ABSTRACT

MICROFLORAL ZONATION AND CORRELATION OF SOME LOWER TERTIARY ROCKS IN SOUTHWEST WASHINGTON AND SOME CONCLUSIONS REGARDING THE PALEOECOLOGY OF THE FLORA

by Dennis M. Sparks

The study area is located in southwest Washington and northwest Oregon, west of the Cascade Mountains and south of the Olympic Mountains. It is part of a large Tertiary geosyncline which extended from the Klamath Mountains to Vancouver Island. The strata included in this study comprise a composite section 9,000 feet thick, ranging in age from late Middle Eocene to Late Eocene or Early Oligocene. The McIntosh and Skookumchuck Formations represent marine and non-marine phases of the same sedimentary cycle and are in part contemporaneous. The Keasey Formation comprises the uppermost portion of the composite section, representing at least part of the rock removed by late Eocene uplift and erosion of the Skookumchuck Formation in part of the study area.

The two principal objectives have been to establish a relative chronologic framework for the units described and to elucidate the nature and distribution of the early Tertiary flora based on the dispersed plant microfossils.

Five palynologic zones are recognized, based on the stratigraphic range of 53 plant microfossils. Quantitative

data provide additional stratigraphic subdivision of the zones, based on relative abundance of ten selected forms. Independence of these ten forms from control by environmental factors is shown by the relative relationships within the sum of the ten compared with microplankton-fungi ratios, rock facies, and total numbers.

Correlation of the zones in an east-west cross section shows the McIntosh Formation on-lapping the Crescent Formation in the Willapa Hills. The Skookumchuck Formation is shown to have been deposited during a regressive phase of sedimentation. A north-south cross section indicates considerable relief on the unconformity below the Lincoln Formation in the Skookumchuck section.

One hundred twelve plant microfossils have been identified. Included in the list of taxa with which some of the dispersed pollen and spores may have affinities, are some with centers of distribution in the subtropics, a large number of temperate forms, and several cool temperate or boreal genera. The climate was warm and humid in the lowland, where swamp forests and wet forests were developed. The upland was more temperate, and supported a mixed, more mesic forest. Coniferous trees were the major constituent of a montane element which occupied higher regions to the east.

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By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Geology

1967

646148
9/27/67

ACKNOWLEDGMENTS

Several individuals and organizations have provided inordinate aid and assistance to me during the various phases of this study. Dr. Aureal T. Cross, Professor of Geology and Botany-Plant Pathology, has served as major professor for this dissertation. He has provided material help in preparing the thesis, as well as providing a stimulating atmosphere of diverse research in palynology at Michigan State University. I am grateful to Drs. James Trow, Jane Smith and John Cantlon for critical reading of the manuscript. Dr. Chilton Prouty, Chairman of the Geology Department, provided helpful critism of the thesis, and also helped me in many other ways during my tenure at Michigan State.

Pan American Petroleum Corporation, through their Research Center, introduced me to the problem, and generously supported the field work. The Geological Society of America and the Society of the Sigma Xi provided funds for laboratory equipment and supplies, photographic supplies and a portion of the field work.

From September 1963 to March 1965 I was under the tenure of a National Defense Education Act Fellowship at Michigan State University, and I am deeply appreciative of the opportunity to have been part of that federal program.

Finally, I wish to acknowledge the stoic patience and spartan fortitude of my wife Shirley, whose encouragement and material assistance has helped bring this academic effort to a successful end.

It is my sincere hope that this dissertation is worthy of those persons who have helped in its completion.

TABLE OF CONTENTS

PART		PAGE
	INTRODUCTION	1
	General Statement	1
	Methods	5
I.	GEOLOGY	10
	Introduction	10
	Physiography	10
	Structural Framework	12
	General Features	12
	Structural History	16
	Stratigraphy	19
	General Statement	19
	Crescent Formation	20
	Cowlitz Formation	22
	McIntosh Formation	24
	Northcraft Formation	26
	Skookumchuck Formation	26
	Keasey Formation	30
II.	STRATIGRAPHIC PALYNOLOGY	32
	General Statement	32
	Studied Sections	33
	Stillwater-Olequa Creek Section	33
	Willapa River Section	34
	Chehalis River Section	34
	McIntosh Lake Section	35
	Rock Creek Section	35

PART PAGE

The Composite Reference Section 36

Zonation 38

Qualitative Method 38

Qualitative Results 40

Quantitative Method 44

Quantitative Results 49

Correlation of Zones 55

Correlation of McIntosh Section 59

Correlation of the Skookumchuck Section . 59

Correlation of the Willapa River Section . 60

Correlation of the Chehalis River Section. 61

Summary of Palynologic Correlations 62

III. FLORAL AND ENVIRONMENTAL SECTION 69

Introduction 69

Composition of the Flora 69

Methods 69

Flora List 70

Environmental Indicators in Flora 72

Tropical - Subtropical Plants 72

Warm Temperate Plants 74

Temperate Plants 76

Relative Abundance Diagram 76

Ecological Elements Within the Flora 78

Swamp Element 79

Wet Forest Element 82

Mesic Forest Element 83

PART PAGE

Montane Element 84

Areal Distribution of the Floral Elements . 85

Summary of Environmental Conditions 87

IV. SUMMARY AND CONCLUSIONS 90

V. SYSTEMATIC SECTION 96

Nomenclature 96

Location and Collection Information . . . 98

Descriptions 100

SELECTED LIST OF REFERENCES 158

LIST OF TABLES

TABLE PAGE

1. Floral List. Includes Sporophytes Inferred From Fossil Spores or Pollen, and Plants Identified From Leaves, Wood, etc. (From Published Sources) 71

LIST OF FIGURES

FIGURE		PAGE
1.	Generalized Early Tertiary Paleogeography in Study Area	2
2.	Code Designations for Morphologic Classes and Ornamentation Types	8
3.	General Geology and Structure: Southwest Washington and Northwest Oregon	13
4.	Stratigraphic Correlation Chart	15
5.	Stratigraphic Range of 53 Palynomorph Species	41
6.	Relative Abundance - Ten Selected Types	50
7.	Occurrence Check-list of Selected Stratigraphic Types	57
8.	Relative Abundance of Ten Selected Stratigraphic Types in Correlated Sections	58
9.	Correlation of Zones: East-West Cross Section	63
10.	Correlation of Zones: North-South Cross Section	66
11.	Relative Abundance - Total Population Grouped as Sporophyte Taxa	77
12.	Inferred Distribution of Major Vegetational Assemblages	86

LIST OF APPENDICES

APPENDIX PAGE

A A-1

INTRODUCTION

The Tertiary rocks of western Oregon and Washington represent a vast and little known sedimentary province. In an area of approximately 60,000 square miles, lying west of the Cascade Mountains and extending from the Olympic Mountains on the north to the Klamath Mountains on the south, about 20,000 feet of sedimentary rocks are preserved. These rocks range in age from Middle Eocene to Pliocene. The sequence of sediments rests conformably upon, and is intimately related to, a series of basic volcanic rocks of Early to Middle Eocene age, with a thickness in excess of 10,000 feet. The inferred paleogeography in Eocene time is shown in Figure 1.

To describe the area as a basin is a misleading over-simplification. The western limits have not been established, and rocks extend onto the continental shelf, and even beyond to the continental rise. To most geologists the area represents a geosyncline, but within the broad context of that concept it is a special case, requiring, like most geosynclines, a complete and unique definition. That kind of definition and understanding has not as yet been realized, nor is it the purpose of this paper to attempt it. Rather, this project focuses on a very small part of the geographic and stratigraphic extent of this Tertiary geosyncline, in an attempt to establish a chronologic framework for the lower Tertiary sedimentary rocks of southwest Washington and part of northwest Oregon.

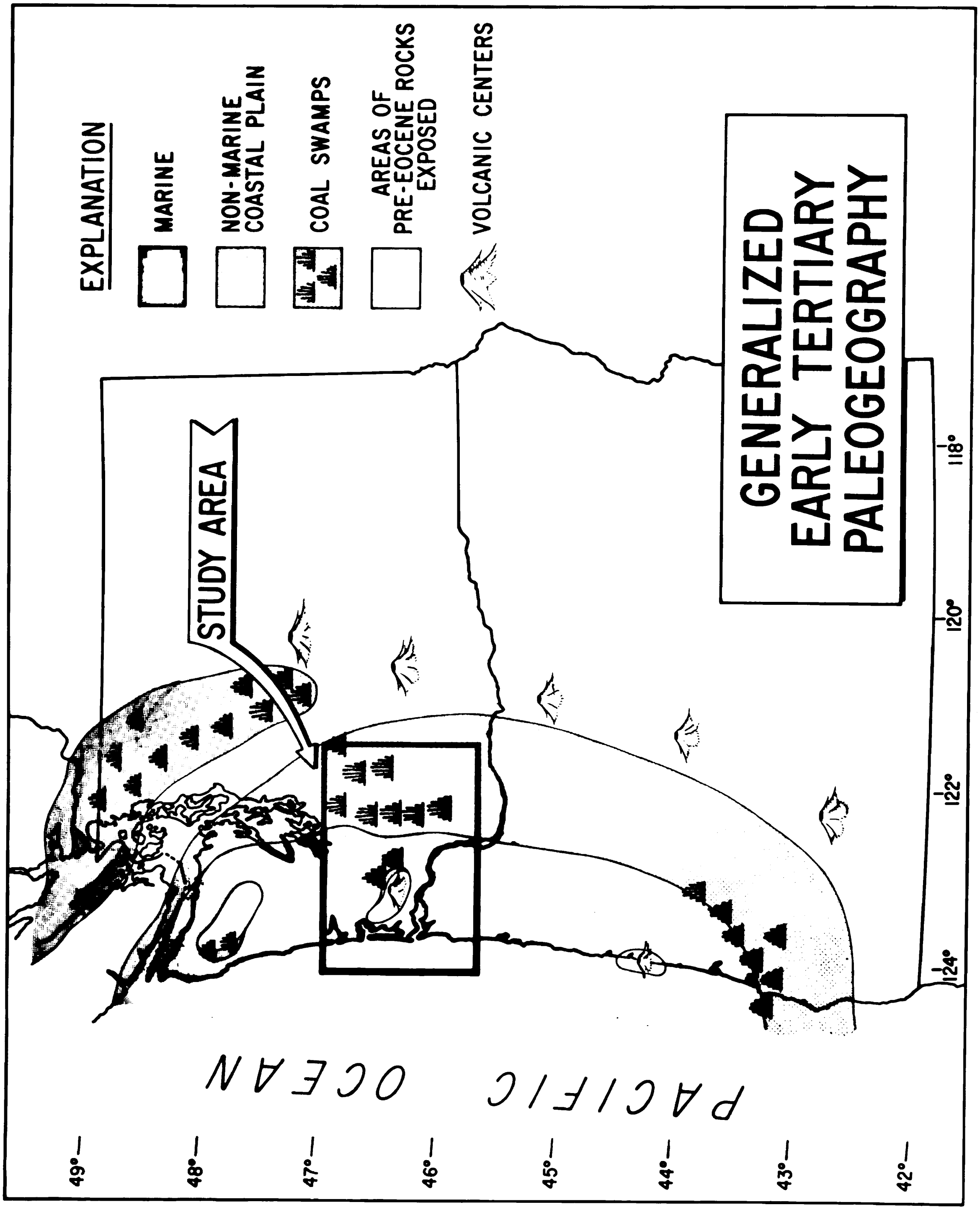

EXPLANATION
MARINE
NON-MARINE COASTAL PLAIN
COAL SWAMPS
AREAS OF PRE-EOCENE ROCKS EXPOSED
VOLCANIC CENTERS
STUDY AREA
GENERALIZED EARLY TERTIARY PALEOGEOGRAPHY
PACIFIC OCEAN
49°
48°
47°
46°
45°
44°
43°
42°
124°
122°
120°
118°

FIGURE 1

To this end, the dispersed spores and pollen of plants growing on the land adjacent to the area of accumulating sediments are utilized in a biostratigraphic fashion. Several characteristics of plant microfossils uniquely qualify these entities for biostratigraphic application; (1) they are nearly ubiquitous in their occurrence in most types of sedimentary environments; (2) they are remarkably resistant to most degradational processes in sedimentation and diagenesis; (3) they possess characteristic morphological features which allow differentiation and recognition; and (4) they reflect time related changes in their qualitative and quantitative distribution in the stratigraphic column caused by evolutionary and/or environmental conditions.

In the process of analyzing dispersed plant microfossils in a stratigraphic section, two kinds of results may be obtained. First the data show qualitative and quantitative characteristics which provide time-stratigraphic information. Second, these same data comprise a fossil record of the plants which grew in the area, from which compositional, distributional, and ecological information may be obtained. These two kinds of information are closely and genetically related, although conclusions about one may be made without reference to the other, sometimes, however, with less than satisfactory results. This study approaches both aspects in the hope that a working hypothesis regarding the ecological conditions of

the early Tertiary vegetation will facilitate the construction of a time-stratigraphic framework, as well as being of significant interest in itself.

There are three principle objectives sought in the study: first, the zonation and correlation of outcrop sections of Middle Eocene and Upper Eocene rocks in western Washington and northwest Oregon; second, interpretation of the composition and general distribution of a portion of the early Tertiary flora, and possible environmental implications; and third, an adequate systematic treatment of the microfossils to allow wider application of the information by other workers.

The amount of published information available pertinent to this study is not extensive. Much of the geologic work done before 1950 in western Washington and Oregon was of a reconnaissance nature, and the paleontologic investigations were largely concerned with faunal assemblages described from isolated localities. During the period from 1950 to the present, The United States Geological Survey has been conducting a series of studies in conjunction with the Washington State Department of Conservation that has led to the publication of descriptive maps and reports prepared on a considerably more detailed scale. Frequent and repeated reference to these publications is made in this report. The literature of Tertiary palynology is not extensive. Several hundred published reports are available, some of which concern lower Tertiary rocks. Studies dealing with

the Tertiary section of western North America number only about 15. A much larger number of publications is available dealing with more conventional paleobotanical aspects (leaves, wood, etc.) of the Tertiary section of the west coast, and these were consulted often, although they generally are not cited directly in the text. Current interest in petroleum exploration in the offshore area adjacent to the states of Washington and Oregon has led to a rapid increase in the amount of work carried out in the region, both stratigraphically and palynologically. The extent of this effort and the results of it, both economically and geologically, is, at present, competitive information and is not available. Perhaps much of this information will eventually be published and our understanding of the events of the Tertiary Period in western North America will be greatly enhanced.

Methods

Several different methods were used in the collection and synthesis of the data contained in this report. These can be conviently classed as: (1) field methods; (2) laboratory methods; and (3) analytical methods.

The field methods used were determined by the objectives of the study. The purpose was to establish an abstract chronologic framework for the rock column. The sections that were selected for detailed study had, for the most part, been previously described in detail. The samples were collected along paced traverses, with brunton compass

readings of attitude to establish vertical distance between samples. The total thickness of sections determined in this manner agrees well with those measured more accurately and described in the published reports. Where detailed geologic maps were available, the samples localities were placed directly thereon; otherwise localities were plotted on United States Geological Survey 15' topographic quadrangle maps.

Laboratory preparation procedures were the same as those used in many palynological laboratories. The inorganic rock matrix was removed by treatment with 10% hydrochloric acid, followed by 70% hydrofluoric acid. The organic fraction, which was large in almost every sample, was then treated with Schulze's solution (one part aqueous potassium chlorate to three parts concentrated nitric acid) for five to thirty minutes, depending on the amount of organic detritus. This usually resulted in the oxidation of most of the organic residue, but left the pollen and spores, along with cuticular fragments, various lignified plant cells, and often an assemblage of fungal and algal cells, including dinoflagellate cysts. The oxidized organic detritus was dissolved in a 5% potassium hydroxide solution. The sample was then washed free of that solution, and a stain was added (usually safranin). A glassware detergent, Alcojet, was used to advantage on many samples to hold very fine debris in suspension before staining, and thus further concentrate the pollen and spores, etc. Permanent

slides were prepared in Clearcol with Harleco Synthetic Resin used to cement the coverslip.

The analytical methods consisted of making a qualitative collection of the dispersed spores and pollen by morphological class, the establishment of stratigraphic range for these classes, and a quantitative evaluation of certain morphologic types. The classification is based upon a scheme proposed by Tschudy (1957) in which the morphological types are designated by descriptive formulae. This permits the handling of large numbers of different kinds of pollen and spores when their proper nomenclature may not be established in the early phases of an investigation. Figure 2 shows the classification used and the formula designation for each class. Abbreviations of certain distinctive types are occasionally used as well, such as Al-1 (Alnus-like).

The entire area of the mount under the coverslip was scanned systematically and both the qualitative and quantitative data were collected simultaneously. An effort was made to control the quality of the preparations and to obtain approximately the same number of pollen on each slide. By extrapolation the total number of grains per slide generally ranges from about 1000 to as high as 8500, but the average is between 2000 and 3000. The quantitative data consists of two kinds of relative abundance counts. The objective of the first was to determine the most abundant types in the sample, some of which

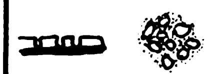
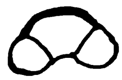
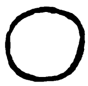
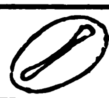
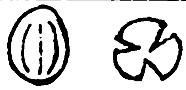
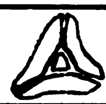
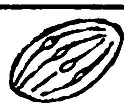
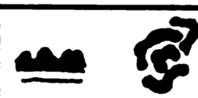
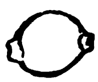
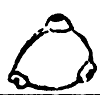
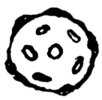
MORPH. CLASS			ORNAMENTATION		
TYPE	CODE	DIAGRAM	TYPE	CODE	DIAGRAM
trilaesurate	Tl		psilate	sm	
monolaesurate	Ml		foveolate	fov	
vesiculate	V		fossulate	fos	
inapertuate	I		vermiculate	v	
monosulcate	S_1		scabrate	sc	
monocolpate	C_1		granulate	g	
tricolpate	C_3		verrucate	ver	
polycolpate	C_∞		gemmate	gm	
syncolpate	Syn		clavate	cl	
tricolporate	CP_3		echinate	sp	
polycolporate	CP_∞		rugulate	rug	
diporate	P_2		striate	st	
triporate	P_3		reticulate	r	
polyporate	P_∞		cicatricose	cic	

FIGURE 2

reflect the local environmental or ecological conditions, and the second count was designed to provide stratigraphically significant data, independant of local conditions. The first count was a 200 grain fixed sum count of every pollen or spore encountered in traversing the slide until that sum was reached. Hopefully, these data make possible an interpretation of the distribution of plants growing in the vicinity of the depositional site, especially as they may be related to environments reflected in the lithologic record, such as with the coals and lignitic siltstones. The second kind of count was a fixed area count of ten specific types of pollen, the sum being the total number of the ten types present on the slide. If the assumptions which are made regarding these ten types are valid then the data collected by this method will yield results that are significant to the time-stratigraphy of the area. These quantitative methods are discussed in more detail in a following section.

All microscopic work was carried out with Leitz Ortholux microscope. A 35mm Leica camera mounted on the microscope provided the photographs. Kodak Panatomic-X and Adox KB-14 films were used, and the prints were enlarged to standard magnifications of 500x, 1000x, or 1250x.

