may not be possible to divide the bathyal environment into numerous subenvironments using foraminifera. Any subdivisions beyond upper and lower bathyal are somewhat conjectural.

McDougall's bathymetric interpretations indicate that the deepest faunas ("upper middle" bathyal) occur in the middle part of the Sweet Home Creek member with slightly shallower faunas at the base (upper bathyal) and top (outer neritic to upper bathyal). According to Rau, the shallowest faunas occur at the base of the unit ("upper middle" to upper bathyal) (appendix 2). In summary, the foraminiferal data indicates that the Sweet Home Creek member was deposited somewhere between 150 m and 1,500 m in an outer shelf to "middle" slope (outer neritic to "middle" bathyal) setting. The data are slightly suggestive of a deepening depositional trend followed by a shallowing trend.

Diatom assemblages from three localities in the Sweet Home Creek member were identified by John Barron of the U.S. Geological Survey (appendix 1). He considered these diatoms to be a shelf edge fauna. Therefore, there appears to be a slight discrepancy between water depths determined from benthic foraminifera and from planktic diatoms which tend to be less environmentally sensitive. The pelecypod Delectopecten sp. is present at several localitilies (e.g., 221) (identification by Ellen Moore of the U.S. Geological Survey). This genus is commonly found on the continental slope but lives at depths ranging from 25-2,000m (Moore, personal communication, 1983). Helmenthoida burrows are common in the Sweet Home Creek member. These trace fossils commonly occur in slope deposits but are also present in deeper-and shallower-marine environments (Chamberlain, pers. comm. to Nelson, 1985). Non-biogenic clays and silts are the dominant constituents of the Sweet Home Creek member. Microfossils account for roughly 0.1-3% of the rock. Benthic foraminifera (~2% agglutinated) are volumetrically the most abundant microfossils followed by calcareous nannofossils, planktonic foraminifera, and diatoms with radiolarians being relatively rare. Delicate spines on small formainifera, calcareous nannofossils, and diatoms show no signs of dissolution. This indicates that there was little post-depositional alteration of the fauna. Some microfossils have been filled with pyrite but are still recognizable. The above faunal abundances are characteristic of upper slope, open ocean environments (McDougall, 1980; Dott and Bird, 1979). In lower slope environments planktonic foraminifera, calcareous nannofossils, agglutinated foraminifera, and radioloria tend to be fairly abundant. In shelf environments ostracods are often present, radiolarians and calcareous nannofossils are rare to absent, and the foraminifera species diversity is low (approximately 1-12 species per sample) (McDougall, 1980; Dott and Bird, 1979). Several samples in the Sweet Home Creek member contain more than 15 species of foraminifera (appendix 1).

Upper slope deposits of of Oregon have variable textures and range from clayey silts to silty clays and generally contain less than 5% sand (Kulm and Scheidegger, 1979). The Sweet Home Creek member consists of hemipelagic mudstones and a few siltstones which are generally massive and bioturbated but may be thinly laminated. Therefore, the Sweet Home Creek member is lithologically similar to modern upper slope deposits.

Carbonaceous debris and authigenic pyrite are fairly common throughout the Sweet Home Creek member. Two fresh samples (559 and 628) analyzed by AMOCO Production Co. averaged 1% total organic carbon (appendix 13). The preservation of organic matter and the formation of pyrite require a low Eh (reducing) environment (Blatt et al., 1980). It can be concluded that the Sweet Home Creek member was deposited under lightly reducing conditions, as is common in upper slope environments. Microfossils and molluscan fossils collected from the unit show that strongly reducing (anoxic) conditions did not exist.

The rare basaltic sandstones in the Sweet Home Creek member are interpreted as turbidite deposits which originated on the shelf. These turbidites were, however, infrequent events as they have been found at only three localities and occur as single beds. The sandstone beds are thin (1/4m to 1m), have sharp basal contacts with mudstones, and have slightly gradational upper contacts with mudstones. In hand sample the sandstones are fine-grained and massive to parallel laminated. These sandstones crop out underwater in the stream bed of Sweet Home Creek and in the North Fork of the Nehalem River, and they may contain unobserved sedimentary structures. The contacts and thicknesses of the sandstones are consistent with turbidite deposits. The parallel lamination in sample 604 may represent Bouma interval B. Foraminifera collected from mudstones adjacent to one of the sandstone beds (locality 615) indicate an upper bathyal depositional environment. Turbidity currents are the dominant process resulting in the transportation of fine-grained sands onto the slope (Blatt et al., 1980). Leckie and Walker (1982) describe similar sandstone beds in the Cretaceous Moosebar Formation of western Canada which they interpret to be offshore, storm-generated, turbidity current deposits. The fine-grained basaltic sandstone beds in the Sweet Home Creek member are litholigically identical to shelf sandstones in the underlying Roy Creek member. Therefore, it is quite possible that storms on the shelf generated turbidity currents which transported the sands to a deeper water environment in the Sweet Home Creek member.

An average sedimentation rate of 10 cm/1,000 years was calculated for the Sweet Home Creek member using a time of 3 my. and a thickness of 300m. The time constraints are based on calcareous nannofossil subzones and the thickness is approximate due to relatively poor exposure. Therefore, the actual time could range from 1-5 my. and the thickness from 200-500 m. Using these constraints maximum sedimentation rates are 50 cm/1,000 years and minimum rates are 4 cm/1,000 years. Kulm and Scheidegger (1979) calculated a sedimentation rate of 10-14 cm/1,000 years for the present upper slope of Oregon and rates of 20-65 cm/1,000 years for the lower slope. Since sedimentation rates calculated by Kulm and Scheidegger are for uncompacted muds the rates should be reduced by approximately 35% to allow for better comparison with partially compacted muds of the Sweet Home Creek member. In any case, the above data are supportive of an upper slope depositional environment for the Sweet Home Creek member. The data also show that the relatively thin upper Narizian section in the thesis area could be the result of low sedimentation rates rather than the result of an unconformity.

Outside the thesis area the Sweet Home Creek member appears also to have been deposited in an outer shelf to middle slope environment. Mumford (in prep.) has collected a number of assemblages of outer neritic to middle bathyal foraminifera to the east of the thesis area.

In summary, abundant fossil and lithologic evidence shows that the Sweet Home Creek member was deposited in a "middle" slope to outer shelf, open marine, slightly reducing environment. Petrography and heavy minerals indicate that the sediments were derived from two distinct sources, a local Tillamook Volcanics source and an "ancestral Columbia River" granitic-metamorphic source. The depositional setting of the Sweet Home Creek member in relationship to other upper Narizian in the region will be discussed in the following section.

Depositional Model for the Hamlet Formation

The upper Narizian (middle to upper Eocene) strata of northwest Oregon include the Cowlitz Formation, Spencer Formation, Hamlet formation, and the upper part of the Tillamook Volcanics. The stratigraphic relationships of these units, except for the Spencer Formation, are shown in plate IV. The Spencer Formation is lithologically and depositionally similar to the Cowlitz Formation (Jackson, 1983). A comprehensive depositional model for these units outcropping in northwest Oregon, emphasizing relationships with units in the thesis area, is presented in the subsequent discussion. Plate IV is a fence diagram showing the interrelationships of the upper Narizian strata in northwest Oregon. It should be used in conjuction with the following discussion. The depositional environments of the Roy Creek and Sweet Home Creek members were discussed in detail in preceding sections. The reader is referred to Mumford (in prep.), Safley (in prep.), Jackson (1983) for a more detailed discussion of the Cowlitz Formation and the Sunset Highway member of the Hamlet formation.

Cessation of Tillamook volcanism resulted in rapid subsidence which was probably due to thermal cooling of the crust beneath the Tillamook Volcanics. Transgressive, shoreline to middle shelf, storm-dominated, basaltic sandstones and conglomerates of the Roy Creek member were deposited over and around the subsiding Tillamook Volcanics "island". Within the thesis area, all of the shoreline to middle shelf sandstones are composed entirely or almost entirely of Tillamook volcanics detritus derived from wave erosion of basaltic sea cliffs, from small streams, and from coastal landslides. Overlying the Roy Creek member, within the thesis area, is the Sweet Home Creek member which consists of middle-slope to outer shelf mudstones and rare fine-grained basaltic sandstones. The micaceous mudstones in the Sweet Home Creek member were derived from the

Tillamook Volcanics and from an eastern continental granitic-metamorphic source via an "ancestral Columbia River". Rare basaltic sandstone beds in the lower part of the Sweet Home Creek member were probably derived from Roy Creek Member shelf sands by storm-generated turbidity currents. During this period the irregular rocky coastline was probably located near the Clatsop County-Columbia County line (fig. 57).

