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Stratigraphy and Foraminifera of the SATSOP RIVER AREA, Southern Olympic Peninsula, Washington

By
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FOREWORD

This bulletin deals with the Satsop River area in the southern Olympic Peninsula, an area for which only general geologic information has been published prior to this time. Some of the details of the paleontology, structure, and stratigraphy of the area have been studied by oil company geologists in the past, but the results of their work have not been published.

This report includes data that will be of interest to anyone concerned with the geology of this part of the State, not only for use in the specific area under discussion but also in studies of adjacent areas where similar rocks occur. Because the Satsop River area is part of a much larger area in western Washington that has been in the past and will continue to be of interest to those who are searching for oil in this region, we expect that this report will be most valuable to those who engage in this search.

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By WELDON W. RAU

ABSTRACT

A sequence of Tertiary marine strata, measuring some 13,000 feet in thickness and dipping generally to the south, is exposed in the vicinity of the tributaries of the Satsop River immediately south of the Olympic Mountains. Detailed studies of foraminifers from four measured sections through these beds indicate that the rocks range in age from middle Eocene to at least late Miocene. The oldest rocks are referred to the middle Eocene Crescent Formation and are unconformably overlain by rocks of late Eocene age. The overlying Lincoln Creek Formation comprises one of the thickest and most complete sections of rock of the Refugian and Zemorrian Stages in western Washington. Foraminifers indicate that the *Sigmomorphina schencki* Zone and the *Cassidulina galvinensis* Zone are present in strata of the Refugian Stage, but the Zemorrian Stage is divided informally into a lower zone and an upper zone. Rocks of the Astoria(?) Formation are present in a small area; they are referred to the Saucesian Stage and are here considered early Miocene in age.

The Montesano Formation rests unconformably on both the Astoria(?) Formation and the Lincoln Creek Formation. Its age is regarded as either late Miocene or early Pliocene.

Paleoecologic conditions within the mapped area, as suggested by the foraminifers together with the nature of the containing rocks, are believed to have been relatively uniform throughout much of the Tertiary period. It is probable that upper bathyal to lower neritic depths prevailed and that water temperatures were cool to cold throughout most of the time. Shoaling conditions existed during the deposition of much of the Montesano Formation.

INTRODUCTION

LOCATION

The southern part of the Olympic Mountains is flanked by a sequence of south-dipping marine sedimentary strata of Tertiary age. They lie unconformably on the Crescent Formation, a thick sequence of volcanic rocks of Eocene age that form the foothills on the south, east, and north sides of the Olympic Mountains. The overlying marine strata are well over 10,000 feet thick and dip monoclinally south, representing an almost continuous depositional record from late Eocene through early Miocene time. These rocks are capped by the latest Tertiary deposits known in the region, rocks of late Miocene or perhaps early Pliocene age.

Although many areas along the flanks of the Olympic Mountains are mantled with debris of Pleistocene age, the area of this report is relatively well exposed, particularly in the valleys where the streams have cut well into the rocks of Tertiary age. Furthermore, the area is reasonably free of structural complication, being broadly folded, and broken by only one or possibly two major faults. The four principal streams of the area, the West Fork and Middle Fork of the Satsop River, the Little River, and the Canyon River, all flow southward, thus forming four major pathways over the essentially west striking strata. The area therefore affords an excellent opportunity for studying the biostratigraphy of a major part of the Tertiary sequence of western Washington. It is in parts of Tps. 20 and 21 N., Rs. 6 and 7 W., and is included in the southeast part of the Grisdale, southwest part of the Mount Tebo, northwest part of the Elma, and northeast part of the Wynoochee Valley quadrangle maps. It is bordered on the west by the east side of the Wynoochee River valley, on the east by the east side of the Middle Fork of the Satsop River valley and its tributaries, and to the north by the foothills of the Olympic Mountains; it extends south to the confluence of the Canyon River and the West Fork of the Satsop River (Fig. 1).

SCOPE

Stratigraphic mapping was undertaken in the area not only to show the distribution of the rocks, but also to establish a framework from which foraminiferal studies could be conducted. The principal objective of this foraminiferal study is to present, as accurately as possible, facts concerning the stratigraphic distribution of Foraminifera in a particularly thick sequence of rocks that represents a major part of the Tertiary section of the Pacific Northwest. The stratigraphic distribution of Foraminifera in rocks of similar age has been observed previously in other areas of the Northwest, but in many cases, observations for any one area have been from a single section. Therefore, the validity of the observed range of given species was not verified by supplementary observations from nearby sections or wells.

This report deals with the distribution of Foraminifera in strata from four measured sections, all of which cross a major part of the sequence at 1- to 2-mile intervals along the general strike of the beds. Marker beds in more than one section have been used to more accurately determine the local stratigraphic range of each species contained in the sequence.

Comparisons are made with known ranges of the same species of Foraminifera from surface sections and wells of other parts of the Northwest. These faunal observations suggest correlations of the beds of the area with strata in other parts of the Pacific North-

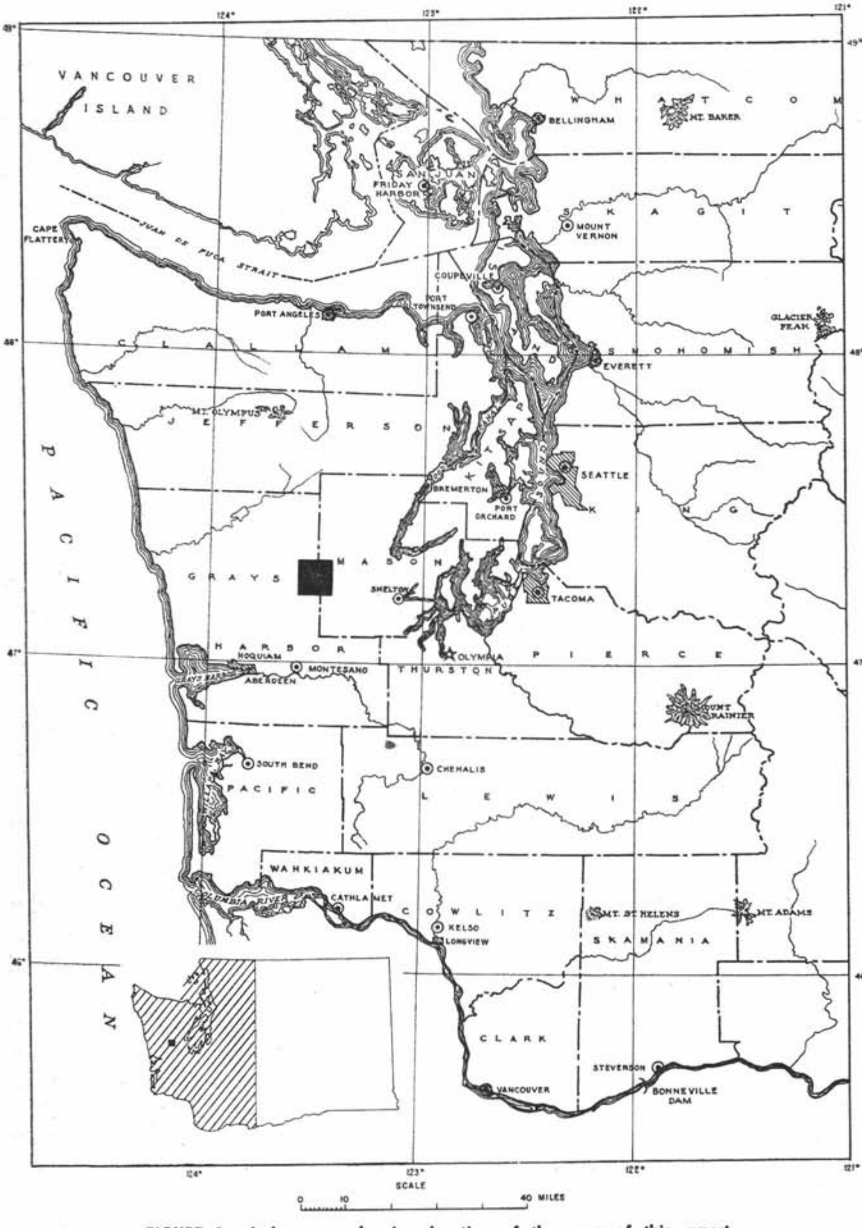

FIGURE 1.—Index map showing location of the area of this report.

west as well as broad correlations with parts of the Tertiary sequence in other regions of the Pacific Coast. A summary of the paleoecologic conditions is presented (p. 43); it is based on an evaluation of the more common species of Foraminifera that were found in the rocks.

ACKNOWLEDGMENTS

The generous cooperation of all landowners of the area, principally the Simpson Timber Company, is greatly appreciated. Numerous oil companies have made available much information and have loaned foraminiferal material for study. Special thanks are due, in this regard, to the Continental Oil Co., the Phillips Oil Co., the Shell Oil Co., the Standard Oil Co. of California, and the Union Oil Co. of California. All staff members of the Washington State Division of Mines and Geology in various ways have aided greatly in the preparation of the report. Particular thanks are due to Marshall T. Huntting, Supervisor, for his editorial advice and for administratively making it possible to publish the report.

The capable assistance of both Frank Kistner and John Braislin in the field and laboratory is gratefully acknowledged.

GENERAL GEOLOGY

CRESCENT FORMATION

The oldest rocks exposed within the mapped area (Fig. 2, in pocket) are the upper part of a thick sequence of predominantly volcanic rock known to form a horseshoe-shaped outcrop extending along the northern and eastern part of the Olympic Peninsula and westward into and to the north of the area of this report. Arnold (1906) named these rocks the Crescent Formation, for exposures of volcanic and sedimentary rocks at Crescent Bay, in the northern part of the Olympic Peninsula. The usage of the term has been perpetuated recently by most workers (Berthiaume, 1938; Durham, 1942; Brown, Gower, and Snavely, 1960; and Gower, 1960). In addition, Pease and Hoover, (1957) have tentatively correlated with the Crescent Formation a sequence of lava flows, pyroclastic rocks, and sedimentary beds exposed in a nearby area to the southeast. Because only the upper part of the unit is exposed in the area of this study, no attempt was made to measure its thickness. However, in the northern part of the Olympic Peninsula the Crescent Formation is known to be more than 10,000 feet thick (Brown, Gower, and Snavely, 1960). The Crescent Formation within the mapped area forms a rugged topography of decidedly greater relief than that of the sedimentary rocks exposed to the south, and therefore its outcrop area is easily distinguished from that of the overlying sedimentary rocks.

The Crescent Formation in the area of the report consists of pillow lava, flow breccia, massive lava flows, and sedimentary rocks. Pillow structures are particularly common and well formed in the upper 300 to 400 feet of the unit. Occasionally, sedimentary rocks of siltstone and (or) sandstone are found in intimate association with and around pillows, indicating a close proximity of volcanism with marine sedimentation. In many places near the top of the sequence the volcanic rocks are intensely fractured, in some cases by autobrecciation, in others by structural deformation. Some of the rocks, particularly those well below the top of the formation, are relatively massive and unfractured. Most of them are finely crystalline, but some of the autobrecciated rocks have a matrix of devitrified glass. Some lavas are vesicular, and the vesicles are almost always filled with zeolite minerals. Zeolitic material is disseminated throughout the brecciated rock and is in some of the more massive flows also.

Marine sedimentary rocks of dark-gray siltstone and sandstone are interbedded in the volcanics, especially in the eastern part of the mapped area. They vary in thickness from a few feet up to several hundred feet. Siltstone beds are not highly indurated; however, most of the sandstones are well cemented. The sandstone consists largely of basalt fragments and in some places contains shell fragments. Foraminifers were found in some of the siltstone beds.

Although it is not possible to accurately trace the sedimentary beds from outcrop to outcrop, inferred correlations are shown on the map (Fig. 2), which indicates a general structural trend striking west and northwest and dipping approximately 35° to the southwest.

In many places, particularly in the western and north-central parts of the area, siltstone and sandstone assigned to the Crescent Formation are present above the highest volcanic rock, indicating that sedimentation continued for some time after volcanism ceased. These rocks are differentiated from the overlying sedimentary rocks on the basis of their lithology, deformation, and contained foraminifers. The foraminifers indicate an age similar to that of the sedimentary interbeds in the volcanic rocks, but distinctly older than that of the sedimentary rocks that lie immediately above. Lithologically, the distinction between the two sedimentary rock types is not as apparent, although rocks of the Crescent Formation are generally more indurated and deformed. Although the obvious break in lithology is between the uppermost volcanic rocks and the overlying sedimentary rocks, the geologically significant break is between the uppermost sedimentary rocks of the Crescent Formation and the overlying sedimentary beds. This stratigraphic boundary cannot always be determined in the field, unfortunately, and thus is inferred in many places on the map.

Age and Correlation

Two foraminiferal assemblages were found in the sedimentary interbeds of the formation (F-1 and F-137, Fig. 2, in pocket). Both are from a stratigraphic position high in the formation. They indicate generally a middle Eocene age, details of which are discussed in a later section of this report (page 23).

In addition, foraminiferal assemblages found in the West Fork of the Satsop River, Little River, and Canyon River sections (F-2, F-36, F-37, F-38, F-39, F-62, F-63) in the uppermost part of the Crescent Formation above the highest volcanic rock also indicate a middle Eocene age, similar to that of the assemblages from the interbedded sedimentary rocks of the formation.

Aside from a correlation of these rocks with those assigned to the Crescent Formation in the northern part of the Olympic Peninsula, they may be compared in age, as well as lithology, with the Metchosin Volcanics of Vancouver Island (Clapp, 1917, p. 255-292), the Siletz River Volcanic Series of Oregon (Snavely and Baldwin, 1948, p. 806-812), and volcanic rocks associated with the Umpqua Formation of Oregon (Hoover, 1963).

SEDIMENTARY ROCKS OF LATE EOCENE AGE

A sequence of marine sedimentary rocks of late Eocene age unconformably overlies the Crescent Formation in most places. Its outcrop area forms a wedge-shaped pattern that thins eastward to a point between the Canyon River and the Middle Fork of the Satsop River (Fig. 2, in pocket). From there eastward, rocks of a younger age lie directly on the Crescent Formation. The maximum thickness of the unit, measured in the West Fork section, exceeds 2,900 feet. The rocks consist largely of gray micaceous mudstone, siltstone, and silty sandstone. Many of the beds are carbonaceous, and a few contain stringers or pods of glauconite. An occasional bed of intraformational gritty conglomerate occurs in association with siltstone. Swirl patterns can be seen in other beds. In a few places poorly developed crossbedding can be observed. Many thin beds of siltstone and fine silty sandstone are present, and in places they are laminated. A few small concretions are present in the more massive mudstone and siltstone beds. A well-cemented conglomerate bed approximately 100 feet thick is present in the area of the West Fork of the Satsop River. It consists of sand and grit, cobbles and boulders of basalt, indurated sandstone and siltstone, and concretions. Locally, this bed probably represents a basal conglomerate. The sedimentary rocks of late Eocene age, as a unit, can be differentiated generally from other rocks by the presence of mica and the thin-bedded nature of many of the rocks. Furthermore, due to the incompetency of most of the beds, landslides are common within the outcrop area.

Age and Correlation

Numerous foraminiferal assemblages were found in the sedimentary rocks of late Eocene age, all of which indicate a high position in the Eocene sequence of the Pacific Coast and may therefore be referred to the Narizian Stage of Mallory (1959). Locally, the unit may be correlated with the Skookumchuck Formation (Snavely and others, 1951b) and an upper part of the McIntosh Formation (Snavely and others, 1951a and 1951b) of southwest Washington. West of its type area the Skookumchuck Formation grades laterally into the more marine fine-grained rocks of the upper part of the McIntosh Formation, and therefore at least parts of these units are stratigraphic equivalents. Because the rocks of late Eocene age of this report have not been mapped to outcrops of either the Skookumchuck Formation or the upper part of the McIntosh Formation, neither of these names have been applied to the unit. However, the sedimentary rocks of late Eocene age are considered to be a close correlative of the Skookumchuck-upper McIntosh sequence. Furthermore, they may be correlated more generally with the Cowlitz Formation of southwest Washington (Weaver, 1912). In the northern part of the Olympic Peninsula, faunas contained in the lower part of the Twin River Formation (Rau, 1964) are similar to those of the rocks of late Eocene age of this report.

The upper parts of both the Nestucca Formation (Snavely and Volkes, 1949) and the Coaledo Formation (Diller, 1899) of Oregon generally represent a stratigraphic position similar to that of the upper Eocene sequence of the mapped area.

In California, numerous units are assigned to a similar stratigraphic position. The Butano Sandstone (Branner, Newsom, and Arnold, 1909) in the Santa Cruz Mountains is among those, as its lithology and fauna are similar and it is overlain by a sequence of rocks much like those in the area of this report. Those rocks of California assigned to the upper part of the Narizian Stage of Mallory (1959) are regarded here as broad correlatives of the sedimentary rocks of late Eocene age of this report.

LINCOLN CREEK FORMATION[1]

Overlying the rocks of late Eocene age with apparent conformity, and in some places lapping unconformably onto the Crescent Formation, is a thick sequence of tuffaceous mudstone, siltstone, and sandstone. On the basis of lithology and contained fossils, these rocks are assigned to the Lincoln Creek Formation as defined by Beikman and Rau (in press). This formation constitutes the Lincoln Formation of Weaver (1912) as used by Snavely and others (1958) in the Centralia-Chehalis area and by Pease and Hoover (1957) in the Doty-Minot Peak area of southwest Washington. It is reported to

[1]Rocks that are called the Lincoln Creek Formation are regarded as a part of what was originally named the Lincoln Formation by Weaver in 1912. Because "Lincoln" is preempted by several other geologic units in various parts of the United States, the name, according to rules that govern stratigraphic nomenclature, is not acceptable for this rock sequence in southwest Washington. Therefore, in a forthcoming report (Beikman and Rau, in press) the name Lincoln Creek Formation is proposed to replace the name Lincoln Formation.

be approximately 3,500 feet thick in the latter area. In the area of this report the formation attains a thickness of over 9,000 feet and contains a sequence of Foraminifera similar to that found in the areas of Centralia-Chehalis and Doty-Minot Peak. Locally, the area of outcrop forms a broad belt approximately 3 miles wide that has a generally east-west strike and an average dip of approximately 35° to the south. Because of the formation's apparent conformable relationship in places with both underlying and overlying rocks, its exposure within the area forms a complete stratigraphic sequence. Although the formation is generally tuffaceous and massive or thick-bedded siltstone and sandstone, there are variations of lithology that can be traced laterally throughout the area. Some of the differences between units are much more subtle than others, but all major lithologic units are shown on the geologic map (Fig. 2, in pocket) and columnar sections (Fig. 3, in pocket) and are informally referred to as local members of the formation.

The basal member, Tl-1, of the formation is a dark-gray massive fossiliferous basaltic sandstone that, in places, attains a thickness of over 100 feet. It rests on the Crescent Formation in the area of the Middle Fork of the Satsop River and can be traced westward to the West Fork of the Satsop River, where it lies on sedimentary rocks of late Eocene age. In most places within the area it is one of the more pronounced units in the Lincoln Creek Formation. However, in the area of the West Fork of the Satsop River the unit is less distinct, as there it is a series of thin beds of basaltic sandstone and siltstone, rather than the massive basaltic sandstone that is present to the east. This basal member corresponds to the basaltic sandstone member of the Lincoln Creek Formation formerly described in other parts of southwest Washington (Snavely and others, 1958; Beikman and Rau, in press).