PART I: GEOLOGY

Introduction

In undertaking to establish a relative chronology for the rocks within an area, it is imperative that the geologic setting of the area is clearly understood by the investigator. This is no less true in attempting to portray the distribution and development of a flora from the fossil record. The understanding of the geologic setting is not necessarily intended to imply a knowledge of the "true" geologic relationships; but rather an awareness of the extent of objective data available and the limitations of those data, familiarity with the various hypotheses advanced for the historical development of the area, and some first-hand observations of the structural and stratigraphic relationships of the rocks in the field. The following parapgraphs summarize the geologic setting of the area under consideration in this study. This will be followed in the second section by the analysis of the time-stratigraphic distribution of the plant microfossils within this geologic setting.

Physiography

The present day topography in western Washington and northwest Oregon is directly related to the structure and composition of the local bedrock. The structural highs are the prominent topographic elevations, and the

crystalline volcanic rocks exposed in the high areas hold up sharp ridges and steep-sided canyons. The maximum relief in the area is in the Willapa Hills which have an elevation of about 3000 feet and the peaks stand some 1500-2000 feet above the valleys. The structurally low areas between the prominent northwest-southeast trending anticlinal ridges are in part occupied by the major streams of the area, and present a low rolling topography developed on the partly truncated folds of the lower Tertiary sediments. The rate of chemical degradation of the largely basic bedrock is high. Soils are frequently thick, and the area is densely covered with vegetation. For these reasons, the surface expression of many faults and minor folds cannot be seen. Geomorphically, the entire area is in a stage of early maturity, with the exception of areas where Miocene basalts lie unconformably upon older deposits, producing a youthfully dissected appearance. Most of the interstream divides are sharp, and about 70 per cent of the region is in slope. Two of the major streams of the area, the Cowlitz River and the Chehalis River, are mature in their lower courses, but are more youthful in their headwater regions. The Columbia River is youthful throughout its course, expecially where it is incised across the structure of the Coast and Cascade Ranges. The Cowlitz River has a wide flood plain, and shows a number of terrace levels above the present river plain. The Chehalis River also shows several terraces along it's lower course.

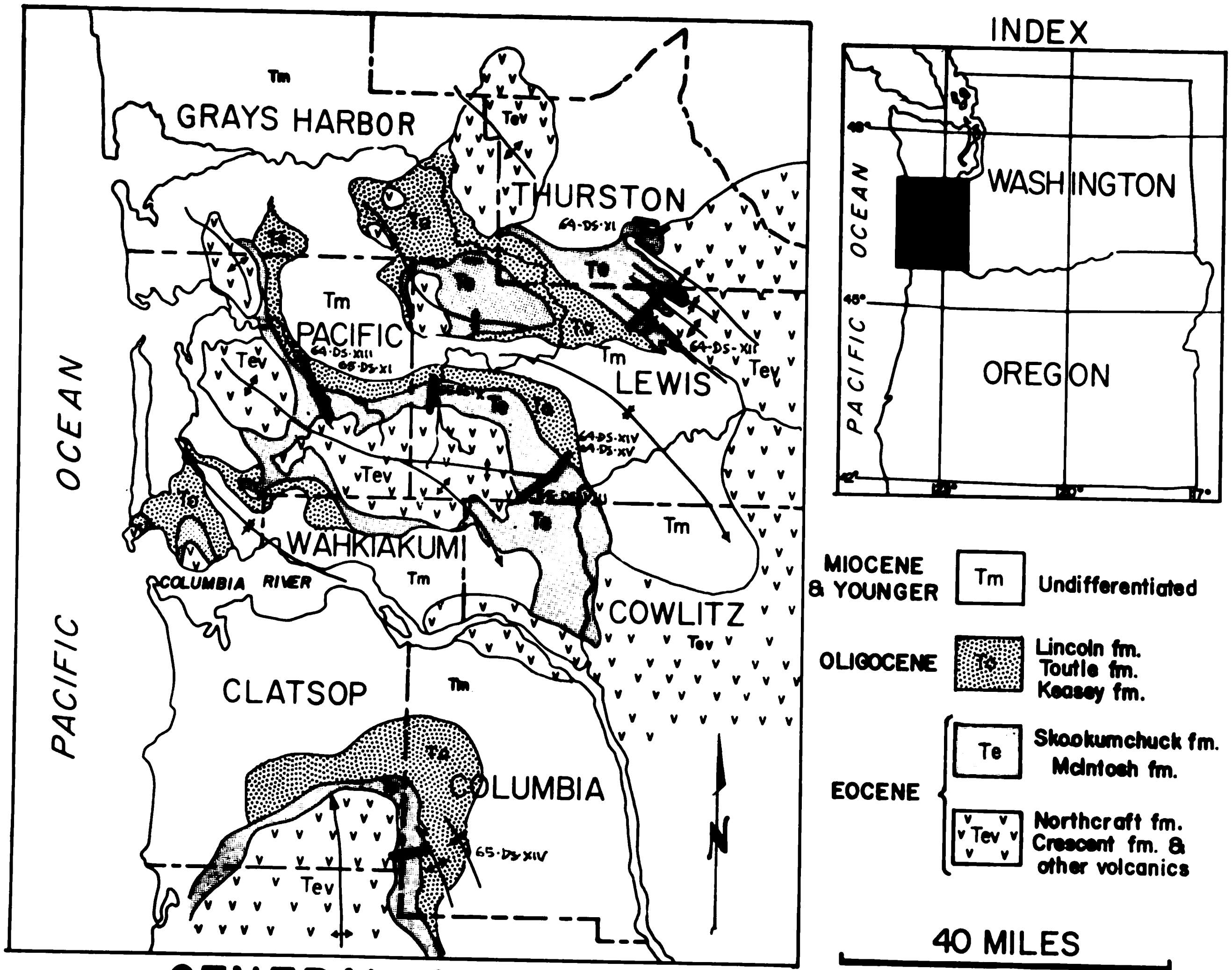
These probably reflect changes in base level (sea level for these streams) during Pleistocene time, and may also indicate the continued process of orogenic uplift in Pleistocene and Recent time.

Structural Framework

General Features

The major structural features in the study area are northwest-southeast trending uplifted areas exposing cores of early Tertiary volcanics. Between these major high areas and associated with them, in part, are a series of rather poorly defined anticlines and synclines. Faults occurring in the area are usually high angle, sometimes reverse, and occasionally show a slip-strike component. Bounding the area in a tectonic sense are the Cascade Ranges to the east, the Olympic Mountains to the north, and the east Pacific basin on the west. The major structural axes are shown on Figure 3.

The present day Cascade Ranges are the result of Pliocene and Pleistocene activity, although the tectonic history of that mountain belt involves more than a single orogenic phase. Misch (1952) describes several periods of folding, metamorphism, and intrusion which took place in Paleozoic, Mesozoic, and Cenozoic time. Of particular interest to this study is the history of early Tertiary deformation that produced an area of considerable relief trending northwest-southeast, and located further to the



GENERAL GEOLOGY AND STRUCTURE
S.W. WASHINGTON & N.W. OREGON

FIGURE 3

east than the present day Cascades. The forces which produced that uplift were probably responsible for the structural trend seen today in the area of this study. The presence of a highland area to the east (see Figure 1), and it's subsequent erosional history, certainly played a part in the source and distribution of the lower Tertiary sediments, as well as affecting the distribution of the Eocene flora. Although the dominant source of sediments has been a volcanic terrane, located, in part, within the sedimentary province itself, many of the more arkosic and quartzitic sediments were derived from the igneous and metamorphic terrance of the early Cascade Mountains.

The Willapa Hills are developed upon a northwest-southeast trending anticlinal high which lies near the center of the study area (Figure 3). The axis plunges toward the southeast, and the lower Tertiary sediments exhibit an erosional off-lap relationship, dipping at low angles away from the plunging crest. Crescent Formation volcanics (see stratigraphic units, Figure 4) are exposed in the axial portion, and have been a source of sediments during early Tertiary time.

The Doty Uplift is an anticlinal fold trending northwest-southeast, located about 10 miles to the north of the Willapa Hills anticline. The lower Tertiary sediments bear a similar erosional off-lap relationship to the Doty Uplift as they do in the Willapa Hills, although faulting has brought Oligocene or Miocene rocks in contact

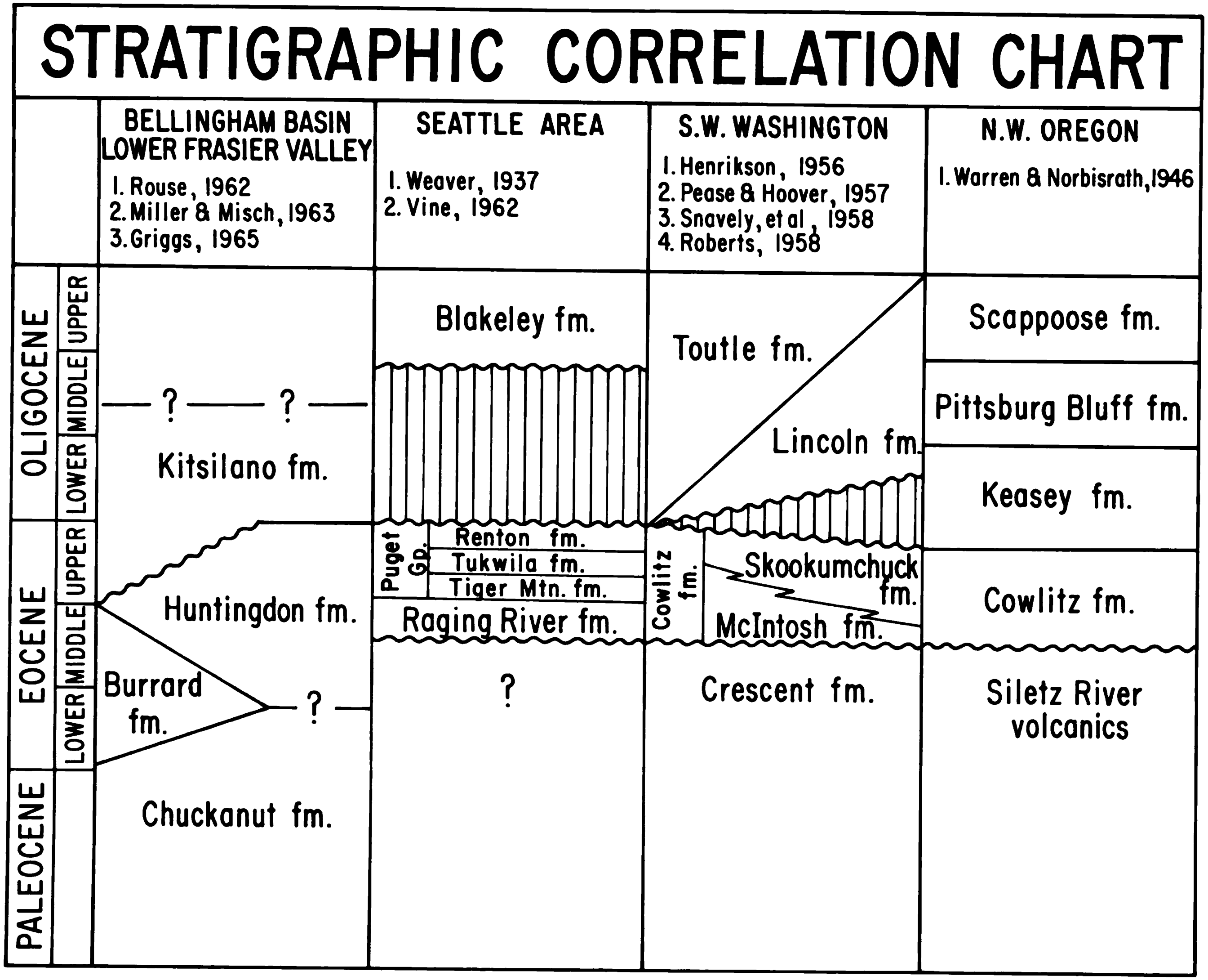

STRATIGRAPHIC CORRELATION CHART
BELLINGHAM BASIN LOWER FRASIER VALLEY
1. Rouse, 1962
2. Miller & Misch, 1963
3. Griggs, 1965
SEATTLE AREA
1. Weaver, 1937
2. Vine, 1962
S.W. WASHINGTON
1. Henrikson, 1956
2. Pease & Hoover, 1957
3. Snavely, et al, 1958
4. Roberts, 1958
N.W. OREGON
1. Warren & Norbisrath, 1946
OLIGOCENE
EOCENE
PALEOCENE
UPPER
MIDDLE
LOWER
UPPER
MIDDLE
LOWER
Kitsilano fm.
Huntingdon fm.
Burrard fm.
Chuckanut fm.
Blakeley fm.
Puget Gp.
Renton fm.
Tukwila fm.
Tiger Mtn. fm.
Raging River fm.
?
Toutle fm.
Lincoln fm.
Cowlitz fm.
Skookumchuck fm.
McIntosh fm.
Crescent fm.
Scappoose fm.
Pittsburg Bluff fm.
Keasey fm.
Cowlitz fm.
Siletz River volcanics

FIGURE 4

with the Crescent volcanics in some places. The Black Hills are located on the Doty Uplift as a topographic high.

Farther to the north, southwest of Olympia, another unnamed anticlinal high occurs with Crescent volcanics exposed along the axis. The sedimentary cover, if it ever completely over-lapped the area, has been stripped off by erosion.

The southeastward extension of these structural features terminates where the axes plunge as the result of the late Tertiary diastrophism in the Cascade Mountains. Some of the major structural trends can be traced north-west to the coast line, but their extension onto the continental shelf is as yet unknown. Between these major structurally-high areas, the lower Tertiary rocks are folded in a series of smaller anticlines and synclines almost all of which trend between N60°W and N75°W.

Structural History

Several periods of tectonic activity have affected the area under consideration. The structural events prior to Eocene time are not evident in southwestern Washington, since the base of the Lower and Middle Eocene Crescent volcanics is not exposed. On Vancouver Island, however, and in the Olympic Mountains, the Crescent formation lies unconformably upon Cretaceous and older rocks (Weaver, 1937, 1945). This relationship is not well established, however, and all that is certain is that in Early (?) and Middle Eocene time a great out-pouring of basic volcanics

occurred, covering effectively the underlying rocks from southern Vancouver Island to the Klamath Mountains. It was upon this basement, and associated with it in part, that the sedimentary rocks of Middle to Late Eocene age began to accumulate in different areas.

In early Late Eocene time, and perhaps earlier, movements along pre-Tertiary structural trends began to uplift portions of the crust, exposing the underlying volcanics in northwest-southeast oriented highs. These movements probably were continuous from Middle Eocene time, although the first evidence of sediments derived from them occur in early Late Eocene. The effect of these movements was relatively minor, and usually of local extent.

Near the close of Eocene time, more significant diastrophic events took place. Further uplift in the Willapa Hills, Doty Uplift, and other northwest-southeast features occurred, as well as positive movement in the Coast Range and Olympic Mountains. Some minor folding of the Eocene sediments also occurred near the uplifts, allowing erosion to strip away part of the section in some areas. Often the effects of these movements were relatively minor. However, in some sections near the structural highs, the marine sediments of Oligocene age lie with considerable unconformity upon the Eocene rocks.

The major structural events that affected the area occurred in Miocene and Pliocene time. In early Miocene, uplift and erosion of Eocene and Oligocene rocks took place.

Lower and Middle Miocene marine sediments lie unconformably upon the Eocene and Oligocene rocks. Further uplift and extensive vulcanism in later Miocene time caused a retreat of marine waters, and the structural pattern presently seen was established. The Miocene deformation occurred from compressive forces acting to fold the sedimentary rocks into a pattern trending northwest-southeast, parallel with the earlier trends. During Late Pliocene time, major tectonic activity occurred in the Cascade Mountain area. This folding and accompanying intrusion brought the Cascade Mountain ranges to their present day configuration and caused further movement along faults as well as more folding within the Tertiary section of western Washington. Down-warping occurred along the Puget-Willamette Trough, the Grays Harbor embayment, and the lower Columbia River valley allowing non-marine sediments to accumulate.

Tectonic activity has continued in the area through Pleistocene time to the present as shown by movement along several active faults, explosive volcanic activity, and evidence of recent uplift in the Coast Range. The present sedimentary province is displaced westward, where sediments are accumulating on the continental shelf and slope that are very similar to those of the Tertiary section on the adjacent land area. The Pleistocene glaciations have altered the pattern of structural development, certainly, but there is no sound evidence that any of the events initiated in early Tertiary time have yet come to an end.

Stratigraphy

General Statement

The stratigraphic sequence of rocks considered in this study consists of about 10,000 feet of clastic sediments with some associated volcanics, and represents approximately 8-12 million years of time (Kulp, 1961), from Middle Eocene to earliest Oligocene. The stratigraphic section consists of rocks exhibiting facies[1] indicative of a wide range of depositional environments. Sedimentary accumulations in deep, offshore waters, shallow marine and neritic areas, estuary and delta environments, and non-marine coastal swamp environments are represented. The present outcrop pattern is the result of middle and late Tertiary tectonic events, and is shown in Figure 3. The present land surface is densely covered with vegetation, dominated by the coniferous forests which are so characteristic of the

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[1]The term "facies" is one that has a long history of diverse usage. Unfortunately, the many different uses, and misuses, reduces its value in conveying the concept for which it was originally coined. Teichert (1956) presents an excellent review of the problem and suggests some practical solutions. When the word "facies" is used in this paper, it refers to the collective assemblage of characteristics that the sedimentary rock possesses. It includes composition, grain size, primary structures, sorting qualities, fossil content, organic matrix, and any other observable feature of the rock. From these facies features the depositional environment may be interpreted. For example, a sample of lignitic-siltstone facies is interpreted as having been deposited in a swamp or estuarine environment. The facies are the observable, unequivocal, aspects of the rock; the depositional environment is the analytical interpretation based upon them.

northwest. These forests, along with the general lack of relief in the area make it difficult to locate outcrops. Stream beds, and railroad and highway cuts provide most of the exposures, but these are not abundant. A description of the rock units within the stratigraphic interval studied follows. Figure 4 shows the relationships of the stratigraphic units from published sources.

Crescent Formation

The Crescent Formation is the name given by Arnold (1906) to the thick sequence of volcanic flows and associated tuffaceous sediments exposed on the north side of the Olympic Mountains at Crescent Point. Some controversy regarding the nomenclature of these volcanics has ensued, and in several reports (Weaver, 1945, and Henrikson, 1956), the name Metchosin Formation (Clapp, 1910) has been applied to volcanic rocks occupying a similar stratigraphic position in other areas. That some question regarding these rocks should arise is not surprising. The entire region, from southern Vancouver Island to the Klamath Mountains, is underlain at the base of the Tertiary section by a thick sequence of volcanic rock which appears to be genetically related over the whole region. Weaver (1944, p. 1407) describes the distribution of the Metchosin volcanics as "one vast lava field extending from Vancouver Island southward to the north slope of the Klamath Mountains and eastward to the present site of the western foothills of the Cascade

Mountains." He indicates that the volume of rock involved is probably greater than that of the Miocene basalts of the Columbia Plateau. Recent workers with the United States Geological Survey (Brown, Gower and Snavely, 1960, 1961; Gower, 1960; Snavely, Brown, Roberts, and Rau, 1958) use the name Crescent Formation for these rocks, and that practice is followed in this study. The thickness of the Crescent Formation is probably quite variable, but in the Willapa Hills it is at least 8000 feet (Henrikson, 1956) and near Lake Crescent, north of the Olympic Mountains, it is in excess of 10,000 feet (Brown, Gower, and Snavely, 1960). The flows within the formation often show pillow structure, indicating submarine extrusions, but part of the volcanic activity was probably subaerial as well.