Directly east of the thesis area arkosic to basaltic, shelf to upper-slope sandstones and siltstones of the Sunset Highway member interfinger with basaltic sandstones of the Roy Creek member (Olbinski, 1983; Nelson, 1985; Mumford, in prep; Safley, in prep.) (Plate IV). Therefore, as the transgression proceeded eastward, a significant amount of extrabasinal continent derived, moderately coarse, micaceous-arkosic detritus entered the system (fig. 58). This indicates that the remaining highlands of Tillamook Volcanics were connected to or very close to the continent at that time. It is not certainly known if the molluscan bearing arkosic sandstones entered the system via longshore drift or if they were deposited in shelf channels similar to those described by Dott and Bird (1979). The lower part of the Sunset Highway member consists of interbedded basaltic and arkosic sandstones and, therefore, was sourced from both the Tillamook Volcanics and from an extrabasinal metamorphic-granitic source (Olbinski, 1983; Nelson, 1985; Mumford, in prep.). Inner shelf to shoreline basaltic sands may have been deposited over middle to outer shelf arkosic sands by storm rip currents (fig. 58). Within the thesis area, during this time interval, upper to possibly middle slope mudstones of the Sweet Home

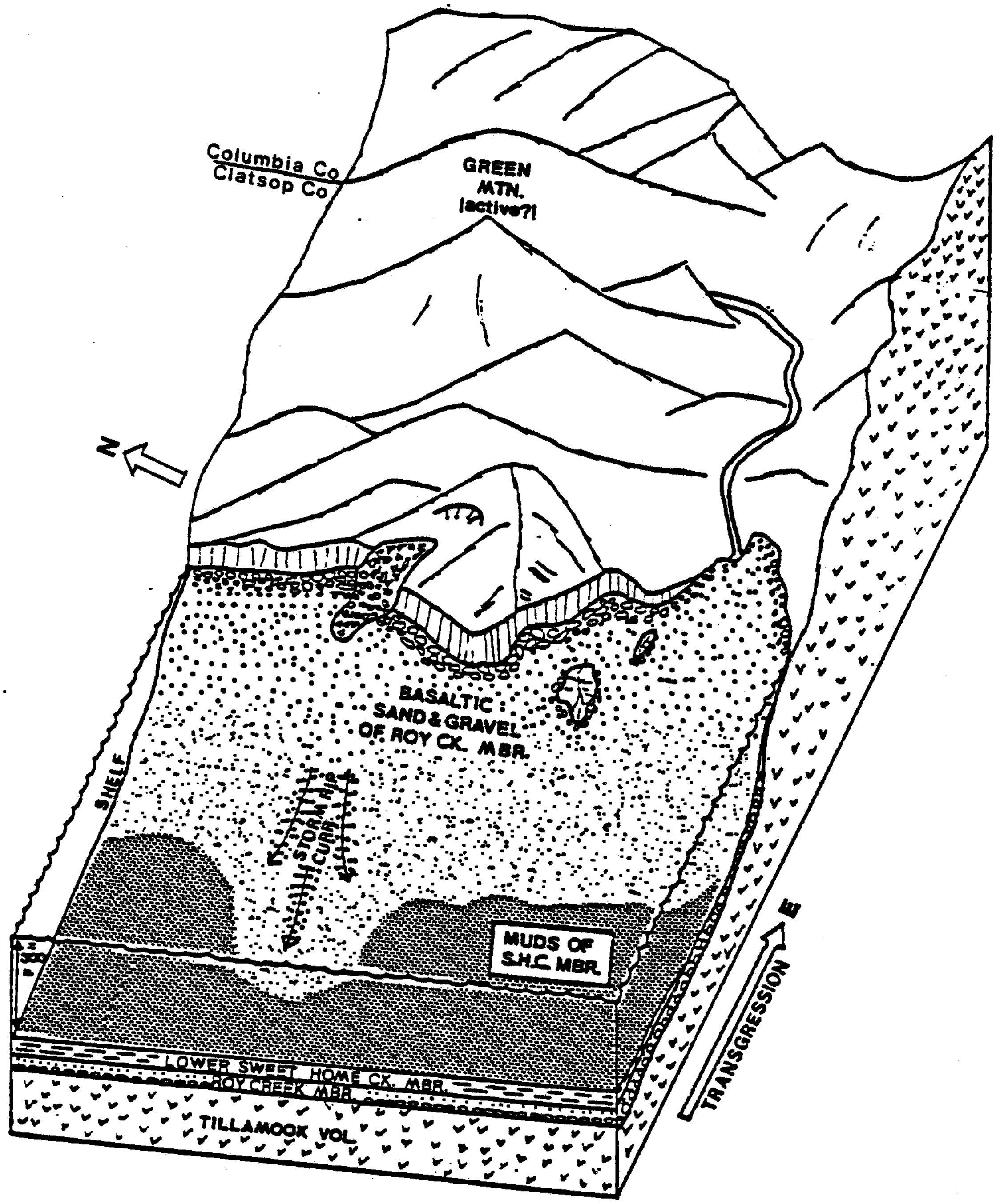


Fig. 57. Reconstruction of depositional environments during the initial phase of the Hamlet formation transgression. The thesis area is represented in the lower part of this diagram and the following diagrams with the upper part representing eastern Clatsop Co. and Columbia Co.

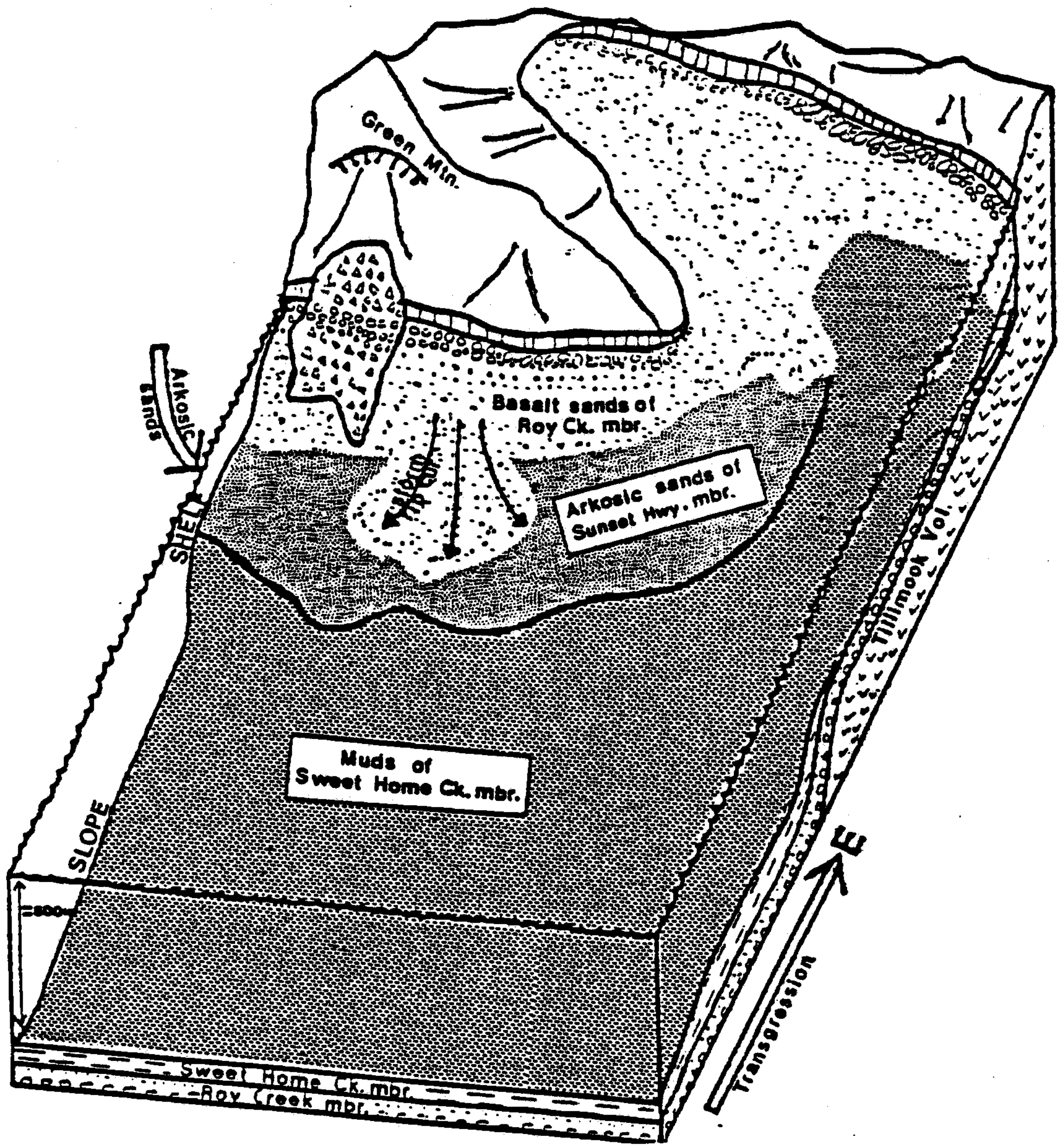


Fig. 58. Reconstruction of depositional environments during continued transgression. Arkosic sands entered the depositional system near the Clatsop Co.-Columbia Co. border. It is possible that some of these arkosic sands were deposited in a "sea gully" setting.

Creek member continued to be deposited. Fossil evidence is slightly suggestive of a continued deepening depositional environment for the unit (fig. 58).

The transgression continued and deep marine (upper slope to outer shelf) mudstones were deposited thoughout much of Clatsop and Columbia counties (fig. 59; Plate IV). A major regression occurred near the end of the late Narizian. This regression resulted in the progradation of extensive arkosic sandstone shelf to deltaic fringe deposits of the Cowlitz and Spencer formations of northwest Oregon and southwest Washington (Armentrout and Suek, 1985). These storm-dominated shelf sandstones pinch-out into outer shelf and slope mudstones to the west. The sandstones are absent in the thesis area with the pinch-out occurring some 8 km to the east (Nelson, 1985; Safley, in prep.; Mumford, in prep.) (Plate IV). The upper part of the Sweet Home Creek member in the thesis area is thought to be a slope facies equivalent of the shallow marine sandstones of the Cowlitz Formation (fig. 60). Transgression followed deposition of the Cowlitz Formation sandstones resulting in the outershelf to upper slope deposits of the upper Cowlitz Formation mudstones (Bruer, 1984).