Member Tl-2, overlying the basaltic sandstone, consists of 800 to 1,600 feet of generally massive tuffaceous siltstone that contains scattered concretions. In the eastern part of the mapped area the upper part of this member consists of a very massive mudstone, whereas to the west, in the West Fork section, these strata are interbedded with thin sandstone beds.

The third successive member, Tl-3, ranges in thickness from 700 feet in the west to over 1,100 feet in the eastern part of the area. It consists mainly of beds of highly tuffaceous siltstone and poorly sorted sandstone. In some places the sandstone is composed largely of glass shards. Concretionary layers are common, and fossils are scattered throughout the member. This unit differs generally from member Tl-2 in that it contains much more sandstone.

One of the most distinctive units seen locally in the Lincoln Creek Formation is the fourth member, Tl-4. It consists largely of thick beds of very poorly sorted conglomerate and sandy grit interbedded with massive siltstone beds of various thicknesses. The coarse-grained beds are composed largely of glass shards and pumice fragments together with grit-size particles of basalt and sedimentary clasts. The siltstone beds appear to be highly tuffaceous. This unit ranges from 500 to 1,000 feet in thickness and is best developed in the Little River section.

An abrupt change to a massive fine-grained lithology occurs in the overlying member, Tl-5. These strata consist mainly of massive siltstone that contains a few scattered concretions. To the east in both the Canyon River and Middle Fork sections this member is particularly massive and is broken only by occasional thin sandstone beds. To the west, in the valleys of the Little River and the West Fork of the Satsop River, sandstone beds are more common, and in places there the massive siltstone is sandy. Member Tl-5 ranges in thickness from approximately 600 to 1,200 feet and is thickest in the Canyon River area.

Member Tl-6 consists of sandstone and sandy siltstone interbedded with massive siltstone. It ranges in thickness from some 300 feet in the eastern part of the area to as much as 900 feet in the west. This member constitutes a relatively sandy and well-bedded interval between the two essentially massive siltstone units of members Tl-5 and Tl-7. In most places the base is a fossiliferous sandstone or sandy siltstone. Most of the rocks are tuffaceous, and glauconite is present near the base in the West Fork section.

Member Tl-7 is primarily a massive siltstone unit that ranges from 900 to 1,400 feet in thickness. The central part contains a considerable amount of tuffaceous sandstone, most of which is thin bedded. However, one sandstone stratum attains a thickness of as much as 5 feet in the vicinity of the Middle Fork of the Satsop River. A limestone bed some 100 feet thick occurs within the central part of this member. It forms a strike ridge on the east side of the West Fork of the Satsop River immediately south of the mouth of the Little River. It appears to have been formed as the result of solution and redeposition of calcium carbonate in the form of aragonite. This bed can be traced along the strike for about a quarter of a mile south of the Little River, but it was not found in any other part of the area.

The overlying member, Tl-8, ranges in thickness from 1,600 to 2,400 feet and consists largely of massive siltstone and sandy siltstone interbedded with thin sandstone beds. It differs basically from the members above and below in that it is noticeably more sandy and its bedding is generally more apparent. A fossiliferous glauconite bed is present in the lower part of the member both in the West Fork of the Satsop River and in the Canyon River valleys, and the two occurrences may actually be the same bed. Concretions are present in layers as well as scattered throughout much of the member.

Member Tl-9, the uppermost in the Lincoln Creek Formation, is a very massive siltstone. Practically no sandstone was found in any part of this member. Bedding is extremely rare, and therefore it is almost impossible to determine the attitude of rocks within this part of the formation. A thickness of approximately 2,000 feet is exposed in the valley of the Middle Fork of the Satsop River, but the unit thins to the west and is approximately 500 feet thick in the vicinity of the West Fork of the Satsop River. This apparent thinning to the west is due, at least in part, to onlap of younger rock.

Very massive and fine-grained tuffaceous sedimentary rocks not only characterize the upper part of the Lincoln Creek Formation locally, but this lithology is known to occur in the upper part of the formation in many places in the Grays Harbor Basin (Beikman and Rau, in press). Therefore, the lithologic characteristic of the uppermost part of the Lincoln Creek Formation is nearly as consistent throughout southwest Washington as is the basal part, where basaltic sandstone is found widespread. Many of the rocks throughout the formation give off a strong petroliferous odor when freshly broken.

Age and Correlation

On the basis of Foraminifera, the Lincoln Creek Formation in the area of this report ranges in age from latest Eocene to late Oligocene, as does the Lincoln Creek Formation in its type area in the Centralia-Chehalis area (Snavely and others, 1958). The lower part of the formation is referred to the Refugian Stage of Schenck and Kleinpell (1936), and the remainder of the formation to the Zemorrian Stage of Kleinpell (1938). There is little doubt that most of the formation is best assigned to the Oligocene as used by most workers on the west coast. However, interpretations of the age of both the lowermost and uppermost parts of the formation may vary, as would be expected where attempts are made to draw specific lines or boundaries between such general or broad concepts as are the various series of the Tertiary System. Furthermore, as pointed out by Kleinpell (1938, p. 174, 181), it is debatable whether the Refugian Stage is uppermost Eocene or lowermost Oligocene in age, but it is generally agreed that strata below are Eocene and those above are post-Eocene in age. Therefore, in view of these problems, in this report the Refugian Stage, as represented by the rocks of the lower part of the Lincoln Creek Formation, is regarded as a sequence whose exact age is unknown, but that divides those strata well established as Eocene in age below and those Oligocene in age above. Thus, a boundary line or horizon between rocks of Eocene and those of Oligocene age is arbitrarily considered to fall within the Refugian Stage, or within the lower part of the Lincoln Creek Formation (Fig. 4, in pocket).

Similar problems exist in precisely determining the age of the upper part of the Lincoln Creek Formation assigned to the Zemorrian Stage of Kleinpell (1938). Although the exact position of this stage with respect to a world-wide scheme of correlation is indeed debatable, current usage favors either placing the top of the Oligocene at the top of the Zemorrian Stage or placing the Oligocene-Miocene boundary within the Zemorrian Stage. Because in many places on the west coast a major change in fauna occurs between rocks assigned to the Zemorrian and the Saucesian Stages, and because the fauna below this horizon within the Zemorrian Stage are usually uniform throughout thousands of feet of section, the writer prefers to regard the boundary between the Oligocene and Miocene as coinciding with the faunal break between the Zemorrian and the Saucesian Stages, which, in this area, is at the top of the Lincoln Creek Formation (Fig. 4).

Besides having a direct correlation with the type Lincoln Creek Formation of southwest Washington, the Lincoln Creek Formation of the Satsop River area correlates in part with the type Blakeley Formation exposed on Bainbridge Island and vicinity. On the basis of unpublished foraminiferal studies by the author, all the strata of the type Blakeley Formation are Zemorrian in age. Therefore, the sequence of rocks of the Lincoln Creek Formation of this report that is referred to the Zemorrian Stage is a correlative of the type Blakeley Formation. In the Port Angeles area to the north, the Twin River Formation, as redefined by Brown and Gower (1958), is, in part, a correlative of the Lincoln Creek Formation of this report. Those rocks referred to the Zemorrian and Refugian Stages are correlatable with the Lincoln Creek Formation, but the lower part of the Twin River Formation, which contains pre-Refugian Foraminifera, is excluded from this correlation.

In Oregon, Refugian and (or) Zemorrian foraminiferal faunas are known from several units and therefore, at least in part, are general correlatives of the Lincoln Creek Formation. Among these are the Bastendorff Shale and the Keasey Formation (Cushman and Schenck, 1928; Detling, 1946), and an upper part of the Toledo Formation. Among the units in California from which Refugian and (or) Zemorrian faunas are recorded are the San Lorenzo Formation (Sullivan, 1962), the Tumey Formation (Cushman and Simonson, 1944), the Wagonwheel Formation (Smith, 1956), and the Gaviota Formation (Wilson, 1954). These units, therefore, broadly correlate with the Lincoln Creek Formation of the mapped area.

ASTORIA(?) FORMATION

A sequence of marine siltstones and sandstones overlies the Lincoln Creek Formation in a small area that is cut by the Canyon River (Fig. 2, in pocket). These rocks are correlated with a lower part of strata that are tentatively referred to the Astoria Formation of Oregon by Pease and Hoover (1957) and Snavely and others (1958) in the Doty-Minot Peak and Centralia-Chehalis areas, respectively. This correlation is based on similarity of fauna, stratigraphic position, and lithologic characteristics.

Outcrops of the Astoria(?) Formation in the area are confined to approximately half a square mile in the vicinity of the Canyon River. These rocks lie in the axis of a small syncline, where the contact relationships with the underlying Lincoln Creek Formation are not clearly known because of a considerable amount of landsliding. However, structural and faunal relations suggest that the two formations are conformable.

The Astoria(?) Formation is composed of light-gray silty sandstone and dark-gray sandy siltstone that are characteristically micaceous and carbonaceous. Generally, the rocks are massive and are bedded in only a few places with 1- to 3-foot resistant limy layers. The sandstone is always poorly sorted. Megafossils are found at several horizons, and foraminifers are found throughout the unit. Many of the rocks emit a petroliferous odor when freshly broken. Locally, the most striking lithologic difference between the Astoria(?) Formation and the Lincoln Creek Formation is the presence of abundant mica and carbonaceous material in the Astoria(?) Formation.

Age and Correlation

Foraminifera from the Astoria(?) Formation of this report correlate well with those of the Saucesian Stage of Kleinpell (1938). In this report the Saucesian Stage is regarded as early Miocene in age. Aside from a local faunal correlation with other rocks of southwest Washington that are assigned to the Astoria(?) Formation (Rau, 1958), the strata of the Astoria(?) Formation may also be correlated faunally with the Clallam Formation of the northern part of the Olympic Peninsula (Rau, 1964). In Oregon the type Astoria Formation in the vicinity of Astoria, Oregon, as well as a lower part of strata assigned to the formation exposed along the coast in the vicinity of Newport, Oregon, (Cushman, Stewart and Stewart, 1947) contain foraminifers comparable to those of the Astoria(?) Formation of this report. Furthermore, the Nye Mudstone exposed along Yaquina Bay contains a comparable fauna and should be included in a correlation with the strata under discussion.

In California a number of rock units contain foraminiferal assemblages that generally compare with that of the Astoria(?) Formation and, in almost all cases, have been referred to the Saucesian Stage. Therefore, these units are considered broad correlatives of the Astoria (?) Formation of this report.

MONTESANO FORMATION

A unit of sandstone, conglomerate, and sandy siltstone containing fossils that suggest either a late Miocene or early Pliocene age onlaps beds of both the Astoria(?) and Lincoln Creek Formations in the southern part of the mapped area (Fig. 2, in pocket). On the basis of lithology, stratigraphic and geographic position, and general age, these rocks are referred to the Montesano Formation (Weaver, 1912). They consist largely of light-gray massive, fine- to medium-grained, well-sorted sandstone composed mainly of quartz and feldspar grains. Numerous lenses and, in places, thick beds of basaltic conglomerates are interbedded in the sandstone. A small part of the rocks consist of dark-gray massive sandy siltstone. They usually contain considerable amounts of mica and carbonaceous material. Megafossils are common, particularly in association with conglomerate lenses; they are also concentrated in layers in some of the sandstone beds, and a few are dispersed through much of the siltstone. Foraminifers were found only in the siltstone beds. Much carbonaceous material is present in all the rocks. In some places macerated plant material is common in the finer grained rocks, and in some of the conglomerate large pieces of coalified wood are present. Most of the rocks of the Montesano Formation are massive, but occasionally crude bedding may be observed, in which case crossbedding is usually apparent.

The beds strike generally northeast and dip to the southeast a maximum of 21° in the western part of the area. However, the beds are nearly flat-lying in the southeastern part of their outcrop area.

The unit may be distinguished from the older rocks upon which it rests by its high content of clean or well-sorted sand, its younger age, and by its ability to stand in high, nearly vertical cliffs where dissected by major streams.

Age and Correlation

Foraminifers are not well distributed in the Montesano Formation of the mapped area; they were found only in a few localities in the siltstone facies of the formation. Furthermore, the fauna consists of a limited number of species. Therefore, it is not possible at this time to accurately determine the age of the unit on the basis of Foraminifera. Most authorities on megafossils have generally regarded the unit elsewhere to be late Miocene or Pliocene in age (Weaver, 1912, p. 20-22; Weaver, 1937, p. 187-191). The available foraminiferal evidence substantiates this general age. Several species are not recorded from rocks older than late Miocene age, and some may be restricted to rocks no younger than Pliocene.

Weaver (1912) originally suggested a relationship between the megafauna of the Montesano Formation and that of the Empire Formation of Coos Bay, Oregon, and also of the San Pablo Formation of California. In addition, some of the Foraminifera species of the Montesano Formation are known to occur in the Purisima Formation of San Mateo County, California (Goodwin and Thomson, 1954), which may prove to be significant in future studies of the relationship of these formations.

GRAVEL OF PLEISTOCENE(?) AGE

Much of the mapped area is covered with gravel and some silt, particularly along both the western and eastern edges of the area (Fig. 2, in pocket). Many small deposits are present in the central part of the area, but they are generally thin and discontinuous. No attempt is made in this report to determine in detail the distribution, composition, source, or age of these rocks, but rather, only general observations of gross distribution and rock type have been noted. On this basis, at least two major units may be recognized, the first of which is restricted mostly to the region west of the Middle Fork of the Satsop River. These gravels may well be a part of what Bretz (1913) referred to as the Satsop Formation. The surface of this unit is usually deeply weathered, and the rocks are highly stained with iron oxide. These gravels are composed, for the most part, of basalt, red and gray argillite, and other types suggesting a local origin from the Olympic Mountains. They are found at considerable heights and completely cover Reed Hill (secs. 20 and 21, T. 21 N., R. 7 W.) in the northwestern part of the area at an elevation of 1,443 feet. In places on the east slope of the hill, boulders were found measuring as much as 8 feet in diameter, which suggests direct ice deposition or ice rafting. Terraces are developed at several levels, particularly at elevations of 850 feet and 1,050 feet. An excellent example may be seen in sec. 16, T. 21 N., R. 7 W., immediately northeast of Reed Hill.

The origin and exact age of these gravels is not fully known. However, it is reasonable to assume that their source is local, from the Olympic Mountains, and that they are largely of fluvial origin. Because of their deeply weathered surface, there is little doubt that the gravels are older than those of the Vashon outwash deposits of other parts of the area. However, in this report their maximum age is regarded only as younger than the Montesano Formation.

A second gravel type covers much of the eastern margin of the mapped area, east of the Middle Fork of the Satsop River. In this area a relatively flat surface ranges in elevation from approximately 500 feet at the north to 400 feet at the south. This surface is underlain by fresh gravel composed largely of volcanic, coarse-grained igneous, and high-grade metamorphic rocks, most of which are foreign to the area. This gravel probably represents the western margin of the Matlock Pathway of Bretz (1913) and is the western edge of recessional outwash of the Vashon continental glacier.

LANDSLIDE DEBRIS

Although landslides are common, large areas of landsliding are confined mainly to regions underlain by fine-grained rock, particularly where principal stream valley walls have been over-steepened during Recent or perhaps even late Pleistocene time. Inasmuch as most outcrops of Tertiary rock are found along major stream courses, particular care must be taken to avoid confusing local structure of landslide masses with regional structure.

Areas underlain by sedimentary rocks of late Eocene age are particularly susceptible to the occurrence of landslides. In addition, landslides are common in areas underlain by the massive fine-grained rocks of the Astoria(?) Formation and the uppermost part of the Lincoln Creek Formation.

Almost all landslides occur in areas underlain by fine-grained rocks that slack readily under seasonal variation of moisture content.

Although small landslides or small areas of mass wasting are distributed over much of the area mapped, only the principal landslides are shown on Figure 2, (in pocket) along the valley of the West Fork of the Satsop River and in the Canyon River valley near the center of the mapped area.

ALLUVIUM

Recent stream deposits are limited in their extent because most of the streams in the area are eroding rather than depositing material. Nevertheless, thin deposits of small areal extent are present in the major streams, but because of their limited size and shifting nature from season to season, they are not shown on Figure 2. Furthermore, most of the outcrops of Tertiary rock are in the principal stream valleys, and it is not possible to show the extent of both the Tertiary rocks and the alluvium at the scale of the map.

Alluvial deposits consist largely of gravel and some silt and sand in the form of bars and other veneer-like deposits in the stream beds. These deposits are derived mainly from Pleistocene outwash materials and underlying rocks of Tertiary age.

STRUCTURE

The Tertiary rocks of the area generally form a homoclinal structure having an east-west strike and a dip to the south (Fig. 2, in pocket). The east-west-trending highlands of the northern part of the area are composed of the volcanic rocks of the Crescent Formation of middle Eocene age. These rocks strike northwest and in places dip more than 60° SW. Sedimentary strata of late Eocene and Oligocene age onlap these volcanic rocks from the west and southwest. They strike generally west and dip southward 50°-60°

near the contact of the Crescent Formation and progressively less to the south from the contact. The homoclinal structure of the area has been modified by broad folding and at least two major faults. The major fold is a broad south- to southeast-plunging syncline. Its axis passes through the Canyon River valley, in the central part of the mapped area.

The west limb of this structure may also represent the east limb of an anticlinal nose, but this possibility cannot be substantiated on the basis of surface observation because much of the critical area is concealed beneath gravel deposits of Pleistocene(?) age.

A major fault displaying horizontal displacement of over half a mile extends from the northeast part of the mapped area southward between the valleys of the Canyon River and the Middle Fork of the Satsop River to the contact of the Montesano Formation. From this point southward it is believed to be concealed beneath the Montesano Formation, thus indicating a pre-Montesano and post-Astoria age. Evidence for the fault is easily observed in the northeast part of the area, where the contact between the Crescent Formation and overlying younger strata is displaced over half a mile southward on the southeast side of the fault. In addition, the volcanic rocks of the Crescent Formation in the immediate area of the faults are badly shattered and the overlying sedimentary rocks also are badly broken. Evidence for this fault in the area of its southern extent is suggested by the absence of the Astoria(?) Formation in the valley of the Middle Fork of the Satsop River and in the area east of the Canyon River valley. All evidence indicates that the east side of this fault has moved south with respect to the west side.

A second fault also trends northeastward in the northwest part of the mapped area. Its apparent horizontal displacement of nearly half a mile can also be observed by the displacement of the contact of the Crescent Formation and the overlying sedimentary strata. This contact has moved south on the east side with respect to the same contact on the west side of the fault. The southerly extent of this fault is masked by deposits of Pleistocene(?) age.

Both faults are believed to be strike slip faults because of the manner in which the adjacent rocks are folded into the faults. It can be observed on aerial photographs that in the northeast part of the area the beds are dragged laterally into the fault, particularly on the east side of the fault.

In addition to the two principal faults mentioned, many with only a few feet of displacement were observed in isolated localities, but none were traced any great distance or proved to be of any major significance.

FORAMINIFERA

The following observations on the distribution of Foraminifera within the local Tertiary sequence were made largely from foraminiferal occurrences recorded from four measured sections in the valleys of the West Fork of the Satsop River (Fig. 5), the Little River (Fig. 6), the Canyon River (Fig. 7), and the Middle Fork of the Satsop River (Fig. 8). The stratigraphic range of each species as recorded from these four sections, along with a composite columnar section, is shown in Figure 9. All the figures mentioned in this paragraph are in the pocket accompanying this report.