The Crescent Formation is exposed in numerous localities in western Washington and Oregon. In the Central Coast Range of Oregon, the Siletz River volcanics were named by Snavely and Baldwin (1948) where they crop out in many places along the crest of that anticlinal high. These volcanics are for the most part equivalent in age and origin to the Crescent Formation. In northwestern Oregon, outcrops of Crescent-like volcanics were called the Tillamook volcanic series by Warren and Norbisrath (1946). In Washington, the Crescent Formation forms the bedrock in most of the structurally high areas where the sedimentary cover has been stripped away. The Willapa Hills, the Doty Uplift, and others structurally high areas shown in

Figure 3, illustrate the outcrop distribution.

The age of the Crescent volcanics has been based largely on stratigraphic position, and on a few foraminiferal and molluscan assemblages. The fossils indicate an Early to Middle Eocene age, at least for parts of the Crescent Formation.

Cowlitz Formation

The Cowlitz Formation was named and described by C. E. Weaver (1912). Later, Weaver (1944) designated the type section as that exposed in the banks of Olequa Creek, from the confluence of that stream with the Cowlitz River north to the contact with the overlying Oligocene strata near Winlock. Henrikson (1956), in a study of the Eocene stratigraphy of the area, emended the type section by including the rocks exposed in the bed of Stillwater Creek from 3 miles west of Ryderwood to the point where they overlap Weaver's original section in Olequa Creek. Thus, at the present time, the Cowlitz Formation includes about 8000 feet of rock divided into four members: (1) the Stillwater Creek member, (2) the PeEll volcanics member, (3) the Olequa Creek member, and (4) the Goble volcanics member. The volcanic members are, at best, difficult to recognize as mappable units in the field and are not conspicuously present in the Olequa-Stillwater Creek section. As now defined, the Cowlitz Formation is a very thick and diverse rock unit, and not amenable to mapping except on a very large scale. Snavely et al., (1951)

proposed the names McIntosh, Northcraft and Skookumchuck Formations for the sequence of rocks apparently stratigraphically equivalent to the emended Cowlitz Formation but 15-20 miles to the north of the Stillwater-Olequa Creek section in the Centralia-Chehalis district. In ascending stratigraphic order, the section consists of marine siltstones and sandstones of the McIntosh Formation, volcanic breccias and flows of the Northcraft Formation, and a lignitic siltstone, sandstone and coal sequence in the Skookumchuck Formation. With the possible exception of the volcanic Northcraft Formation, these represent mappable lithologic units of a scale which permit detailed investigation and an understanding of the relationship of depositional environments. The McIntosh Formation corresponds in general to the Stillwater Creek member of Henrikson, although it would also include marine siltstones occurring higher in the Olequa Creek member, the non-marine portion of which corresponds to the Skookumchuck Formation. The relationship of the volcanics in the two areas is not clear, and Henrikson (1956) indicates that the Northcraft volcanics differ petrographically from the PeEll and Goble members of the Cowlitz Formation. There were certainly many centers of volcanic activity in early Tertiary time within the area considered in this study, and lack of continuity over the area of a single, recognizable unit is not surprising. The names McIntosh, Northcraft, and Skookumchuck Formations are used in this study in order

to consider the marine — non-marine phases of deposition more easily, and to maintain consistancy with current work of the United States Geological Survey in the area.

McIntosh Formation

This rock unit was named by Snavely, Rau, Hoover, and Roberts (1951) for good exposures on the south shores of McIntosh Lake and in cuts along State Highway 5H, 3 1/2 miles east of Tenino, Thurston County (Figure 3). A total thickness of about 4000 feet is given for the formation in the type area, with the base not exposed. The rocks consist of dark gray, tuffaceous, massive to fissile, siltstone and sandstone. The beds commonly contain calcareous concretions and lenses. The sandstones are generally poorly sorted, feldspathic or lithic wackes (Williams, Turner and Gilbert, 1954) with basaltic or andesitic fragments the most abundant constituent. They appear to be immature sediments both texturally and compositionally. Fossils of neritic communities are not common in the type area, although foraminiferal assemblages are abundant. East of the type area, the sediments become generally more coarse, and lignitic stringers are present with plant fossils preserved in them. The rocks in the type area generally exhibit facies that indicate deposition at a rapid rate in off-shore, marine waters, without a great deal of high energy sorting action. Further to the west, the lithologies become finer grained and often exhibit fair to good fissility. The formation occurs discontinuously throughout

the study area. In the Black Hills area, Snavely, et al. (1958), have mapped the McIntosh Formation with extensive interbedded basic volcanics in the lower part. Pease and Hoover (1957) recognized two members in the McIntosh Formation in the Doty-Minot Peak area. The lower member in the Chehalis River valley near PeEll consists of sandstone and siltstone, dark in color, poorly sorted, and often showing graded bedding with interbedded basic volcanics. These can be seen to lie directly upon or interbedded with the Crescent Formation and are about 900 feet thick. The upper member consists of dark gray, tuffaceous, somewhat fissile, siltstone with thin interbeds of feldspathic sandstones. The total thickness of the McIntosh Formation in this area is about 2500 feet. Further to the west, in the Willapa River valley near Raymond, less than 1000 feet of McIntosh Formation is present (Rau 1958) and represents the upper member of Pease and Hoover (1957). It rests directly upon Crescent Formation volcanics without the coarse clastic and volcanic transition beds of the lower member which are present near PeEll.

The age of the McIntosh Formation is late Middle to early Late Eocene. This has been established on the basis of many well preserved foraminiferal assemblages (Snavely, et al., 1951 and 1958). Those authors correlate the McIntosh foraminiferal assemblages with the upper Domengene and lower Tejon stages of California. The McIntosh

Formation transgresses time toward the west, where the age of these marine rocks is entirely Late Eocene.

Northcraft Formation

The Northcraft Formation was named by Snavely, et al., (1951) from outcrops of andesitic flows and breccias occurring in the vicinity of Northcraft Mountain, Thurston County (Figure 3). In the type area, these volcanic rocks are about 1000 feet thick and conformably overlie the McIntosh Formation. The formation has not been recognized as such west of the Chehalis River, and a source toward the east is indicated by an increase in the thickness of the flows in that direction. Snavely, et al., (1958) suggest a correlation of the Northcraft Formation with a lower part of the Goble Series (Wilkenson, Lowry, Baldwin, 1946) in northwestern Oregon, and it seems likely that the Goble member of the Cowlitz Formation (Henrikson, 1956), (Goble member of the Skookumchuck Formation of this paper), represents the same lithologic unit.

The age of the Northcraft volcanics, as determined largely by stratigraphic position, is early Late Eocene. Directly overlying the Northcraft Formation, in part unconformably, and in some cases interbedded with the upper portion, are the non-marine rocks of the Skookumchuck Formation.

Skookumchuck Formation

Snavely, Roberts, Hoover and Pease (1951) applied the name Skookumchuck Formation to a series of non-marine sandstones, lignitic siltstones, and coals, with some intertongues of marine siltstone exposed along the Skookumchuck River near Centralia, Washington. The formation has a thickness of 3500 feet in the type area, and crops out in an irregular belt across Chehalis district, in the lower Toutle River valley, along the Cowlitz River and Olequa Creek, and in the PeEll-Doty area (Figure 3). The rocks exhibit sandy, lignitic and coaly facies which indicate deposition in a generally non-marine environment with rapid changes between very high energy and low energy conditions. In part the rocks probably represent a deltaic environment, as indicated by the proximity of marine tongues associated with cross-bedded, fairly well-sorted channel sands and coal, indicative of swamps. Also present are massive sandstone beds, crossbedded in part, and lenticular in shape, which may represent channel mouth bars, or larger offshore bars.

The sandstones, which predominate in the lower and upper most part of the section, are bluish-gray, poor to fairly well-sorted, feldspathic or lithic wackes, with a fairly high percentage of volcanic rock fragments. They are generally friable, with the grains angular to subrounded, and are often carbonaceous and micaceous, which gives the rock a well bedded appearance in some areas. Quartz is not a dominant constituent, although it is present in small percentages (10 - 30%). The siltstones

are generally feldspathic, always carbonaceous, sometimes lignitic and they often contain brackish water molluscan fossils. The color is dark gray to dark brown, depending on the amount of plant detritus present. The lignitic siltstones are often associated with coal seams which range in thickness from one inch to several feet. The coals are often banded, subbituminous in rank, and contain a large amount of recognizable plant remains, including whole logs, leaves, and roots which sometimes are seen in growth position, penetrating the former soil layer beneath the coal.

The non-marine phase of deposition represented by the Skookumchuck Formation is thickest toward the east, and thins rapidly toward the west. In the Chehalis River valley between PeEll and Doty, the Skookumchuck Formation is several hundred feet thick, and contains only small amounts of coal and lignitic siltstone. Massive, bluish-gray to greenish gray sandstone and carbonaceous, micaceous siltstones are the most common lithologic types in that section. Further west, in the Willapa River valley, rocks of the Skookumchuck Formation are absent.

Where the Northcraft Formation does not separate them, the McIntosh and Skookumchuck Formations show an inverse relationship in thickness from east to west. In the eastern part of the study area, deposition in the brackish, non-marine environment of the Skookumchuck Formation began earlier and lasted longer than in the western part, the reverse is true for the McIntosh Formation. From this it is obvious that the two formations are in part genetically related to the same depositional cycle, but represent different environments.

The age of the Skookumchuck Formation is given as Late Eocene, based on limited foraminiferal and macrofaunal evidence (Snavely, et al., 1958). Plant fossils, which at best have been studied only generally, indicate an Eocene, probably Late Eocene, age (Brown, in Snavely, et al., 1951). The Skookumchuck Formation has been correlated with Weaver's original Cowlitz Formation at Olequa Creek, and in this paper is recognized at that locality as equivalent to part of the Olequa Creek member of Henrikson (1956).

In most of the study area, the Skookumchuck Formation is overlain by rocks of the Lincoln Formation. The contact is not conformable and there is some evidence that the Skookumchuck Formation underwent a period of lithification, slight uplift, and, in some areas, erosion before deposition of the Lincoln Formation. In several exposed sections, a thick breccia or conglomerate of volcanic rock fragments and some pebbles of Skookumchuck-like lithology marks the base of the Lincoln Formation. In other sections, the overlying rocks are nearly conformable, but marked by a distinct change in facies. Only in a few places where the contact is exposed is it gradational between the Skookumchuck Formation and the Lincoln Formation, although the length of time involved in the observed unconformity is open to question.

Keasey Formation

Schenck (1927) applied the name Keasey Formation to about 500 feet of dark gray, tuffaceous, marine sediments exposed along Rock Creek for two miles east of Keasey, Columbia County, Oregon. This description has since been emended to include beds stratigraphically higher that crop out farther down Rock Creek (Weaver, 1937; Warren and Norbisrath, 1946). The formation consists of three members, the lower of which represents the original type section. The total thickness of the Keasey Formation is about 2000 feet, and it rests with apparent conformity upon rocks that have been mapped as Cowlitz Formation (Skookumchuck of this paper). The underlying sediments consist of bluish-gray sandstones, lignitic siltstones and gray, micaceous siltstones that are very similar lithologically to the Skookumchuck Formation, except that no coal is present. The upper part of the Skookumchuck beds along Rock Creek are mainly massive to slightly bedded sandstones that appear to grade into the dark, glauconitic, tuffaceous siltstone of the lower member of the Keasey Formation.

The Keasey Formation is exposed in numerous localities in northwest Oregon, but an especially good section is exposed along the Wolf Creek Highway near Sunset Tunnel in Washington County, Oregon. The upper two members are both well exposed in road cuts, although the lower member is not definitely present in this section. For this study, the lower member is of particular interest, and when the

term Keasey Formation is used henceforth, the lower member of the Keasey Formation will be implied. The Keasey Formation has been recognized in Washington State (Rau, 1951; Weaver, 1937), but current workers do not use that designation, referring instead to the Lincoln Formation, which occupies in large part a similar stratigraphic position, and is similar lithologically.

The age of the Keasey Formation is given as Early Oligocene in Schenck's original description, based on foraminiferal and molluscan assemblages which are common throughout the section. Moore and Vokes (1953) give a brief but convincing argument for an earliest Oligocene age for the Keasey Formation (rather than Eocene), although Weaver (1944) and Warren and Norbisrath (1946) indicate the possibility of Late Eocene age for the lower member. That the Keasey Formation is correlative in part with the Lincoln Formation is clear, but the exact time relationship is not yet established.

PART II: STRATIGRAPHIC PALYNOLOGY

General Statement

The zonation of the time-rock column represented by the rock units described in the previous section is a primary objective of this study. For this purpose a total of 120 samples were prepared and examined. Well-preserved plant microfossils in large numbers were present in all but eleven of the samples. Two of the eleven were fairly well sorted sandstones from which the microfossils had been winnowed in the sorting process accompanying deposition. Eight barren samples came from one section located east of Seattle in the foothills of the Cascades. The section consists of the Raging River and Tiger Mountain formations, which are probably partly correlative with the McIntosh and Skookumchuck Formations further south. The sediments were complexly interbedded with volcanic rocks, however, and the lack of plant microfossils in the collected samples is attributed to the effect of high temperatures and the subsequent development of locally degrading conditions. Because of the lack of microfossils, the attempt to include that section in the correlation had to be abandoned. Only one other sample was barren, and that also was associated with a volcanic flow in the lower part of the Stillwater Creek section. The samples that were used came from six separate measured sections in western Washington and Oregon. The location of these sections and the subsequent

correlation between them are described in the following paragraphs.

Studied Sections

The location of the sections is shown in Figure 3, and are described in greater detail in Appendix A.

Stillwater-Olequa Creek Section

This section is exposed in the banks of Stillwater and Olequa Creeks, from three miles west of Ryderwood to one mile south of Winlock, Lewis and Cowlitz Counties, Washington. The total section is 8000 feet thick and consists predominantly of marine siltstone and sandstone of the McIntosh Formation, with increasing amounts of interbedded non-marine siltstone, sandstone, and coal of the Skookumchuck Formation near the top. These beds dip 8-10° east to northeast, strike from N45°W to due north, and are off-lapping by erosion relative to the underlying Crescent Formation. This section is located on the northern flank of the south-eastward plunging Willapa Hills anticline. The rocks range in age from late Middle Eocene to Late Eocene and are overlain by the Oligocene Lincoln Formation which appears unconformable on top of the Eocene sediments. This section has been measured in detail by Henrikson (1956); the upper part, only, by Weaver (1934); and the lower part, only, by Rau (1958).

Willapa River Section

About 1250 feet of gray marine siltstone and sandstone are exposed in the Willapa River stream bed over a distance of three miles, about 10 miles southeast of Raymond, Pacific County, Washington. This represents only the lower portion of the total exposed section which is one of the best Tertiary exposures in the area, ranging from the Upper Eocene McIntosh Formation to the Miocene Astoria Formation. This section is very similar lithologically to the lower part of the Olequa-Stillwater section (McIntosh Formation) but it is greatly shortened. Non-marine rocks of the Skookumchuck Formation are entirely lacking. The rocks dip 10-20° NE and strike about N30°W, and the section is part of the north limb of the Willapa Hills anticline. Rau (1951 and 1958) has studied the section in detail and described the foraminifera.

Chehalis River Section

The Chehalis River section is a composite of several discontinuous outcrops in the vicinity of PeEll, Lewis County, Washington. A total thickness of about 4500 feet is represented, consisting mostly of McIntosh Formation. Near the top, however, beds of lignitic siltstone containing coalified wood and massive bluish-gray sandstone are present, which are assigned to the Skookumchuck Formation. The rocks dip generally north at 5-25°, strike nearly east-west, and are located on the north flank of the Willapa Hills anticline. This section was included within the area studied by Pease and Hoover (1957). The Eocene rocks appear to be conformably overlain by the Lincoln Formation in this section, although there is an abrupt facies change and a coarse clastic basal unit is present.

McIntosh Lake Section

This section is located about 5 miles east of Tenino, Thurston County, Washington, in a road cut along State Highway 5A on the south side of McIntosh Lake. It is part of the composite type section of the McIntosh Formation, and consists of about 300 feet of dark gray, fissile to massive marine siltstone, with interbedded calcareous horizons. The section dips uniformly 12-15° S.E., strikes N40°W, and is located on the northeast flank of the Crawford Mountain anticline which plunges to the southeast. The McIntosh Formation at this locality has been dated as late Middle Eocene, and has been measured in detail by Snavely, et al., (1958). The upper and lower contacts are not exposed at this locality, but nearby, the volcanic rocks of the Northcraft Formation lie directly upon the McIntosh Formation.

Rock Creek Section

The Keasey Formation is exposed in the banks of Rock Creek between Keasey and Vernonia, Columbia County, Oregon. This section is discontinuously exposed and consists of nearly 1000 feet of tuffaceous, gray, marine siltstone with some horizons of calcareous concretions. The locality is on the northeast flank of the Coast Range of Oregon where that structural high plunges toward the north. Several smaller folds complicate the section somewhat, but the deformation is not extensive. The section was originally measured and described by Schenck (1927), and Warren and Norbisrath (1946) discuss it in detail. The age is given as Early Oligocene. The Keasey Formation overlies sandstone and siltstone of the Skookumchuck Formation with an apparently conformable contact. Only the lower member of the Keasey Formation is represented in this section, and the top is not exposed.

The Composite Reference Section

In order to establish a time-stratigraphic reference for the rocks within the area, it is necessary to have a complete rock section which represents all of the time in question. This is the purpose of the composite reference section. An abstract rock column is pieced together from separate outcrops in such a way that any gaps in a given section are filled by rocks from another section. In the area presently being considered, there is no single section which gives a complete record of Middle Eocene through Early Oligocene time, although the 8000 feet of the Olequa-Stillwater section apparently approaches that. It was determined that part of the record was missing in the unconformity at the top of the Skookumchuck Formation in the Olequa-Stillwater section. From field investigations

it was apparent that this same break was present in several sections, and possibly present in others where the contact was concealed. However, in the Rock Creek section, rocks lithologically similar to the Skookumchuck Formation grade without any apparent break into the greenish-gray, glauconitic, tuffaceous siltstones of the lower member of the Keasey Formation. Paleontologic work (Warren and Norbisrath, 1958; Moore and Vokes, 1953), indicates that the Keasey Formation along Rock Creek is older than the type Lincoln Formation, but younger than the Skookumchuck Formation along Olequa Creek. This does not offer conclusive evidence for the placement of the Rock Creek section on the top of the Stillwater-Olequa section in the composite section, but it lends support. A preliminary examination of the plant microfossils showed that the lowermost samples from the Rock Creek section are not only lithologically similar, but also bear a spore - pollen assemblage that is very similar to the Skookumchuck Formation at Olequa-Stillwater section and the Rock Creek section to construct the composite reference section from which the stratigraphic ranges of the plant microfossils could be established. The time represented in this section is from late Middle Eocene to Early Oligocene, although the Eocene-Oligocene boundary is not well established in the area.