Data from Van Atta (1971) and from the Quintana Watzek well show that some and probably all of the Cole Mountain basalt was emplaced after deposition of the Cowlitz Formation sandstones (see following section). This igneous activity may, however, have been contemporaneous with deposition of the uppermost Sweet Home Creek member and the overlying Cowlitz Formation mudstones. Outermost shelf to middle bathyal tuffaceous mudstones, siltstones, and

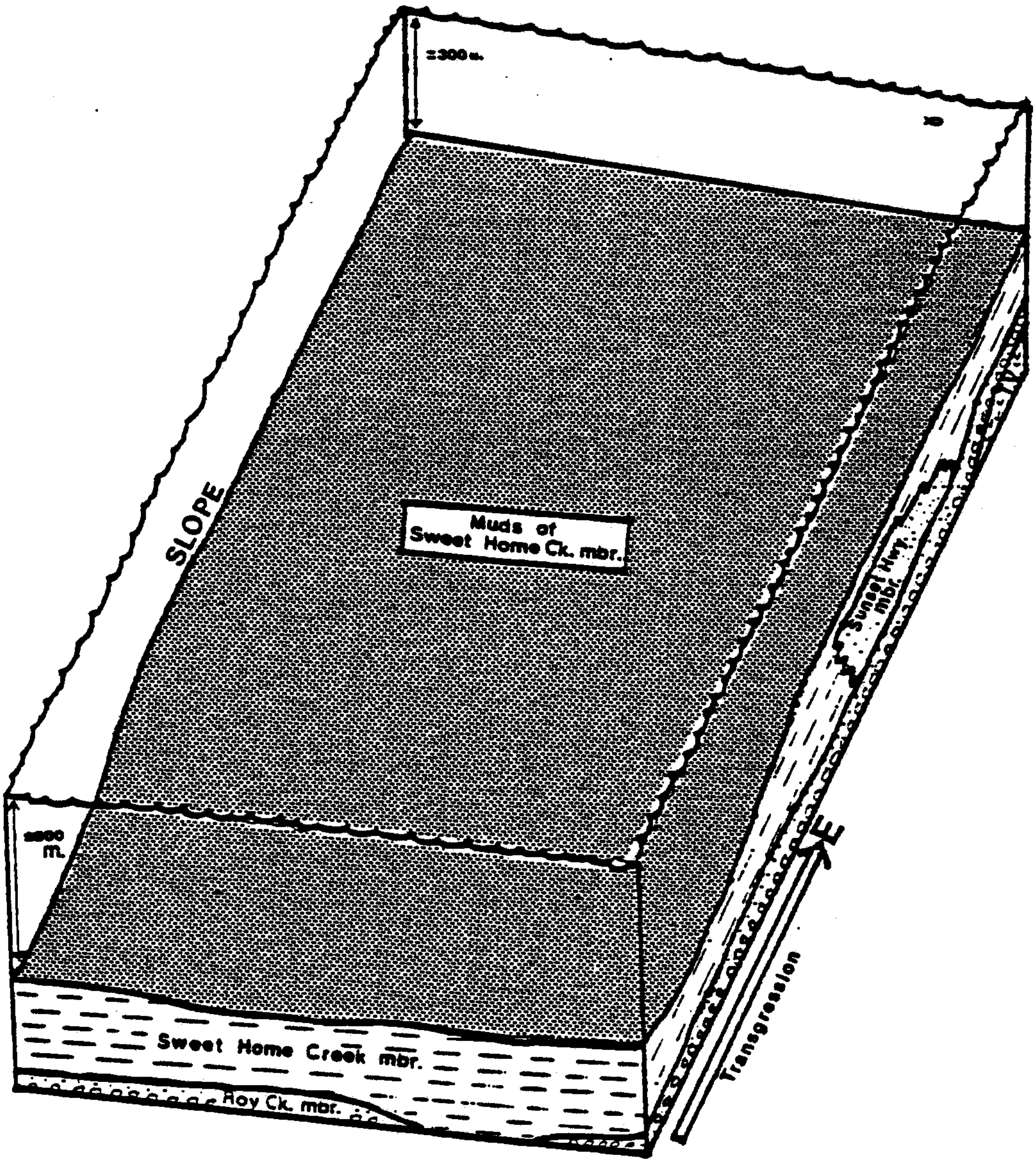


Fig. 59. Continued transgression resulted in deposition of deep-marine (mid to upper slope) muds of the Sweet Home Creek member throughout much of northwest Oregon.

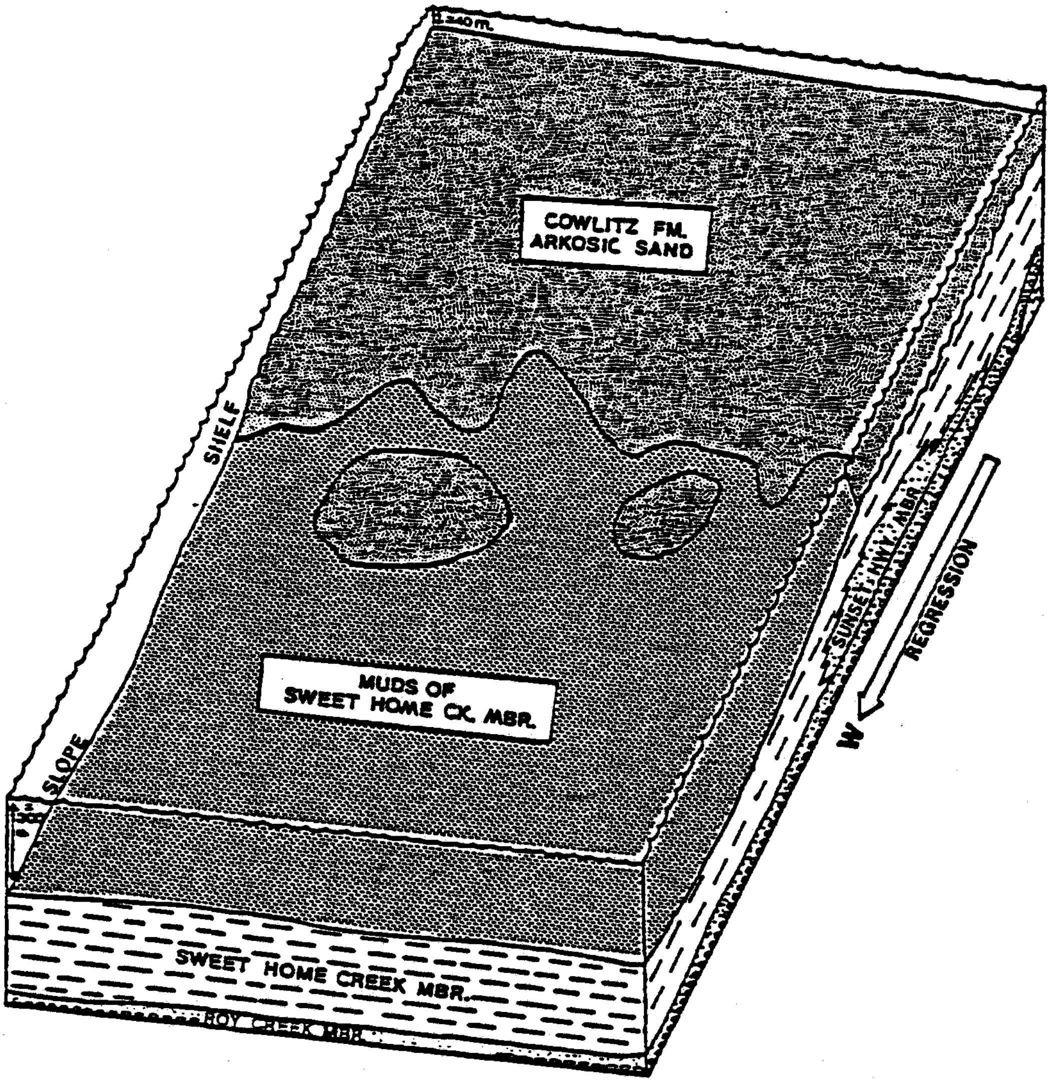


Fig. 60. Reconstruction of depositional environments during the Cowlitz Formation regression. Within the thesis area outermost shelf to upper slope muds of the upper part of the Sweet Home Creek member were being deposited.

minor sandstones of the Keasey Formation unconformably overlie the late Narizian section in northwest Oregon.

The thickness of the Hamlet formation increases towards the north and northeast of the thesis area (Martin et al., in press). This is partially due to the greater percentage of shelf deposits to the east, which tend to have higher sedimentation rates than upper slope deposits (Kulm and Scheidegger, 1979). The much thicker mudstone section towards the north indicates that the depositional center of the basin was located in that direction, possibly seaward of the main Cowlitz Formation delta in southwest Washington.

The depositional models presented in figures 57-60 for the Hamlet formation are similar to the depositional model for the Cretaceous lower Gates Formation presented by Leckie and Walker (1982). However, the Hamlet formation differs in two significant ways; first, sediment source area plays an important role and secondly, the major transgression occurred over a hard, mountainous, oceanic "island" resulting in extensive coastline boulder conglomerates and a few debris flow deposits. Bridges (1975) described a transgression that occurred over an elevated, hard landmass during the Silurian. This Silurian sequence is similar to the Hamlet formation except that extensive restricted marine deposits are present.

Modern analogs to the Hamlet formation include the present rocky Oregon coastline off of the regged basaltic Tillamook Headland and Heceta Headland as well as the coastline of Papua, New Guinea island arc of the southwest Pacific. Basaltic conglomerates and coarse-grained basaltic sandstones derived from adjacent cliffs are being deposited in the beach zone off of Tillamook Head and Heceta Head (reconnaissance, this study). Seaward, arkosic inner shelf sands and outer-shelf to upper slope mudstones are being deposited (Kulm et al., 1975). The Hamlet formation differs in that in the initial transgressive phase continentally-derived arkosic shelf sands were not present (see fig. 5). In addition, Miocene basaltic headlands occur at local isolated areas on the present Oregon coast whereas the Hamlet formation coastline initially consisted entirely of basaltic "headlands". Around Papua, New Guinea volcanic-clast-rich sediments are accumulating adjacent to mountainous volcanic land masses (Ruxton, 1970). This area does, however, differ from the probable environment of the Hamlet formation in that it is tropical and carbonate reefs are also widespread.