CRESCENT FORMATION FORAMINIFERA

The basal lithologic unit of the area, the Crescent Formation, contains a foraminiferal assemblage that is decidedly distinct from any of those of the overlying strata. On the basis of the fauna alone, a hiatus is indicated between the Crescent Formation and the overlying rocks. As pointed out previously, this unconformity is substantiated both structurally and stratigraphically.

The following 27 species, nearly half of those recorded here from the Crescent Formation, are not known in any of the overlying strata of the area, and therefore set the Crescent Formation apart faunally from the overlying strata:

Amphistegina californica Cushman and M. A. Hanna
Anomalina cf. *A. crassisepta* Cushman and Siegfus
Anomalina garzaensis Cushman and Siegfus
Bifarina nuttalli Cushman and Siegfus
Bulimina corrugata Cushman and Siegfus
Bulimina lirata Cushman and Parker
Bulimina cf. *B. serratospina* Finlay
Cibicides cf. *C. martinezensis* Cushman and Barksdale
Dorothia cf. *D. principiensis* Cushman and Burmudez
Gaudryina coalingensis (Cushman and G. D. Hanna)
Globigerina cf. *G. pseudo-bulloides* Plummer
Globorotalia aragonensis Nuttall
Gyroidina cf. *G. simiensis* Cushman and McMasters
Nodosaria cf. *N. deliciae* Martin
Nodosaria latejugata Gümbel
Pseudoglandulina cf. *P. conica* (Neugeboren)
Pullenia eocenica Cushman and Siegfus
Quadrimorphina allomorphinoides (Reuss)
Quinqueloculina triangularis d'Orbigny
Robulus cf. *R. pseudovortex* Cole
Silicosigmoilina californica Cushman and Church
Spiroplectammina directa (Cushman and Siegfus)
Textularia? aff. *T. mississippiensis* Cushman

Tritaxilina colei Cushman and Siegfus
Uvigerina churchi Cushman and Siegfus
Vaginulinopsis asperuliformis (Nuttall)
Vaginulinopsis vacavillensis (G. D. Hanna)

Of the 27 species listed above, 6 are not recorded by Mallory (1959) above his Ulatisian Stage and 15 are not recorded above the lower part of his Narizian Stage, thus firmly suggesting that the Crescent assemblage is almost certainly no younger than early Narizian and probably no younger than late Ulatisian. The lower limit to which the Crescent assemblage may be correlated is suggested by the fact that 6 of the above-listed species are not recorded by Mallory below the Ulatisian Stage, 9 are not recorded below the Penutian Stage, and 14 are not recorded below the Bulitian Stage. It is, therefore, reasonable to assume that the assemblage is no older than Penutian, and probably no older than early Ulatisian.

By combining the above evidence, a general correlation of the present assemblage from the Crescent Formation is best made with Mallory's Ulatisian Stage of the California Coast Ranges. The major part of the stage is usually regarded as representing the middle Eocene of the Pacific Coast. The lowermost part of the stage may be extended into the early Eocene by some workers (Mallory, 1959).

Among those species commonly found in the Crescent Formation or rocks of equivalent age and recorded here are *Amphistegina californica* Cushman and M. A. Hanna, *Bulimina lirata* Cushman and Parker, *Spiroplectammina directa* (Cushman and Siegfus), *Textularia?* aff. *T. mississippiensis* Cushman, and *Vaginulinopsis vacavillensis* (G. D. Hanna). Of these, *A. californica* is probably the most significant, because Mallory (1959) records it from the California Coast Ranges as occurring only in his Ulatisian Stage. It is also common in the Crescent Formation on the north flank of the Olympic Mountains. In that area, parts of the Crescent Formation have been regarded variously as Penutian in age (Mallory, 1959) and Ulatisian in age (Rau, 1964).

In other areas of southwest Washington, rocks have been questionably referred to the Crescent Formation (Pease and Hoover, 1957, Rau, 1958) and are regarded here as general correlatives of the rocks under discussion. In Oregon, at least an upper part of the Siletz River Volcanic Series (Snavely and Baldwin, 1948) and part of the Umpqua Formation contain faunas that show reasonable correlations with that of the Crescent Formation. However, the author's recent studies of the Foraminifera from a lower part of the Siletz River Volcanic Series and also from a lower part of the Umpqua Formation suggest that the lower parts of these units may well be as old as early Eocene. This may also be the case with the lower part of the Crescent Formation of Washington. However, in this report only the upper part of the sequence has been studied, and therefore the lower age limit of the Crescent Formation cannot be evaluated.

FORAMINIFERA FROM SEDIMENTARY ROCKS OF LATE EOCENE AGE

Overlying the Crescent Formation and at the base of a thick and relatively uninterrupted record of marine sedimentation are strata here referred to as sedimentary rocks of late Eocene age. They are set apart from the underlying Crescent Formation by an unconformity made apparent by differences in the fauna, lithology, and structure. The upper limit of the sedimentary rocks of late Eocene age is marked by a lithologic change but has no apparent structural discordancy with overlying rocks. A major faunal change also occurs generally at this stratigraphic position. The lowest occurrence of many species is within or immediately above the basaltic sandstone of the basal part of the overlying Lincoln Creek Formation (Fig. 9, in pocket).

Although the first occurrence of these species best defines the lower limits of the overlying faunal unit of the Lincoln Creek Formation, it also defines the upper extent of the fauna of the underlying sedimentary rocks of late Eocene age. Because the species of this large group make their lowest appearance over a stratigraphic interval of several hundred feet in thickness rather than at one precise horizon, a stratigraphic position where most of them first occur is chosen as the specific boundary between these two faunal units.

This faunal break or change is within the basaltic sandstone of the lower part of the Lincoln Creek Formation and coincides generally with the major lithologic break between the basaltic sandstone of the basal part of the Lincoln Creek Formation and the micaceous siltstones and sandstones of the sedimentary rocks of late Eocene age. The many forms making their first or lowest appearance at this general level characterize the fauna above this horizon and will be discussed under "Lincoln Creek Formation Foraminifera," in the following section. The foraminiferal assemblage of the sedimentary rocks of late Eocene age constitute an easily recognized assemblage in their own right.

Fourteen species were found to be restricted locally in their occurrence to the sedimentary rocks of late Eocene age. They are:

Amphimorphina californica Cushman and McMasters
Bolivina basisenta Cushman and Stone
Bulimina sculptilis laciniata Cushman and Parker
Bulimina schencki Beck
Cibicides haydoni (Cushman and Schenck)
Eponides yeguaensis Weinzierl and Applin

Karreriella cf. *K. elongata* Mallory
Planularia barksdalei (Beck)
Planulina cf. *P. venezuelana* Nuttall
Quinqueloculina goodspeedi Hanna and Hanna
Robulus welchi Church
Spiroplectammina cf. *S. warreni* (Cushman and Ellisor)
Triloculina cf. *T. gilboei* Beck
Valvulineria tumeyensis Cushman and Simonson

All these forms are known in the late Eocene of other areas, and many of them have not been recorded from rocks older than the Narizian Stage. A few forms, such as *Amphimorphina californica* and *Eponides yeguaensis* are known to extend down into an older part of the Eocene; however, the greater part of these species characterize the Narizian Stage, particularly the upper part of the stage. Such species as *Valvulineria tumeyensis, Quinqueloculina goodspeedi, Bolivina basisenta, Bulimina sculptilis laciniata, Bulimina schencki,* and *Cibicides haydoni* may be regarded as typical Narizian forms and are especially common in rocks of the upper part of the stage.

The following species make their highest or last appearance somewhere within the sedimentary rocks of late Eocene age but are also found in the underlying Crescent Formation:

Asterigerina crassiformis Cushman and Siegfus
Bulimina ovata cowlitzensis Beck
Cibicides hodgei Cushman and Schenck
Cibicides cf. *C. pachecoensis* Smith
Marginulina subbullata Hantken
Nonion micrum Cole
Nonion cf. *N. planatum* Cushman and Thomas
Pleurostomella acuta Hantken
Valvulineria jacksonensis welcomensis Mallory
Valvulineria willapaensis Rau

With the exception of *Valvulineria willapaensis,* which seems to be an anomalous occurrence with respect to its previously known occurrence in rock of younger age, these species are known in the middle and upper part of the Eocene of the Pacific Coast. Therefore, their presence firmly suggests an age no younger than the Narizian Stage.

Those species making their first or lowest appearance in the section within the unit designated as sedimentary rocks of late Eocene age outnumber both those restricted to and those making their highest appearance in this rock unit. The following 27 forms were found to make their lowest appearance at various levels from near the bottom to near the top of this rock unit:

Alabamina kernensis Smith
Bolivina spp.

Bulimina cf. *B. ovula* d'Orbigny
Ceratobulimina washburnei Cushman and Schenck
Cornuspira byramensis Cushman
Dentalina sp. A [of Rau, 1948]
Dentalina spp.
Dentalina quadrulata Cushman and Laiming
Ellipsonodosaria cocoaensis (Cushman)
Epistomina eocenica (Cushman and Hanna)
Eponides umbonatus (Reuss)
Globigerina spp.
Guttulina irregularis d'Orbigny
Gyroidina condoni (Cushman and Schenck)
Involutina sp.
Karreriella chilostoma (Reuss)
Lagena substriata Williamson
Nodogenerina lohmani Kleinpell
Nodogenerina sanctaecrucis Kleinpell
Nodosaria cf. *N. raphanistrum* (Linné)
Plectofrondicularia packardi multilineata Cushman and Simonson
Plectofrondicularia vaughani Cushman
Pseudoglandulina inflata (Bornemann)
Pullenia bulloides (d'Orbigny)
Quinqueloculina imperialis Hanna and Hanna
Spiroloculina texana Cushman and Ellisor
Spiroplectammina sp.

Many of these forms range through much of the local section and therefore have very little value with respect to age and correlation. Nevertheless, the occurrence of 7 forms was not found to extend above those rocks referred to the Refugian Stage. These species are:

Alabamina kernensis Smith
Bulimina cf. *B. ovula* d'Orbigny
Ceratobulimina washburnei Cushman and Schenck
Gyroidina condoni (Cushman and Schenck)
Involutina sp.
Karreriella chilostoma (Reuss)
Spiroplectammina sp.

Although *Alabamina kernensis* is shown as restricted to the Refugian by Kleinpell and Weaver (1963) in the type area of the Refugian Stage, it, along with other forms such as *Gyroidina condoni* and *Ceratobulimina washburnei*, is particularly common locally in rocks of late Narizian as well as those of Refugian age.

The foraminiferal fauna of sedimentary rocks of late Eocene age is regarded here as one faunal unit. On the basis of those species discussed as having some significance to their occurrence in this part of the section, the fauna as a whole can best be compared locally with those of the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* Zone (Rau, 1958) of southwest Washington. In places, particularly to the west in the section of the West Fork of the Satsop River where the containing rocks are thickest and represent the earliest deposition of the unit, these strata may extend into the underlying *Uvigerina* cf. *U. yazooensis* Zone. However, no attempt is made here to differentiate these zones. Regardless of detailed faunal zoning of these Eocene strata, the foraminifers they contain indicate that they can best be referred to a late part of the Narizian Stage of Mallory (1959) and are therefore of late Eocene age according to biostratigraphic standards employed on the west coast (Fig. 4, in pocket).

LINCOLN CREEK FORMATION FORAMINIFERA

Refugian Stage

The lower part of the Lincoln Creek Formation within the area of this report contains Foraminifera that indicate a Refugian age. These strata vary in thickness from 2,600 feet in the Little River valley (Fig. 6, in pocket) to some 3,000 feet in the Canyon River valley (Fig. 7, in pocket). The base of the Refugian Stage coincides generally with the base of the basaltic sandstone bed, member Tl-1, at the lower contact of the Lincoln Creek Formation. The top of the Refugian Stage coincides with the top of the highly tuffaceous, thickly bedded, poorly sorted, coarse-grained unit, member Tl-4, also in the lower part of the formation (Fig. 3, in pocket).

The Refugian Stage is particularly well defined with respect to the underlying Narizian Stage, because a great number of species make their first or lowest appearance within the Refugian Stage. Many of these first occur at or near the base of the stage and continue on into, and in many cases through, the Zemorrian and even into the Saucesian Stage. Sixteen species make their first appearance in the basaltic sandstone at the base of the stage. Thirty-one forms make their first appearance within 500 feet of the base, and some 45 species first occur somewhere within the Refugian Stage (Fig. 9, in pocket).

The upper limit of the Refugian Stage is not well marked, because a large number of the species that first occur in the basal part of the stage continue on into the overlying Zemorrian Stage. However, the following species make their lowest appearance at or near the base of the overlying Zemorrian Stage and thus indirectly mark the top of the Refugian Stage:

Buliminella curta Cushman
Elphidium cf. *E. minutum* Cushman
Eponides mansfieldi oregonensis Cushman, R. E. and K. C. Stewart
Nodosaria pyrula d'Orbigny
Uvigerina gallowayi Cushman

In addition, *Cassidulina galvinensis* Cushman and Frizzell makes its highest appearance at about the same horizon.

The Refugian Stage within the area of this report is characterized by many forms well known elsewhere as species typical of the stage. Some of these are:

Cancris joaquinensis Smith
Cassidulina galvinensis Cushman and Frizzell
Ceratobulimina washburnei Cushman and Schenck
Dentalina dusenburyi Beck
Guttulina hantkeni Cushman and Ozawa
Listerella nodulosa (Cushman)
Nonion halkyardi Cushman
Plectofrondicularia packardi packardi Cushman and Schenck
Sigmomorphina schencki Cushman and Ozawa
Uvigerina cocoaensis Cushman
Vaginulinopsis saundersi (Hanna and Hanna)

Plectofrondicularia packardi packardi was found to extend down into an upper part of the underlying Narizian Stage in the local sections, but all other species in the above list were found in the Refugian Stage only.

An upper and a lower part of the Refugian Stage can be recognized in the faunas of the area. Although a precise boundary between them is not strongly expressed, nevertheless the faunal composition of the lower part is appreciably distinct from that of the upper part. Therefore, two zones are recognized locally within the Refugian Stage.

SIGMOMORPHINA SCHENCKI Zone

The lower of these two zones is referred to as the *Sigmomorphina schencki* Zone and represents a direct correlation with the zone of the same name previously established for southwest Washington (Rau, 1958). The boundary, or horizon, between this and the overlying zone is placed where *Sigmomorphina schencki* makes its highest appearance. Additional forms making their highest appearance at or near this horizon are:

Ceratobulimina washburnei Cushman and Schenck
Nonion halkyardi Cushman
Angulogerina cf. *A. occidentalis* (Cushman)

Although not known in the *Sigmomorphina schencki* Zone, the following forms make their lowest appearance at or near this horizon:

Virgulina bramlettei Galloway and Morrey
Guttulina frankei Cushman and Ozawa
Eggerella bradyi (Cushman)

The *Sigmomorphina schencki* Zone is characterized locally by the occurrence of the following species:

Angulogerina cf. *A. occidentalis* (Cushman)
Cancris joaquinensis Smith
Ceratobulimina washburnei Cushman and Schenck
Dentalina dusenburyi Beck
Listerella nodulosa (Cushman)
Nonion halkyardi Cushman
Plectofrondicularia packardi packardi Cushman and Schenck
Sigmomorphina schencki Cushman and Ozawa
Uvigerina cocoaensis Cushman
Vaginulinopsis saundersi (Hanna and Hanna)

Plectofrondicularia packardi packardi, as previously mentioned, was found to extend down into the upper part of the underlying Narizian Stage, and both *Angulogerina* cf. *A. occidentalis* and *Nonion halkyardi* were found in the lower part of the overlying zone. However, all other species listed above were found only in the *Sigmomorphina schencki* Zone of the area. These species not only typify the zone locally but show similar ranges in other areas of southwest Washington (Rau, 1958). The upper limit of the occurrence of these species corresponds particularly well with that previously established in southwest Washington.

The *Sigmomorphina schencki* Zone was originally recognized in a lower part of the Lincoln Creek Formation in the Centralia-Chehalis area (Snavely and others, 1958) and was extended laterally to eight wells or surface sections throughout southwest Washington (Rau, 1958). Its presence immediately south of the Olympic Mountains is a northern extension of the known occurrence of the zone.

The faunal composition of the zone in the area of this report, although somewhat varied, is strikingly similar to that described in other parts of southwest Washington. Therefore, those beds containing this assemblage directly correlate with beds of the originally described *Sigmomorphina schencki* Zone (Fig. 4, in pocket).

A number of correlations were suggested at the outset of the original description of the zone (Rau, 1958; Snavely and others, 1958). These correlations also apply to the zone as seen in the area of the present report. The foraminiferal fauna of the so-called Gries Ranch horizon of southwest Washington and that of a part of a massive siltstone unit in northwest Washington, now known to be a lower part of the Twin River Formation, were both correlated with the *Sigmomorphina schencki* Zone. Those faunas of both the Keasey Formation and the Bastendorff Shale of Oregon were also mentioned as being similar to that of the zone in question. The writer would now restrict such a comparison to a lower part of the Keasey Formation and possibly also to a lower part of the Bastendorff Shale. Additional assemblages from an unnamed part of the Toledo Formation in the Waldport area of Oregon also compare favorably with that of the *Sigmomorphina schencki* Zone. In California the faunas of the Tumey, Gaviota, and Wagonwheel

Formations were compared to that of the *Sigmomorphina schencki* Zone. The writer now believes this comparison should be restricted to that of the *Uvigerina cocoaensis* Zone of the Tumey Formation (Cushman and Simonson, 1944), to a lower part of the Wagonwheel Formation (Smith, 1956), and to an upper part of the Gaviota Formation (Wilson, 1954). In addition to previously suggested correlations, foraminifers from a middle part of the San Lorenzo Formation (Sullivan, 1962) should also be included among the faunas similar to those of the *Sigmomorphina schencki* Zone of southwest Washington.

In the type area of the Refugian Stage, Kleinpell and Weaver (1963) recognize a twofold division of the stage. The lower of the two divisions, the *Uvigerina cocoaensis* Zone, displays a striking faunal similarity to the *Sigmomorphina schencki* Zone of southwest Washington. Most significant is that *Uvigerina cocoaensis* Cushman is restricted to the zone of its name in the type area, also to corresponding beds in the area of this report, and nearly always is restricted to equivalent beds in other areas of southwest Washington. *Uvigerina atwilli* Cushman and Simonson is recorded only from the lower zone of the Refugian Stage, both in the type area and in southwest Washington. However, it is not recorded from the area of this report. *Plectofrondicularia packardi packardi* Cushman and Schenck is common both in the type area of the *Uvigerina cocoaensis* Zone and in the *Sigmomorphina schencki* Zone of southwest Washington, but in both cases is not restricted to the respective zones, as it extends into the upper part of the underlying Narizian Stage. In addition, numerous other species are common to, but not particularly restricted to, the lower zone of the Refugian Stage in the type area of the stage in California and also in southwest Washington.

Kleinpell (1938, p. 177) and Kleinpell and Weaver (1963, p. 34) point out the similarity of their *Uvigerina cocoaensis* fauna to that of the Cocoa Sand of the Gulf states. On this basis they refer the *Uvigerina cocoaensis* Zone to the late Eocene. Others have referred the lower part of the Refugian Stage to an "Eo-Oligocene" age (Weaver and others, 1944). Although it is beyond the scope of this report to attempt an intercontinental correlation of the boundary between the Eocene and Oligocene epochs, the lower part of the Refugian Stage is regarded here as late Eocene in age. Regardless of its geologic age, a correlation is confidently made of the *Sigmomorphina schencki* Zone of southwest Washington with the *Uvigerina cocoaensis* Zone of the Refugian Stage of California.