Zonation

Qualitative Method

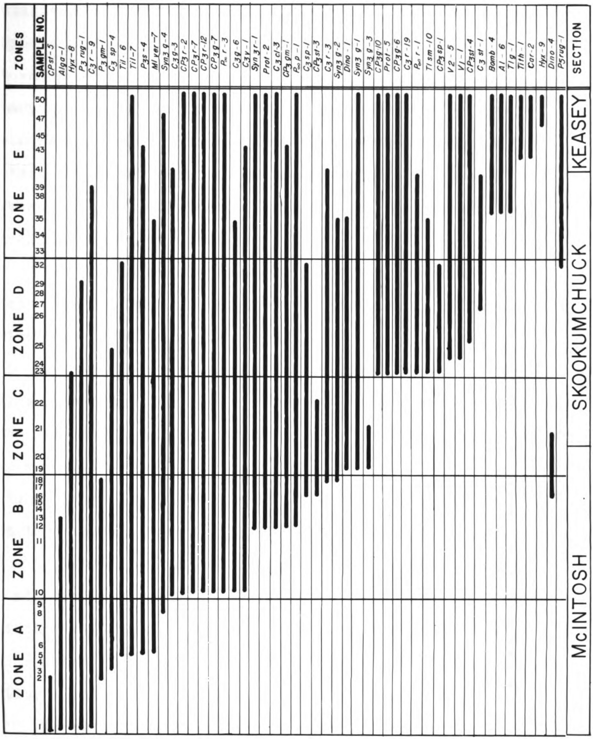
Two fundamental kinds of information are available in the fossil record; one is qualitative, or the kinds of fossils present; the second is quantitative, the number of fossils present, both individuals and species. Both the qualitative and quantitative data may contain significant information, but it is available only if methods can be devised to extract it. The qualitative methods of this paper are entirely empirical. The stratigraphic ranges within the reference section of all of the microfossil classes comprise the data. Of the two possible kinds of stratigraphic distribution, long ranging or limited range, only the second is of stratigraphic value qualitatively. Several factors may contribute singly or through interactions, to limiting of the range of an organism. If the time involved is sufficient, evolutionary processes within a population may lead to the creation of distinct, new forms. Through essentially the same selective processes, established forms may become extinct. Even the most sedentary of biologic organisms may alter their distributional patterns in response to changing environmental conditions, and new forms may occur in a stratigraphic sequence as the result of immigration. Likewise, established forms may emmigrate, with a resulting termination of their fossil record in a given area. The full understanding

and appreciation of all of these factors may eventually lead to establishment of continental or even inter-continental recognition of biostratigraphic age determinations, and that is the ultimate objective of biostratigraphy in general. However, in the present study, considering the state of the art in palynology, the simple recognition of the effect of any of these factors is considered significant. The most conspicuous effects recognized are the first occurrence of new forms and the last occurrence of established types. The latter is generally less reliable than the first occurrence, stratigraphically. Reworking of fossils from older into younger rocks is an occurrence often observed by palynologists. If the time interval represented by the total range of a species is small, that species may become a key form for a particular zone or horizon. Factors such as distinctive morphology, consistency or frequency of occurrence, and extent of dispersal, etc. may increase or decrease the value of a species as a key fossil. By utilizing these empirical relationships, a zonation can be achieved. Of 300 or more entities differentiated during the course of this study, which comprise only those types represented by a significant number of individuals, 53 show a restricted stratigraphic distribution. The remainder are either long ranging forms, or they occur in such a sporadic manner that their range is not reliably indicated. Many more palynomorphs were observed in the samples studied, but they generally were

represented by single specimens and thus lack statistical significance. The placement of zone boundaries, based on the qualitative aspect of the microfloral assemblages, is largely subjective. There is no evidence of large scale changes which are reflected in grossly different palynological assemblages. The changes are rather subtle, producing a gradational sequence of characteristic assemblages with many more species in common than unique. The boundaries were selected where the most conspicuous differences were evident at a midpoint between distinctive floral assemblages, or at the transition zone between them.

Qualitative Results

Five zones are established on the basis of the stratigraphic range of 53 palynomorph species. Those ranges are shown in Figure 5. The chart is arranged according to the position of first occurrence of the palynomorphs in the composite reference section. The zones are designated by letters, starting with the lowermost as zone A. The palynomorph types are listed by code designation. These codes are included with the formal names applied in the systematic section. These forms include pollen of gymnospermous and angiospermous plants, fern spores, and a few dinoflagellates in encysted stages and marine organisms of unknown affinity. The ranges shown here are not intended to indicate the absolute range of the species in time, but the sample size considered in establishing these ranges has been large enough that they may be



STRATIGRAPHIC RANGE OF 53
SELECTED PALYNOMORPH SPECIES
FIGURE 5

utilized with some degree of confidence locally. The 53 species selected represent only a small portion of the total palynomorph content of the rocks studied. Certainly many of the 300 other differentiated forms, as well as others that were not recognized as distinct, do exhibit a distribution in time that is of stratigraphic value. Perhaps further study will allow a more precise and far reaching zonation.

Several characteristic features of each zone are described in the following paragraphs, including the most significant forms of each zone.

Zone A is characterized by the association of P3gm-1, Alga-1, Hyx-8, and C3gm-1. These forms are not restricted to this zone, but they do not appear in the younger zones as a recognizable assemblage. The form CP3st-5 is not found above zone A, and, although it is not a common type, it is a useful key fossil. C3r-9, Til-6, Til-7, P3sm-4, and Syn3g-4, have their first occurrence within zone A. A significant feature of this zone is the lack of many distinctive forms which are present in the younger zones. This negative evidence is not conclusive, but it is useful. Plate 1 illustrates the zone A palynomorphs.

In zone B, sixteen forms occur for the first time. Alga-1 and P3gm-1 disappear in this zone and do not reappear until much later in zone E. The presence of such forms as CP3g-7, P r-3, Syn3r-1, and CP3r-7 in association with P3gm-1 and Alga-1, and the absence of forms from higher zones, characterize zone B. The most characteristic palynomorphs are shown on plate 3.

The first common occurrence of six distinctive palynomorphs, a key form, and the lack of lower and higher forms, characterize zone C. Several appear first in the uppermost part of zone B, but are most characteristic of zone C. P5rug-1, Syn3g-2, Dino-1, and C3r-1 are especially significant in this zone. Hyx-4 has been found only in zone C, and is common in some samples. All of these forms are illustrated on plate 2.

Zone D is the most distinctive of the five zones. Twelve common and distinctive forms appear for the first time and the ranges of six forms terminate in this zone. Also, CP3sp-1, an uncommon but consistently occurring form, is a key fossil. Of particular interest in the recognition of the zone is the absence of Hyx-8, and the first common representation of Tsuga and Picea types. The presence of P_{∞}r-1, C3r-19, CP3st-4, CP3g-6, and Prot-5 are also significant in this zone. Plate 4 illustrates the types of zone D.

Zone E is a very significant time-stratigraphic unit. The ranges of fifteen common forms terminate in this zone, some of which have been important members of the microfloral assemblage throughout the lower part of the section. Six forms appear in abundance for the first time in this zone, including Al-6 and Car-3, both of which are abundant forms in samples from overlying Oligocene rocks that have been

examined, but not included in this study. It is probable that this zone represents the early part of the transition from Eocene to Oligocene microfloral assemblages, and forms such as P3sm-4 and C3sp-4 may be reliable indexes to the Eocene rocks of the area. The microplankton forms Hyx-9 and Tith-1 are conspicuous in the all marine rocks of this zone. Tytthodiscus is a very common element in the Oligocene marine rocks higher in the section as well. Zone E forms are illustrated on plate 5.

Quantitative Method

The quantitative aspects of a fossil floral assemblage (abundance, inverse-positive associations, diversity, etc.) may be of stratigraphic value, especially when the time and area under consideration are fairly limited. The number of individuals of different species (sporophytes) growing within an area is, in a general way, in ecological equilibrium with the environmental forces acting upon them. Changes in the environmental conditions are reflected in the numbers of individuals of different species, as some gain competitive advantage at the expense of others. These changes are also reflected in the microfloral record, since the amount of pollen available for incorporation in sediments as fossils is in large part determined by the abundance of the parent plants in the vegetation. Ideally, the absolute number of individuals of various species of palynomorphs originally deposited in a unit volume of sediment, or per unit area on a depositional surface, is required for stratigraphic evaluation. The absolute abundance of a single palynomorph is not affected by the abundance of others. If a high or low abundance of a particular type is stratigraphically significant, this maximum or minimum will be present in all comparable sediments deposited at the same time, regardless of the numbers of other individuals present. This cannot be realized practically, however, because of the difficulties of sampling an area of a depositional plane, and the lack of information regarding rates of sedimentation. Therefore, relative numbers of palynomorphs present are utilized. The relative abundance of one kind of pollen or spore is a function of how many individuals of other kinds are present. Several factors may contribute to variations in the relative abundance of individuals of different species in a stratigraphic section. Many of these factors may have nothing at all to do with time-related phenomena, but rather may be the result of local variations in pollen output, accumulation, or preservation. In this case, a form which has a constant absolute abundance in the sediment may show wide variation in its relative abundance, because of the increased or decreased abundances of other palynomorphs. Therefore, it is imperative that relative abundance data be carefully analyzed before stratigraphic conclusions are drawn. The data gathered are simple counts of individuals within a population and percentages are computed on the basis of the total count. Often a fixed sum is used. The fixed sum should be sufficiently large that the sample means are reliable estimates of the population means. Another possibility is to count a fixed area of a slide instead of a fixed sum. Both of these techniques are used in this study, but for gathering different kinds of information. A fixed sum count of 200 grains was made, including all plant microfossils arranged into 35 classes. This provides information concerning the most abundant forms represented, which in turn may yield conclusions regarding the distribution of the plants and their environments. A fixed area count was made of ten pollen and spore species to provide stratigraphic information.

If the hypothesis that relative abundance data has time-stratigraphic significance is to be utilized, several assumptions must be accepted. The first is that the plant microfossils contained on a slide are a random sample of the pollen-spore assemblage present at a given stratigraphic level. Second, it is assumed that on a single time plane, the distance between any two samples is small relative to the distance from the source of the pollen and spores. This means that at any given time the distribution of the plant microfossils and their relative abundances are constant over the area under consideration or have a definable gradation in their areal distribution. Sorting action or selective degradation in the sedimentary environment creates variations in the pattern of distribution, but these variables are not random and can usually be compensated for in the final analysis. Third, it is assumed that the ratios among spore and pollen types in a sediment sample reflect specific, although usually unknown, ratios among the sporophytes from which they came. It follows from this that changes in the abundance of pollen and spores reflect changes in the sporophyte population. Fourth, it is assumed that any condition which leads to a change in the abundance of individuals of different species (sporophytes), as that change is reflected in the related abundances of the palynomorphs selected, is operative over a regional extent. This assumption is necessary in order that fluctuations in the abundances of the selected palynomorphs can be interpreted as having correlative stratigraphic value. The conditions which might be effective in this way include climatic shifts, major edaphic alterations, and evolutionary trends.

The validity of these assumptions, and hence the hypothesis, depends on the careful choice of the microfossil types selected for quantitative analysis. It is obvious that the assumptions do not hold if pollen from indigenous swamp plants are included in the count of a coal. Several factors determined the choice of the ten forms counted in this phase of the study: (1) they were long ranging forms; (2) they were common enough that they could be expected to be found in most samples; (3) they were distinctive enough morphologically that no confusion over identification would occur, even at fairly low magnifications of study; and (4) the source of the pollen or spore was removed from the depositional environment. Some control for the determination of the fourth condition was developed by determining the relationship of various palynomorphs to different lithologic types, and the elimination from consideration of those which show a significant correlation with particular lithologies. Also, in the final counts, a continual comparison was made with several attributes of the samples which clearly have environmental significance, such as relative numbers of microplankton and fungi, and the facies of the rock itself. Consideration was also given to pollen and spore types referable to extent genera whose known ecological requirements preclude the reasonable possibility of their growth in proximity to the depositional environment in which these palynomorphs were found. The ten types are: Osmundacites (1 species); Schizeaceous spores (3 species); Podocarpidites (2 species); Pinuspollenites (1 species); Sabalpollenites (1 species); Momipites (2 species); Ilexpollenites (1 species); Pterocaryapollenites (1 species); Proteacidites (1 species); and Ephedripites (1 species). These forms are illustrated on plates 6 and 7. To provide the data on the ten selected classes, the fixed area was the center 18 x 18 mm square of a 22 x 22 mm coverslip. Each occurrence of the ten types within the square was recorded. The total of all pollen and spores, exclusive of microplankton and fungi, was e

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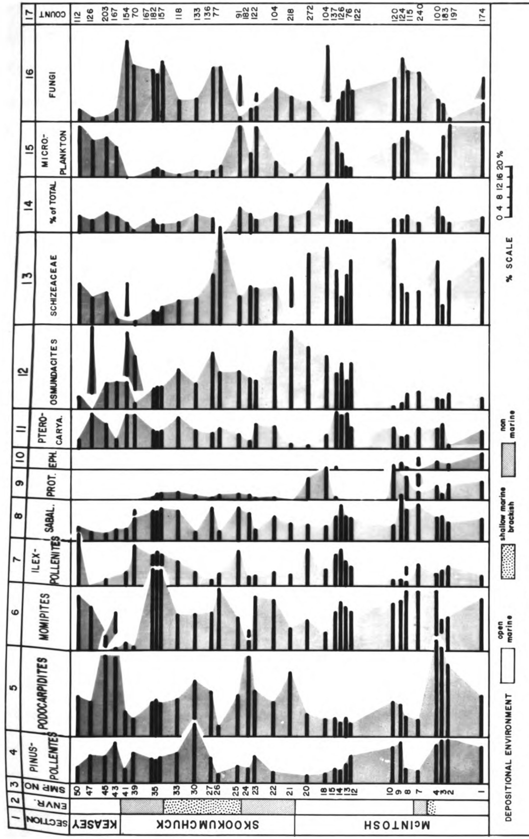
was extrapolated from four random traverses, with all forms counted which could be referred at least to a gross morphological class, such as tricolpate pollen or trilete spore, etc. The relative abundance of the ten types was computed as a percentage of the sum of those ten. The abundance of the ten collectively, relative to all pollen and spores, was computed as a percentage of the extrapolated sum of all palynomorphs on the slide. The figures for the microplankton and fungi were obtained by fixed sum counts of 200 grains and are relative to all other palynomorphs on the slide. The data obtained are discussed in the following section.

Quantitative Results

The quantitative data are shown in Figure 6. The diagram is arranged into 16 columns which contain all of the pertinent information. Column 1 is the composite geologic reference section, showing lithology and the distribution of samples. Column 2 is a representation of the depositional environment as determined from the facies present in the section. It is a very general representation and consists of only three divisions: (1) marine environment at a depth greater than that where breaking waves are dominant energy source; (2) marine environment, but including all nearshore or shoal conditions, some of which may be represented by brackish water; and (3) non-marine environment which may include swamps, freshwater estuaries, parts of delta developments, etc. These interpretations are based entirely



RELATIVE ABUNDANCE - TEN SELECTED TYPES

FIGURE 6

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on the facies present, which include poorly sorted gray siltstone facies; sandy, partly well sorted, carbonaceous, fossiliferous siltstone facies; and lignitic siltstone or coaly facies. Columns 3 through 12 show the relative abundance profiles for the ten selected forms. The abundance of the ten types relative to the sum of all spores and pollen is shown as a curve in column 13. Column 14 shows the abundance of microplankton relative to all palynomorphs. The same is shown for fungi in Column 15. Finally, column 16 shows the sum of the ten types counted.

Initial attention to the diagram should be focused on the effect, or lack of effect, of depositional environment on the abundances of the ten types selected. Three features of the diagram are indicative of the depositional environment. If the profile of column 13 is compared with column 2, it can be seen that the percentage total of the ten types is highest when the sample is from an offshore marine sediment. Likewise the numbers of the ten types are relatively small in nearshore or non-marine samples. This indicates that in the nearshore or onshore area an indigenous plant population deposited greater numbers of pollen than the plants represented by the ten types selected here. This lends support to the assumption that these ten types had a source area more distantly removed from the depositional environment, but it is not conclusive. It appears then, that the relative abundance of the ten taken collectively is, in a general way, indicative of

depositional environment. Also, when column 14, the microplankton profile, is compared with column 2, a striking relationship is seen. The microplankton, being totally indigenous in the marine environment, are very reduced in relative numbers in the samples which are close to a vegetated shoreline. A comparison of the microplankton and fungi curves, columns 14 and 15, shows that an inverse relationship generally holds for these two groups. In this case, the fungal remains are considered indigenous to the non-marine environments and the distributional pattern would be expected to be opposite the microplankton. Columns 2, 13, 14, and 15, therefore, provide a reference to the changing depositional environments, and provide a control to which the relative abundances of the ten selected pollen and spores can be compared. When this comparison is made, it is apparent that the depositional environment exerts little obvious control over the abundance of the ten. At the generalized level at which the depositional environments are considered, the numbers of the ten selected forms relative to one another are independent of depositional environment. There are specific exceptions to the generalization, but these do not invalidate the rule, the exceptions and limitations of the generalization are discussed briefly in a later paragraph.

Another significant feature to note is the distance between samples in the section. Although the time involved is not great, the thickness of the section is.

Thirty two samples were analyzed from the 9,000 feet of composite section for an average of 280 feet between samples. The samples are not evenly distributed, however, and an attempt to provide some control was made. The three samples shown at the 7200 foot level of the section represent a close interval sampling taken as ten inch channel cuts ten feet apart in a continuous outcrop. The very similar values for these samples indicates that the time involved in the deposition of 30 feet of sediment was probably not sufficient for evolutionary of climatic changes of the magnitude necessary to be recognizable in the fossil record. On that basis, the sample interval over the rest of the section is assumed to be adequate for the conclusions that are reached.

Relative abundance profiles may show three major features: first, maximum and minimum values for given species are shown; second, trends within the profile may be indicated, either decreasing or increasing; and third, profiles of different species may exhibit a significant relationship to each other in particular zones or through certain parts of the section. If these features cannot be related to differences in the depositional environments, then they must result largely from the distributional patterns of the plants which produced the pollen and spores, or from error in obtaining the data. The latter has been minimized as much as possible by careful attention to procedures, and it is therefore assumed that the variations in the profiles result from the differences in the composition and distribution of plant communities which produced the pollen and spores. In a previous paragraph it has been argued that the relationship among the members of pollen and spores reflect a specific but unknown relationship among the sporophytes which produced them, and that changes in the percentage relationships of the sporophytes will be reflected by changes in the pollen-spore ratios. Also it is assumed that the relationship among the numbers of spores and pollen is generally constant between two sites on a time plane, provided the distance between the two is small relative to the distance to the source of the pollen and spores, and environmental conditions are not controlling factors. This provides the hypothetical basis by which the fluctuations in the profiles shown in Figure 6 take on meaning in a stratigraphical sense. The maxima and minima, the general trends, and the positive and inverse relationships are the result of dynamic changes within the plant communities that produced the spores and pollen. The changes were effective over fairly broad areas in a short time, geologically, and recognition of the changes in the fossil record provides useful stratigraphic information.