COLE MOUNTAIN BASALT

Nomenclature and Distribution

The Cole Mountain basalt is informally proposed in this report and that of Mumford (in prep.) for a sequence of upper Eocene, basaltic to andesitic intrusives and less common submarine volcanics. These rocks crop out over 10 square kilometers within the thesis area and have been mapped to the east by Mumford (in prep.) and Safley (in prep.). Isolated late Eocene dikes and sills related to the Cole Mountain basalt occur in southwestern Columbia County and south of the thesis area in Tillamook county (Wells et al., 1983) (see fig. 21). The maximum thickness of the unit is approximately 300 m.

The proposed type section for Cole Mountain volcanics is at Cole Mountain in the west central portion of the thesis area. The type section occurs along an unnamed logging road from the extreme southwest corner of sec. 12 (T4N, R9W) for 1/4 mile to the intersection of a southbound logging road spur. The type section continues along this southbound spur, which makes a turn to the east and follows the crest of Cole Mountain in the northernmost part of section 13 (T4N, R9W) (Plate I). Since Cole Mountain basalt is moderately weathered at the above type section a principal reference section along the bed of the North Fork of the Nehalem River in the south central part of the thesis area has been proposed. This section extends from the upper contact of Cole Mountain basalt (SE 1/4 NE1/4 sec. 25, T4N, R9W) upstream 1.5 miles to the basal contact with Sweet Home Creek member mudstones (boundary line between sections 19 and 20, T4N, R8W). Cole Mountain basalt is exposed in the streambed of this section and is, therefore, fairly fresh.

The Cole Mountain basalt in the thesis area has been mapped previously, on a reconnaissance basis, as Tillamook Volcanics and undifferentiated sedimentary rocks (e.g., Warren et al., 1945; Beaulieu, 1973). Detailed mapping, detailed biostratigraphic analysis, petrographic work, and chemical correlations by the author and by Mumford (in prep.) clearly show that the Cole Mountain basalt is younger than and distinct from the Tillamook Volcanics. The Cole Mountain basalts intrude and overlie the Hamlet formation which, in turn, overlies the Tillamook Volcanics. The Cole Mountain basalt is stratigraphically and chemically similar to the type area Goble volcanics along the Columbia River (see Tillamook Volcanics section) but form a distinct, isolated igneous center. The area inbetween the type area Goble Volcanics and the Cole Mountain basalt lacks these basalts. For example, well data in northern Columbia County (Bruer et al., 1984) and geologic mapping in southwest Columbia County and southeast Clatsop County (Timmons, 1981; Olbinski, 1983) show that the Cole Mountain basalt-Goble Volcanics are absent in this area except for isolated, small intrusions. Goble Volcanics previously have been mapped in southeastern Clatsop County (e.g., Wells and Peck, 1961), but Safley (in prep.) has shown that most of these volcanic rocks are an upfaulted block of Tillamook Volcanics. Since the Cole Mountain basalt is an isolated unit and since there are problems with the Goble Vocanics nomenclature it is felt that a new informal nomenclature is warrented.

The Cole Mountain basalt crops out throughout the central part of the thesis area (plate I). Unlike Tillamook Volcanics exposures logging road exposures of Cole Mountain basalt are commonly well-weathered with the freshest exposures occurring in the banks of the North Fork of the Nehalem River. A basal contact is well exposed at locality 258 and the uppermost contact is best exposed at localities Q-850, 163, and 328. Good, but weathered, exposures are also present on the northern slope of Cole Mountain (localities 163, 165, 206, 212, and 219). Cole Mountain basalt is more resistant to erosion than the surrounding sedimentarly rocks and typically form small mountains (e.g., Cougar Mtn. and Cole Mtn.).

The thickness of the unit, where it can be accurately estimated (sec. 20, T4N, R8W) is approxmately 210 m. This measurement does not include small dikes and sills which occur beneath the main mass of the unit. The above measurement is thought to be the average thickness of the unit in the central part of the thesis area. The unit pinches out towards the west-southwest and is absent in the CZ 11-28 well, located 3 km west of the thesis area (Plate II). The unit also appears to be absent in the extreme southwest corner of the thesis area (Plate I). To the east, the Cole Mountain basalt ranges from 75 to 250 m in thickness (Mumford, in prep.) and eventually pinch out in Columbia County (see fig. 21).

Lithology

The Cole Mountain basalt in the study area consists of dikes, thick sills, irregular intrusions, submarine flows, and local hyaloclastites. Porphyritic, vesicular to amygdaloidal, basalts and basaltic andesites are the dominant litholgy. Phenocrysts of plagioclase and, less commonly, augite comprise from 1-35% of the rock. In outcrop, Cole Mountain basalt is typically well weathered and light gray (N 4) but some fresh dark gray (N 2) exposures occur in stream beds.

Thin (>4 m), discrete dikes and sills are locally present in the lower and middle parts of the Sweet Home Creek member (eg. localities 560, 605, 607, 610). These intrusions have sharp linear contacts with surrounding mudstones, have few or no vesicles, and are relatively glassy. A well-exposed east-west trending dike occurs at localities 552, 609, 610, and 611 along the North Fork of the Nehalem River. The trend of the dike parallels the major faults mapped in the southern part of the thesis area (Plate I).

The majority of the Cole Mountain basalt overlies or is present in the upper part of the Sweet Home Creek member. Here the unit consists of thick (40-200 m), roughly tabular, broadly concordant, basalt and basaltic andesite sill-like bodies which have highly irregular basal contacts (fig. 61). The Basalt bodies are commonly massive except near basal contacts where pillows may be present. In the vicinity of Hamlet, there are two distinct stratigraphic levels of Cole Mountain basalt in the upper part of the Sweet Home Creek member. The lower level (e.g., localities 198, 251, and 750) tends to be denser, less vesicular, and less porphyritic than the upper level. The two levels are separated by approximately 60 m of mudstone assigned to the uppermost Sweet Home Creek member (e.g., localities 193 and 221).

Fig. 61. Basal contact of the Cole Mtn. basalt with the Sweet Home Creek member (locality 258, NW 1/4 SW 1/4 sec. 20, T4N, R8W). Note the irregular contact into the mudstone and the pillow basalts (p) which have glassy rinds.

In the southern outcrop area only one major stratigraphic level is present. This unit is thick (approx. 200 m), has a very irregular basal contact, is locally very vesicular to amygdaloidal, contains chalcedony filled fractures, and has varying lithologies (ie., differing amount of phenocrysts, vesicles, and glass). Irregular masses of baked mudstone are locally present in the basalts and basaltic andesites. The unit is typically massive, but amygdaloidal to vesicular zones (e.g., localities at type section), columnar jointing (e.g., localities 251 and 257), and pillows (e.g. locality 258) are locally present. The pillows, are concentrated at the basal contact, are small (1 m dia.), have glassy rinds, and have radial fracture. Distinct flow contacts were not observed but, locally lithologically different basaltic rocks occur in close proximity (e.g., locality 192 north of Hamlet). Spheroidal weathering is common in the larger exposures of Cole Mountain basalt.

Hand samples of Cole Mountain basalt are distinct from other basaltic units in the area. They are typically basalt and basaltic andesite, well-weathered, light to medium gray (N 4-N 3), vesicular to amygdaloidal, may contain abundant plagioclase phenocrysts, and have a glassy groundmass. Rocks with abundant plagioclase phenocrysts are generally very vesicular and amygdaloidal. Vesicles and amygdules are oval-shaped, range from 2-15 mm in diameter, and comprise as much as 35% of some rocks. Amygdules consist of silica, calcite, chlorite, and zeolites; all are equally abundant. The plagioclase phenocrysts range from 2-10 mm in length and are commonly weathered to greenish chloritic clays or to very light gray clays. Siliceous nodules (20 cm in dia.) and chalcedony veins (10 cm thick) are locally present and are most common in the upper part of the Cole Mountain basalt (e.g., localities 226, 575, and 542). At some locations the rock may be completely weathered to soil, leaving a residue of siliceous nodules. East of the thesis area Mumford (in prep.) has recognized chalcedony between pillows in Cole Mountain basalt.

A normally graded hyaloclastite deposit is locally present at the uppermost contact of Cole Mountain basalt in the bed of the North Fork of the Nehalem River and northeast of Hamlet (e.g., localities Q-350 and 332). This deposit is approximately 1 m thick, contains a few siltstone rip-up clasts, and is composed of fine- to coarse sand-sized, angular, highly vesicular, glassy, volcanic rock fragments which are cemented by calcite.

Petrography

Samples from thirteen localities were thin-sectioned for petrographic analysis (Appendix 8). Six of these samples were point-counted (300-600 points) and visual estimates of mineral abundances were performed on the remaining samples (appendix 8). Several samples had undergone significant surficial weathering and deuteric alteration making it difficult to determine the original mineralogy (e.g., samples 159 and Q-180).