CASSIDULINA GALVINENSIS Zone

The upper part of the Refugian Stage is referred to in this report as the *Cassidulina galvinensis* Zone. It corresponds to the *Eponides kleinpelli* Zone in other parts of southwest Washington (Rau, 1958), but because *Eponides kleinpelli* Cushman and Frizzell was not found to occur in the area of this study, *C. galvinensis* Cushman and Frizzell, a rather common form in the upper part of the Refugian Stage throughout southwest Washington, is used here to designate the subdivision (Fig. 4, in pocket). *C. galvinensis* Cushman and Frizzell also occurs in the subjacent *Sigmomorphina schencki* Zone and therefore is not restricted to the zone of its name, but it is one of the more common forms in the upper part of the Refugian Stage. Furthermore, the upper limit of this species defines the upper boundary of the Refugian Stage, both locally and throughout other areas of western Washington. No species was found to be confined to the upper zone of the Refugian Stage in the area of this report. Furthermore, only a few species are confined to the zone in other areas in the Northwest. In addition, only a few species make their first or last appearance at the top or bottom of this zone. Therefore the zone is not as well defined, nor does it display as distinct a character as the subjacent *Sigmomorphina schencki* Zone. Most of the Foraminifera found in the *Cassidulina galvinensis* Zone make their first appearance at the base of the Refugian Stage and extend on into and, in some cases, through this zone. Therefore, this zone may be regarded as a transition between typical Refugian assemblages of the *Sigmomorphina schencki* Zone and faunas of the Zemorrian Stage above.

The following species make their lowest appearance locally within the *Cassidulina galvinensis* Zone and therefore are useful for defining the zone:

Bolivina marginata adelaidana Cushman and Kleinpell
Cassidulina cf. *C. oblonga* Reuss
Lagena semistriata Williamson
Massilina? sp.
Plectofrondicularia cf. *P. packardi multilineata* Cushman and Simonson
Virgulina bramlettei Galloway and Morrey

Although *B. marginata adelaidana* heretofore was not known to extend below the Zemorrian Stage, it nevertheless does occur locally in the Canyon River section in strata placed in the Refugian Stage. *Plectofrondicularia* cf. *P. packardi multilineata* differs from Cushman and Simonson's type in being broader, and more completely covered with more and finer striae. It first appears in the *Cassidulina galvinensis* Zone and extends into the uppermost part of the sections studied in this report, whereas those forms typical of Cushman and Simonson's type first occur in the rocks of the Narizian Stage and extend only to the lower part of the Zemorrian Stage.

The following species make their highest or last appearance in the *Cassidulina galvinensis* Zone:

Angulogerina cf. *A. occidentalis* (Cushman)
Cassidulina galvinensis Cushman and Frizzell
Cassidulina cf. *C. kernensis* Smith
Guttulina hantkeni Cushman and Ozawa
Involutina sp.
Karreriella chilostoma (Reuss)
Nonion halkyardi Cushman
Spiroplectammina sp.

Of these species, *Cassidulina galvinensis*, as previously mentioned, is particularly significant because its highest occurrence defines the upper limit of the zone, as well as that of the Refugian Stage. Locally, *Cassidulina* cf. *C. kernensis*, *Guttulina hantkeni*, *Angulogerina* cf. *A. occidentalis*, and *Nonion halkyardi* make their highest appearance in the lower part of the *Cassidulina galvinensis* Zone but occur more extensively in the subjacent *Sigmomorphina schencki* Zone.

The *Cassidulina galvinensis* Zone of this report, elsewhere in southwest Washington known as the *Eponides kleinpelli* Zone, was first recognized in the Lincoln Creek Formation of the Centralia-Chehalis area by Snavely and others (1958) and was extended over much of southwest Washington by Rau (1958). Foraminifera of the zone have been described by Cushman and Frizzell (1943) from Weaver's original type locality of his Lincoln Formation (1912) and by Rau (1951) from the Willapa River section. Although in the original discussion of the *Eponides kleinpelli* Zone no correlations were suggested, the writer now believes that its position in the upper part of the Refugian Stage is better established, and therefore it can be regarded as a correlative of other biostratigraphic units on the west coast. Probably because of facies differences, faunal characteristics are somewhat varied from place to place in southwest Washington. Nevertheless, the biostratigraphic position, the upper part of the Refugian Stage, is present throughout much of western Washington as well as in California and Oregon. Therefore, the following correlations are suggested.

On the northern Olympic Peninsula, Refugian faunas are present in the Twin River Formation (Rau, 1964), and although an upper Refugian Zone does not manifest itself as a separate faunal unit, the biostratigraphic position is present; therefore, on the basis of superposition, it is regarded as a correlative of the *Cassidulina galvinensis* Zone of this report.

In Oregon, the upper part of the Refugian Stage may well be represented in the Keasey Formation of the northwest part of the State. The writer has not studied these assemblages in detail; therefore, on the basis of the current studies, such a correlation is tentative. However, in the Newport-Waldport area of west-central Oregon the "Oligocene" sequence is well represented and includes strata containing faunas broadly correlative with those of the upper Refugian *Cassidulina galvinensis* Zone of southwest Washington. These faunas occur in an unnamed part of the middle to upper part of the Toledo Formation as mapped by Vokes and others (1949). Strata containing these faunas are thickest and most fossiliferous along a part of the north shore of Alsea Bay, where they rest on rocks of lower Refugian age and are overlain by strata of Zemorrian age. Here again, *C. galvinensis* Cushman and Frizzell, in association with other species characteristically common in the upper part of the Refugian Stage, makes its highest appearance within the Tertiary sequence.

Biostratigraphically, the *Cassidulina galvinensis* Zone corresponds to the *Uvigerina vicksburgensis* Zone of the type area of the Refugian Stage in California (Kleinpell and Weaver, 1963); that is, stratigraphically between faunas of the lower Refugian and lower Zemorrian. The fauna of the "Leda" Zone of the upper part of the Tumey Formation (Cushman and Simonson, 1944) is considered by Kleinpell and Weaver as typifying their *Uvigerina vicksburgensis* Zone. There, both *Uvigerina cocoaensis* Cushman and *Uvigerina atwilli* Cushman and Simonson are absent, although present in strata below —an occurrence similar to that found in the Refugian sequence of the Northwest.

Also in California, of particular interest is the fauna known in the Wagonwheel Formation, of the Devil's Den district (H. P. Smith, 1956). In an upper part of the middle member of the formation that is referred to by Smith as the *Cibicidoides-Anomalina* Zonule, *Cassidulina galvinensis* was found to occur along with *Anomalina californiensis* Cushman and Hobson, *Cassidulina kernensis* Smith, and other species generally common to the Refugian Stage. However, *C. galvinensis* was not found below this zonule in the Wagonwheel Formation. Furthermore, *U. atwilli* and *U. cocoaensis* were found below but not in the *Cibicidoides-Anomalina* Zonule—an occurrence similar to that in southwest Washington. Therefore, part of the Wagonwheel Formation not only represents a biostratigraphic position similar to that of the *Cassidulina galvinensis* Zone between the lower Refugian and the lower Zemorrian, but it also either contains or displays an association of species that can be related to that of the *Cassidulina galvinensis* Zone.

The upper part of the Refugian Stage is regarded by most workers as Oligocene in age (Kleinpell and Weaver, 1963); therefore, the *Cassidulina galvinensis* Zone is also regarded as such.

Zemorrian Stage

The upper part of the Lincoln Creek Formation contains Foraminifera that indicate a Zemorrian age. These strata attain a thickness of over 6,000 feet in the valley of the Middle Fork of the Satsop River and therefore constitute a major part of the Lincoln Creek Formation within the area. The base of the Zemorrian Stage coincides with the base of siltstone member Tl-5, and the top of the stage corresponds to the top of the Lincoln Creek Formation (Fig. 3, in pocket).

In the area of this report the fauna of the Zemorrian Stage consists largely of a continuation of the species that first appear at or near the base of the Refugian Stage, many of which make their last appearance somewhere within the Zemorrian Stage. Distributed throughout the strata of Zemorrian age, 58 species make their highest appearance, whereas only 16 species make their first or lowest appearance in these rocks (Fig. 9, in pocket). Therefore, a large part of the fauna that first appears at the base of the Lincoln Creek Formation gradually disappears within the strata of the Zemorrian Stage, and particularly in the upper part of the stage.

Locally, the base of the Zemorrian Stage is not clearly marked. There is no evidence of a hiatus or rapid ecologic change at this horizon, but, as pointed out under the discussion of the Refugian Stage, the first or lowest occurrence of 5 species is considered to mark the base of the Zemorrian Stage (see the first list under "Refugian Stage," page 28). The top of the stage is best marked by the lowest occurrence of a number of species immediately above in strata of the Astoria(?) Formation. They are especially significant in defining the base of the overlying Saucesian Stage, but nevertheless also serve to define the upper limit of the Zemorrian Stage. Of these species the following are particularly significant in marking the horizon, as they are not known below the Saucesian Stage, at least in the Northwest:

Bolivina astoriensis Cushman, R. E. and K. C. Stewart
Bolivina chehalisensis Rau
Cassidulina pulchella d'Orbigny
Nonion costiferum Cushman
Uvigerina cf. *U. montesanensis* Rau

Those species found only in the local strata of Zemorrian age are:

Cassidulina subglobosa Brady
Cibicides pseudoungerianus evolutus Cushman and Hobson
Nodosaria pyrula d'Orbigny
Plectofrondicularia cf. *P. californica* Cushman and Stewart
Pseudopolymorphina cf. *P. ligua* (Roemer)
Robulus brevispinosus (Nuttall)

Siphogenerina nodifera Cushman and Kleinpell
Uvigerina gallowayi Cushman

Of these species, *R. brevispinosus* (sometimes referred to as *R.* cf. *calcar*), *S. nodifera,* and *U. gallowayi* are especially indicative of Zemorrian strata, as their previously known occurrence has been largely in rocks assigned to this stage.

Because the Zemorrian Stage is represented by a thick sequence of strata, it would be highly desirable to establish faunal subdivisions within these rocks. Unfortunately, stratigraphic faunal variations throughout the sequence are not particularly significant. Apparently, deposition of the Zemorrian strata took place uninterrupted, rather rapidly, and under somewhat uniform but gradually changing conditions, thus leaving behind no evidence of sudden faunal changes.

Assemblages from the lower part of the stage are generally distinguishable from those of the upper part, even though no precise division is apparent between them. This is largely because the lower part contains many more of the species that first appear in the underlying Narizian and Refugian Stages than does the upper part. Furthermore, because very few species make their first or lowest appearance throughout the Zemorrian Stage, the upper part contains fewer species than does the lower part. Therefore, a twofold division of the Zemorrian Stage is tentatively recognized and informally referred to as the lower and upper zones of the stage. Because no single species of Foraminifera particularly characterizes either of the units, they are not given formal names.

Lower Zone of the Zemorrian Stage

The following species make their highest appearance locally within the lower part of the Zemorrian Stage:

Cassidulina cf. *C. oblonga* Reuss
Cornuspira byramensis Cushman
Eggerella bradyi (Cushman)
Guttulina problema d'Orbigny
Lagena hexagona (Williamson)
Marginulina cf. *M. alazanensis* Nuttall
Planularia cf. *P. markleyana* Church
Plectofrondicularia cf. *P. californica* Cushman and Stewart
Plectofrondicularia packardi multilineata Cushman and Simonson
Pseudopolymorphina cf. *P. ligua* (Roemer)
Sigmoilina tenuis (Czjzek)

Of these species only two, *Plectofrondicularia* cf. *P. californica* and *Pseudopolymorphina* cf. *P. ligua,* were found to occur only in the lower part of the Zemorrian Stage, but their restricted occurrence is not regarded as significant, as they are known to occur in other parts of the Tertiary sequence in other areas. Probably of greatest significance in the lower zone of the Zemorrian Stage is the combination of species. Those species that make their lowest occurrence here, such as *Elphidium* cf. *E. minutum* Cushman, *Eponides mansfieldi oregonensis* Cushman, R. E. and K. C. Stewart, and others previously listed on page 28, together with those either restricted to the stage or listed above as making their highest appearance in the lower zone of the stage, constitute a combination of species characteristic of only the lower zone of the stage.

Upper Zone of the Zemorrian Stage

Well over 40 species make their highest appearance in the upper zone, and they constitute a large part of the species that die out locally in the Zemorrian Stage (Fig. 9, in pocket). The foraminifers of the upper zone of the stage suggest more rapidly changing conditions to probably shallower and perhaps warmer water conditions than are expressed in the lower zone of the stage.

Of those species not found above the stage, the following occur only in the upper zone of the Zemorrian Stage:

Sigmoilina? sp.
Cassidulina subglobosa Brady
Siphogenerina nodifera Cushman and Kleinpell
Cibicides pseudoungerianus evolutus Cushman and Hobson

Of these species, *S. nodifera* is of particular significance because, although very sporadic in its occurrence, it is known throughout the Northwest only from a high position in the Zemorrian Stage.

Epistominella parva (Cushman and Laiming) occurs most commonly in strata of the overlying Saucesian Stage, but also is found occasionally in the uppermost part of the Zemorrian Stage in the area of this report as well as in other areas of the Northwest. *Nonion incisum kernensis* Kleinpell also occurs in both the Saucesian strata and the upper part of the Zemorrian Stage. Locally, its lowest occurrence roughly marks the base of the upper zone of the Zemorrian Stage.

The recognition of the upper part of the stage is best made on the basis of a combination of species, much the same way as in the case of the lower part of the Zemorrian Stage. Those species whose range extends from above the stage down into the upper Zemorrian, together with those confined to or extending up into the upper Zemorrian from below, together best characterize the upper zone of the stage (Fig. 9).

In other areas of southwest Washington, rocks of Zemorrian age also constitute an upper part of the Lincoln Creek Formation but have not been subdivided on the basis of Foraminifera. They have been referred to as the *Pseudoglandulina* aff. *P. inflata* Zone (Rau, 1958). The only small exception has been that the strata of the uppermost part of the Lincoln Creek Formation in the Willapa Valley area have been referred to the lower part of the superjacent *Epistominella parva* Zone. Originally these beds were regarded as Zemorrian in age (Rau, 1958), but they are now considered to be a lower part of the Saucesian Stage (Beikman and Rau, in press). However, in the southern Olympic Peninsula area the entire upper part of the Lincoln Creek Formation is considered an equivalent of the *Pseudoglandulina* aff. *P. inflata* Zone and is of Zemorrian age.

In the northern part of the Olympic Peninsula, the Zemorrian Stage is also represented by a substantial thickness of marine strata in the upper part of the Twin River Formation. There the stage was also informally divided into a lower and an upper part (Rau, 1964). Although some of the details of the faunal composition differ, the general characteristics of the two parts are similar to those of the southern Olympic Peninsula area. Therefore, the respective parts of the Zemorrian Stage in the two areas are regarded as general correlatives (Fig. 4, in pocket).

In the Puget Sound area immediately east of the Olympic Peninsula, the type Blakeley Formation is exposed on the southeast part of Bainbridge Island and also on the mainland immediately south of the island. Based on an informal study, by the writer, of the stratigraphy and foraminiferal occurrences in these rocks, all strata containing Foraminifera in the area normally exposed are regarded as Zemorrian in age. It has been informally reported that rocks containing a Refugian fauna are present beneath low tide level in the vicinity of Waterman Point (Fullmer, oral communication, 1965). However, these beds lie stratigraphically below normally exposed rocks of the type Blakeley section.

Although the writer has not recognized faunal subdivisions in the strata of the type Blakeley section, the fauna as a whole indicates a close correlation with that of the Zemorrian Stage both in the area of this report and in the northern part of the Olympic Peninsula.

In Oregon, Zemorrian faunas are probably best developed in the Newport-Waldport area of the central part of the Oregon coast. There they are contained in an upper part of what was originally referred to by Harrison and Eaton (1920) as the Toledo Formation. These strata are now regarded as an unnamed formation (Snavely, oral communication, 1965). In addition, a few foraminiferal assemblages from the overlying Yaquina Formation, although somewhat nondiagnostic as to age, are referred to the Zemorrian Stage. The Zemorrian strata of the Newport-Waldport area contain foraminiferal assemblages that firmly indicate a general correlation with those assigned to the Zemorrian Stage in the southern Olympic Peninsula area.

Also in Oregon, some assemblages from the Eugene Formation of the Willamette Valley are best referred to the Zemorrian Stage.

Although no extensive study of the foraminifers of this formation has been made by the writer, general observations indicate that at least a part of the formation is of Zemorrian age. Therefore, part of the strata may be correlated with the Zemorrian rocks of southwest Washington.

In the type area of the Zemorrian Stage in California, two zones are also recognized, the *Uvigerina gallowayi* Zone and the *Uvigerinella sparsicostata* Zone (Kleinpell, 1938; Kleinpell and Weaver, 1963). Although a twofold subdivision is recognized both in the type area of the stage and in western Washington, the individual parts are not necessarily precise correlatives. The Zemorrian Stage is recognized in western Washington in a broad sense. Species associations, the restricted occurrence of some species, and the stratigraphic relationships of the containing rocks with strata both above and below firmly suggest that certain rocks are best referred to the Zemorrian Stage. However, these similarities are general, and therefore no precise correlation can be made of any particular segment of the rocks with those of the type area of the stage. The observed ranges of species that play a significant part in establishing a Zemorrian age for certain strata are not necessarily the same as they are in the type section of the stage in California. For example, *Uvigerina gallowayi* Cushman, an apparent key form for the lower Zemorrian in the type area, is found to range through much of both the lower and upper Zemorrian of southwest Washington. However, such occurrences as that of *Bolivina marginata adelaidana* Cushman and Kleinpell, *Siphogenerina nodifera* Cushman and Kleinpell, and *Uvigerina gallowayi* in some part of the Zemorrian strata both in the type area of California and in western Washington suggest a general correlation of the two widely separated groups of strata.

The faunas of a number of formations or parts of formations in California have been correlated with and included as part of the Zemorrian Stage (Kleinpell, 1938; Kleinpell and Weaver, 1963). Some of these faunas are particularly significant with respect to correlations with strata of western Washington. This is well summarized by Kleinpell and Weaver (1963, p. 45) in their studies of the Santa Barbara Embayment:

> . . . In terms of age-relationship between the Santa Barbara Embayment column and those of the Pacific Northwest, and especially the age-relationships between the molluscan faunas of the two areas, probably the most significant implications of these foraminiferal and stratigraphic studies are not only the correlation of the Bastendorff and Keasey Formations with the middle and upper members of the Gaviota, and of the Blakeley Formation with the middle and upper Alegria and the Vaqueros and part of the Rincon Formation, but also the implied correlation in age of the lower 200 feet of the Alegria Formation and the uppermost "*Turritella variata* zone" molluscan fauna with that of the Lincoln Formation and its equivalents in the Pacific Northwest.

Because the type Blakeley is well recognized as a correlative of the type Zemorrian, a firm correlation of the fauna of some of the strata of the southern Olympic Peninsula area with that of the type Blakeley Formation here implies a correlation of these strata with those of the type Zemorrian of California. This indirect correlation is in addition to actual similarities of the faunas of the southern Olympic Peninsula area and the Zemorrian faunas of California.

Of particular significance, and in addition to the faunas of those units in California previously mentioned, are faunas of the upper part of the San Lorenzo Formation of the Santa Cruz Mountains of California (Cushman and Hobson, 1935; Sullivan, 1962). Because the Zemorrian faunas of the San Lorenzo Formation are particularly similar to some of those in Zemorrian strata of the southern Olympic Peninsula area, they are also included among the correlatives.