When the information contained in the relative abundance diagram is utilized for correlation, several factors should be considered. First, the absolute values obtained for a specific species is not as important as it's relative valu

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value. That is, a maximum value in a profile is important, but whether the absolute figure is 15% or 50% of the sum is less significant. Likewise, a decreasing trend in the abundance of a species is significant whether the trend is going down from 5% to 1% of the total or from 25% to 15%. Second, the profiles are in no way a continuous log, and analogies drawn between the discrete samples in a section and a continuous profile such as obtained in an electric log are misleading. The lines connecting the bars in the graph are simply the shortest distance between ends. They represent an interpolation of sorts, but the possibility of great quantitative variation in the palynomorphs abundances in the intervals between sampled horizons must be recognized. Third, the quantitative results do not necessarily show any relationship to the qualitative results. The quantitative data may be used to establish an independent part of the zonation, but they are put to use here as correlative points with the qualitative zones.

Correlation of Zones

The extent to which zones established on certain criteria for the reference section may be recognized by those same criteria in other areas is a measure of the stratigraphic usefulness of the zones. In this study, four separate sections were examined and compared with the composite reference section to determine the extent to which these zones could be recognized laterally. These sections have been described previously. In order to

facilitate the comparison of the microfloral assemblages, a qualitative checklist was devised (Figure 7). Some of the palynomorphs selected for the qualitative zonation are shown along the top of the chart, grouped under the zone in which their first occurrence is found. Since many of the species found first in the lower zones have a range which extends into higher zones, the groupings of species are not totally diagnostic assemblages for the zone under which they appear. The zonal groupings shown provide a maximum relative age, i.e. a comparison sample containing species with first occurrences in zones A, B, and C is indicated as being not older than zone C. If species which first appear in zone D or higher are not present in the sample being correlated, a tentative minimum relative age is provided, that is, not younger than zone C. The four sections being correlated with the reference section are shown along the side of the chart. A check mark (X) in the sample column of these other sections indicates the occurrence of the characteristic palynomorph indicated in the zonal groupings.

The quantitative data from the sections to be correlated is shown in Figure 8. Several points should be mentioned regarding these diagrams. First, not all of the profiles show correlative values at the same horizon. This discrepancy may be due either to failure to meet all of the necessary assumptions completely (as discussed previously), or to a difference in the stratigraphic positions of samples for which the interpolation between known values in

ZONE A B C D E

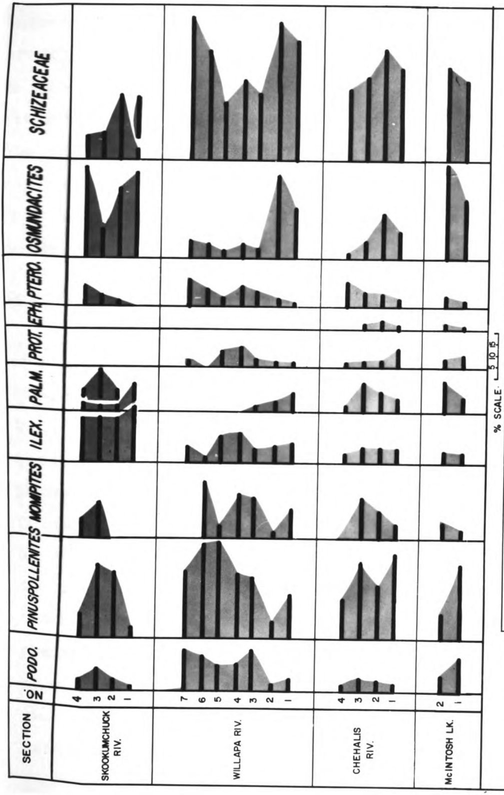
Section & Sample	Code	ALGA-1	HYX-8	Mlver-7	C3so-4	Syn3g-4	P3gm-1	Til-6	Til-7	P3rug-1	C3g-3	C3g-6	C3cl-2	Syn3r-1	CP3r-2	CP3r-7	CP3r-11	CP3r-12	CP3gm-1	P3r-3	CP3g-7
ZONE		A									B										
SKOOKUMCHUCK RIV.	4			X		X		X	X				X			X			X		X
	3				X	X			X				X			X			X		X
	2					X			X		X	X	X	X	X	X	X	X	X	X	X
	1						X			X		X				X			X	X	X
WILLAPA RIVER	7					X			X									X			X
	6					X			X					X				X			X
	5		X	X		X						X		X		X		X	X		
	4		X	X		X			X									X	X		X
	3		X						X					X							X
	2		X	X		X			X	X									X		X
	1		X	X					X	X				X							X
CHEHALIS RIVER	5								X			X	X		X	X	X	X	X	X	X
	4		X	X		X				X	X	X				X			X		X
	3	X		X		X		X			X				X	X			X		X
	2										X			X		X					
	1	X							X							X					
McINTOSH LAKE	2	X	X		X		X	X		X	X										X
	1	X					X			X	X	X									X

Section & Sample	Code	Syn3g-2	Syn3g-3	C3so-3	C3r-1	CP3st-3	P5rug-1	Syn3g-1	Dino-1	Hyx-4	CP3gm-2	C3r-19	CP3ver-2	Cn3st-4	CP3g-10	P r-1	Prot-5	Al-6	V2-5	V1-1	Tlsm-10	CP3g-6	P3gm-1	Car-2	Hyx-9	Tlth-1	Tlg-1	Alga-1a
ZONE		C										D											E					
SKOOKUMCHUCK RIV.	4				X	X	X	X					X		X	X	X	X	X	X		X						
	3	X		X		X						X	X					X	X	X		X						
	2	X		X	X			X				X		X	X				X	X		X						
	1				X	X		X	X																			
WILLAPA RIVER	7	X		X			X					X	X						X		X	X	X	X	X	X	X	X
	6	X		X			X								X											X		X
	5	X																	X			X			X	X	X	X
	4	X					X													X		X						
	3	X	X				X			X												X						
	2	X		X							X			X	X		X					X						
	1								X	X					X	X	X		X	X	X	X						
CHEHALIS RIVER	5	X			X		X		X			X		X	X		X	X	X	X		X			X		X	
	4											X										X	X		X			X
	3								X	X												X						
	2	X										X																
	1																											
McINTOSH LAKE	2																											
	1																											

OCCURRENCE CHECK-LIST OF SELECTED STRATIGRAPHIC TYPES

FIGURE 7

SECTION	%	PODO.	PINUSPOLLENITES		ILEX	PALM					



RELATIVE ABUNDANCE OF TEN SELECTED STRATIGRAPHIC TYPES IN CORRELATED SECTIONS

FIGURE 8

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the reference section is not valid. Both factors probably interact to produce the observed anomalies. The profiles of Ilexpollenites, Palm and to some extent, Momipites, seem to be the least consistent of the ten forms. In a later section it is suggested that these forms may have grown close enough to the swamp environment that they are over-represented there, and thus do not meet the conditions of the assumption that the distance from deposition site to the source is large.

Correlation of the McIntosh Section

The two samples examined from the McIntosh Lake section are from the dark, calcareous, carbonaceous, marine siltstone in the upper part of the McIntosh Formation. Sample 2 is located about 100 feet stratigraphically above Sample 1 and both contain large numbers of palynomorphs. The presence of six types in the two samples that are commonly found in zones A and B (see Figure 7) and the total absence of typical zone C or higher types indicates that the rocks in this section should be correlated with zone B. Quantitatively the two samples are quite similar and are characterized by fairly low Podocarpidites values, significant percentages of Proteacidites, and high values for the two fern groups. Within zone B, these samples seem to match samples 14 and 15 of the reference section most closely.

Correlation of the Skookumchuck Section

The lowermost of the four samples examined from the

Skookumchuck section is correlated with zone C (Figure 7). The three higher samples all contain types indicative of zone D. The quantitative correlations were made as follows:

Sample 1--The very high Osmundacites value, and the low Podocarpidites value indicates a correlation near Sample 21 of the reference section.

Sample 2--This sample also has a high percentage of Osmundacites, but is declining relative to Sample 1, while Podocarpidites is increasing. This pattern, as well as the relative values of the rest of the spectrum correlates with interpolated values between Samples 22 and 23 of the reference.

Sample 3--This fits into the same pattern as 2.

Sample 4--This sample appears to correlate near Samples 26 and 27. The high Osmundacites and low Podocarpidites fit well into the interpolated pattern near those two reference samples.

Correlation of the Willapa River Section

Palynologic assemblages in the lower part of the Willapa River section correlate with assemblages in the upper part of the composite reference section. Of the seven samples analyzed, the lower four samples contain palynomorphs indicative of zone D while the upper three contain typical zone E palynomorphs (Figure 7). The quantitative correlations follow:

Sample 1--The spectrum of this sample is very similar to t

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to that of Sample 25 of the reference section, and probably correlates fairly near that position.

Sample 2--This sample has a lower percentage of Podocarpidites and a greatly increased value for Osmundacites. Considering the rest of the spectrum as well, it correlates near Sample 26 of the reference section.

Sample 3--This sample is similar in many respects to reference Sample 30.

Sample 4--The significant percentage of Protiacidites in this sample, and the relative values of Podocarpidites and Osmundacites, indicate a correlation near reference Samples 30 and 33.

Sample 5--This sample is compared well near Samples 33 and 35 of the reference section. The quantity of Proteacedites present is significant, although not conclusive.

Sample 6--The relative values and trends of this sample spectrum correspond quite closely to reference Sample 35.

Sample 7--This sample possesses a characteristic spectrum that cannot be compared directly with any reference sample in zone E, but it is most comparable to Sample 43.

Correlation of the Chehalis River Section

From the data of Figure 7, Samples 1 and 2 are correlative with zone D of the reference section, and Samples 3 and 4 are correlative with zone E. Within these two zones, the relative abundance spectra of the four samples are compared with the reference section as follows:

Sample 1--The low Podocarpidites value, significant

Proteacidites and moderate Osmundacites correlate with the interpolated values between 25 and 26 of the reference section. The forms Ilexpollenites, Pterocaryapollenites and the Schizeaceous fern spores also show similar relative values.

Sample 2--This spectrum is very similar to sample 26 of the reference section, with Podocarpidites, Proteacidites and Osmundacites present in identical percentages.

Sample 3--This sample appears to correlate near Samples 35 and 39 of the reference section. The absolute values are lower, but the whole spectrum shows a fairly good relative fit with 35.

Sample 4--The very low values for Podocarpidites and Osmundacites, and an exceptionally high value for Pterocaryapollenites indicate a correlation with, or near, Sample 39 of the reference section.

Summary of Palynologic Correlations

Figures 9 and 10 are cross sectional diagrams of the study area. The base of the Lincoln Formation is used as a datum, and thicknesses and distances are drawn to scale. Figure 9 is an east-west cross section including the Stillwater-Olequa section, Chehalis River section, and the Willapa River section. Several features of this diagram are significant:

1. The Skookumchuck Formation thins and finally pinches out towards the west.

2. The Skookumchuck-McIntosh contact transgresses the

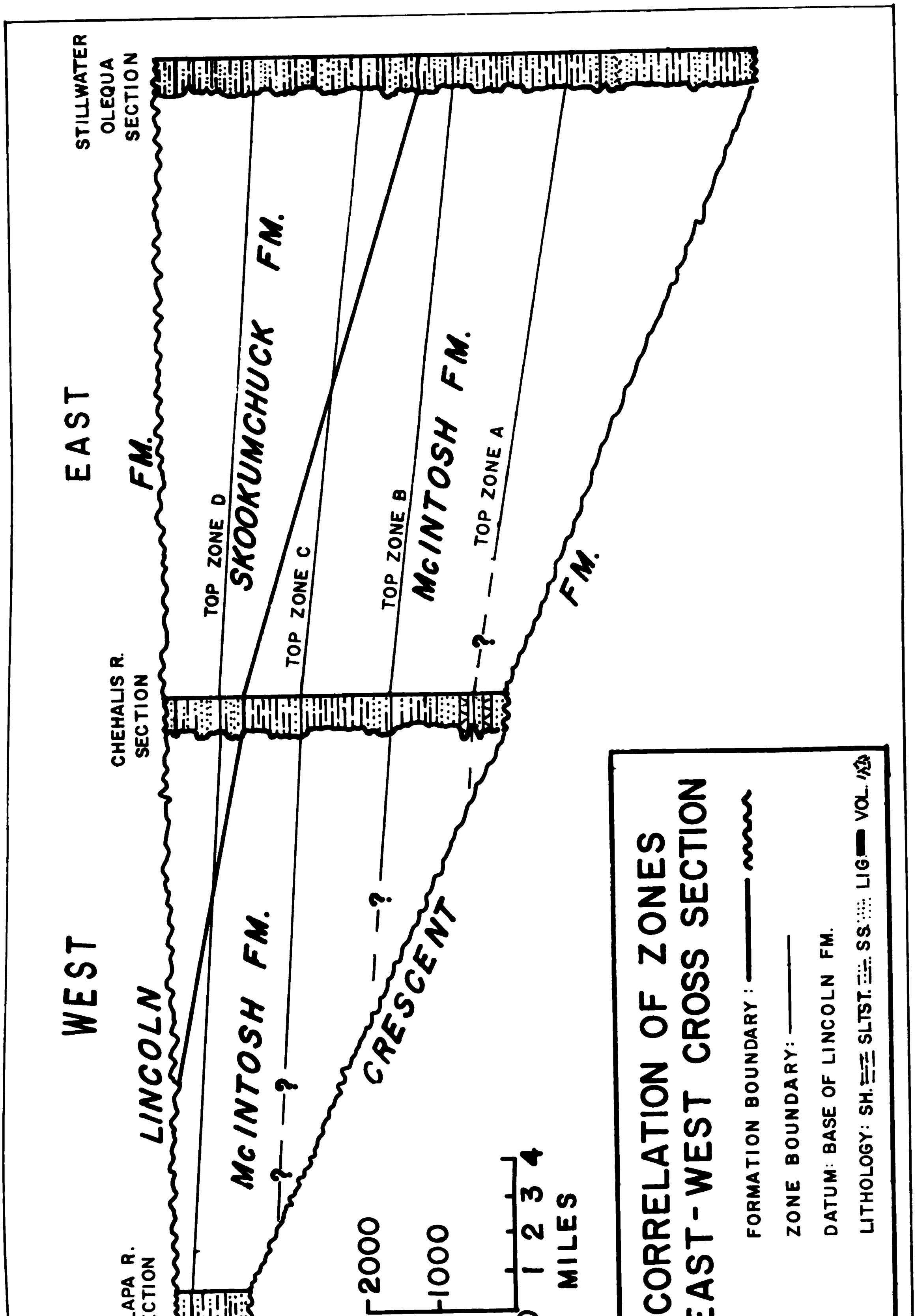
WEST
EAST
WILLAPA R. SECTION
CHEHALIS R. SECTION
STILLWATER OLEQUA SECTION
LINCOLN FM.
SKOOKUMCHUCK FM.
McINTOSH FM.
McINTOSH FM.
CRESCENT FM.
TOP ZONE D
TOP ZONE C
TOP ZONE B
TOP ZONE A
FEET
2000
1000
0 1 2 3 4
MILES
CORRELATION OF ZONES
EAST-WEST CROSS SECTION
FORMATION BOUNDARY :
ZONE BOUNDARY:
DATUM: BASE OF LINCOLN FM.
LITHOLOGY: SH. SLTST. SS. LIG. VOL.

FIGURE 9

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3. The McIntosh Formation is onlapping the Crescent Formation to the west.

From field observations it is possible to observe the thinning of the mostly non-marine rocks of the Skookumchuck Formation westward. A general regressive trend of the marine deposits toward the west is indicated, with a shoreline stand only a few miles from the present day coastline in Late Eocene time. It is possible that the non-marine rocks of the Skookumchuck Formation extend even farther to the west, but have been removed by erosion, although the unconformity in the Willapa River section does not appear to support that idea. The uplifting forces which caused a westward retreat of marine conditions probably continued so that the Eocene sediments were exposed to erosion at the end of Eocene time, thus producing the unconformity below the marine Lincoln Formation. It is also possible that the effects seen in this cross section are fairly local in extent, reflecting the presence of a volcanic high area in the Willapa Hills. The onlap of the McIntosh shows the presence of such a high area, and it was probably the source for many of the sandstones in the McIntosh Formation composed of volcanic rock fragments. The westward displacement of marine conditions seems to have been more general, however. Field data and published reports (Vine, 1962 and Vine, 1963) farther to the north indicate a similar continental overlap by the Puget Group on middle Eocene marine sediments (Raging River Formation).

Figure 10 shows a north-south section including the McIntosh Lake section, the Skookumchuck section, the Stillwater-Olequa section, and the Rock Creek section. Two features are particularly noteworthy in this diagram:

1. The Skookumchuck section is considerably shortened by erosion relative to the Olequa-Stillwater section.

2. The Keasey Formation (lower member) represents at least part of the time represented by the unconformity at the top of the Stillwater-Olequa section.

The upper part of the Skookumchuck section collected in this study lies very near the unconformity below the Lincoln Formation, although the actual contact is not exposed. It appears that considerably more of the Skookumchuck section was removed by erosion than of the Stillwater-Olequa section. About 2,000 feet of mostly non-marine sediments are represented by zones D and E in the latter that are not present in the Skookumchuck section. This represents a significant amount of relief along the unconformity, although only local angular discordance can be seen. This may be related to the volcanic activity which produced the Northcraft Formation and the extensive volcanic terrane of late Eocene age to the east.

To the south, the unconformity seems to disappear, and the boundary between the Skookumchuck and Keasey Formations is indicated by a gradual lithologic change only. This provides a rock record for at least a part of the time involved in the unconformity in other sections.