Seven of the samples are porphyritic to glomeroporphyritic with phenocrysts of plagioclase and augite in an intersertal to hyalopilitic groundmass (fig. 62). The remainder of the samples lack true phenocrysts and display intersertal to hyalopilitic

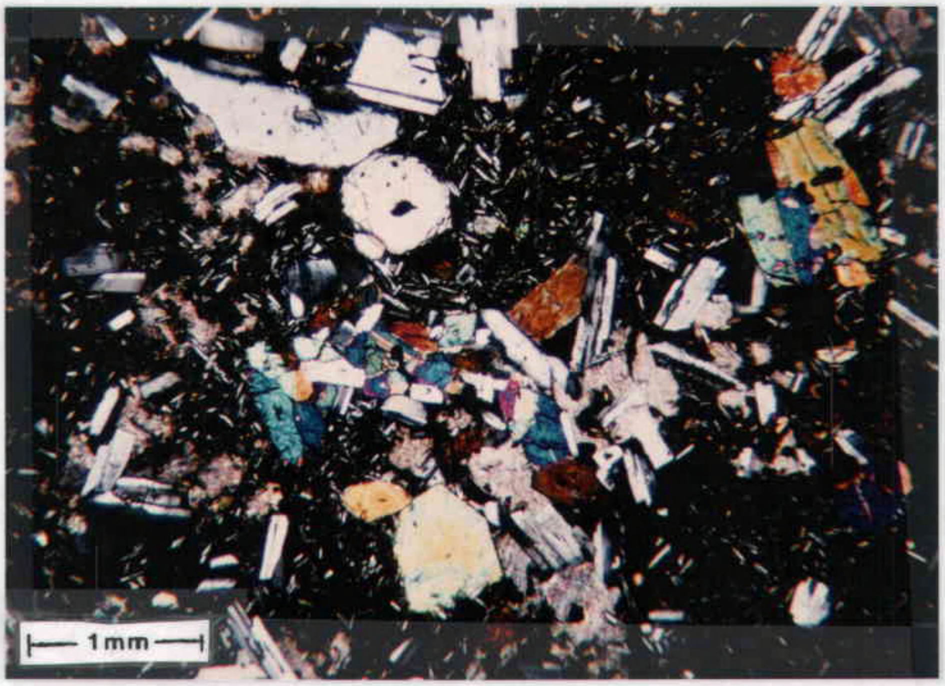


Fig. 62. Photomicrograph of sample Q-850 from the Cole Mtn.basalt (crossed micols). Note the very small plagioclase microlites surrounded by opaque basaltic glass and the larger labradorite and augite.

textures in thin sections. It is generally difficult to distinguish plagioclase phenocrysts from groundmass plagioclase in the Cole Mountain basalt. Those samples classified as porphyritic have plagioclase phenocrysts ranging from 0.8 to 2.5 mm in length and contain very small (0.05-0.2mm) plagioclase microlites surrounded by glass. In a number of samples (e.g., 192, 229, 614, and 470) the plagioclase is gradational in size (0.2-2 mm) and, therefore, true phenocrysts are not present (fig. 63).

Albite twinned plagioclase phenocrysts range in composition from An 58 to An 69 (labradorite), are euhedral to subhedral, may be partially resorbed, and commonly show extensive normal zonation (e.g., core An 69, rim An 53 in sample 610). Labradorite phenocrysts comprise from 0 to 23% of samples thin-sectioned. Augite phenocrysts are less common forming 0-5% of the rock. They are euhedral to subhedral, may be zoned, range from 0.5 to 3 mm in diameter, and have an average 2Vz of 55o. Plagioclase and augite phenocrysts are commonly partially altered to dusky green chloritic clay. Plagioclase chloritization commonly follows polysynthetic twinned lamella and, in heavily zoned phenocrysts, may be restricted to the more calcic core. Some choritic clays may be light brown due to surficial oxidation of iron in the clay. The majority of the greenish to brownish clays have a radiating fibrous habit and are more than likely chloritic in composition but it is possible that some of the more massive clays are glauconite or nontronite. The chloritization observed in the Cole Mountain basalt is a very common occurrance in basaltic rocks according to Augustithis (1978). Some augite and, more rarely, labradorite phenocrysts are replaced by

Fig. 63. Photomicrograph of sample 614 from the Cole Mtn. basalt. Note the abundant albite twinned labradorite of gradational size as well as the opaque glass and rare augite (crossed nicols).

calcite (*e.g.*, samples 599 and 610). In several highly weathered samples (not thin-sectioned) the plagioclase phenocrysts are altered to a white clay. In sample Q-850 from the North Fork of the Nehalem River bed an augite phenocryst has been partially replaced by iddingsite. Olivine phenocrysts were not observed.

The groundmass of the porphyritic rocks and the texture of the non-porphyritic rocks in intersertal to hyalopilitic (*i.e.*, glass occupies minute spaces between plagioclase microlites in a haphazard orientation). The groundmass of the porphyritic rocks consists of labradorite (8-43%, An 50-60), augite (0-13%), opaque minerals (0-9%), chloritic clay (1-30%), and glass (18-73%). The non-porphyritic rocks are composed of labradorite (30-61%, An 55-65), augite (1-20%), opaque minerals (0-5%), chloritic clay (1-10%), and basaltic glass (18-60%).

The Cole Mountain basalt is characterized by abundant (avg. 40%) basaltic glass, partially devitrified glass, and chloritic alteration products of glass. The glass is usually black, or moderate brown in color. Yellow-orange palagonite is rarely present (*eg.*, sample Q-850) and is probably a result of partial devitrification of black tachylytic glass. In some samples (*e.g.*, 251, 470 and 546) a brownish colored glass has partially devitrified, forming axiolitic feldspars. Chloritic alteration of the groundmass, especially the glass, can be rather extensive forming from 1-50% of the rock. In sample Q-180 the majority of the glass is altered to chloritic clays with only the phenocrysts remaining fresh. The chlorite is usually either colloform or has radiating fibrous habit.

Vesicles and amygdules are relatively common, forming 0-17%

(avg. 4%) of thin-sectioned samples. The average rock in the Cole Mountain basalt is probably more vesicular and amygdaloidal than thin sectioned samples but, vesiculated rocks appear to be more susceptible to surficial weathering and, therefore, are difficult to section. The vast majority of what appear to be vesicles in outcrop are at least partially lined with chlorite and are properly classified as amygdules. Amygdule compositionas are chlorite, calcite, glass, cryptocrystalline quartz, and zeolites. Chlorite is the most common; the other minerals occur in roughly equal abundance. Many amygdules are lined with dark green chloritic clay and filled with one of the other constituents (fig. 64). In some cases, radiating chloritic aggregates fill entire vesicles. X-ray diffraction of a fibrous zeolite amygdule showed that the zeolite is thomsonite (locality 257). This sample is physically identical to most zeolites in the Cole Mountain basalt; and, therefore, thomsonite is considered to be the most common zeolite in the unit. Thomsonite has been reported from the type area of the Goble Volcanics (Welton, 1984) and in the Tillamook Volcanics (this study). It is considered to be characteristic of Tertiary basaltic rocks which have not been deeply buried (Walker, 1960).

In the vicinity of sec. 19 (T4N, R8W) in the bed of the North Fork of the Nehalem River four samples were collected at roughly equal spacings from near the base to the top of the main body of Cole Mountain basalt. This locality is by far the best for obtaining a suite of samples through the unit. The following apparent trends were noted: phenocrysts are more abundant near the top; glass and vesicles are more abundant at the margins but are locally abundant in

Fig. 64. Thomsonite (t) and chloritic clay (c) filling a vesicle in the Cole Mtn. basalt (sample 257, crossed nicols).

the interior; and augite is more common in the central part. The tendency for the upper part to be more porphyritic was also observed in the field. Field observations also suggest that vesiculation and glass are more common in the upper parts of the units.

Best (1982) suggested that thick basaltic sills typically have glassy margins, are relatively coarsely crystalline in the upper-central part, and may have a concentration of olivine and pyroxene phenocrysts near the base. With the exception of being relatively glassy at the top these features are not observed in the Cole Mountain basalt. Even thick basaltic sills intruded into wet semi-consolidated sediments are usually not finely crystalline, glassy, and vesiculated throughout the entire sill as is the Cole Mountain basalt (Cressy, 1974). This indicates that either the Cole Mountain basalts were cooled extremely quickly or that several emplacement events occurred. The presence of relatively abundant glass throughout the unit shows rapid quenching and indicates that little differentiation took place after emplacement.

A hyaloclastite? deposit is present at the upper contact of the Cole Mountain basalt at localities 327 and Q-350. A thin-section of sample Q-350 shows that the deposit consists of angular, glassy, highly vesicular basaltic rock fragments (77%), sparry calcite cement (20%), and labradorite (3%) with minor amount of augite, hornblende, and glauconite (fig. 65). Volcanic rock fragments consist of albite twinned labradorite laths and some augite set in a clear, commonly vesiculated, volcanic glass. These clasts are texturally identical to some of the glass-rich rocks in the Cole Mountain basalt. Calcite cement was precipitated soon after deposition as