The age of the Zemorrian Stage is regarded by its author as Oligocene (Kleinpell, 1938; Kleinpell and Weaver, 1963). Subsequently, workers have followed this concept generally, but in some cases modifications have been inferred. Some have suggested an "Oligo-Miocene" age, and others have considered at least some strata contained in the stage to be of Miocene age (Weaver and others, 1944). In this report the Zemorrian Stage as recognized in the southern Olympic Peninsula area is regarded as Oligocene in age.

ASTORIA(?) FORMATION FORAMINIFERA

Saucesian Stage

Because the outcrop area of the Astoria(?) Formation is relatively small, the number of samples studied from these rocks is limited. Therefore, faunal characteristics are not as well developed locally for this part of the section as they are for other areas of the Northwest. Nevertheless, a number of important occurrences and combinations of species are found here that indicate a Saucesian age for these strata.

In most areas of western Washington and Oregon the distinction between the Zemorrian Stage and the Saucesian Stage is particularly well marked, largely by the first or lowest occurrence of a substantial number of species. Furthermore, most of those species common to the Refugian-Zemorrian sequence either dropped out throughout the upper Zemorrian or extend only a short distance upward into rocks of the Saucesian Stage (Rau, 1958, 1964). The fauna of the Saucesian Stage in the Pacific Northwest therefore is relatively distinct from that of the underlying Zemorrian Stage.

Locally, the following species make their first appearance at the base of the Astoria(?) Formation (Figs. 7 and 9, in pocket):

Bolivina astoriensis Cushman, R. E. and K. C. Stewart
Bolivina chehalisensis Rau

Cassidulina pulchella d'Orbigny
Nonion costiferum Cushman
Uvigerina cf. *U. montesanensis* Rau
Uvigerinella obesa impolita Cushman and Laiming

With only rare exceptions, these species have not been found elsewhere in the Northwest below rocks of the Saucesian Stage. The presence of *N. costiferum* is particularly significant, because it is well known not only in western Washington but elsewhere on the west coast as first occurring at the base of the Saucesian Stage.

The following species, although present both in the underlying rocks and in the Astoria(?) Formation, are locally common in the Astoria(?) Formation and are characteristically present in rocks of the Saucesian Stage:

Bulimina alligata Cushman and Laiming
Buliminella curta Cushman
Cassidulina crassipunctata Cushman and Hobson
Elphidium cf. *E. minutum* Cushman
Epistominella parva (Cushman and Laiming)
Eponides mansfieldi oregonensis Cushman, R. E. and K. C. Stewart
Nonionella miocenica Cushman
Valvulineria menloensis Rau
Virgulina bramlettei Galloway and Morrey

The combination of these species together with those not found below the Astoria(?) Formation not only characterizes the fauna of the formation both locally and in other areas of western Washington and Oregon but it also indicates a Saucesian age.

In other areas of southwest Washington, similar assemblages have been referred to the *Epistominella parva* Zone (Rau, 1958). In the original concept of this zone the lower limits extended (mainly in the Willapa Valley area) into the uppermost part of what is regarded lithologically as the Lincoln Creek Formation. In the Satsop River area the base of this zone corresponds essentially to the base of the Astoria(?) Formation. The only significant variation is that the lowest occurrence of *E. parva* is in the upper part of the Lincoln Creek Formation, as it is in the Willapa Valley area. However, all other significant elements do not extend below the base of the Astoria(?) Formation. Therefore, *E. parva* is not restricted to the zone of its name; nevertheless, the major development of this species is within the limits of the zone.

The known foraminiferal assemblage of the Clallam Formation of the northern Olympic Peninsula (Rau, 1964) compares well with that of the Astoria (?) Formation of the southern Olympic Peninsula area of this report. Probably most significant is the occurrence of *Nonion costiferum* Cushman down to the base of the Clallam Formation, much as it extends down to the base of the Astoria(?) Formation of the Satsop River area and other areas of western Washington and Oregon.

In northwest Oregon the foraminiferal fauna of a lower part of the type Astoria is similar to that of the *Epistominella parva* Zone. Farther south, in the west-central part of Oregon, the foraminiferal fauna of the Nye Mudstone is also much like that of the *E. parva* Zone. There again, *Nonion costiferum* makes its lowest appearance, locally, at the base of the Saucesian Stage.

The *E. parva* Zone was originally referred both to an upper part of Kleinpell's Zemorrian Stage and to his Saucesian Stage of California (Rau, 1958). Currently, the writer regards the *E. parva* Zone as correlative with a lower part of the Saucesian Stage only, thus placing the base of the Saucesian Stage and the base of the *E. parva* Zone at the same horizon (Fig. 4, in pocket).

The Saucesian Stage has been regarded as Oligocene, Miocene, and Oligo-Miocene by various workers. In this report the *E. parva* Zone is placed at the base of the Miocene, thus making the Saucesian Stage lower Miocene in age. At this horizon a significant foraminiferal break occurs, one that is apparent throughout western Washington and Oregon. It marks the last occurrence of species common throughout the "Oligocene" strata of the region, those species that characterize the Refugian and Zemorrian Stages of western Washington and Oregon. Possibly even more apparent at this horizon is the lowest or first occurrence of numerous species that continue to occur in strata above. Regardless of where the Oligocene-Miocene boundary is placed, the horizon here used best divides the foraminiferal faunas of strata that are regarded by most authorities as Oligocene in age from those that most workers agree are Miocene in age in western Washington and Oregon.

In other areas of southwest Washington, additional foraminiferal zones are now recognized informally in the upper part of the Astoria(?) Formation. However, they are not represented in the present area of this study and therefore a discussion of them is deferred until a future time.

MONTESANO FORMATION FORAMINIFERA

Because a limited number of assemblages, species, and individuals of Foraminifera were found in the Montesano Formation within the area studied, identifications of many forms are regarded as tentative. Therefore, no attempt is made to evaluate the significance of the Foraminifera in the Montesano Formation.

Ten species were found at four localities, F-31, F-32, F-134, and F-186 (Table 1). All four localities are in the same sandy siltstone strata, well above the base of the formation and distributed laterally in the three major stream valleys (Fig. 2, in pocket). None of the species are particularly indicative of age, either because (1) the identity of some is uncertain, (2) others are possibly new and their geologic range is not known, or (3) the known geologic range of additional species is too great to be of value. Therefore, those species encountered in the Montesano Formation are merely recorded here for future study (Table 1), and no attempt is made to interpret their significance. As previously stated, workers with megafossils have variously referred to the Montesano Formation as late Miocene or as Pliocene in age (Weaver, 1912, p. 20-22; Weaver, 1937, p. 187-191; Fowler, 1965). Forthcoming reports on Foraminifera of the Montesano Formation in surrounding areas possibly will add substantially to the knowledge of the age and ecology of the formation.

SUMMARY OF GEOLOGIC HISTORY AND PALEOECOLOGY

A summary of the paleoecology, as suggested largely by the salient aspects of the foraminiferal faunas contained in the local stratigraphic sequence, is presented in the following discussion. This basic data on the occurrence of species may be useful in future, more exhaustive studies on paleoecology.

Interpretations of the paleoecology represented by the stratigraphic sequence in the southern Olympic Peninsula area are based largely on the assumption that fossil species contained therein required the same environment as similar living species. Those species that occur in substantial numbers or are found to persist throughout major segments of the local sequence are mostly likely to be the ones that were best adapted to the ecology in which they lived. Therefore, particular attention has been given to such species in the interpretation of the paleoecology of the local sequence. But, because the occurrence of many species is rare or sporadic, the number of useful species is somewhat limited.

Those generalized paleoecologic interpretations presented here are based on depth and temperature records of living species that are either identical with or similar to species known in the southern Olympic Peninsula. The following references are cited as the major sources of depth and temperature data used in this report: Bandy (1953, 1961), Natland (1957), Parker (1948), Phleger (1956), and Phleger and Parker (1951).

At the base of the local stratigraphic sequence, pillow structure is common in the volcanic rocks of the middle Eocene Crescent Formation, and indicates an aqueous environment. Sedimentary interbeds in these volcanics contain marine fossils, among which are foraminifers that are discussed in this report. These fossils suggest that the upper part of the Crescent Formation was deposited under open-sea conditions, varying from medium to shallow depths—upper bathyal (approximately 1,300 feet) to upper neritic (approximately 100 feet or less). Substantial numbers of planktonic forms,

TABLE 1.—Check list of Foraminifera from miscellaneous localities

(● = common, X = few, / = rare, ? = questionably identified.)

Species \ Localities	F-1	F-31	F-32	F-33	F-34	F-35	F-61	F-128	F-129	F-130	F-131	F-132	F-133	F-134	F-135	F-136	F-137	F-138	F-186
Allomorphina macrostomata Karrer						/													
Amphistegina californica Cushman and M. A. Hanna				●															
Angulogerina hannai Beck						?													
Anomalina californiensis Cushman and Hobson											/								
Anomalina dorri aragonensis Nuttall																	X		
Asterigerina crassiformis Cushman and Siegfus				●													/		
Bolivina cf. B. advena Cushman					X														
Bolivina basisenta Cushman and Stone					X	●													
Bolivina chehalisensis Rau												X							
Bulimina alligata Cushman and Laiming										/	/	/	/			●			
Bulimina ovata cowlitzensis Beck					/	X													
Bulimina pupoides d'Orbigny							/			?	?	●						/	
Bulimina sculptilis laciniata Cushman and Parker						?													
Buliminella curta Cushman		X	●											X					
Buliminella elegantissima (d'Orbigny)			/										●						
Cassidulina crassipunctata Cushman and Hobson								●	X	●	X	/	X		/				
Cassidulina globosa Hantken					●	●												/	
Cassidulina quadrata Cushman and Hughes		/																	
Cassidulina subglobosa Brady										/									
Cassidulinoides sp.								/			/	X				X			
Cibicides elmaensis Rau sensu lato					/			●	/							/		/	
Cibicides elmaensis Rau sensu stricto							X												
Cibicides hodgei Cushman and Schenck					/	/	/												
Cibicides cf. C. martinezensis Cushman and Barksdale																	X		
Cibicides pachecoensis Smith	?																?		
Cibicides cf. C. perlucida Nuttall										X	X		●						
Dentalina spinosa d'Orbigny																		X	
Dentalina sp. A [of Rau, 1948]							X												
Dentalina spp.													X						
Dorothia cf. D. principiensis Cushman and Bermudez																	/		
Elphidium cf. E. minutum Cushman											/		/						
Entosolenia sp.								/	/	/					/	/		/	
Epistomina eocenica (Cushman and Hanna)							X										?	/	
Epistominella pacifica (Cushman)		●	X											●					
Eponides dupréi Cushman and Schenck																		/	
Eponides kleinpelli Cushman and Frizzell							X												
Eponides mansfieldi oregonensis Cushman, R. E. and K. C. Stewart													?						
Eponides aff. E. mexicana (Cushman)																	/		
Eponides umbonatus (Reuss)									?										
Gaudryina alazanensis Cushman							X												
Globigerina nitida Martin																	X		
Globigerina triloculinoides Plummer																	X		
Globigerina sp.								/			/	/	X						
Globigerina spp.					●	X									/	/		/	
Globobulimina pacifica Cushman									X							/			
Globobulimina pyrula (d'Orbigny)		/											?	●					?
Guttulina frankei Cushman and Ozawa							X												
Guttulina irregularis d'Orbigny							/												
Gyroidina condoni (Cushman and Schenck)					X	X													

TABLE 1. — Check list of Foraminifera from miscellaneous localities — Continued

(● = common, X = few, / = rare, ? = questionably identified.)

Species \ Localities	F-1	F-31	F-32	F-33	F-34	F-35	F-61	F-128	F-129	F-130	F-131	F-132	F-133	F-134	F-135	F-136	F-137	F-138	F-186
Gyroidina soldanii d'Orbigny					/	?	●	/		/	/	/			/		/	/	
Karreriella washingtonensis Rau							X												
Lagena costata (Williamson)													/						
Lagena semistriata Williamson								/											
Listerella communis (d'Orbigny)																		/	
Marginulina sp. B [of Beck, 1943]																	?		
?Martinottiella sp.													/						
Nodogenerina advena Cushman and Laiming								/								?			
Nodogenerina lohmani Kleinpell					/					?		/							
Nodogenerina sanctaecrucis Kleinpell									X						/	/		?	
Nodosaria anomala Reuss					X	?													
Nodosaria grandis Reuss								/		/									
Nodosaria latejugata Gümbel	/																		
Nodosaria pyrula d'Orbigny																?			
Nodosaria cf. N. raphanistrum (Linné)										?			/						
Nonion incisum kernensis Kleinpell										/	/								
Nonion pompilioides (Fichtel and Moll)								X					X					●	
Nonionella miocenica Cushman												/							
Plectofrondicularia packardi multilineata Cushman and Simonson																		/	
Plectofrondicularia cf. P. packardi multilineata Cushman and Simonson										/						/			
Plectofrondicularia packardi packardi Cushman and Schenck							X												
Plectofrondicularia searsi Cushman, R. E. and K. C. Stewart												/							
Plectofrondicularia vokesi Cushman, R. E. and K. C. Stewart					X	X													
Pseudoglandulina inflata (Bornemann)							●	/		/			X					/	
Pseudononion cf. P. cushmani (Stewart and Stewart)		●	X											●					●
Pyrgo sp.							/												
Quadrimorphina allomorphinoides (Reuss)																	/		
Quinqueloculina goodspeedi Hanna and Hanna				●		?													
Quinqueloculina imperialis Hanna and Hanna					/	X	/											/	
Quinqueloculina weaveri Rau																		/	
Quinqueloculina sp.													/						
Robulus cf. R. pseudovortex Cole	X																		
Robulus spp.				/	/		●		X	/					/		/	/	
Rotalia cf. R. tenerrima Bandy		X	X											●					
Silicosigmoilina californica Cushman and Church																	X		
Siphonodosaria frizzelli Rau																/			
Sphaeroidina variabilis Reuss									/				?						
Spiroplectammina directa (Cushman and Siegfus)																	/		
Tritaxilina colei Cushman and Siegfus																	/		
Uvigerina cocoaensis Cushman							●												
Uvigerina garzaensis Cushman and Siegfus								●	/	X	X					/			
Uvigerina cf. U. hootsi Rankin		/																	
Uvigerinella obesa impolita Cushman and Laiming													/						
Vaginulinopsis cf. V. goajiraensis (Becker and Dusenbury)													●						
Valvulineria araucana (d'Orbigny)													X						
Valvulineria menloensis Rau												?							
Valvulineria tumeyensis Cushman and Simonson					?														
Virgulina californiensis Cushman		●												●					

mainly *Globigerina*, in most of the assemblages from the formation suggest that open-sea conditions prevailed. The greatest depth is probably indicated by the foraminifers contained in the sedimentary interbeds between the earlier flows. Some of the more significant forms are *Nonion pompilioides* (Fichtel and Moll), *Uvigerina garzaensis* Cushman and Siegfus, and *Tritaxilina colei* Cushman and Siegfus. Depths probably became progressively less as lava accumulated, because such shallow-water forms as *Amphistegina*, *Quinqueloculina*, and certain *Cibicides* appear immediately above the highest flow, thus suggesting possible reef conditions, perhaps in places less than 100 feet in depth, in warm clear water. The sedimentary rocks of the uppermost part of the formation, above the highest flow, contain substantial numbers of such forms as *Robulus*, *Nodosaria*, *Vaginulinopsis*, *Tritaxilina*, and a few costate *Uvigerina*. These suggest that open-sea conditions prevailed once again at greater depths and lower temperatures, much like the conditions that probably prevailed during the earlier deposition of some of the sedimentary interbeds.

Following a period of emergence and erosion of the middle Eocene Crescent Formation, the area once again became submerged during the late Eocene, at which time the seas encroached generally from west to east. Here again, substantial numbers of planktonic *Globigerina* were deposited, suggesting that ocean currents circulated at least to some extent in the area.

Aside from *Globigerina*, the three most abundant and frequently occurring forms in the strata of late Eocene age are: *Robulus* spp., *Uvigerina garzaensis* Cushman and Siegfus, and *Cassidulina globosa* Hantken. In present-day seas, similar forms are found most commonly at depths between 800 and 3,000 feet within the upper part of the bathyal depth zone, where temperatures range from 45° to 40° F. The occasional occurrence of *Gyroidina orbicularis planata* Cushman in rocks of late Eocene age suggest considerable depths and cool to cold water temperatures. *Plectofrondicularia searsi* Cushman, R. E. and K. C. Stewart, *P. vaughani* Cushman, and *Valvulineria tumeyensis* Cushman and Simonson also suggest substantial depths in cool water.

Some time during the transition of Eocene and Oligocene time, during the beginning of the Refugian Stage and the deposition of the Lincoln Creek Formation, erosion of surrounding land areas was intense for a short period, causing the deposition of coarse-grained sediments. These strata are highly basaltic in composition, indicating a volcanic source. Almost certainly, the Crescent Formation served largely as this source. Basaltic sandstone at the base of the rocks of the Refugian Stage not only is present locally but extends throughout much of the Grays Harbor Basin (Snavely and others, 1958; Rau, 1958), particularly in its fringe areas.

The foraminifers contained in the basaltic sandstone of the local part of the Lincoln Creek Formation suggest cool to cold water at medium depths. *Quinqueloculina*, large *Robulus*, *Pseudoglandulina*, robust *Plectofrondicularia*, *Epistomina*, and *Gyroidina* are some of the more prominent elements of the foraminiferal fauna of these rocks and together suggest at least medium depths (lower neritic to possibly upper bathyal) at a substantial distance from shore in cool to cold water.

Immediately following the deposition of basaltic sandstone during the early part of the Refugian Stage, normal, relatively fine grained deposition was resumed and continued through much of the early part of Refugian time. However, during the latter part of the stage unusual sources of pyroclastic material became available periodically, resulting in the deposition of much volcanic ash, lapilli tuff, and related material. These coarse-grained pyroclastic rocks are interbedded with normal fine-grained sediments, thus indicating frequent outbursts of pyroclastic material. The high degree of angularity of the various clasts suggests that their source was nearby and that in many cases they dropped directly into the sea in which they were deposited.

The foraminifers contained in the strata of the lower part of the Lincoln Creek Formation, or that part which represents the entire Refugian Stage, generally indicate open-sea conditions in cool to cold water temperature at medium depths, upper bathyal depth zone. These conclusions are based largely on the following seven forms, which noticeably occur with the most frequency and (or) in larger numbers per sample than any of the others in the Refugian strata:

Anomalina californiensis Cushman and Hobson
Globigerina spp.
Gyroidina spp.
Listerella communis (d'Orbigny)
Pseudoglandulina inflata (Bornemann)
Robulus spp.
Uvigerina garzaensis Cushman and Siegfus

A reasonably good circulation of ocean currents is suggested by the fact that the planktonic form *Globigerina* is among the most common of those listed. In modern seas the remaining forms would best thrive together in water temperatures between 35° and 45° F. and at depths between 2,500 and 1,500 feet.