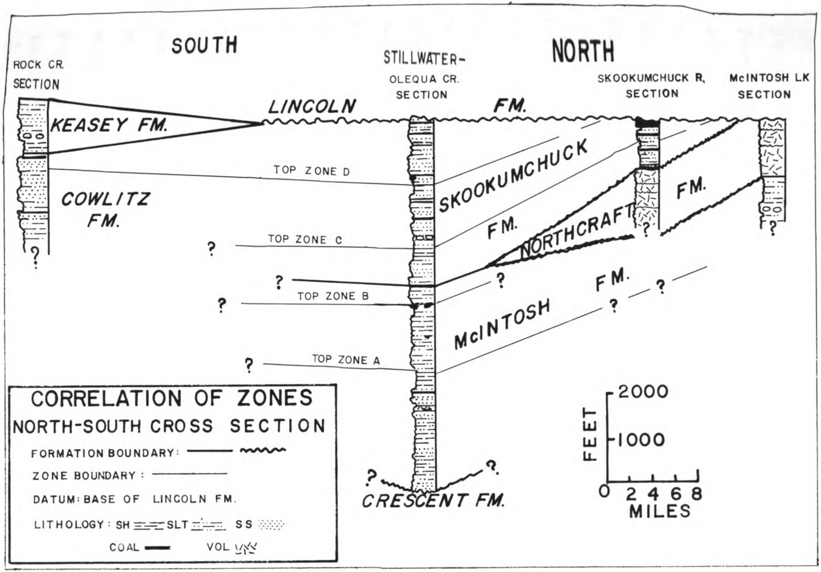

SOUTH
NORTH
ROCK CR. SECTION
STILLWATER-OLEQUA CR. SECTION
SKOOKUMCHUCK R, SECTION
McINTOSH LK SECTION
LINCOLN FM.
KEASEY FM.
COWLITZ FM.
SKOOKUMCHUCK FM.
NORTHCRAFT FM.
McINTOSH FM.
CRESCENT FM.
TOP ZONE D
TOP ZONE C
TOP ZONE B
TOP ZONE A
CORRELATION OF ZONES
NORTH-SOUTH CROSS SECTION
FORMATION BOUNDARY:
ZONE BOUNDARY:
DATUM: BASE OF LINCOLN FM.
LITHOLOGY: SH SLT SS
COAL VOL
FEET
2000
1000
0 2 4 6 8
MILES

FIGURE 10

The Eocene-Oligocene time boundary is not well defined in the region. Most authors agree that the Lincoln Formation is Oligocene, but the lower part may be Upper Eocene on paleontologic evidence (Rau, 1958). The Skookumchuck Formation is well established as Upper Eocene. The Keasey Formation (lower member) is probably Upper Eocene, although it has been called Lower Oligocene (Moore and Vokes, 1953). No evidence of a definable time boundary was found in the palynological record. Many of the species of pollen and spores found have been reported from both Eocene and Oligocene rocks. The literature in Tertiary palynology is not extensive enough at present to permit an accurate evaluation of absolute age relationships of that order. Many of the forms identified may well be index forms for Eocene rocks, but such an assignment at this time would be premature. The best alternative is to depend upon age assignments based on other fossil assemblages. Tschudy (1964) presents a good review of these stratigraphic principles.

The value of palynological analysis is clearly demonstrated in the correlation of marine and non-marine rocks within the cross-sections shown. With study of additional sections, it should be possible to accurately portray the paleogeographic and environmental setting, including the extensive areas of non-marine deposits which extend over the eastern part of the study area and into the Cascade Mountains. Only by the establishment of a relative

chronologic framework can the distribution of facies, and their lateral changes, be fully appreciated.

PART III: FLORAL AND ENVIRONMENTAL SECTION

Introduction

To obtain a better understanding of the composition, distribution, and development of the fossil flora of the earth is a legitimate goal of the palynologist. A contribution to the composition and distribution of the lower Tertiary flora is one of the objectives of this study. Data of this type contribute mainly to the purely botanical aspects of the plants of the Tertiary Period, but they also have stratigraphical significance. If the goal of regional biostratigraphic correlation is to be realized, full appreciation of the past phytogeographical relationships is necessary, especially when dealing with relatively small time-stratigraphic units. A great deal yet needs to be done before any synthesis of data on the Tertiary flora, its composition and distribution, can be accomplished, but progress is being made. Papers by Tschudy (1964) and Schopf (1964) are especially valuable in providing guidelines along which to proceed.

Composition of the Flora

Methods

The data for this portion of the study was obtained at the same time as the stratigraphic data, and is in part the same. The qualitative classification of the pollen and spores present in the samples, and their subsequent naming,

provides the floral data. The procedures followed in nomenclature are discussed in the next section, but several related aspects are pertinent now. It is assumed that pollen or spore morphology is genetically linked with the sporophyte. That is to say, a taxonomic group of plants (sporophytes) can often be recognized by the morphological characters exhibited by their dispersed spores or pollen. The identity often extends only to family level, frequently to generic level, but only seldom to species. It is also assumed that it is perfectly reasonable to recognize the presence of an extant plant taxon in the fossil record on the basis of dispersed spores or pollen, even though the dispersed spores or pollen may possess a different taxonomic name. Further, it is assumed that fossil plants referable to extant taxa possessed ecological requirements that were, in general, similar to those of the modern plant. On the basis of these assumptions, the results shown in the next paragraphs were obtained.

Flora List

Table 1 is a generic plant list for the study area. It is based on assumed affinities of the pollen and spores found in this study, and on the published identifications of isolated leaf floras from the Puget Group (late Middle and Late Eocene), the McIntosh Formation, and the Skookumchuck Formation. The megafloral data comes from Wolfe, et al., (1962); Wolfe (in Vine, 1962); Warren, Norbisrath, and Grivetti (1945); and Brown (in Roberts,

Table 1: Floral List. Includes Sporophytes Inferred From Fossil Spores or Pollen, and Plants Identified From Leaves, Wood, etc. (From Published Sources).

	POLLEN-SPORES	LEAVES, STEM, ETC.
Equisetum		x
Sphagnum	x	
Lycopodium	x	
Selaginella	x	
Isotes	x	
Anemia	x	x
Lygodium	x	
Gleichenia	x	
Cyathea	x	
Hemitelia		x
Allantodiopsis		x
Lastrea		x
Dicksonia	x	
Polypodium	x	x
Asplenium		x
Phyllites		x
Osmunda	x	x
Taxodium	x	x
Metasequoia	x	x
Glyptostrobus	x	x
Podocarpus	x	
Pinus	x	
Abies	x	
Picea	x	
Tsuga	x	
Ephedra	x	
Nymphoides		x
Quercus	x	x
Castanea	x	x
Castaneopsis	?	x
Platanus	x	x
Cercidophyllum		x
Davilla		x
Tetracera		x
Cinnomonum		x
Persia		x
Cryptocarya		x
Octea		x
Laurophyllum		x
Machilus		x
Lindera		x
Litsea		x
Aralia	x	x
Ilex	x	
Euphorbiophyllum		x
Prunus		x
Rhododendron	?	x
Rhus	x	x
Cyrilla	x	
Alangium	x	
Nyssa	x	?
Cornus	x	?
Ulmus	x	
Celtis	x	?
Rhamnus	x	x
Ceanothus		x
Gordonia	x	x
Symplocos	x	
Tilia	x	
Trium felta		x
Ficus		x
Betula	x	
Alnus	x	x
Carpinus	x	
Corylus	x	
Juglans	x	x
Carya	x	x
Engelhardtia	x	x
Pterocarya	x	
Platycarya	x	
"Momipites"	x	
Myrica	x	
Bombax	x	
Proteacidites	x	
Maclintockia		x
Cupania	x	x
Liquidambar	x	
Salix	x	
Fuchsia	x	
Epilobium	x	
Bursera	x	
Sabal	x	x
Viburnum	?	x
Stephania		x
Hyperbaena		x
Pachysandra	x	

1958). The occurrence as pollen-spores, as leaves, or both, is indicated by checks adjacent to the name.

It is by no means a complete list. 100 plant taxa (sporophytes) were tentatively identified from dispersed spores and pollen and appear in the table, but a total of more than 300 entities were differentiated in the course of the study. These 300 must certainly represent but a fraction of the total flora extant within the study area in late Eocene time. The area today supports about 1500 species of higher plants, and cannot be considered as having a "rich" flora. In modern sediments of the area, the pollen and spores of only about 50 of these 1500 can be found with the regularity that 200 or more are found in the late Eocene rocks.

Environmental Indicators in Flora

Tropical - Subtropical Plants

Several of the classes of pollen encountered in the study are inferred to represent extant genera or families whose modern distribution sheds light on the operational environment of the early Tertiary plants of the study area. The most significant of these are several plants which indicate a tropical to subtropical element present in the flora. These include the following:

1. Alangium - This genus is restricted to tropical and subtropical parts of the Old World. It occurs consistently in the samples studied above its first

occurrence in the section although never in abundance.

2. Sapotaceae - Species of this family occur today widely in the tropics and subtropics, extending to southern Florida in this country. The pollen of this family is fairly common in many samples, but is found most frequently in the lignitic siltstone facies.

3. Symplocos - This is a tropical genus of Asia and America. It extends today into southern Mexico where it occupies moist habitats as a tree or shrub. The pollen is uncommon in most of the samples studied, but occurs consistently in the lignitic rocks.

4. Araliaceae - The 65 extant genera of this family are primarily tropical. The Indo-Malaysian region and tropical America are the principal centers of distribution. Some genera are solely or almost entirely climbers; others are trees or shrubs, often restricted to wet habitats. The pollen is never abundant, but occurs commonly throughout the section.

5. Burseraceae - The genera of this family are indigeneous mainly to tropical America. They are large trees or shrubs which often occupy drier habitats. Species of Bursera are found in the Sonoran Desert. The family as a whole, however, is not xerophyteic, and the pollen which is fairly common in many samples is not that of Bursera Odorata.

6. Bombax - This genus is most abundant in the American tropics and is indigenous to either damp or dry

habitats. The pollen is not generally common, but does show some abundance in samples of the carbonaceous, micaceous siltstone facies.

7. Palmae - The palms are pan-tropical, subtropical in distribution. They occur in numerous habitats, today, but the high frequency of palm pollen in some samples of coaly facies suggests the presence of a swamp palm in the study area in early Tertiary time. Sabal is a genus of wet habitats of the Carolina and Florida coasts and may be similar to the one represented by pollen in the samples.

Warm Temperate Plants

Several other genera which are less tropical in distribution, but mostly limited to warm temperate areas are also present;

1. Taxodium - This genus is widely distributed as a swamp tree in the southern United States, and it extends to southern Illinois and Indiana. The Taxodium swamps of the Gulf Coast are well known. The pollen of this genus is common in most samples, but is most abundant in the lignitic and coaly facies.

2. Nyssa - The range of this genus includes the eastern United States and China. It is a warm temperate tree or shrub which occupies wet habitats and is often associated with Taxodium. The pollen of Nyssa is present in almost all samples, but its greatest abundance is in the lignitic siltstones.

3. *Liquidambar* - This is a warm temperate to temperate genus common in eastern United States and Asia. It is frequently found in wet forest habitats throughout its range. The pollen is fairly common in certain samples, and is often associated with *Symplocos* and Sapotaceae pollen.

4. *Engelhardtia* - The range of this genus is mostly in southeast Asia and Malaya, but two species occur in Mexico and Costa Rica. It is a warm temperate or sub-tropical plant of upland or mountainous habitat. Pollen of this genus is common in nearly all samples, but it was lumped with *Momipites* in the fixed sum counts. The *Momipites*-*Engelhardtia* values are, however, largely composed of the latter.

Two fern families that are thought to be represented by spores in the samples are also worthy of mention.

1. Osmundaceae - The genera of this family are mostly tropical, although three species of *Osmunda* extend into temperate America. They occur mostly in wet habitats, and in the temperate zone, as damp forest floor and stream side ferns. The spores of *Osmunda* are very common in the samples studied, and are abundant in some carbonaceous siltstones.

2. Schizeaceae - This is an almost wholly tropical family of terrestrial ferns, with only three species present, and these rarely, in temperate North America. The genera *Anemia* and *Lygodium* seem to be the most commonly represented members of this family, and both of these genera grow in fairly dry habitats. *Lygodium* is a climbing fern.

The spores are common throughout the section, but are reduced in relative numbers in the lignitic and coaly facies.

Temperate Plants

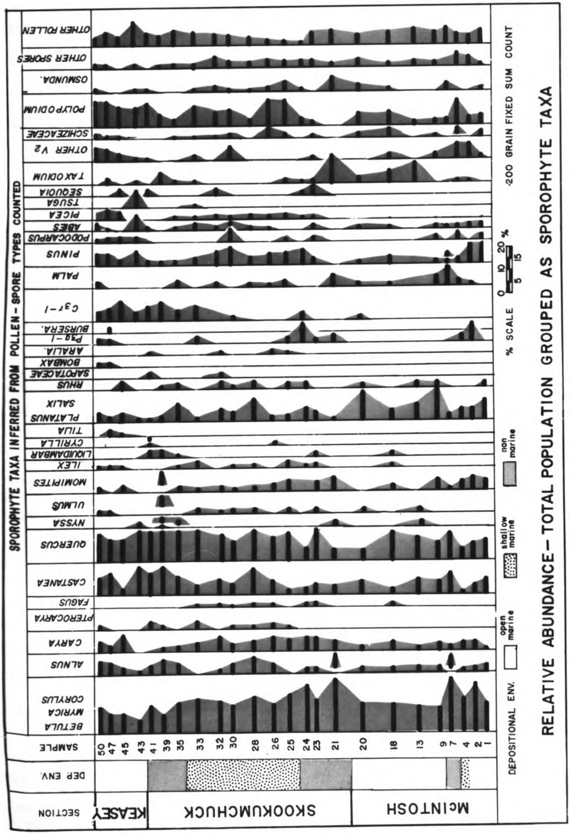
The remaining plant groups represented by pollen, and those that provide the greatest abundance of pollen, are generally temperate in distribution. Most of these, including the Betulaceae, Fagaceae, Juglandaceae, and Ulmaceae, do, however, also have sub-tropical or tropical representatives of considerable importance. Species of both temperate and sub-tropical distribution are probably represented in the microflora. Most of the Coniferales (Abies, Picea, Isuga, Pinus, and Podocarpus) are indicative of a truly temperate element.

Environmental Distribution of the Flora

Relative Abundance Diagram

Figure 11 shows the relative abundance of 43 palynomorph classes which are, for the most part, generic designations. The percentages were obtained by a fixed sum count of 200 grains, exclusive of microplankton and fungi. The right hand column shows the sample distribution from the composite section, and the general lithology for each sample. Although the data consist of relative numbers and are subject to several basic limitations, discussed previously, a careful analysis of the profiles reveals something of the nature of the plant associations which were

SPOROMORPH TAXA INFERRED FROM POLLEN + SPORE TYPES COUNTED



RELATIVE ABUNDANCE – TOTAL POPULATION GROUPED AS SPOROPHYTE TAXA

FIGURE 11

extant at the time of deposition of the sampled sediment. Comparison of particular reconstructed plant associations with the rock facies yields some information about the possible ecologic distribution of the flora. These associations and their distribution are discussed in the following paragraphs.

Ecological Elements Within the Flora

The term "ecological element" is used in this paper to refer to broad groupings of plants growing in the same general habitat. These elements, and their inferred relationship to an ecological gradient (swamp, wet, mesic, dry), are highly speculative and are not intended to represent an ecological analysis in the modern context of that science. Successional development and small scale trends within the ecosystem are beyond the level of this study.

Four separate elements are postulated from the floral data: (1) the swamp element; (2) the wet forest element; (3) the mesic forest element; and (4) the montane forest element. These groupings are based upon significant quantitative relationships within the relative abundance profiles of Figure 11. Several similar ecologic evaluations of palynologic data from Tertiary rocks have provided ideas and guidelines for the identification of the important plant associations (Neuy-Stolz, 1958; Teichmuller, 1958; and Traverse, 1955). An analysis of the modern associations

of plants indicative of specific habitats, can also be useful for interpretation of the fossil record. The floral and vegetational data from modern habitats must be viewed with caution, however, since relatively few studies of microfloral assemblages from specific habitats have been carried out. Many studies of Pleistocene bogs and lakes have been published, and these point out some of the difficulties in reconstructing vegetation from quantitative pollen data (Davis, 1962, 1963).

The swamp element is the only element which is likely to be autochthonous, i.e. growing in, or indigenous, to the depositional environment in which it is found. The other elements are represented in mixed assemblages as part of the allochthonous sedimentary accumulation. With increasing distance from the depositional environment the influence of local plant communities decreases, and the microfossil assemblage becomes a more "average" sample of the entire flora, rather than reflecting a dominance of certain locally important plants. Therefore, attention is centered on those samples of carbonaceous, micaceous, lignitic and coaly facies which are indicative of nearshore or non-marine environments. A good general summary of these principals is presented by Chibrikova (1963).

Swamp Element

Pollen and spores of an indigenous swamp flora are probably widely distributed in the depositional environments

represented in the studied section. The best record of this flora is found, however, in the lignitic and coaly facies. Other floral elements are present in these facies as well, but the dominance of the pollen spectra by certain taxa probably reflects the influence of important members of the swamp flora. A number of different swamp environments are considered together in this analysis, ranging from open water to densely vegetated conditions. The most diagnostic feature from the depositional standpoint, however, is the high concentration of plant detritus relative to the inorganic sediments. It is within that framework that the swamp flora is interpreted. The pollen classes thought to represent Taxodium, Nyssa, Quercus, various triporate grains, probably representing Betula and Myrica in part, and palm show positive abundance relationships at several levels in the reference section (samples 7, 21, and 24). The pairing of peaks in the Taxodium profile with the Nyssa highs, even though Nyssa pollen is not an abundant form, probably indicates the presence of a swamp in which those two genera were important plants. The high quantities of Quercus pollen associated with Taxodium and Nyssa especially in Sample 39, shows that at least one species of that genus was an important constituent. The profile for Quercus shows that it was an important pollen producer at almost all levels in the section, but several species are represented in the counts. Those species probably were distributed in several different habitats, thus accounting for their consistent representation. The high abundance of inferred Betula-Myrica pollen is almost certainly the result of local importance of those trees in proximity to the depositional site. At sample level 7, a high Betula-Myrica value is correlated with an anomalously high percentage of palm pollen. This particular sample is from a 10 inch coal seam located in the lower part of the section. Characteristics of the underlying siltstones indicate that they were deposited in offshore marine conditions. The coal, however, appears to be closely associated with a rather thin basalt flow which thickens abruptly slightly off the line of section. It is postulated that this volcanic unit represents part of a volcanic source area which may have been an island. The coal is separated by about 4,000 feet of marine strata from the next higher non-marine rocks of the Skookumchuck Formation. The depositional environment was certainly non-marine (microplankton) totally absent, and a swamp is a likely interpretation, but Taxodium and Nyssa were not part of the swamp flora. Instead, palm, Betula-Myrica, and other triporate pollen producing plants, and, to some extent, Quercus, were the important plant groups. Neuy-Stolz (1958) describes a similar association from the lower Tertiary brown coals of the Rhine Valley and suggest a possible analogy in some swamps of the east coast of Florida. Fern spores do not play an important role in the swamp microfloral assemblages. Polypodium spores are often common in association with *Taxodium*, *Nyssa*, and *Quercus* assemblages, but their maximum values do not occur in the coaly-lignitic facies.

Wet Forest Element

The habitat of this floral assemblage is probably not often recorded in the sedimentary record, although it must be very closely related to the swamp habitat. The characteristic plants in this group are *Sequoia*, *Liquidambar*, *Carya*, *Rhus*, and *Osmunda*. Also consistently associated with these are members of the families Araliaceae and Sapotaceae. These pollen of these inferred associations are best seen in samples of carbonaceous, micaceous, siltstone facies, as well as being present to some degree in the lignitic coaly facies. Samples 22, 32, and 41 show these relationships. This element is comparable with the "Sequoia Wald" of the German brown coals, (Neuy-Stolz, 1958) although none of the samples studied in this report are thought to be from within the forest itself, as those of the brown coals are supposed to be. This probably results in an admixture of larger numbers of pollen and spores from other parts of the flora, and a less well defined "Sequoia forest" assemblage. Spores of the family Polypodiaceae are often abundant in samples containing a wet forest element, and probably were associated with these plants in life, but were not restricted to that habitat. Sample 24 shows an assemblage

which contains significant amounts of pollen characteristic of both the swamp and wet forest elements, as well as an abundance of Pollenites constans, a pollen of unknown affinity. The facies of Sample 24 is lignitic siltstone, with leaves and stems common, but contains significant numbers of microplankton as well, and it probably represents a depositional area with both swamp and wet forest in close proximity.