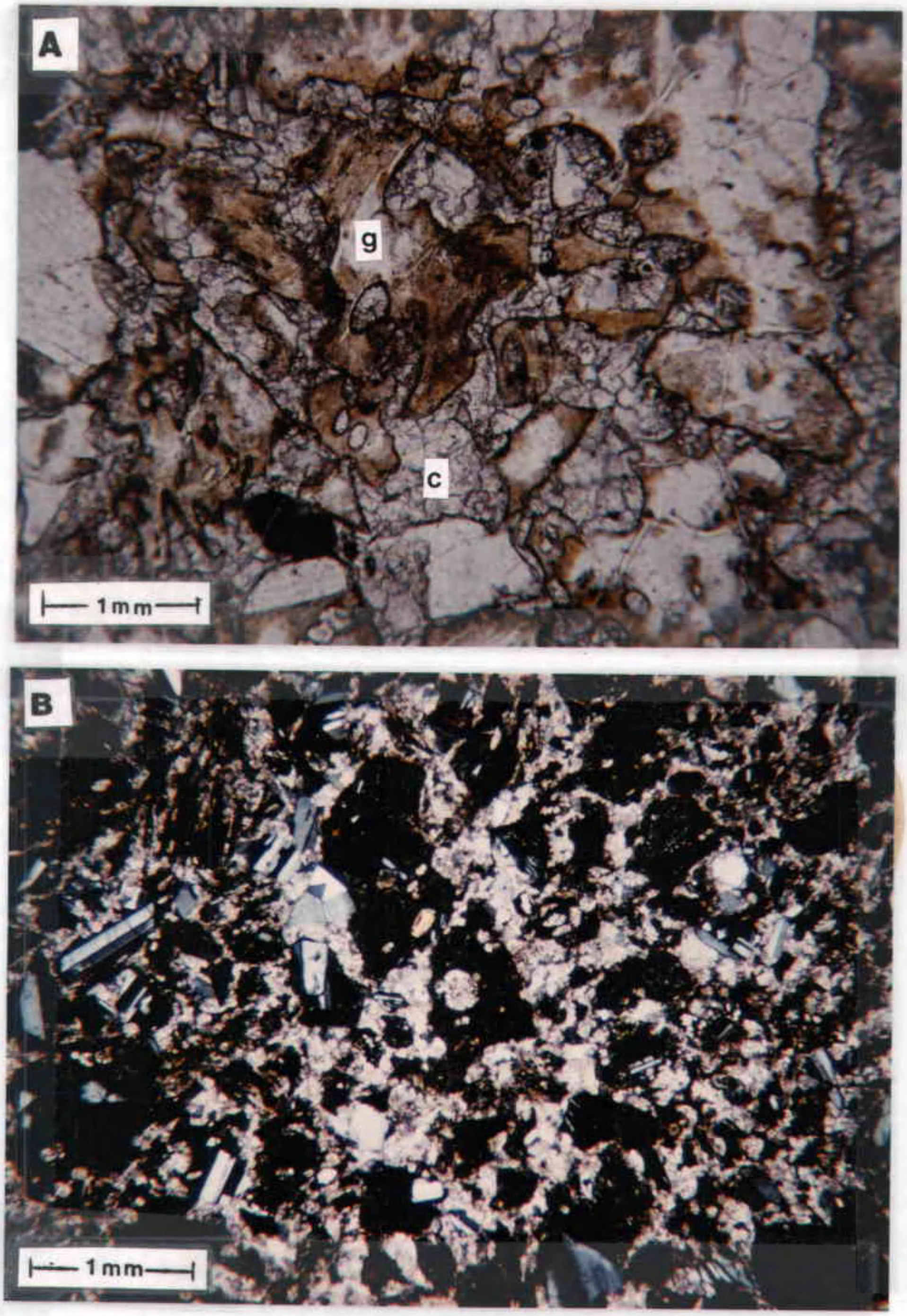


Fig. 65. Photomicrograph of hyaloclastite? deposit from the top of the Cole Mtn.basalt (sample Q-350). A is in plane polarized light and B is with crossed nicols. Note clear sparry calcite cement (c) with high relief and glass-rich volcanic rock fragments (g) with a few large labradorite phenocrysts and ovoid to spherical vesicle and broken, bubble wall grain boundaries in A.

evidenced by a lack of compaction structures, the presence of unaltered glass, and the preservation of delicate "spines" and bubble walls on rock fragments. Very early calcite cementation is commonly the result of hydrothermal action (Best, 1982).

In conclusion, the Cole Mountain basalt is petrographically distinct from other basaltic rock units in the thesis area. Abundant labradorite and augite phenocrysts, common basaltic glass, amygdaloidal textures, and common alteration serve to distinguish them from the middle Miocene Columbia River Basalt Group. The Tillamook Volcanics are usually sparsely porphyritic, have an intergranular groundmass characterized by a pilotaxitic texture, and contain abundant opaque minerals. Type area Goble Volcanics have some petrographic similarities to the Cole Mountain basalt. Both units have relatively few opaque minerals, commonly contain basaltic glass, and may have abundant zoned labradorite phenocrysts (appendix 8).

Geochemistry

The Cole Mountain basalt in the thesis area is characterized by intermediate SiO_2 values (avg. 56,8%), low TiO_2 (avg. 1.7%), low K_2O (avg. 0.8%), and moderately high Al_2O_3 (avg. 16%) (see table 1 and appendix 4). They are chemically distinct from the Tillamook Volcanics, the "Goble Volcanics" in the Grays River area of southwest Washington, and the Columbia River Basalt Group. Late Eocene Goble Volcanics in the type area are, however, chemically "identical" to the Cole Mountain basalt. A more complete discussion on the chemical correlation of the Cole Mountain basalt with other volcanic units in the region was presented in the Tillamook Volcanics section.

The chemical distinction between basalts and andesites has been argued for a number of years. Many authors use a dividing line of 52% SiO_2 to differentiate the two rock types (Cox et al., 1979). Irvine and Baragar (1971) used a plot of normative plagioclase composition vs. normative color index to name volcanic rocks. Under the classification scheme of Cox et al. (1979) all of the Cole Mountain basalt samples in the thesis area and all but one (RCC-1) outside the thesis area classify as andesites (appendices 4 and 5). Using the scheme of Irvine and Baragar (1971) sample 561 classifies as a basalt with other samples in the thesis area classifying as andesites. Outside the thesis area samples classify as both basalts and andesites. Coates (1968) suggested that the term basaltic andesite be used for basic volcanic rocks with phenocrysts of labradorite and SiO_2 in the range 52-58%. Following this definition the vast majority of the Cole Mountain basalts would classify as basaltic andesites with basalts and andesites being relatively rare. Petrographically most Cole Mountain basalt classifies as basalt (e.g., groundmass plagioclase >An 50; Best, 1982). In conclusion, the Cole Mountain basalts are intermediate between typical basalts and typical andesites and will be referred to collectively as basaltic andesites or basaltic rocks in this report.

Irvine and Baragar (1971) used a plot of SiO_2 vs. Na_2O and two normative composition plots to distinguish between alkaline and subalkaline volcanic rocks. All Cole Mountain basalts fall well within the subalkaline fields on these plots (see fig 12). The subalkaline field is further divided into the tholeiitic and calc-alkaline series. Irvine and Baragar (1971) used an AFM diagram and a plot of Al_2O_3 vs. normative plagioclase composition to differentiate the two series. The vast majority of Cole Mountain basalt samples plot within the calc-alkaline field with the remainder of the samples plotting at or near the boundary (fig. 14). Miyashiro (1974) used a plot of FeO*/MgO vs. SiO_2 to distinguish between the calc-alkaline series and the tholeiitic series. The Cole Mountain basalts plot along the dividing line between the two series but have a calc-alkaline trend (fig. 15). Therefore, the Cole Mountain basalt belong to the calc-alkaline series as is defined by most workers. Cole Mountain basalt, is however, somewhat transitional between tholeiitic and calc-alkaline rocks and might best be termed mildly calc-alkaline.

The Cole Mountain basalt appears to become more silicic from east to west. In the Green Mountain area and in Washington County the average SiO_2 content is 53%, whereas the average in the thesis area is 57% (table 1). This suggests that the Cole Mountain basalt within the thesis area is slightly more evolved than the unit elsewhere.

Safley (in prep.) analyzed four deuterically altered Cole Mountain basalt samples in the Military Creek area of southeastern Clatsop County (Appendix 5). These samples contain abundant pyrite and clay. In these samples most of the clinopyroxene and much of the plagioclase has been altered to clay (Safley, pers. comm., 1985). Three of the samples are coarser grained (microgabbroic to gabbroic) than any of the Cole Mountain basalt in the thesis area. The other sample is vesicular and has been completely altered to clay with little of the original texture being preserved. These altered Cole Mountain basalt samples have a major element chemistry that is somewhat intermediate between the Tillamook Volcanics and the Cole Mountain basalt (figs. 17, 18, 20, and table 1). These deuterically altered samples contain significantly more P_2O_5, FeO^* (total iron recalculated as FeO), and TiO_2 than unaltered samples of Cole Mountain basalt. A relative enrichment of FeO^* and TiO_2 is typical of surficially weathered basalts (Best, 1982). Therefore, the somewhat anomalous chemistry of these four samples can be explained at least in part by surficial weathering. It is, however, possible that differentiation and deuteric alteration during slow cooling contributed to the anomalous chemistry in the three gabbroic samples.

A number of chemical plots were used to show that the Cole Mountain basalt has a major element chemistry similar to volcanic rocks formed in compressional tectonic settings (see Tillamook Volcanics, Geologic history and tectonic setting section). This represents a distinct change from the extensional volcanism of the older Tillamook Volcanics. The tectonic significance of the Cole Mountain basalt was discussed in the Tillamook Volcanics, Geologic history and tectonic setting section.

Magnetostratigraphy

The polarity of 25 Cole Mountain basalt samples from 11 sites was determined using a fluxgate magnetometer (Appendix 7 and Plate 1). Corrections were made for structural orientation and for regional tectonic rotations. Ten localities showed a normal polarity and one (locality 60S) had a questionable reverse polarity. Extensive weathering and regional tectonic rotations make the fluxgate determinations somewhat questionable. Nelson (1985), using a spinner magnetometer to magnetically clean the samples, determined a normal polarity for a locality in the Cole Mountain basalt east of the thesis area near Sports Acres above the Nehalem River. Therefore, some or possibly most of the Cole Mountain basalt has a normal polarity. The Cole Mountain basalts have been tentatively assigned to normal magnetic epochs 16 or 17 of Ness et al. (1980)

Age and Contact Relations

The Cole Mountain basalts intrude and overlie upper Narizian (middle to upper Eocene) sedimentary rocks of the Hamlet formation and are overlain by the tuffaceous lower Refugian (upper Eocene) Jewell member of the Keasey Formation. The Cole Mountain basalt appears to intrude the very lowermost part (basal 3 m beneath a glauconitic sandstone unit) of what was mapped as Keasey Formation in the thesis area but does not intrude above the glauconitic sandstone of the lower Keasey Formation. Pillows, soft sediment features, and highly irregular basal contacts of Cole Mountain basalt in the upper part of the Sweet Home Creek member indicate that the sediments were wet and unconsolidated during emplacement of the basaltic rock. In contrast, dikes and sills in the lower part of the Sweet Home Creek member have linear contacts and are not pillowed indicating that the sediments were at least semi-coherent during emplacement.

Baking is usually limited to a 1 meter thick zone resulting in better induration with little color change.