Among those less common yet next most frequently occurring species are a number of forms whose present-day counterparts also prefer cool to cold water at moderate depth. Among these are *Bulimina pupoides* d'Orbigny, *Cassidulina galvinensis* Cushman and Frizzell, *Ellipsonodosaria cocoaensis* (Cushman), and *Epistomina eocenica* (Cushman and Hanna). Of course, species are present which suggest that conditions may have been somewhat different from time to time, either deeper and colder or shallower and warmer. *Quinqueloculina imperialis* Hanna and Hanna is most prominent in suggesting shallow conditions at times, whereas the presence of costate *Uvigerina* and *Nonion pompilioides* (Fichtel and Moll) in certain parts of the section tend to suggest deeper and colder conditions than are indicated by the major elements of the fauna as a whole.

During Zemorrian time, deposition of the middle and upper parts of the Lincoln Creek Formation took place under rather uniform conditions, probably similar to those of the latter part of Refugian time. The great thickness of siltstone, silty sandstone, and fine sandstone deposited during Zemorrian time indicates unusually rapid but generally uniform sedimentation. Therefore, erosion of adjacent land surfaces probably was unusually active and under somewhat uniform conditions, uplift generally keeping pace with erosion. The high content of tuffaceous material in these sediments indicates a continual and plentiful source of such material. However, because these pyroclastic materials are generally fine grained and commonly are completely disseminated throughout the sediments, they probably were mixed with other clastic materials during transportation. Therefore, extrusion of pyroclastic materials probably took place some distance from the area of final deposition.

The foraminifers contained in the sediments that were deposited during Zemorrian time also suggest that conditions were generally quite uniform; furthermore, they suggest that conditions similar to those existing during late Refugian time probably continued well into early Zemorrian time. This is indicated in Figure 9, in that only minor differences appear between the faunal composition of the upper part of the Refugian Stage and that of the lower part of the Zemorrian Stage. It is likely, therefore, that offshore conditions continued at upper bathyal depths, where water temperatures remained cool to cold during much of the early part of the Zemorrian Stage.

During the latter part of Zemorrian time, water depths probably were gradually but continuously reduced. However, water temperatures remained at least cool. A gradual decrease in the number of species, together with the increased provincial appearance of the foraminiferal assemblages, suggests that a general shoaling condition prevailed during late Zemorrian time.

On the basis of the common and most frequently occurring foraminifers found locally throughout Zemorrian rocks, the following general conclusions have been reached regarding water depth and temperature during deposition. *Cassidulina crassipunctata* Cushman and Hobson, *Robulus* spp., *Gyroidina* spp., *Pseudoglandulina inflata* (Bornemann) and *Epistomina eocenica* (Cushman and Hanna) occur noticeably more frequently and in larger numbers than any other foraminifers occurring in Zemorrian strata. The depth and temperature at which these or similar ones from today's seas are recorded suggest that together these species would best thrive at depths between 2,000 and 650 feet at temperatures between 35° and 50° F.—upper bathyal depths in cold to cool water. This type of environment is further substantiated by the next most common and frequently occurring species—*Anomalina californiensis* Cushman and Hobson, *Uvigerina gallowayi* Cushman, *Uvigerina garzaensis* Cushman and Siegfus, *Cibicides elmaensis* Rau, and *Bulimina alligata* Cushman and Laiming. These species or their modern-day counterparts probably would also do well in an upper bathyal environment. The continuation of open-sea conditions, at least locally, through most of Zemorrian time is substantiated by the common and frequent occurrence of the planktonic form, *Globigerina*.

Shoaling conditions continued on into the following Saucesian Stage, at which time depths were reduced to such an extent that the foraminiferal fauna deposited in these beds is markedly distinct from that found throughout the great thickness of Zemorrian rocks. Locally, the outcrop area of Saucesian rocks is relatively small, and therefore the number of assemblages examined is somewhat limited. Nevertheless, they are all easily differentiated from those of the underlying strata, as they are distinctly more provincial and suggest shallow depths, but cool temperatures for such depths.

The following forms are the most abundant and frequently occurring in the Saucesian assemblages:

Bolivina chehalisensis Rau
Cassidulina crassipunctata Cushman and Hobson and *C. pulchella* d'Orbigny
Cibicides cf. *C. perlucida* Nuttall
Eponides mansfieldi oregonensis Cushman, R. E. and K. C. Stewart
Nonion costiferum Cushman

Records of these or similar living forms indicate that each probably was compatible to an environment ranging from neritic to upper bathyal depths. However, as a group they were most likely best suited for a neritic environment between depths of 200 and 600 feet. Other, less common but nevertheless significant forms in the Saucesian assemblages, such as *Elphidium* cf. *E. minutum* Cushman, *Uvigerina* cf. *U. montesanensis* Rau, and *Epistominella parva* (Cushman and Laiming), substantiate relatively shallow depths. *Nonion costiferum,* a few costate *Uvigerina,* and an occasional *Gyroidina* are particularly indicative of cool water temperatures in a neritic environment. Based on records of the five dominant forms of the fauna, they would probably thrive in water temperatures between 45° and 60° F.

Water depths continued to decrease, because some time following the deposition of Saucesian strata, emergence took place, causing a break in the fossil record of the local Tertiary sequence. Marine beds once more accumulated in the area during late Miocene or early Pliocene time, with the deposition of the Montesano Formation. Water depths remained shallow locally during the final part of the Tertiary period. Evidence for such conditions are the numerous conglomerate beds with lenses of shallow-water fossils, cross-bedded, well-sorted sandstone, and in places provincial foraminiferal assemblages typical of litoral or neritic environments, such as *Pseudononion, Buliminella elegantissima* (d'Orbigny), and *Epistominella pacifica* (Cushman)

Final emergence followed the deposition of the Montesano Formation, and an unknown amount of erosion then took place. Glacial deposits, particularly outwash gravels, were deposited during several intervals of time. These deposits are now being removed by present-day streams flowing south from the Olympic Mountains.

IDENTIFIED SPECIES

All identified species from the Satsop River area are listed in Table 2. For each species a reference is given which includes an illustration and a description of the form. In order that a minimum number of references be used, original illustrations and descriptions are not necessarily cited. References for those listed as comparing with (cf.) known species are to forms that are similar to but not identical with those from the Satsop River area.

TABLE 2.—References for All Identified Species From the Satsop River Area

Species	Reference
Alabamina kernensis Smith	Smith, 1956, p. 99, pl. 15, figs. 3, 4.
Allomorphina macrostomata Karrer	Rau, 1948, p. 173, pl. 31, figs. 4, 5.
Amphimorphina californica Cushman and McMasters	Cushman and McMasters, 1936, p. 513, pl. 75, figs. 21-25.
Amphistegina californica Cushman and M. A. Hanna	Cushman and Hanna, 1927, p. 56, pl. 6, figs. 3-5.
Angulogerina hannai Beck	Beck, 1943, p. 607, pl. 108, figs. 26, 28.
Angulogerina cf. *A. occidentalis* (Cushman)	Cushman and Laiming, 1931, p. 112, pl. 12, figs 15, 16.
Anomalina californiensis Cushman and Hobson	Cushman and Hobson, 1935, p. 64, pl. 9, fig. 8.
Anomalina cf. *A. crassisepta* Cushman and Siegfus	Cushman and Siegfus, 1942, p. 422, pl. 18, fig. 11.
Anomalina dorri aragonensis Nuttall	Graham and Classen, 1955, p. 30, pl. 5, fig. 10.
Anomalina garzaensis Cushman and Siegfus	Cushman and Siegfus, 1942, p. 422, pl. 18, fig. 6.
Asterigerina crassiformis Cushman and Siegfus	Cushman and Siegfus, 1942, p. 420, pl. 18, fig. 1.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Bifarina nuttalli Cushman and Siegfus	Cushman and Siegfus, 1942, p. 413, pl. 17, fig. 4.
Bolivina astoriensis Cushman, R. E. and K. C. Stewart	Cushman, Stewart, and Stewart, 1947, p. 47, pl. 6, fig. 3.
Bolivina basisenta Cushman and Stone	Cushman, Stewart, and Stewart, 1947, p. 61, pl. 8, fig. 7.
Bolivina chehalisensis Rau	Rau, 1948a, p. 778, pl. 119, fig. 7 (*B. astoriensis*).
Bolivina marginata adelaidana Cushman and Kleinpell	Rau, 1964, p. G19, pl. 6, fig. 8.
Bulimina alligata Cushman and Laiming	Cushman and Parker, 1947, p. 112, pl. 26, fig. 14.
Bulimina corrugata Cushman and Siegfus	Cushman and Siegfus, 1942, p. 411, pl. 16, fig. 38.
Bulimina lirata Cushman and Parker	Cushman and Parker, 1947, p. 95, pl. 22, fig. 10.
Bulimina ovata cowlitzensis Beck	Beck, 1943, p. 605, pl. 107, fig. 22.
Bulimina cf. *B. ovula* d'Orbigny	Cushman and Parker, 1947, p. 122, pl. 28, figs. 20-22.
Bulimina pupoides d'Orbigny	Cushman and Parker, 1947, p. 105, pl. 25, figs. 3-7.
Bulimina schencki Beck	Beck, 1943, p. 605, pl. 107, figs. 28, 33.
Bulimina sculptilis laciniata Cushman and Parker	Cushman and Parker, 1947, p. 103, pl. 24, fig. 13.
Bulimina cf. *B. serratospina* Finlay	Graham and Classen, 1955, p. 20, pl. 3, fig. 21.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Buliminella curta Cushman	Cushman and Parker, 1947, p. 64, pl. 16, fig. 22.
Buliminella elegantissima (d'Orbigny)	Kleinpell, 1938, p. 249, pl. 16, fig. 10.
Cancris joaquinensis Smith	Smith, 1956, p. 98, pl. 15, figs. 5, 6.
Cassidulina crassipunctata Cushman and Hobson	Cushman and Hobson, 1935, p. 63, pl. 9, fig. 10.
Cassidulina galvinensis Cushman and Frizzell	Cushman and Frizzell, 1943, p. 87, pl. 15, fig. 6.
Cassidulina globosa Hantken	Smith, 1956, p. 100, pl. 14, fig. 2.
Cassidulina cf. *C. kernensis* Smith	Smith, 1956, p. 100, pl. 14, figs. 1, 3.
Cassidulina cf. *C. oblonga* Reuss	Cushman, 1925, p. 55, pl. 9, figs. 19-22.
Cassidulina pulchella d'Orbigny	Cushman, 1925a, p. 34, pl. 5, fig. 16.
Cassidulina quadrata Cushman and Hughes	Cushman and Gray, 1946, p. 42, pl. 7, figs. 11-13.
Cassidulina subglobosa Brady	Cushman, 1925, p. 54, pl. 8, figs. 48-50.
Ceratobulimina washburnei Cushman and Schenck	Cushman and Schenck, 1928, p. 314, pl. 45, fig. 1.
Cibicides elmaensis Rau *sensu lato*	Rau, 1948, p. 173, pl. 31, figs. 18-26.
Cibicides elmaensis Rau *sensu stricto*	Rau, 1948, p. 173, pl. 31, figs. 18-20.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Cibicides haydoni (Cushman and Schenck)	Cushman and Schenck, 1928, p. 316, pl. 45, fig. 7.
Cibicides hodgei Cushman and Schenck	Rau, 1951, p. 451, pl. 67, figs. 28-30.
Cibicides cf. *C. martinezensis* Cushman and Barksdale	Mallory, 1959, p. 267, pl. 35, fig. 7.
Cibicides cf. *C. pachecoensis* Smith	Mallory, 1959, p. 268, pl. 25, fig. 1, pl. 38, fig. 10.
Cibicides cf. *C. perlucida* Nuttall	Rau, 1951, pl. 67, figs. 23-25.
Cibicides pseudoungerianus evolutus Cushman and Hobson	Cushman and Hobson, 1935, p. 64, pl. 9, fig. 11.
Cibicidoides coalingensis (Cushman and G. D. Hanna)	Smith, 1956, p. 101, pl. 16, fig. 2.
Cornuspira byramensis Cushman	Rau, 1948, p. 160, pl. 28, figs. 10-11.
Dentalina dusenburyi Beck	Beck, 1943, p. 599, pl. 105, fig. 23.
Dentalina quadrulata Cushman and Laiming	Cushman and Laiming, 1931, p. 99, pl. 10, fig. 13.
Dentalina spinosa d'Orbigny	Sullivan, 1962, p. 264, pl. 9, figs. 17, 18.
Dentalina sp. A [of Rau, 1948]	Rau, 1948, p. 166, pl. 29, fig. 3.
Dorothia cf. *D. principiensis* Cushman and Burmudez	Mallory, 1959, p. 125, pl. 27, fig. 8; pl. 33, fig. 2; pl. 36, fig. 3.
Eggerella bradyi (Cushman)	Cushman, 1937, p. 52, pl. 5, fig. 19.
Ellipsonodosaria cocoaensis (Cushman)	Beck, 1943, p. 608, pl. 108, fig. 10.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Elphidium cf. *E. minutum* Cushman	Rau, 1964, p. G16, pl. 5, fig. 8.
Entosolenia sp.	Rau, 1964, p. G19, pl. 6, fig. 2.
Epistomina eocenica (Cushman and Hanna)	Rau, 1948, p. 172, pl. 31, figs. 1-3.
Epistominella pacifica (Cushman)	Goodwin and Thomson, 1954, p. 176, pl. 32, figs. 10-12.
Epistominella parva (Cushman and Laiming)	Cushman and Laiming, 1931, p. 115, pl. 13, fig. 5.
Eponides duprėi Cushman and Schenck	Cushman and Schenck, 1928, p. 313, pl. 44, fig. 8.
Eponides kleinpelli Cushman and Frizzell	Cushman and Frizzell, 1943, p. 86, pl. 15, fig. 1.
Eponides mansfieldi oregonensis Cushman, R. E. and K. C. Stewart	Rau, 1964, p. G21, pl. 6, fig. 12.
Eponides umbonatus (Reuss)	Rau, 1951, p. 448, pl. 66, figs. 1-3.
Eponides yeguaensis Weinzierl and Applin	Beck, 1943, p. 608, pl. 108, figs. 1, 4.
Gaudryina alazanensis Cushman	Rau, 1948, p. 158, pl. 27, figs. 3, 4.
Gaudryina coalingensis (Cushman and G. D. Hanna)	Mallory, 1959, p. 122, pl. 27, fig. 7; pl. 39, fig. 3.
Globigerina nitida Martin	Mallory, 1959, p. 249, pl. 30, fig. 5.
Globigerina cf. *G. pseudo-bulloides* Plummer	Graham and Classen, 1955, p. 28, pl. 4, figs. 22, 23.
Globigerina triloculinoides Plummer	Mallory, 1959, p. 250, pl. 30, fig. 6; pl. 38, fig. 3.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Globobulimina pacifica Cushman	Cushman and Laiming, 1931, p. 108, pl. 12, fig. 1.
Globobulimina pyrula (d'Orbigny)	Rau, 1951, p. 441, pl. 65, figs. 16, 20.
Globorotalia aragonensis Nuttall	Mallory, 1959, p. 252, pl. 35, fig. 2.
Guttulina frankei Cushman and Ozawa	Rau, 1948, p. 170, pl. 30, figs. 17, 18.
Guttulina hantkeni Cushman and Ozawa	Rau, 1948, p. 169, pl. 30, figs. 11, 12.
Guttulina irregularis d'Orbigny	Rau, 1948, p. 169, pl. 30, figs. 7, 8.
Guttulina problema d'Orbigny	Cushman and Ozawa, 1930, p. 19, pl. 2, figs. 1-6; pl. 3, fig. 1.
Gyroidina condoni (Cushman and Schenck)	Cushman and Schenck, 1928, p. 313, pl. 44, figs. 6, 7.
Gyroidina orbicularis planata Cushman	Rau, 1951, p. 447, pl. 66, figs. 3-5.
Gyroidina cf. *G. simiensis* Cushman and McMasters	Cushman and McMasters, 1936, p. 514, pl. 76, fig. 3.
Gyroidina soldanii d'Orbigny	Cushman and Siegfus, 1942, p. 418, pl. 17, fig. 31.
Karreriella chilostoma (Reuss)	Graham and Classen, 1955, p. 9, pl. 1, fig. 27.
Karreriella cf. *K. elongata* Mallory	Mallory, 1959, p. 127, pl. 5, fig. 4.
Karreriella washingtonensis Rau	Rau, 1948, p. 158, pl. 27, figs. 5, 6.
Lagena costata (Williamson)	Mallory, 1959, p. 175, pl. 14, fig. 3; pl. 41, fig. 7.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Lagena hexagona (Williamson)	Sullivan, 1962, p. 267, pl. 10, fig. 9.
Lagena semistriata Williamson	Cushman and Parker, 1931, p. 7, pl. 1, fig. 23.
Lagena substriata Williamson	Cushman and Laiming, 1931, p. 100, pl. 11, fig. 1.
Lagena sulcata (Walker and Jacob)	Cushman and Parker, 1931, p. 6, pl. 1, fig. 1.
Listerella communis (d'Orbigny)	Cushman, 1937, p. 148, pl. 17, figs. 4-9.
Listerella nodulosa (Cushman)	Cushman, 1937, p. 150, pl. 17, figs. 13-19.
Marginulina cf. *M. alazanensis* Nuttall	Rau, 1948, p. 164, pl. 29, fig. 4.
Marginulina subbullata Hantken	Cushman and Siegfus, 1942, p. 408, pl. 16, fig. 21.
Nodogenerina advena Cushman and Laiming	Cushman and Laiming, 1931, p. 106, pl. 11, fig. 19.
Nodogenerina lohmani Kleinpell	Kleinpell, 1938, p. 245, pl. 4, fig. 6.
Nodogenerina sanctaecrucis Kleinpell	Kleinpell, 1938, p. 246, pl. 4, fig. 22.
Nodosaria anomala Reuss	Cushman and Parker, 1931, p. 4, pl. 1, figs. 12-14.
Nodosaria cf. *N. arundinea* Schwager	Cushman and Parker, 1931, p. 6, pl. 1, figs. 17-19.
Nodosaria cf. *N. deliciae* Martin	Mallory, 1959, p. 170, pl. 13, fig. 13; pl. 36, fig. 10.
Nodosaria grandis Reuss	Rau, 1948, p. 167, pl. 30, fig. 9.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Nodosaria latejugata Gümbel	Cushman and McMasters, 1936, p. 512, pl. 75, figs. 11, 12.
Nodosaria cf. *N. longiscata* (d'Orbigny)	Graham and Classen, 1955, p. 16, pl. 2, figs. 35, 36.
Nodosaria pyrula d'Orbigny	Sullivan, 1962, p. 265, pl. 10, figs. 3, 4.
Nodosaria cf. *N. raphanistrum* (Linné)	Nuttall, 1932, p. 16, pl. 3, fig. 10.
Nodosaria velascoensis Cushman	Mallory, 1959, p. 172, pl. 13, fig. 24.
Nonion costiferum Cushman	Cushman, 1939, p. 15, pl. 4, fig. 5.
Nonion halkyardi Cushman	Cushman, 1939, p. 8, pl. 2, fig. 6.
Nonion incisum kernensis Kleinpell	Cushman and Parker, 1931, p. 7, pl. 1, fig. 26.
Nonion micrum Cole	Cushman, 1939, p. 5, pl. 1, figs. 20-22.
Nonion cf. *N. planatum* Cushman and Thomas	Cushman, 1939, p. 4, pl. 1, fig. 15.
Nonion pompilioides (Fichtel and Moll)	Cushman, 1939, p. 19, pl. 5, figs. 9-12.
Nonionella miocenica Cushman	Cushman, 1939, p. 31, pl. 8, fig. 9.
Planularia barksdalei (Beck)	Beck, 1943, p. 597, pl. 104, fig. 17.
Planularia cf. *P. markleyana* Church	Rau, 1948, p. 164, pl. 29, fig. 13.
Planulina cf. *P. venezuelana* Nuttall	Mallory, 1959, p. 263, pl. 23, fig. 9.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Plectofrondicularia cf. *P. californica* Cushman and Stewart	Kleinpell, 1938, p. 239, pl. 4, figs. 17, 19.
Plectofrondicularia packardi multilineata Cushman and Simonson	Cushman and Simonson, 1944, p. 197, pl. 32, figs. 2-4.
Plectofrondicularia cf. *P. packardi multilineata* Cushman and Simonson	Cushman and Simonson, 1944, p. 197, pl. 32, figs. 2-4.
Plectofrondicularia packardi packardi Cushman and Schenck	Cushman and Simonson, 1944, p. 197, pl. 31, figs. 17, 18.
Plectofrondicularia searsi Cushman, R. E. and K. C. Stewart	Cushman, Stewart, and Stewart, 1947, p. 78, pl. 10, fig. 5; pl. 11, fig. 8.
Plectofrondicularia vaughani Cushman	Rau, 1951, p. 439, pl. 65, fig. 11.
Plectofrondicularia vokesi Cushman, R. E. and K. C. Stewart	Cushman, Stewart, and Stewart, 1949, p. 132, pl. 15, fig. 4.
Pleurostomella acuta Hantken	Cushman and Siegfus, 1942, p. 415, pl. 17, fig. 8.
Pseudoglandulina cf. *P. conica* (Neugeboren)	Beck, 1943, p. 599, pl. 105, fig. 12.
Pseudoglandulina inflata (Bornemann)	Rau, 1951, p. 434, pl. 64, fig. 3.
Pseudononion cf. *P. cushmani* (Stewart and Stewart)	Goodwin and Thomson, 1954, p. 173, pl. 32, figs. 4-6.
Pseudopolymorphina cf. *P. ligua* (Roemer)	Cushman and Ozawa, 1930, p. 89, pl. 22, figs. 5, 6.
Pullenia bulloides (d'Orbigny)	Kleinpell, 1938, p. 338, pl. 5, figs. 10, 13.
Pullenia eocenica Cushman and Siegfus	Cushman and Siegfus, 1942, p. 420, pl. 18, fig. 2.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Pullenia cf. *P. salisburyi* R. E. and K. C. Stewart	Cushman and Laiming, 1931, p. 117, pl. 14, fig. 2.
Quadrimorphina allomorphinoides (Reuss)	Mallory, 1959, p. 245, pl. 23, fig. 5; pl. 34, fig. 2.
Quinqueloculina goodspeedi Hanna and Hanna	Beck, 1943, p. 592, pl. 99, figs. 1, 2.
Quinqueloculina imperialis Hanna and Hanna	Rau, 1948, p. 159, pl. 27, figs. 12-14.
Quinqueloculina triangularis d'Orbigny	Mallory, 1959, p. 130, pl. 36, fig. 5.
Quinqueloculina weaveri Rau	Rau, 1948, p. 159, pl. 28, figs. 1-3.
Robulus brevispinosus (Nuttall)	Rau, 1951, p. 431, pl. 63, figs. 23, 24, (*R.* cf. *calcar*)
Robulus cf. *R. pseudovortex* Cole	Cushman and McMasters, 1936, p. 510, pl. 74, fig. 12.
Robulus welchi Church	Mallory, 1959, p. 143, pl. 7, fig. 8.
Rotalia cf. *R. tenerrima* Bandy	Bandy, 1950, p. 278, pl. 42, fig. 3.
Sigmoilina tenuis (Czjzek)	Rau, 1951, p. 430, pl. 63, fig. 2.
Sigmomorphina schencki Cushman and Ozawa	Rau, 1951, p. 436, pl. 64, figs. 19-21.
Sigmomorphina undulata Rau	Rau, 1948, p. 170, pl. 30, figs. 15, 16.
Silicosigmoilina californica Cushman and Church	Mallory, 1959, p. 129, pl. 5, fig. 10.
Siphogenerina nodifera Cushman and Kleinpell	Cushman and Kleinpell, 1934, p. 13, pl. 2, figs. 15, 16.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Siphonodosaria frizzelli Rau	Rau, 1948, p. 171, pl. 30, fig. 10.
Sphaeroidina variabilis Reuss	Rau, 1964, p. G23, pl. 7, fig. 7.
Spiroloculina texana Cushman and Ellisor	Rau, 1948, p. 160, pl. 28, figs. 4, 5.
Spiroplectammina directa (Cushman and Siegfus)	Cushman and Siegfus, 1942, p. 409, pl. 16, figs. 27, 28.
Spiroplectammina cf. *S. warreni* (Cushman and Ellisor)	Sullivan, 1962, p. 253, pl. 2, figs. 8, 9.
Textularia? aff. *T. mississippiensis* Cushman	Cushman and Siegfus, 1942, p. 401, pl. 15, fig. 6.
Triloculina cf. *T. gilboei* Beck	Beck, 1943, p. 594, pl. 101, figs. 1-3.
Tritaxilina colei Cushman and Siegfus	Cushman and Siegfus, 1942, p. 403, pl. 15, figs. 12, 13.
Uvigerina churchi Cushman and Siegfus	Cushman and Siegfus, 1942, p. 414, pl. 17, fig. 6.
Uvigerina cocoaensis Cushman	Rau, 1951, p. 444, pl. 65, fig. 28.
Uvigerina gallowayi Cushman	Kleinpell, 1938, p. 294, pl. 5, figs. 1, 2, 5.
Uvigerina garzaensis Cushman and Siegfus	Cushman and Siegfus, 1942, p. 414, pl. 17, fig. 6.
Uvigerina cf. *U. hootsi* Rankin	Cushman and Kleinpell, 1934, p. 22, pl. 3, figs. 8, 9.
Uvigerina cf. *U. montesanensis* Rau	Rau, 1948a, p. 778, pl. 119, figs. 10, 11.
Uvigerinella obesa impolita Cushman and Laiming	Cushman and Laiming, 1931, p. 111, pl. 12, fig. 11.