Mesic Forest Element

This very broad grouping is comprised of a number of generally temperate plants whose identities are based on pollen types which frequently occur together in the abundance profiles. The most characteristic genera are Ilex, Tilia, Ulmus, Quercus, and Castanea. Also often associated in the counts are members of the Polypodiaceae, Schizeaceae, Sapotaceae, and Bombacaceae. The habitats occupied by this group were probably removed from the depositional sites and the unique identity of this element is not well defined. Those samples of supposed nearshore, environments (especially Samples 23, 25, and 47) which received considerable quantities of allochthonous sediments, probably give the best representation of this element. The association would appear to contain several typically temperate deciduous genera, although the species may well not have been restricted as summer green deciduous trees. A temperate element of the sort described here has been demonstrated in other lower Tertiary microfloral studies

(Sharp, 1951; Gray, 1960; Jones, 1962; Engelhardt, 1964). Common forms of the element are also discussed by Neuy-Stolz (1948) from the Rhine Valley, although that author does not recognize the association as such within the brown coal environment. Pollen of the genera Pinus and Podocarpus are frequently associated with the mesic forest element, and it is possible that these trees occurred within the general habitat area occupied by this element.

Montane Element

This element is postulated to account for the frequent association of the coniferous genera Pinus, Abies, Tsuga and Picea. Pollen of pine and spruce are often ubiquitous in sedimentary environments, but their most significant percentages are in samples which represent offshore marine depositional sites. This element is the most remote from the depositional environment, and consequently very little can be said regarding the nature of the plant association.

One further association must be mentioned. Pollen thought to represent Platanus and Salix are significant contributors to the microflora at several horizons, and are generally abundant throughout the section. These plants probably occupied streamsides and lowland habitats in considerable abundance. Their proximity to the streams probably accounts for the consistent representation in all but the closed swamp environments. Other plants, particularly the ferns, may also have been similarly

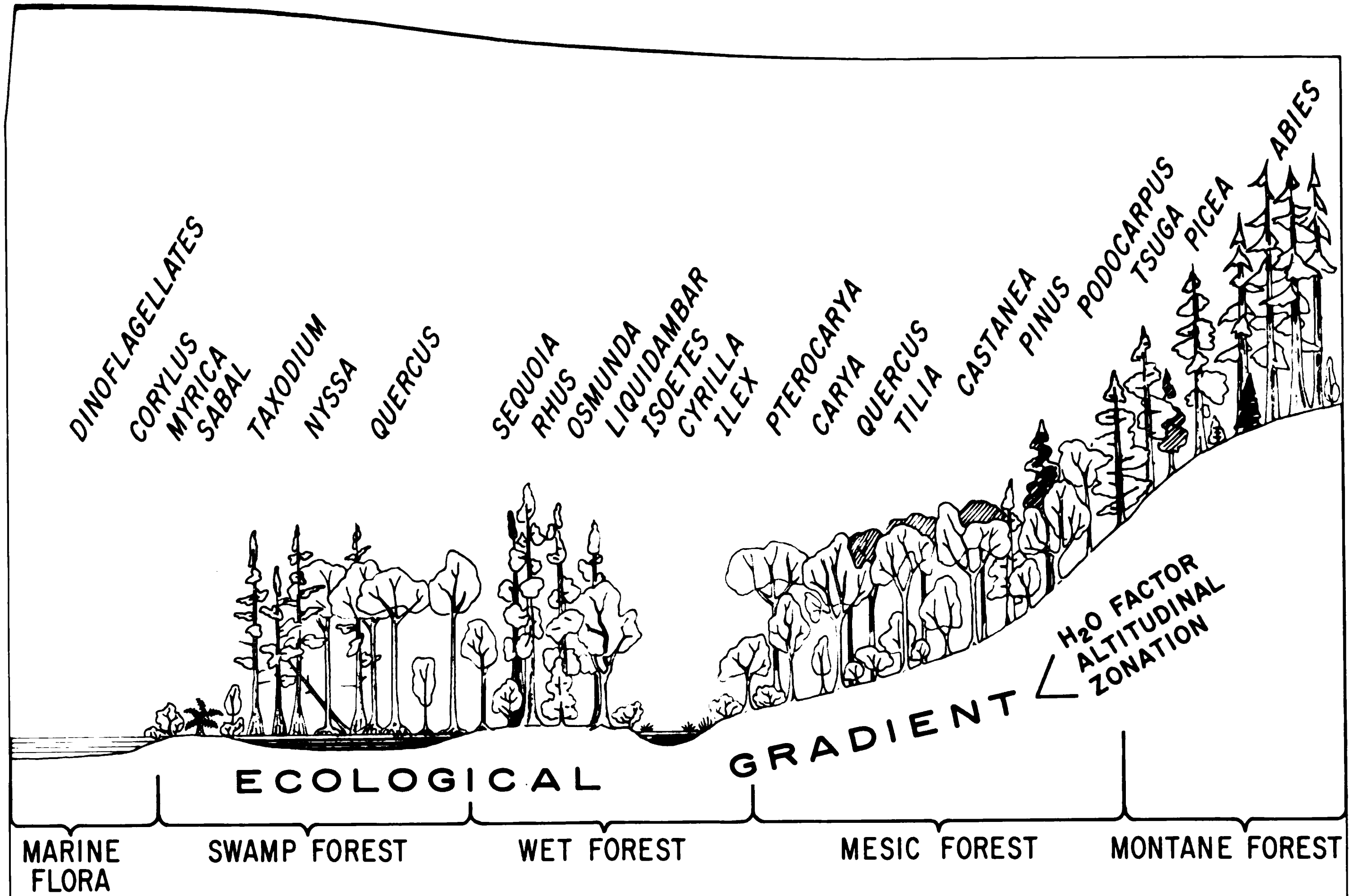
distributed, and their fairly high abundance may be a reflection of the ease with which their spores and pollen were incorporated in the sedimentary load of the streams.

Areal Distribution of the Floral Elements

Figure 12 is an idealized diagram of the study area, showing the postulated floral distribution. The slope represents an ecological gradient in which many environmental factors were operative, but along which water relationships and/or altitudinal effects were dominant factors.

The swamp element probably occupied rather extensive areas of a coastal plain. It represents an area of low relief, near sea-level, and subject to periodic inundation by marine waters as the result of isostatic or eustatic fluctuations. A swamp habitat existed also within the postulated delta complex, occupying interdistributary areas and abandoned channels. This environment is probably represented by some of the lignitic and coaly facies, where channel cuts filled with sand, often containing large logs, are associated with the coals and lignitic horizons.

The wet forest element probably occupied areas adjacent to the swamps. These areas might have included floodplains, large levees in the delta complexes, and more stable areas within the swamps. The pollen of the supposed plants of this element is not abundant, and it may have had a rather restricted distribution in the area.



INFERRED DISTRIBUTION OF MAJOR VEGETATIONAL ASSEMBLEGES

FIGURE 12

Interfingering with these elements was the mesic forest assemblage. It is postulated that this element occupied extensive areas of upland, grading into both the wet forest and the montane habitats. During certain periods of time in the geologic history of the area, this mesic assemblage was probably widespread as either the range of the swamp or montane flora was restricted by tectonic activity.

The distribution of the montane element was probably along the flanks of the early Tertiary counterpart of the Cascade Ranges. The relief in that region is not known, but the degree of orogenic activity described by Misch (1952) probably created mountains of considerable magnitude.

Summary of Environmental Conditions

The composition of the early Tertiary flora within the area, based on the pollen-spore assemblages, indicates a significant subtropical or tropical representation in the flora, as well as major contributions by temperate plants. The frequent occurrence of the subtropical-tropical pollen types in the coaly and lignitic facies, indicates that the plants which produced the pollen were primarily indigenous in the low-lying coastal area. The interfingering of the marine and non-marine rocks in the upper part of the reference section is evidence of a near-shore position and the low relief of the area. To the east, the early Tertiary Cascade Ranges provided a more temperate habitat in an upland or even mountainous area. It is probably most accurate to describe the climate as sub-tropical, with the mountainous areas showing altitudinal zonation comparable to latitudinal belts assigned to the cool temperate or boreal realm (Dansereau, 1957, pp. 101-106). The mountainous regions of Central America might provide an analgous climatic situation. Sharp (1951), Engelhardt (1964) and Gray (1960) have compared the floral assemblages of some Gulf Coast Eocene rocks with that of the eastern slope of the Sierra Madre of Mexico. Many temperate genera are present in the upland areas, coniferous trees are growing in the mountains, and a tropical element occupies the swampy coastline.

Several lines of evidence indicate a wet climate. The presence of extensive swamps indicate a high water table and ample supplies of surface water. The inferred presence of delta complexes, and the massive quantities of allochthonous sediments, some quite coarse, indicate an extensive drainage development. The rivers were probably large and their discharge high in order to accommodate heavy sedimentary loads, perhaps due to high rainfall in the hinterland areas. The early Tertiary Cascades may well have operated as a moisture barrier much as the modern day Cascades do. The pattern of onshore flow of moist air may have been very different from today, but with marine conditions prevailing to the west, and a mountanous region to the east, a very wet belt could be developed.

The marine fauna of the McIntosh and Skookumchuck Formations has been characterized as being sub-tropical (Van Winkle, 1918; Effinger, 1938). Also, Brown (in Roberts, 1958) and Wolfe (1961) indicate a tropical to sub-tropical environment for plant megafossils collected from rocks of the Puget Group to the north and equivalent in age to the Skookumchuck Formation in part. These plants have been listed previously.

The evidence thus suggests that a warm, humid, sub-tropical climate prevailed in southwestern Washington in early Tertiary time. No evidence for a change in that general climate is indicated during Eocene or earliest Oligocene time. Many minor fluctuations must have occurred, but no trend toward the modern wet, cool temperate climate of the area today was seen. The plants of a temperate climate were present in the higher elevations, and with a gradually cooling climate, the distributional range of that element would expand, causing a conspicuous alteration in the pollen abundance relationships. At some higher horizon in the Tertiary section, these changes in the pollen abundance as well as qualitative changes, should be apparent.

PART IV: SUMMARY AND CONCLUSIONS

This study was undertaken to establish a relative chronologic framework for the lower Tertiary sedimentary rocks of western Washington, and to evaluate the composition, distribution, and environmental conditions of the early Tertiary flora. Six outcrop sections were chosen for study, providing a north-south and an east-west cross section of the area. The cross sections intersect at the location of the most complete rock sequence in the area, the Stillwater-Olequa Creeks section. Four of the sections represented type sections of the lithologic units under consideration, and the remaining two had been previously measured in detail.

From the field relationships, and from published data, a composite reference section was established. The Stillwater-Olequa section contains 8,000 feet of Middle and Upper Eocene strata, but an unknown amount of the section is missing at the top as evidenced by the unconformable contact with the overlying Oligocene strata. The lower member of the Keasey Formation provided a rock record for at least part of this gap.

From an analysis of 50 samples in the reference section, 53 stratigraphically limited palynomorphs were found. The vertical distribution of these provides a five part zonation of the refernence section. By comparing the palynological assemblages in the other sections with the reference, a biostratigraphic correlation was achieved.

The Skookumchuck section contained 36 palynomorphs in common with the reference section. The Chehalis River section contained 40 of the 53 stratigraphically significant forms. 39 correlative types occurred in the Willapa River section, and 9 in the McIntosh Lake section.

In addition, ten long ranging palynomorphs were recognized in the reference section whose uniform distribution in all facies indicated that quantitative relationships among them might be of stratigraphic value. Relative abundance profiles for these ten forms were established in the reference section. Individual sample spectra were then compared from the other sections, and correlations made. This provides a further refinement of the correlation within the qualitative zones. Seven of the ten forms showed a distributional pattern that was almost entirely independent of depositional environment. The depositional environment is indicated by the rock facies, the ratio of microplankton to fungal remains, and the ratio of the sum of ten selected forms to all other spores and pollen. The time correlations are shown to cross facies boundaries. In the east-west cross section non-marine rocks in the Stillwater-Olequa section are correlated with marine rocks in the Willapa River section. Coal of the Skookumchuck section correlates with lignitic siltstones in the Stillwater-Olequa section, shown in the north-south cross section.

In all, 112 palynomorph species are identified belonging

to 60 genera in 46 families. These are selected forms and represent only about one third of the total number differentiated in the course of the study. Fourteen of the identified genera or families are today subtropical or tropical in distribution. Twenty taxa are mostly temperate, but with subtropical representatives, and seven are wholly temperate or boreal. A list of 58 taxa based on leaf fossils was made from published data relating to the same general stratigraphic and geographic locality as this study. Almost all of the taxa represented by leaves are tropical-subtropical plants. Twenty three taxa as interpreted by the presence of dispersed spores and pollen presumed to have affinities with those taxa, are present which also are represented by leaves or wood.

The identified forms were grouped into 41 classes and the relative abundances computed by a fixed sum population count of 200 grains. From the abundance profiles of these groups, significant quantitative associations are apparent. By relating the associations with the depositional environment of the samples and to the geologic setting of the area, the distributional patterns of the plant associations was interpreted. Four major forest types were recognized, based on the observed quantitative relationships, the sample facies, and analogous modern plant communities. The four assemblages are swamp forest; wet forest; mesic forest; and montane forest.

From the results of the study summarized in the foregoing

paragraphs, the following conclusions seem justified:

1. The plant microfossils contained in the lower Tertiary rocks of the study area possess qualitative and quantitative characteristics which permit a biostratigraphic zonation to be established.
2. The zonation is laterally correlative in southwest Washington and northwest Oregon, and can probably be extended beyond that region.
3. Depositional environment does not affect the identification of the biostratigraphic zones. This fact suggests the possibility of detailed paleogeographic studies which include the extensive non-marine deposits lying to the east, adjacent to, and within the Cascade Mountains.
4. The McIntosh Formation shows an on-lapping relationship with the Crescent Formation in the east-west cross-section. This indicates that the Willapa Hills structural high was present during late Eocene time, and was probably a source for some of the sediments of the lower part of the McIntosh Formation to the north and east.
5. The Skookumchuck Formation represents a regressive phase of deposition in Late Eocene time. The disappearance of marine conditions was general in the area, and was culminated by uplift and erosion of the underlying sediments. The uplift may have been fairly localized near the volcanic highs, and deposition

seems to have been continuous in some areas (Rock Creek section).

6. Considerable relief exists along the unconformity at the base of the Lincoln Formation. If the correlative time lines within the studied section were extended and used as a datum, a clearer picture of the pre-Lincoln surface could be obtained.

7. The flora occupying the land areas adjacent to the depositional sites was very diverse. The swamps supported forests comparable to the Taxodium Nyssa swamps of southwestern United States, or the open everglades-type vegetation. Wet habitats adjacent to the swamps were occupied by a forest of _Sequoia_, _Quercus_, _Ilex_, Araliaceous plants and others. The drier upland held a forest perhaps in part comparable to that of the southern Appalachian Mountains, with _Tilia_, _Liquidambar_, _Pinus_, _Podocarpus_, _Quercus_, _Juglans_ and many others. The mountainous regions postulated to the east supported a coniferous flora in part, with _Abies_, _Picea_, and _Tsuga_ present.

8. Many plants are represented by leaf or wood fossils which are not represented by pollen or spores, and the reverse is also true. Likewise, a large part of the flora is probably not preserved at all, especially those plants growing outside of the depositional environments.

9. The climate was tropical to subtropical in the lowland,

more temperate in the areas of higher elevation. Water stress was probably not a factor in the environment, with ground and surface water, as well as atmospheric moisture abundant.

10. No significant shift in the climatic conditions is apparent during the time represented in the composite reference section. The beginning of such a shift may be reflected in the uppermost part of the section, however, where the range of the alpine forest element shows signs of expanding as indicated by increased abundance of the pollen of those plants.

11. Further investigation into the Tertiary microfloral record of the area would prove fruitful. The quality and quantity of the plant microfossils, and their demonstrated usefulness in stratigraphy and paleoecology, indicate a high probability of success for such studies.

PART V: SYSTEMATIC SECTION

The purpose of this section is to provide taxonomic names and references for the pollen and spores utilized in the preceding sections of this paper. A rigorous taxonomic treatment is not attempted, and no new names are proposed, although some are altered. The application of published names and their references should provide a means for wider application of the data contained in this paper by other workers, even though there may be disagreement over the validity of the name applied.

Nomenclature

A few comments regarding the names used in this paper are worthy of mention, although the knotty problem of Tertiary palynological nomenclature has been discussed at length by Potonie (1958 and 1960), Traverse (1955, 1956, and 1961), Krutzsch (1959) and many others. First, it is necessary to be aware that of the 300,000 plus described plant species in the world today, practically none possess a morphological description of their pollen or spores as part of the original diagnosis, and the pollen or spores of relatively few taxa have been studied subsequently. This situation is being remedied by the work of Wodehouse, Erdman, Selling, Ikuse, Cookson and Lecompte, to mention only a few workers in modern pollen morphology, but the pace is not rapid. Many hundreds of species of described plants are totally unknown as regards their pollen

morphology, not to mention the number of plants not yet described even as sporophytes. This naturally places a limitation on the degree of confidence with which one may assign fossil pollen to extant taxa. This is not to say that many plant taxa may not have pollen morphological characters which allow them to be identified on that basis alone, but it does mean that the uniqueness of the pollen morphology in many taxa is not established. It follows then, that the assignment of a new species, defined solely on pollen morphology, to an extant genus, may lead to an enlargement of the genus which is unwarranted. It is not reasonable that a new species of modern plant would be adequately described taxonomically by a complete eleucidation of its pollen. As Potonie (1958, p. 38) points out, if a genus is defined by a type species, based on a sporophyte holotype, it is not reasonable to add a new species to that genus which is based on a spore or pollen holotype. The name is a means of referring to a specific category, and the description and classification of that category could well carry whatever information the data reasonably allows as to botanical affinity. In this study, the floral and environmental descriptions have utilized the names of extant plant taxa, but those names have applied to the inferred sporophytes. The sporophytes are an analytical interpretation based on the empirical presence of pollen and spores which are classified by their similarity to their similarity to known forms. This is in no way affected by the valid taxonomic names applied to the specific pollen or spores.

In this study, the validity of the names utilized in publications is not generally challenged, and only slight changes have been made to maintain consistency. The names are based largely on Potonie's work (1960), but other references are utilized as well. Published illustrations and descriptions were used, and no type specimens were examined. The catalog of Fossil Spores and Pollen published by Pennsylvania State University has been helpful in this effort, although original references were available for most species. The descriptions are arranged in a broad morphological form classification following the Turma and Subturma of Potonie. The abundance notations in the descriptions have the following approximate values;

very abundant	$>$ 25 per 1000
abundant	10-25 per 1000
common	5-10 per 1000
uncommon	3- 5 per 1000
rare	$<$ 2 per 1000

<u>Location and Collection Information</u>

Each specimen described carries a reference to a slide and position on the slide. The coordinates are from the stage of a Leitz Ortholux microscope. The latitude coordinate is given, followed by the longitude. Conversion to other stages can be accomplished by reference to one of three index slides marked with an "X". The coordinates of

the index are marked on the slide, and a conversion factor for all readings can be obtained by taking the difference between the corresponding readings on the index slide and those of the new stage. The difference is then added to the coordinates given for a specimen (one may add a negative number in some cases). If the scale direction is opposite on the second microscope an additional negative sign is involved, in which case additions may change to subtractions. Close attention to the signs avoids confusion (Traverse, 1955).