The upper contact of the Cole Mountain basalt appears to be fixed at a distinct stratigraphic level. Within the thesis area a thin, well bedded, light-colored very tuffaceous to pumiceous siltstone always directly overlies the basaltic rocks and is, in turn, overlain by lower Refugian glauconitic siltstones of the Keasey Formation. As part of this study a "sill" at 4600 feet in the Quintana Watzek well (15 km northeast of the thesis area) has been correlated to the Cole Mountain basalt (fig. 66). Olbinski (1983) thought that the "sill" was middle Miocene Grande Ronde Basalt but reexamination of the petrographic and chemical characteristics indicate that it is related to the Cole Mountain basalt. The "sill" consists of deuterically altered gabbro which is petrographically similar to Cole Mountain basalt sills mapped by Safley (in prep.) east of the thesis area in the vicinity of Military Creek. The "sill" in the Quintana Watzek well is chemically similar to Cole Mountain basalt (Appendix 4). This "sill" is underlain by upper Narizian Cowlitz Formation siltstones and is directly overlain by lower Refugian glauconitic siltstones of the Keasey Formation (Olbinski, 1983).

Jackson (1983) mapped a small area of Tillamook Volcanics in northernmost Washington County (fig. 21) (chemistry sample RCC-1) and invoked a peculiar array of faults to uplift this block. These basaltic rocks were field-checked in detail and analyzed for major element chemistry (sample RCC-1, appendix 5). Field data show that the unit is directly overlain by a glauconitic tuffaceous lower

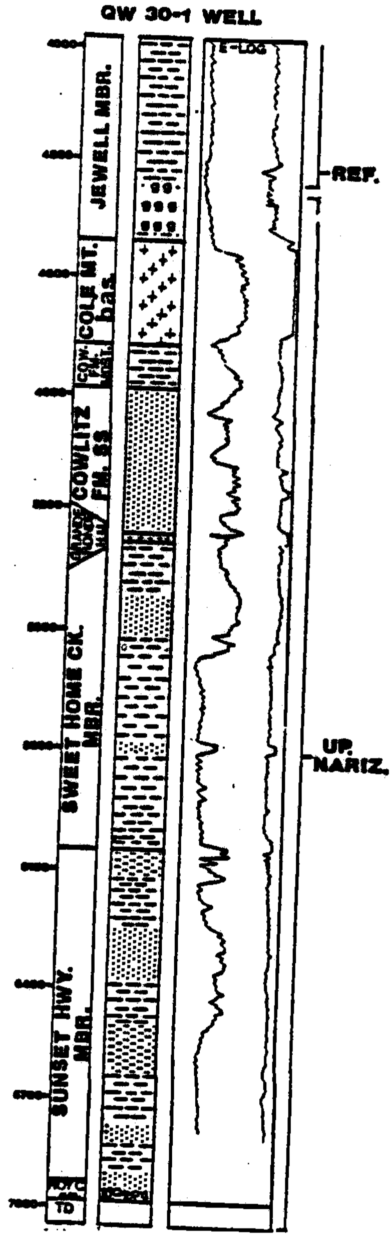


Fig. 66. Simplified diagram if the stratigraphic sequence present in the QW 30-1 well. Note the position of the Cole Mtn. basalt directly beneath the glauconitic siltstones of the Jewell member (significantly modified from Olbinski, 1983).

Refugian siltstone and underlain by upper Narizian mudstones. The faults mapped by Jackson (1983) do not appear to exist. Chemical data show the rock to be Cole Mountain basalt chemical type (appendix 5, fig. 24). Therefore, it can be demonstrated that the upper contact of the Cole Mountain basalt occurs at a fixed stratigraphic level over a large area. The earliest Refugian to possibly latest Narizian age of the overlying tuffaceous glauconitic siltstone has been well documented to the east of the thesis area (Nelson, 1985; Newton and Van Atta, 1976) and within the thesis area two samples (535 and 659) from Keasey Formation directly above (approx. 3 m) the upper contact of the Cole Mountain basalt contain lower Refugian foraminiferal assemblages (McDougall, personal communication, 1983) (Plate 1).

The absence of wet sediment features at basalt intrusive contacts with the lower and middle parts of the Sweet Home Creek member indicates that all of the Cole Mountain basalt is younger than these units. However, the presence of abundant wet sediment features such as pillows and highly irregular contacts within the upper part of the Sweet Home Creek member demonstrates that the Cole Mountain basalt is roughly the same age as or slightly younger than the upper part of the Sweet Home Creek member (upper Narizian, calc. nanno. subzones CP-14ab). Wet sediment structures demonstrate that a significant amount of time did not elapse between deposition of the sediments and emplacement of the magma (Hanson and Schweickert, 1982). The occurrance of a fixed upper contact and the presence of a turbiditic hyaloclastite composed of Cole Mountain basalt clasts at the upper contact indicates that the volcanic rocks are younger than most or all of the lower Refugian Jewell member. Therefore, biostratigraphic and sedimentologic data tightly constrain the age of the Cole Mountain basalt to the latest Narizian or the earliest Refugian. This would be equivalent to calcareous nannofossil subzones CP-14b and CP-15a (Burky, 1983).

The absolute (radiometric) age of the Narizian-Refugian boundary is somewhat in question. Armentrout (1981) placed the boundary at 32 Ma. This was revised in 1983 to 38 Ma (Armentrout et al., 1983) and, most recently, has been placed at approximately 37 Ma (Prothero and Armentrout, 1985) which is considered to occur within the late Eocene. A sample from locality 753 within the town of Hamlet in the upper part of the Cole Mountain basalt was collected for whole rock K-Ar dating. This sample, which was run by Kristin McElwee (Oregon State University) and Leda Beth Pickthorn (U.S. Geological Survey), yielded unreliable and inconsistant ages (range of 42-24 Ma) which were probably a result of potassium contamination (McElweee, personal communication, 1983). The Ar40/Ar39 date of a Cole Mountain basalt sample to the east of the thesis area (area mapped by Mumford, in prep.) yielded an age of 34.3 + 2.1 m.y. and an overlapping isochron age of 36.0 + 1.7 m.y. (McElwee, pers. comm., 1985).

Prothero and Armentrout (1985) have suggested that the Narizian-Refugian boundary is approximately 37 Ma. Therefore, the Ar 39/Ar 40 radiometrically determined age (34-38 Ma) of the Cole Mountain basalt is consistant with the biostratigraphically determined age of the Cole Mountain basalt (Narizian-Refugian boundary).

A major unconformity is thought to occur at or near the Narizian-Refugian boundary in northwest Oregon (Bruer, 1980; Warren and Norbisrath, 1946; Van Atta, 1971). Field evidence for this unconformity occurs to the east of the thesis area (Kadri, 1980; Olbinski, 1983). The presence of soft sediment features at the basal contact of the Cole Mountain basalt, radiometric age data, and fossil data demonstrate that there is not a major unconformity between the Cole Mountain basalt and the Hamlet formation. The upper Narizian section in the thesis area is relatively thin but this is thought to be due to slower sedimentation rates rather than due to removal of a part of the unit at an unconformity. The Cole Mountain basalt has been correlated in this study to the type area Goble Volcanics. Wilkinson et al. (1945) considered the type area Goble Voclanics along the Columbia River to be conformable upon and intercalated with upper Narizian sedimentary rocks.

Overlying the Cole Mountain basalt is a sequence of tuffaceous to glauconitic, thinly laminated to bedded, siltstones and a few glauconitic sandstones of the Jewell Member of the Keasey Formation. Glauconite typically forms in outer shelf environments in areas of slow or negative sedimentation and is commonly present at unconformities or diastems (McRae, 1972). The glauconitic sandstones and siltstones in the thesis area are thought to represent a submarine unconformity or diastem between the Cole Mountain basalt and the overlying Jewell member of the Keasey Formation. Microfossil and radiometric data indicate that the unconformity was of short duration and stratigraphic data suggest that no significant erosion occured.

Mode of Emplacement and Setting

Dikes and distinct sills of Cole Mountain basalt with baked upper and lower contacts occur in the lower part of the deep-marine Sweet Home Creek member. The basaltic andesites which overlie and are intercalated with the upper part of the Sweet Home Creek member have features that some workers have considered to be characteristic of submarine flows (e.g. McBirney, 1963). These features include a glassy to vesicular texture, pillows, and highly contorted basal contacts with sedimentary rocks. Recently it has been shown that these features can develop when magma is intruded into wet, semi-consolidated sediments (Hanson and Schweickert, 1982; Kokelaar, 1982; Einsele, 1982; Einsele et al., 1980). Therefore, it may be difficult to distinguish between sills emplaced at shallow levels beneath the ocean floor and true submarine flows formed on the ocean floor.

Several lines of evidence can be used to demonstrate an intrusive origin: 1) substantial truncation of sedimentary beds; 2) development of contact breccia, peperites, or baking at the upper contact; 3) warping of overlying sedimentary layers; and 4) dissolution of delicate carbonate skeletons directly above the volcanic rocks (Snyder and Fraser, 1963; Einsele, 1982). Evidence for eruption on the ocean floor includes: 1) absence of the previosly mentioned features; 2) presence of volcanic debris flow deposits; and 3) the presence of hyaloclastite material in sediment gravity flow deposits rather than in peperitic deposits (Kokelaar, 1982).