TABLE 2.—References for All Identified Species From the Satsop River Area—Continued

Species	Reference
Vaginulinopsis asperuliformis (Nuttall)	Cushman and Siegfus, 1942, p. 408, pl. 16, figs. 18-20.
Vaginulinopsis cf. *V. goajiraensis* (Becker and Dusenbury)	Becker and Dusenbury, 1958, p. 17, pl. 1, fig. 23.
Vaginulinopsis saundersi (Hanna and Hanna)	Beck, 1943, p. 598, pl. 105, figs. 1, 2, 4, 5, 10.
Vaginulinopsis vacavillensis (G. D. Hanna)	Mallory, 1959, p. 157, pl. 11, fig. 8; pl. 40, figs. 1, 7.
Valvulineria araucana (d'Orbigny)	Rau, 1951, p. 446, pl. 67, figs. 18-20.
Valvulineria jacksonensis welcomensis Mallory	Mallory, 1959, p. 231, pl. 20, figs. 3, 5.
Valvulineria menloensis Rau	Rau, 1951, p. 446, pl. 66, figs. 17-22.
Valvulineria tumeyensis Cushman and Simonson	Cushman and Simonson, 1944, p. 201, pl. 33, figs. 13, 14.
Valvulineria willapaensis Rau	Rau, 1951, p. 447, pl. 66, figs. 23-25.
Virgulina bramlettei Galloway and Morrey	Cushman and Laiming, 1931, p. 109, pl. 12, fig. 4.
Virgulina californiensis Cushman	Cushman and Laiming, 1931, p. 108, pl. 12, fig. 2.
Vulvulina curta Cushman and Siegfus	Cushman and Siegfus, 1942, p. 401, pl. 15, figs. 7, 8.

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Errata sheet for Washington Division of Mines and Geology Bulletin 53,

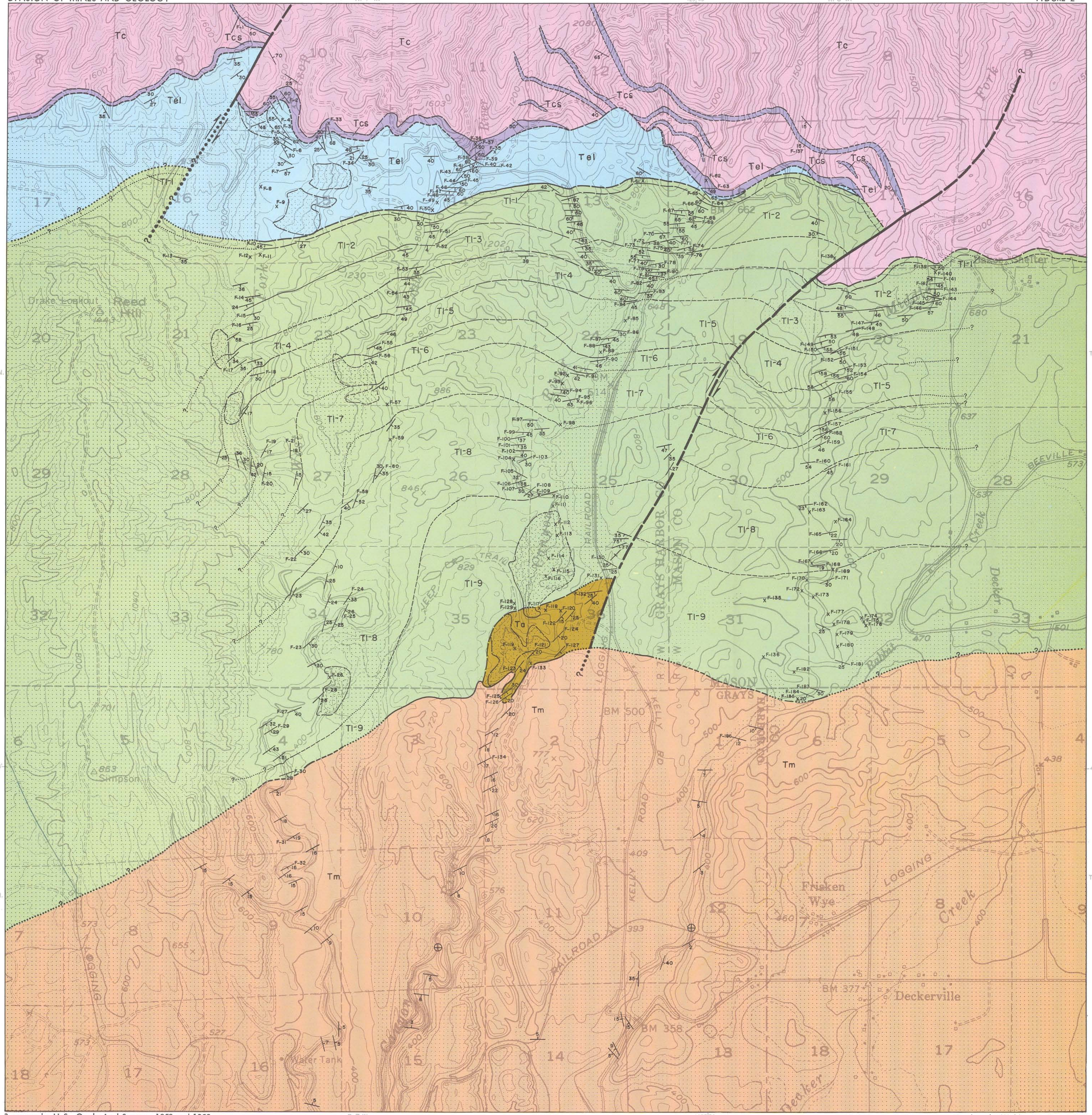
Stratigraphy and Foraminifera of the Satsop River Area, Southern Olympic Peninsula, Washington

By Weldon W. Rau

Figure 4. In "formations" column under "This Report," change Lincoln Formation to Lincoln Creek Formation.

Figure 9. Change 100 feet intervals on composite section to read 1,000 feet intervals.

Figure 9. Move line showing base of Lincoln Creek Formation, *Sigmomorphina schencki* Zone, and Refugian Stage, from top of basaltic sandstone unit to bottom of this unit.



Base map by U.S. Geological Survey, 1953 and 1955

SCALE

1 ½ 0 1 2 Miles

Contour intervals 40, 80, and 100 feet

Geology by Weldon W. Rau, 1963

GEOLOGIC MAP OF THE SATSOP RIVER AREA OF WESTERN WASHINGTON

EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

Quaternary

Pleistocene and Recent

Landslide

Areas of slumped masses of bedrock

Approximate area covered by gravel of Pleistocene(?) age

Gravel and sand with minor silt and clay, largely of fluvial origin. Gravel commonly iron stained and deeply weathered in western part, but usually fresh and unaltered east of the middle fork of the Satsop River.

UNCONFORMITY

Tertiary

Upper Miocene and/or lower Pliocene

Tm

Montesano Formation

Well-sorted fine- to coarse-grained sandstone, sandy siltstone, and pebble and cobble conglomerate. Conglomerate common near base, lenticular in other parts of Formation.

UNCONFORMITY

Miocene

Ta

Astoria(?) Formation

Dark-gray, micaceous, calcareous, sandy, siltstone and poorly sorted silty sandstone. Few resistant limey beds.

Eocene and Oligocene

Tl-9, Tl-8, Tl-7, Tl-6, Tl-5, Tl-4, Tl-3, Tl-2, Tl-1

Lincoln Creek Formation

Tuffaceous siltstone and silty fine to medium-grained poorly sorted sandstone.

Tl-9, massive siltstone.
Tl-8, massive siltstone and silty sandstone with some thin-bedded sandstone and siltstone.
Tl-7, massive siltstone with a few thin beds of tuffaceous fine-grained sandstone in middle part.
Tl-6, tuffaceous sandstone and sandy siltstone with interbedded massive siltstone beds.
Tl-5, massive siltstone with scattered concretions. Some sandstone and sandy siltstone in western part of area.
Tl-4, tuffaceous poorly sorted conglomerate and sandy grit interbedded with massive siltstone.
Tl-3, tuffaceous siltstone and poorly sorted sandstone.
Tl-2, massive, tuffaceous siltstone with scattered concretions.
Tl-1, dark-gray massive basaltic sandstone.

Eocene

Tel

Sedimentary rocks of late Eocene age

Gray micaceous thin-bedded mudstone, siltstone, and silty sandstone. Some sandstone beds cross bedded.

UNCONFORMITY

Tcs Tc

Crescent Formation

Pillow and massive lava flows, volcanic breccia, and interbedded siltstone and sandstone beds. Tcs, sedimentary rocks.

Contact

Long dash where approximately located; short dash where indefinite; dotted where concealed; queried where doubtful.

Fault

Dashed where approximately located; dotted where concealed; queried where doubtful. Arrows indicate direction of apparent movement.

Strike and dip of beds

Horizontal beds

F-23

Collection locality

TRUE NORTH 22½° MAGNETIC NORTH

Approximate mean declination, 1962

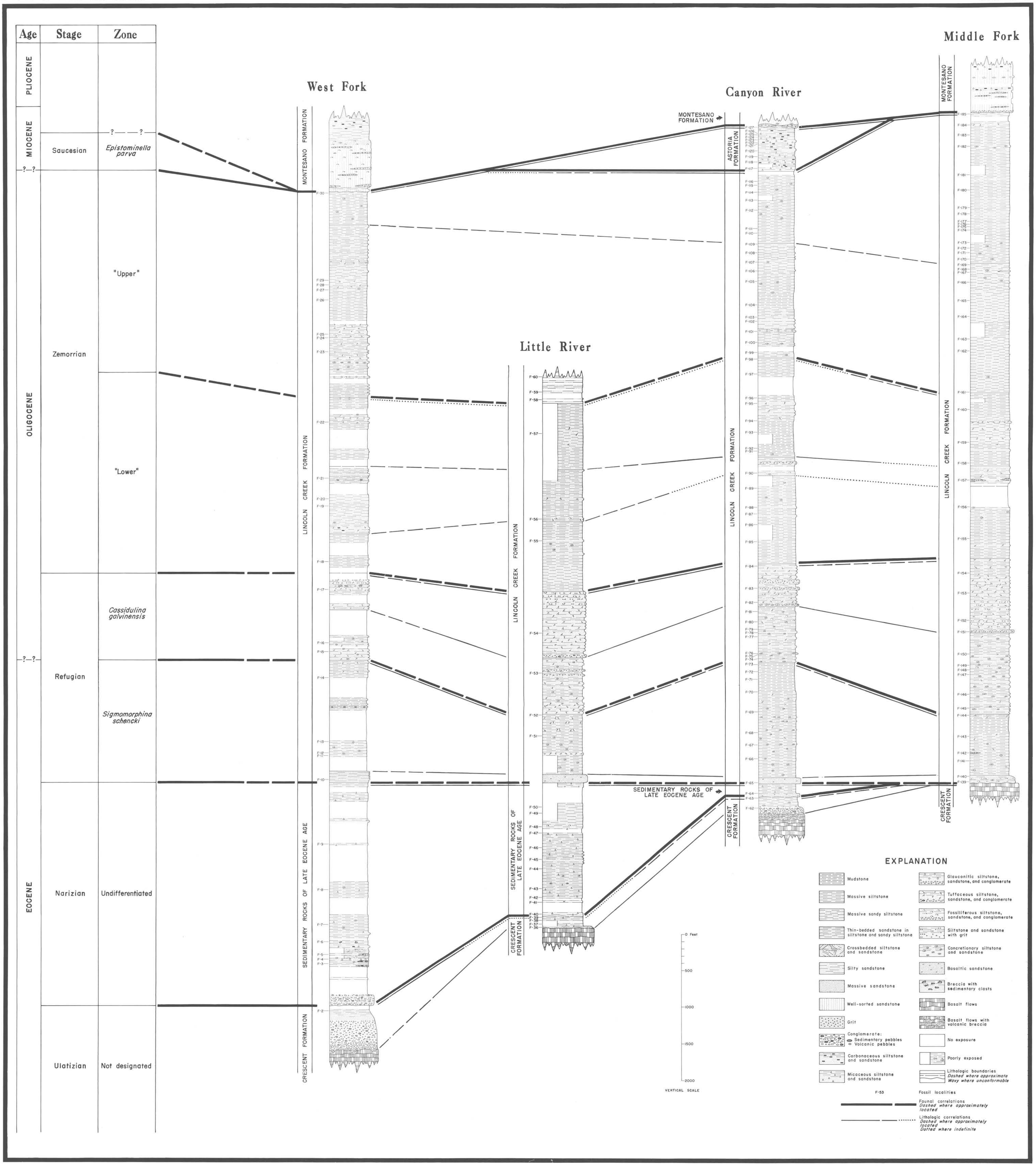
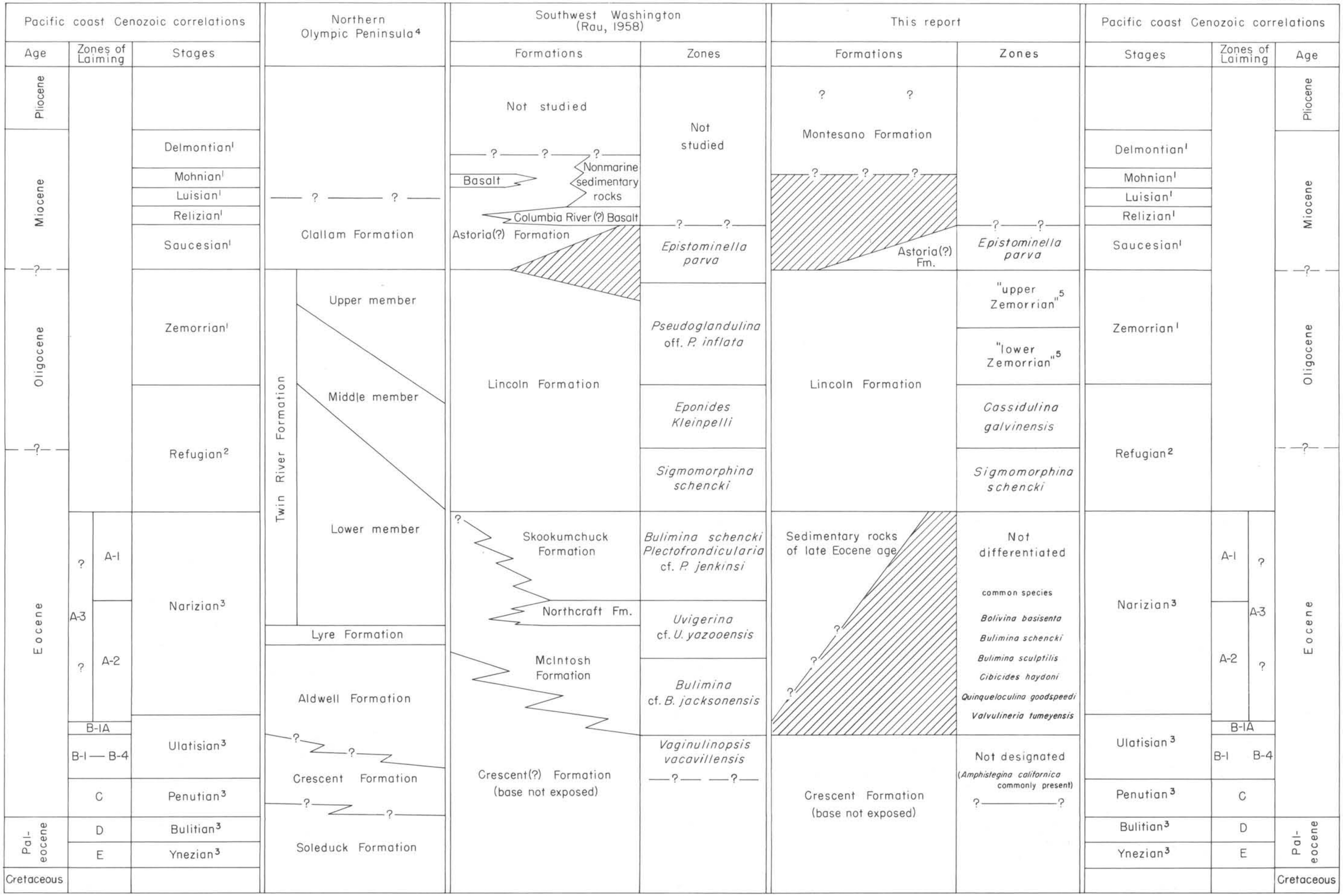


FIGURE 3. - CORRELATION OF COLUMNAR SECTIONS IN THE SATSOP RIVER AREA



[1] Of Kleinpell, 1938.
[2] Of Schenck and Kleinpell, 1936.
[3] Of Mallory, 1959.
[4] Adapted from reports by Brown, Gower, and Snavely, 1960; Gower, 1960; Rau, 1964.
[5] The strata assigned to the Zemorrian stage of this report are divided into two general parts and informally referred to as the "lower" and "upper" zones of the Zemorrian stage (see text under Foraminifera of the Zemorrian stage).

FIGURE 4.-Correlation of formations and faunal units of the Satsop River area

FIGURE 5.- STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA IN ROCKS OF EOCENE AND OLIGOCENE AGE FROM THE WEST FORK OF THE SATSOP RIVER SECTION

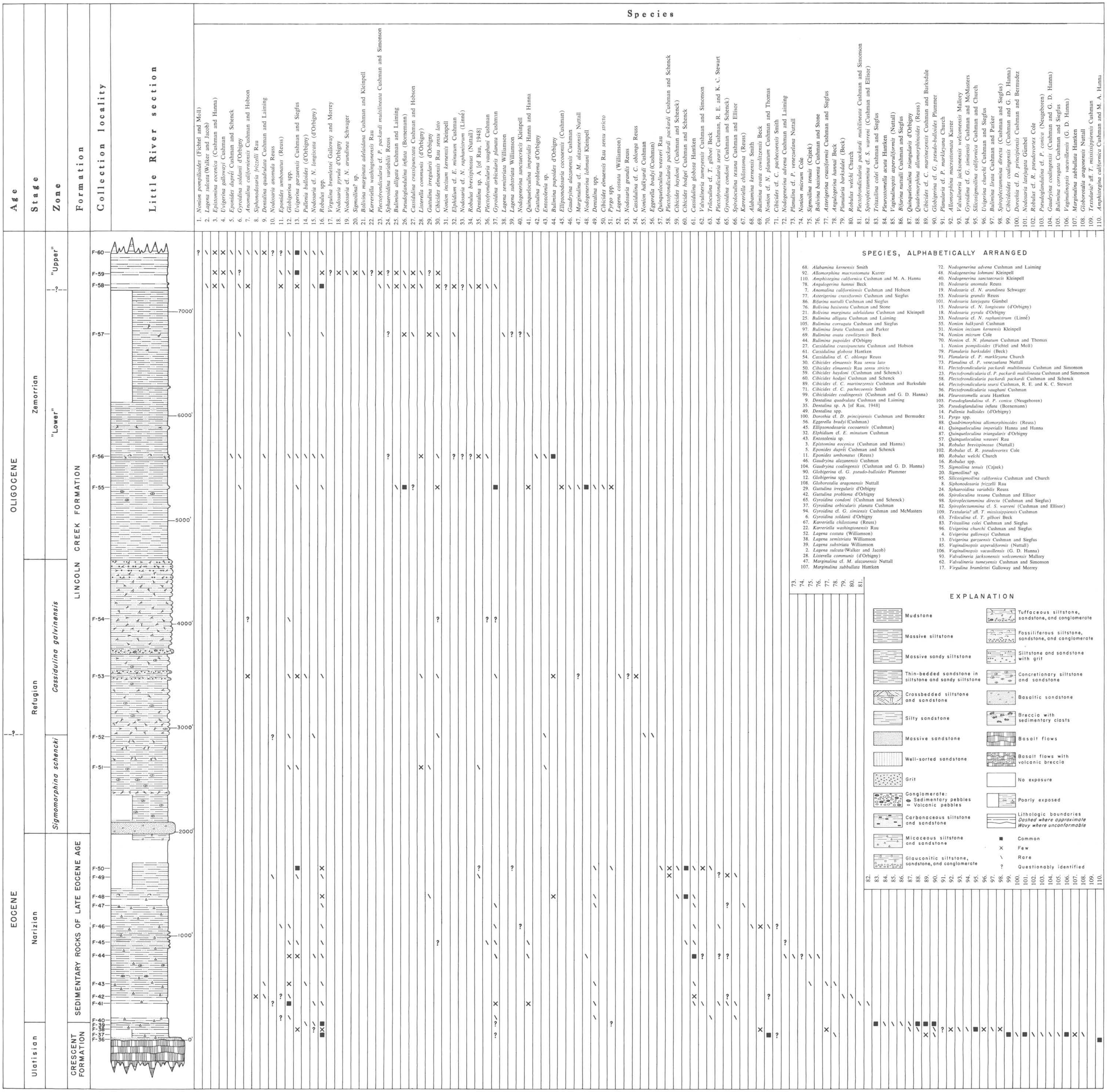


FIGURE 6 - STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA IN ROCKS OF EOCENE AND OLIGOCENE AGE FROM THE LITTLE RIVER SECTION

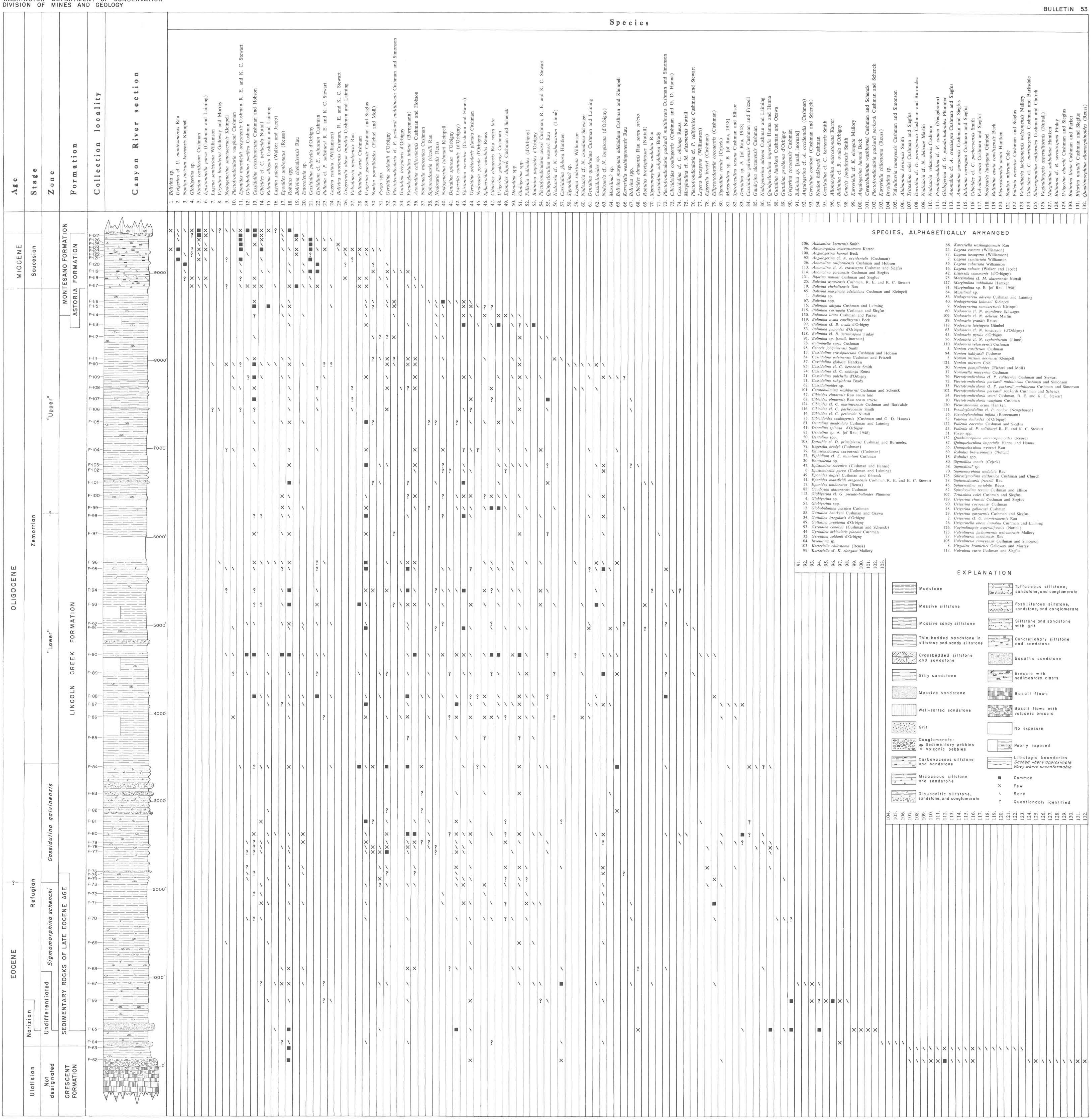


FIGURE 7.- STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA IN ROCKS OF EOCENE, OLIGOCENE, AND EARLY MIOCENE AGE FROM THE CANYON RIVER SECTION

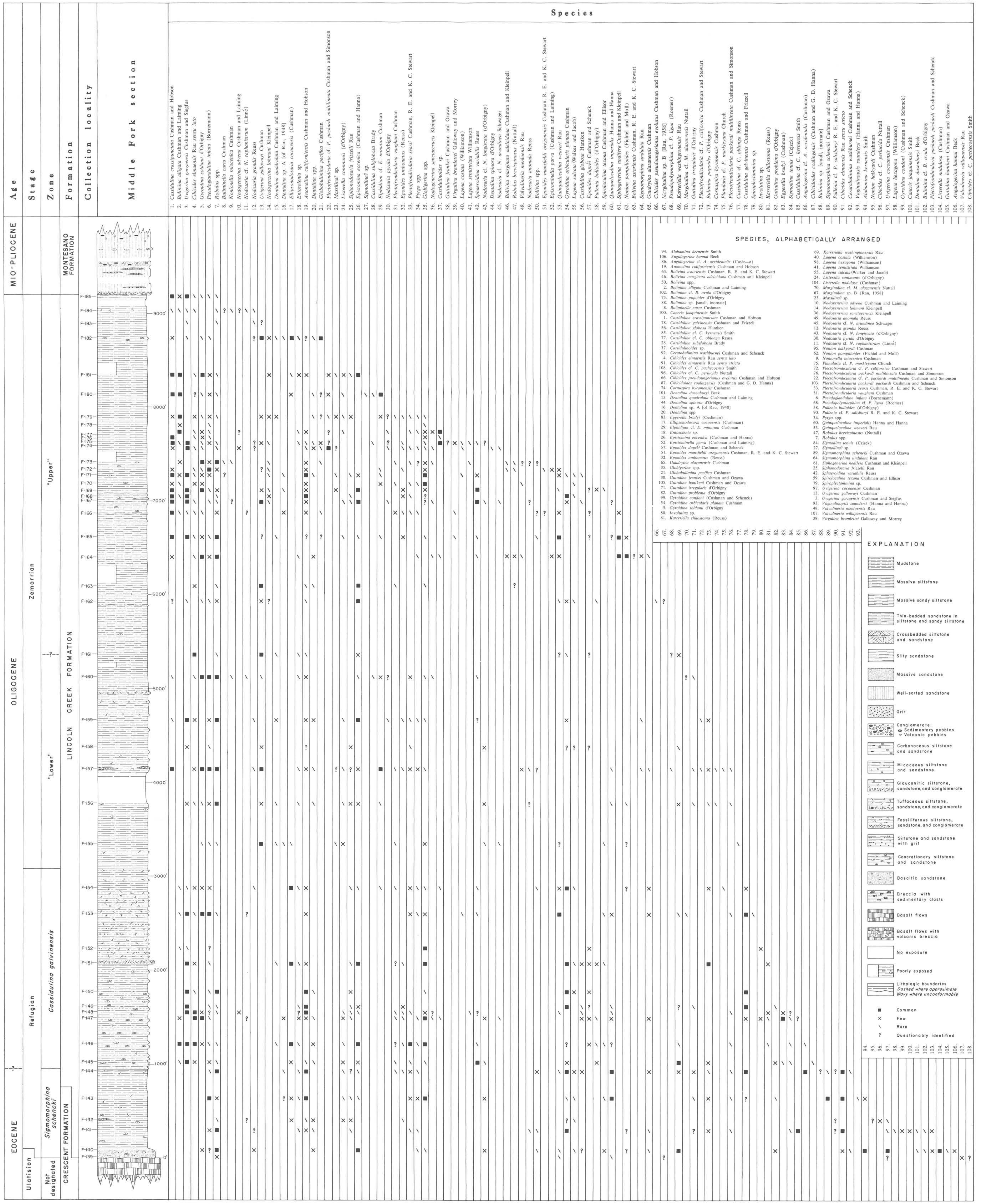


FIGURE 8 - STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA IN ROCKS OF EOCENE AND OLIGOCENE AGE FROM THE MIDDLE FORK OF THE SATSOP RIVER SECTION

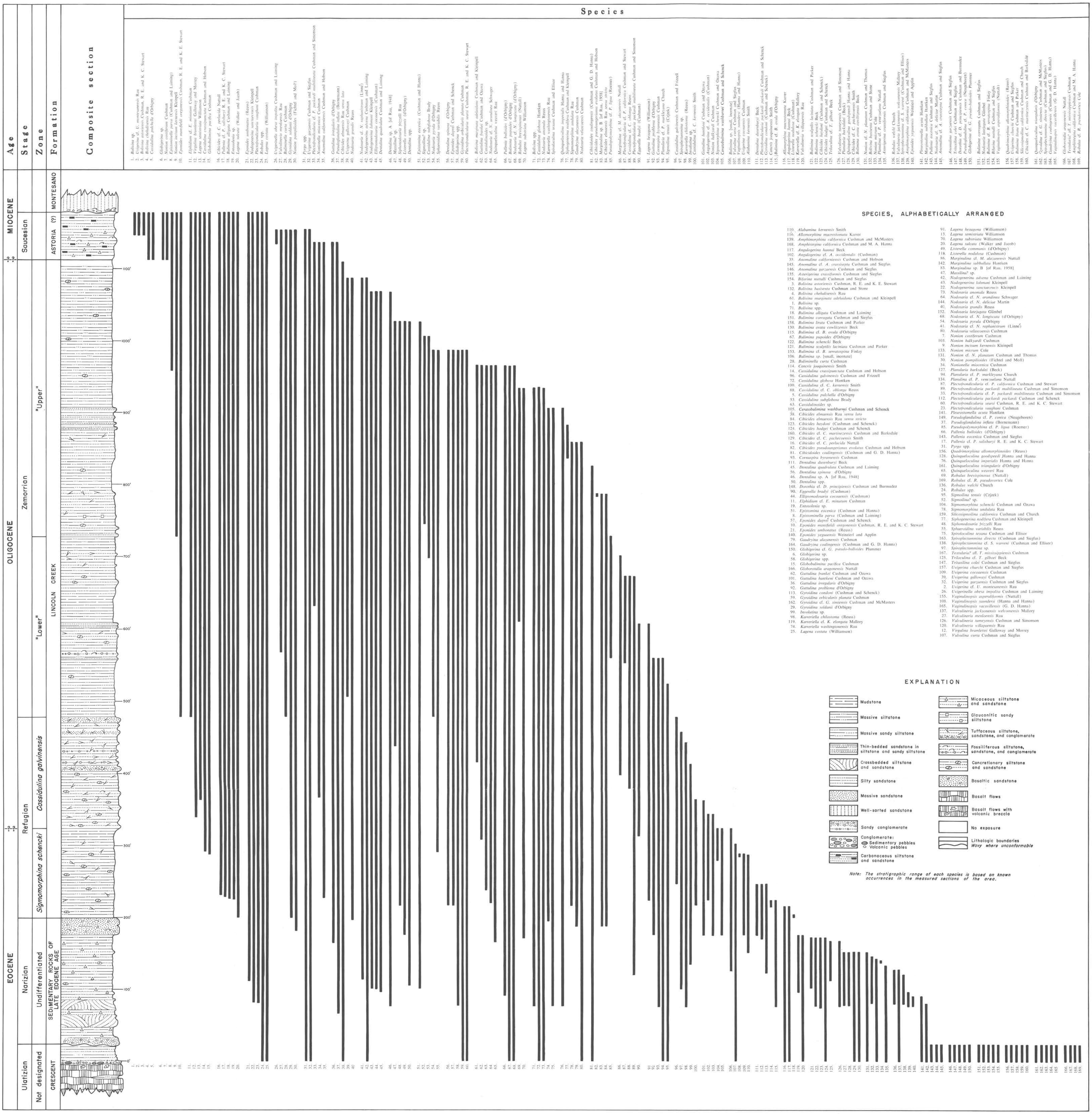


FIGURE 9. - STRATIGRAPHIC RANGE OF FORAMINIFERA IN THE SATSOP RIVER AREA