Although peperite deposits were not found in the Cole Mountain basalt there is evidence of baking above some of the smaller "sills" in the middle part of the Sweet Home Creek member (e.g., localities 561 and 563). At the upper contact of the Cole Mountain basalt there is no evidence of baking or brecciation (e.g. localities Q-850, and 659). At some localities (e.g. locality 162) the uppermost body of Cole Mountain is overlain by a whiteish, very tuffaceous pumiceous siltstone (assigned to the base of the Jewell member of the Keasey Formation). Smear slide data, the presence of pumice fragments, and the whitish color of this unit in the absence of Cole Mountain basalt suggests that the light color is more likely due to a very high tuff content and than to baking by intrusions. The overlying deep marine siltstones are commonly well laminated to thinly bedded, undisturbed, and concordant with the volcanic rock. Sample Q-570, collected from 15 cm above the upper contact of a very thick (>150 m) body of Cole Mountain basalt in the North Fork of the Nehalem River, contains well-preserved calcareous nannofossils and has a thermal maturation (Ro) value of 0.58% (Schlaefer, personal communication, 1983). This value is similar to unbaked mudstones in the Sweet Home Creek member (appendix 13) and is much lower than values obtained by Safley (in prep.) for Eocene mudstones adjacent to a relatively thin (<15 m) (Cole Mountain basalt dike (Ro = 1.68). Therefore, there is no compelling evidence to suggest that the uppermost body of the basalts is intrusive. There is, however, little doubt that volcanic rocks in the middle part of the Sweet Home Creek member are intrusive.

A normally graded, 1/2 m thick, hyaloclastite-sediment gravity flow deposit composed of vesicular, calcite cemented, glassy basaltic clasts occurs directly above the upper contact of the Cole Mountain basalt at locality Q-350. The basaltic clasts are petrographically identical to the Cole Mountain basalt directly beneath the deposit (sample Q-180). The angularity, glassy texture, and identical composition of all the basaltic ċlasts indicates that they were derived from a single igneous event that resulted in vesiculation and fragmentation. Hyaloclastite material simultaneously with or subsequent to the eruption moved downslope as a sediment gravity flow. The deposit is cemented by sparry calcite cement and contains very little (< 2%) mud-clay matrix indicating the occurance of winnowing by currents. Therefore, the deposit is clearly not a peperite. The presence of very minor glauconite, hornblende, and one granitic rock fragment shows that minor mixing with extrabasinal marine sediments occurred. Therefore, there is little doubt that this sediment gravity flow deposit represents extrusion of the Cole Mountain basalt onto the ocean floor.

A debris flow deposit composed of large (1/2 m dia.) laminated, very tuffaceous, light colored, rounded, siltstone blocks occurs between two Cole Mountain basaltic bodies near the upper contact (locality 164) (fig. 67). This debris flow may have been deposited simultaneously with the emplacement of the basaltic rocks. The close association of the two units suggests that they are related.

In the previous section it was shown that the Cole Mountain basalt has an upper contact which is stratigraphically fixed directly beneath a glauconitic and very tuffaceous siltstone unit (basal Keasey Formation) over a large area. It is unlikely that a series of

Fig. 67. Debris flow deposit composed of very tuffaceous, laminated siltstone blocks intercalated with the upper part of the Cole Mtn. basalt (locality 162, SW 1/4 SW 1/4 sec 12, T4N, R9W).

sills would have systematically exploited the boundary between the glauconitic unit and the underlying Sweet Home Creek member as they have similar rheological properties. Therefore, the presence of a "fixed" upper contact in addition to hyaloclasstite and debris flow deposits demonstrates that at least a part of the Cole Mountain basalt was erupted on the ocean floor.

Cole Mountain basalt in the thesis area is very glassy, vesicular, and aphyric even in central portions of thick (> 100m) basaltic bodies (Appendix 8). Figures 62 and 63 are photomicrographs of samples from two of the coarsest-grained Cole Mountain basalt localities (Q-850 and 614). As can be seen even these basaltic rocks are still very glassy with the largest clasts being approximately 1 mm in length. This is in contrast to several Cole Mountain basalt dikes and sills mapped by Safley (in prep.) which intrude the base of the Hamlet Formation and have microgabbroic to rarely gabbroic textures. The glassy aphyric nature of Cole Mountain basalt in the thesis area strongly supports either very shallow emplacement or submarine eruption of the unit.

In conclusion, there is good evidence that the Cole Mountain basalt was emplaced as shallow intrusives as well as erupted on the ocean floor. In small outcrops it is difficult to distinguish between shallow submarine intrusives and true submarine flows. Therefore, the proportion of flows to intrusions in the Cole Mountain basalt is unknown, but it is thought that most of the unit consists of shallow intrusive rocks.

Einsele (1982) has described a similar sequence of shallow basaltic sills in the Guaymas Basin in the Gulf of California. He concluded that younger sills tend to intrude on top of the baked better indurated sediment zone above older sills forming a series of dike-fed sills alternating with sedimentary rocks (fig. 68 b). If the buildup of sills is faster than the accumulation of sediment, then the basaltic magma will eventually reach the ocean floor and form submarine flows. Einsele (1982) also showed that a marked increase of bulk density and shear strength occurred in the sediments of the Guaymas Basin 200 m beneath the ocean floor (fig. 68); 200 m is the theoretical depth at which dikes should reorient as sills.

The Cole Mountain basalt probably had a similar emplacement history to the basaltic sills in the Guaymas Basin. The lowest Cole Mountain sill (locality 563) occurs approxmately 250 m beneath the upper contact of the Sweet Home Creek member. Below this sill only dikes have been found. Above the sill there are several more sills separated by sedimentary rock and an uppermost very thick (>200m) body of glassy, vesicular basaltic andesite. Within this large body there are a few irregular "pods" of mudstone, but laterally persistent beds of sedimentary rock are not present. The volcanic rocks are glassy and show significant petrographic diversity, suggesting that the unit is made up of several flow or multiple intrusive units. The uppermost part of the unit, as was previously discussed, contains features indicative of eruption of the ocean floor (e.g. hyaloclastites). This uppermost, thick basaltic body may be analogous to a submarine "volcano" in which the initial eruptive phase occurred in water-saturated, unconsolidated muds rather than above the sediment-sea water interface (fig. 68). As a result of moderate viscosities and rapid cooling, the volcanic pile

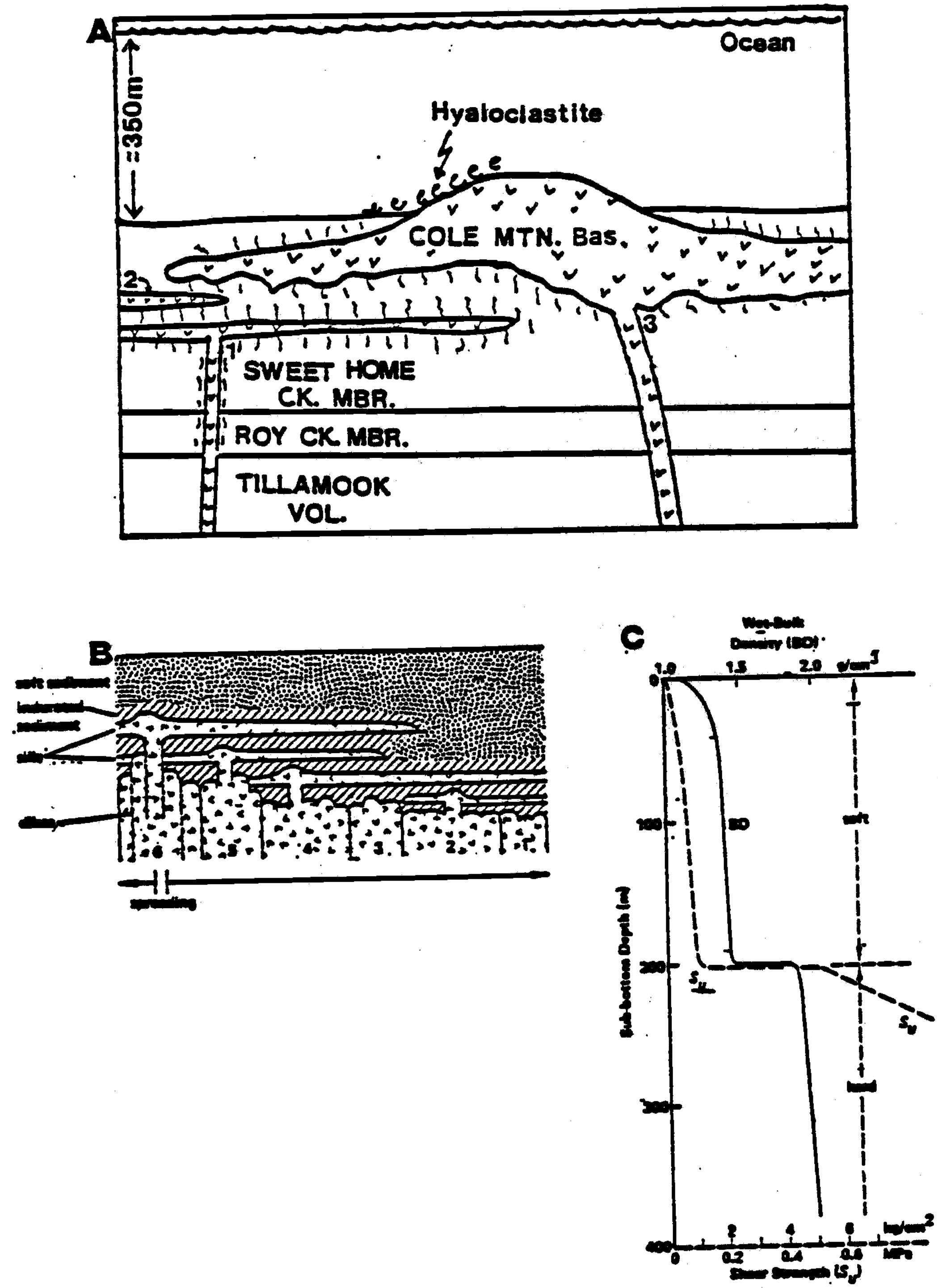


Fig. 68. Schematic diagrams for the emplacement of the Cole Mtn. basalt (A) and for emplacemnt of basaltic sills in the Guaymas Basin (B), Numbers indicate the order of emplacement. C shows the changes in bulk density and shear strength of "muds" in the Guaymas Basin with depth. Note the sharp change in physical properties at 200m beneath the ocean floor.