Each slide is complete with a collection and a maceration number. The collection number refers to the section and sample position in the field, the maceration number refers to the laboratory preparation schedule. All rock samples processed in the Michigan State University Palynological Laboratory are prefixed by the letters Pb (Paleobotanical), followed by a number. By reference to the master file, the collection site, age, lithology and preparation procedure for each sample can be obtained. Vials containing the sample residues, and slides of illustrated specimens are on file at Michigan State University.

FERN SPORES

Genus POLYPODIISPORITES Pot., 1934

Polypodiisporites cf. favus Pot., 1934

(Plate 8, Figures 2 and 3)

The comparison with P. favus is close, however, the illustrated form generally possesses slightly larger verrucae. The botanical affinity is probably with the family Polypodiaceae, and this species comprises a large part of the percentages shown under that heading in Figure 11.

Occurrence: Common throughout section, one of the most abundant spores represented.

Location: Pb 3801 5 ; 38.0 x 119.3 (Fig. 2)
Pb 3802 7 ; 38.2 x 120.4 (Fig. 3)

Code: Mlver-4

Polypodiisporites sp. 1

(Plate 1, Figure 1; Plate 8, Figure 1)

The affinity of this species with Polypodiaceae is not certain. The exine is very thick, in some cases, appearing to result from a fusing of distally expanded clavate projections in a tectate fashion.

Occurrence: Generally rare, but most frequent occurrence in Zone A.

Location: Pb 3809 6 ; 45.9 x 124.2 (Pl. 1, Fig. 1)
Pb 3805 5 ; 45.0 x 124.9 (Pl. 8, Fig. 1)

Code: Mlver-7

TRILETE SPORES

Genus LAEVIGATISPORITES Pot., 1931

Laevigatisporites cf. pseudomaximus Pf., in Thom. and Pf., 1953

(Plate 8, Figure 7)

This species bears a close resemblance to Cyathidites australis Couper, 1960, although it is less angular in outline. The botanical affinity may be with the genus Cyathia. The comparison with L. pseudomaximus is very close.

Location: Pb 3883 6 ; 47.8 x 122.8

Code: Tlsm-11

Genus OSMUNDACITES

Osmundacites wellmanii Couper, 1953

(Plate 6, Figure 1; Plate 8, Figure 11)

This species is one of the more common spores in the samples studied. It almost certainly represents the genus Osmunda, and it comprises the total percentages of that type shown in Figure 11. Baculatisporites gemmiculavatus Pot., 1934 is a very similar species.

Occurrence: Common to abundant, ranges throughout the section.

Location: Pb 5622 1 ; 59.0 x 119.0 (Pl. 6, Fig. 1)

Pb 3832 5 ; 35.5 x 118.2 (Pl. 8, Fig. 11)

Code: Tlgm-1

Genus CICATRICOSISPORITES

Cicatricosisporites cicatricosoides Krutzsch, 1959

(Plate 8, Figures 5 and 6)

The botanical affinity of this species is thought to be with the family Schizeaceae, possibly the genus *Anemia*. It comprises a small percentage of the Schizeaceae profile in Figure 11.

Occurrence: Rare, though it occurs consistently throughout the section.

Location: Pb 3811 1 ; 39.0 x 121.9

Code: Tlclc-1

Cicatricosisporites cf. *hallei* Delcourt and Spurmont, 1955

(Plate 6, Figure 6)

This species probably also has affinities with the Schizeaceae. It comprises most of the percentage of that group in Figure 11. The comparison with C. *hallei* is very close, differing only slightly in the size of the ridges on the distal side of the spore.

Occurrence: Generally fairly common, and very consistent throughout the section and in various facies.

Location: Pb 5621 4 ; 43.0 x 115.0

Code: Tlclc-3

Genus TRILITES (Erdman; Cookson) Couper, 1953

Trilites asolidus Krutzsch, 1959

(Plate 6, Figures 2 and 3)

The botanical affinity of this species is probably the family Schizeaceae, and it resembles quite closely spores of the genus *Lygodium*.

Occurrence: Generally common and very consistent throughout the section in various facies.

Location: Pb 3874; 30.6 x 121.6

Code: Tlfos-1

Trilites cf. *paravallatus* Krutzsch, 1959

(Plate 8, Figure 4)

The comparison with T. *paravallatus* is tentative. The botanical affinity is unknown, but it is similar to some Schizeaceae, and it was included in the counts of Figure 11 under that heading.

Occurrence: Rare in the samples studied.

Location: Pb 5617-3; 42.0 x 116.5

Code: Tlfov-1

Genus POLYPODIACEOISPORITES Pot., 1951

Polypodiaceoisporites sp.

(Plate 8, Figures 8 and 9)

The botanical affinity of this species is not known. It compares well with the diagnosis of the genus Polypodiaceoisporites, but shows no close relationship with any described species of the genus.

Occurrence: Rare, occurs sporadically throughout section.

Location: Pb 3843 2 ; 35.5 x 120.7

Code: Tlfos-3

Genus FOVEOTRILETES (van der Hammen) Pot., 1956

Foveotriletes crassifovearis Krutzsch, 1959

(Plate 8, Figure 10)

The botanical affinity of this species is unknown. It may prove to be an excellent marker within the lower Tertiary.

Occurrence: Rare, although it occurs consistently in the upper part of the section.

Location: Pb 3838 6 ; 54.0 x 111.2

Code: Tlfov-2

Genus CONCAVISPORITES
(Thom. and Pf.) Delcourt and Spurmont, 1955

Concavisporites minimodiversus Nagy, 1963

(Plate 8, Figures 12 and 13)

The botanical affinity is unknown. It is included in the percentages of the "other spores" class of Figure 11.

Occurrence: Generally rare, most frequent in upper zones.

Location: Pb 3804 6 ; 43.2 x 110.3

Code: Tlsm-16

Concavisporites minimus Krutzsch, 1952

(Plate 4, Figure 1)

Gleicheniidites apilobatus Brenner is a very similar form. The affinity of this type may be with the family Gleicheniaceae, although it is not certain.

Occurrence: Rare, but it occurs consistently in Zones D and E.

Location: Pb 3883 4 ; 52.2 x 121.4

Code: Tlsm-10

Genus BACULATISPORIS Thom. and Pf., 1953

Baculatisporis cf. baculatus Krutzsch, 1959

(Plate 5, Figure 1)

The botanical affinity of this grain is not known, but it may represent the family Osmundaceae. The comparison with B. baculatus is only tentative.

Occurrence: Rare to fairly common, especially in Zone E.

Location: Pb 3839 1 ; 45.7 x 127.3

Code: Tlg-1

GYMNOSPERMOUS POLLEN

SACCATE POLLEN

Genus ABIETINEAEPOLLENITES Pot., 1951

Abietineaepollenites microalatus (Pot.) Pot., 1951

(Plate 6, Figure 5)

This is the *Pinus hapoxylon*-type of Thiergart. It appears in the percentages of *Pinus*, Figure 11, and was utilized as a stratigraphic form in the abundance counts of Figure 6.

Occurrence: Fairly common throughout the section.

Location: Pb 5618 4 ; 38.2 x 114.1

Code: V2-4

Genus ABIESPOLLENITES Thiergart, 1937

Abiespollenites cf. *absolutus* Thiergart, in Raatz, 1937

(Plate 9, Figures 1, 2 and 3)

The affinity of this species with *Abies* is not certain, but it resembles pollen of that genus closely. The comparison with A. *absolutus* is close, and examination of the type would probably allow reference of the illustrated form to that species.

Occurrence: Rare to common, generally throughout the section.

Location: Pb 3804 6 ; 40.5 x 110.0 (Fig. 1)
Pb 5617 3 ; 49.0 x 125.0 (Fig. 2)
Pb 5618 4 ; 38.2 x 115.7 (Fig. 3)

Code: V2-1

Genus PICEAPOLLENITES Pot., 1931

Piceapollenites sp.

(Plate 4, Figure 2)

This type is very similar to modern Picea pollen. It probably represents more than a single species, but all specimens fall under the generic diagnosis and are distinguished from Abiespollenites by the relatively thin proximal cap, the fine texture of the body ornamentation, and the characteristic attachment of the bladders.

Occurrence: Generally common, especially in and above Zone D.

Location: Pb 3883 4 ; 40.2 x 115.0

Code: V2-5

Genus PODOCARPIDITES (Cookson) Couper, 1953

Podocarpidites sp.

(Plate 6, Figure 4; Plate 9, Figure 4)

The affinity with modern Podocarpus is almost certain for this pollen, although again several species may be represented. This form represents most of the counts shown in the abundance graph of Figure 6 under Podocarpidites.

Occurrence: Rare to common, throughout the section.

Location: Pb 3838 5 ; 52.5 x 123.2 (Pl. 6, Fig. 4)
Pb 3871 1 ; 35.1 x 120.0 (Pl. 9, Fig. 4)

Code: V2-3

NON-SACCATE POLLEN

Genus TAXODIACEAEPOLLENITES Kremp, 1949

Taxodiaceaepollenites hiatus (Pot.) Kremp, 1949

(Plate 9, Figures 6 and 10)

The affinity of this species is thought to be *Taxodium*, although other genera (*Sequoia*, *Metasequoia*, *Cryptomeria*) also have similar pollen. This species comprises most of the percentages shown for *Taxodium* in Figure 11, although some *Sequoia*, etc. may also be included.

Occurrence: Generally common throughout section.

Location: Pb 5616 1 ; 57.9 x 122.5 (Fig. 6)
Pb 3892 3 ; 32.3 x 111.6 (Fig. 10)

Code: Isc-1

Genus TSUGAEPOLLENITES Pot. and Ven, 1934

Tsugaepollenites viridifluminipites (Wodehouse) Thom. and Pf., 1953

(Plate 4, Figure 3; Plate 9, Figure 5)

This species bears a close resemblance to pollen of *Tsuga heterophylla*, although other species of the genus have similar pollen. Only one species was recognized in the samples studied, and this comprises the total count shown in Figure 11.

Occurrence: Rare, but occurs consistently in and above zone D.

Location: Pb 3896 2 ; 45.9 x 126.1 (Pl. 4, Fig. 3)
Pb 3892 1 ; 39.0 x 118.0 (Pl. 9, Fig. 5)

Code: V1-1

Genus SEQUOIAPOLLENITES Thiergart, 1937

Sequoiapollenites sp.

(Plate 9, Figure 9)

The affinity of this pollen with *Sequoia* is not certain. *Metasequoia* has very similar pollen and is represented in fossil floras of the study area by leaves and cones. Specimens of this genus may have been referred to *Taxodiaceaepollenites* if the distinctive recurved papilla was not apparent.

Occurrence: Rare, occurs throughout the section, but is most abundant in some lignitic siltstone facies.

Location: Pb 3872 3 ; 37.5 x 110.4

Code: Isc-2

ANGIOSPERMOUS POLLEN

MONOSULCATE POLLEN

Genus SABALPOLLENITES Thiergart, 1938

Sabalpollenites cf. *convexus* Thiergart, 1938

(Plate 9, Figure 8)

This species represents the palm family, and possibly the genus *Sabal*. The comparison with S. *convexus* is tentative, the illustrated form being somewhat larger, and with a finer reticulum.

Occurrence: Rare to common, throughout section, but with highest frequencies occurring in some coals.

Location: Pb 3873 1 ; 45.3 x 122.8

Code: Slr-1

Genus LILIACIDITES Couper, 1953

Liliacidites intermedius Couper, 1953

(Plate 6, Figure 10)

This species is similar to *Sabalpollenites* cf. *convexus*, but is generally larger and is more coarsely reticulate. The affinity is thought to be with the family Palmae, and may also represent the genus *Sabal*. This species comprises most of the percentage under Palm in Figure 11, and it is included as one of the ten types in the fixed area counts shown on Figure 6.

Occurrence: Rare to common, throughout section, especially common in some coals.

Location: Pb 3872 3 ; 49.0 x 122.0

Code: Slr-2

COLPATE AND COLPORATE POLLEN

Genus CUPULIFEROIPOLLENITES Pot., 1951

Cupuliferoipollenites cf. *pusillus* Pot., 1951

(Plate 10, Figure 7)

Affinity with the family Fagaceae is suggested, particularly the genus *Castanea*. The pore structure is generally well developed and serves to distinguish this type from the similar forms referred to the genus *Castaneoidites*.

Occurrence: Rare to common, but it occurs most frequently in nearshore sediments.

Location: Pb 3828 5 ; 39.6 x 113.8

Code: CP3sc-1

Genus QUEROIDITES Pot., Thom., and Thierg., 1950

Quercoidites *henrici* (Pot.) Pot., Thom., and Thier., 1950

(Plate 3, Figure 2; Plate 9, Figures 7 and 11)

This species is the most abundant single species represented in the samples. Its botanical affinity is almost certainly *Quercus* and it accounts for a large part of the percentages under that class in Figure 11. More than one species of *Quercus* may be represented by this pollen type, but at least one of the possible species grew as a swamp tree. Large numbers of *Quercus*-like pollen have been noted in several other early Tertiary microfloral assemblages (Traverse, 1955; Nuey-Stolz, 1958).

Occurrence: Common to very abundant, especially in some lignite and coal samples.

Location: Pb 3837 6 ; 38.8 x 125.7 (Pl. 3, Fig. 2)

Pb 3892 1 ; 30.0 x 111.5 (Pl. 9, Fig. 11)

Pb 3897 4 ; 36.6 x 118.9 (Pl. 9, Fig. 7)

Code: C3sc-1

Querocoidites sp. 2

(Plate 4, Figure 12)

This species is included in the Quercus percentages of Figure 11, although its contribution is small. The botanical affinity with Quercus is not definite, but the general morphology is suggestive of that genus. In general, the pores are weakly developed, and it may be sometimes confused with Q. henrici.

Occurrence: Generally rare, but very consistent in Zone D.

Location: Pb 3806 2 ; 32.8 x 110.8

Code: CP3v-1

Genus PLATANOIDITES Pot., Thom., and Thierg., 1950

Platanoidites sp.

(Plate 9, Figures 17 and 18)

The botanical affinity of this species is not certain, but it probably is with the genus Platanus, at least in part. Leaves of Platanus are commonly found in equivalent age rocks in the study area.

Occurrence: Common to abundant in many samples, especially in marine sediments, both near and offshore. The very small size of these grains probably accounts in large part for their wide and abundant dispersal.

Location: Pb 3875 4 ; 42.8 x 121.3 (Fig. 17)

Pb 3896 2 ; 42.0 x 108.0 (Fig. 18)

Code: C3r-12

Genus ARALIACEOIPOLLENITES Pot., 1951

Araliaceoipollenites cf. edmundi (Pot.) Pot., 1951

(Plate 10, Figure 10)

The comparison with A. edmundi is very close, although A. euphorii is also similar. This species, together with Tricolporopollenites satzveyensis, comprise the Araliaceae percentages in Figure 11. The species is common in the lower Tertiary of central Europe. Leaves assigned to the genus Aralia have been recorded from the Eocene rocks of the study area, although pollen with affinities to the family have not been commonly recorded in North America. Stanley (1960) illustrates a form similar to this species, and refers to it as Tricolporopollenites problematicus.

Occurrence: Rare to fairly common, consistently occurring in nearshore carbonaceous siltstones.

Location: Pb 5621 4 ; 52.0 x 114.0

Code: CP3fov-1

Genus CASTANEOIDITES Pot., Thom., and Thierg., 1950

Castaneoidites cf. *exactus* Pot., Thom., and Thierg, 1950

(Plate 9, Figure 12)

The comparison with C. *exactus* is very close, and only a slightly larger size keeps it from being referred directly to that species. The botanical affinity of this type appears to be with the family Fagaceae, and possibly the genus Castanea. The species *Castanea* *minutapollenites* Rouse, is a very similar pollen, perhaps identical.

Occurrence: Common to abundant in almost all samples studied, but especially abundant in some samples containing high frequencies of *Quercus*-like pollen.

Location: Pb 3829 5 ; 34.2 x 111.0

Code: C3sm-1

Genus ILEXPOLLENITES Thiergart, 1937

Ilexpollenites *iliacus* (Pot.) Thierg., 1937

(Plate 1, Figure 6; Plate 9, Figure 14)

This species has commonly been recorded from Tertiary deposits in North America and Europe. The botanical affinity appears to be with the genus *Ilex*, and I. *iliacus* contributes a large part of the percentages under *Ilex* in Figure 11.

Occurrence: Common to abundant in nearly all samples studied.

Location: Pb 6320 1 ; 41.3 x 118.0 (Pl. 1, Fig. 6)

Pb 5617 3 ; 50.0 x 118.0 (Pl. 9, Fig. 14)

Code: C3cl-1

Ilexpollenites inaequaliclaviata (Traverse) Pot., 1960

(Plate 6, Figures 8 and 9)

This species is less common than I. iliacus, although it is a major pollen type represented in the section. The botanical affinity is probably with the genus Ilex.

Occurrence: Rare to common, occurs throughout the study section.

Location: Pb 3877 4 ; 29.8 x 114.0

Pb 3883 4 ; 40.7 x 115.7

Code: C3c1-2

Ilexpollenites cf. marginatus (Pot.) Raatz, 1947

(Plate 3, Figure 1)

The figured specimen is a partially broken example of the species which is significantly larger than the other two species of this genus. It is strongly colpate, with no tendency toward pore development as is seen in other species of Ilexpollenites. The colpi are long, and are often seen gaping open. The clavae are generally equal in size, and extend to the colpi margins.

Occurrence: Rare to common, but occurs only in upper part of the section.

Location: Pb 3839 1 ; 37.5 x 128.2

Code: C3c1-3

Ilexpollenites sp.

(Plate 3, Figures 12 and 13)

Some illustrations of I. *iliacus* show a pore structure similar to this grain, but not generally elongated equatorially. The illustrated species is distinctly colporate, although the heavy ornamentation of clavate projections may obscure the aperture structure in many specimens. The affinity with the genus *Ilex* is not certain, although some individuals are included in the counts under that heading.

Occurrence: Rare to common, occurs very consistently in and above Zone B.

Location: Pb 3875 4 ; 38.3 x 120.3

Code: CP3gm-1

Genus TRICOLPITES (Cookson) Couper, 1953

Tricolpites cf. *striatus* Couper, 1954

(Plate 4, Figure 4)

The specimen illustrated shows a fairly close comparison with T. *striatus*. The gross morphology of the grain suggests a possible affinity with the family Aceraceae, although this is not certain. This species is a useful stratigraphic type even though it is not abundant enough to be included in the relative abundance counts.

Occurrence: Rare, but it occurs consistently in small numbers in and above Zone D.

Location: Pb 3805 5 ; 40.3 x 119.7

Code: C3st-1

Tricolpites sp. 1

(Plate 10, Figures 1 and 2)

This species is usually seen in the polar view, with the colpi long and simple, without longitudinal costae. Covering the colpus is an endexinous membrane, generally with a granular texture. The botanical affinity is unknown.

Occurrence: Common in most samples above Zone C, although rare in lignitic and coaly facies.

Location: Pb 3883 4 ; 38.2 x 114.0

Pb 3895 4 ; 32.2 x 111.9

Code: C3r-15

Tricolpites sp. 2

(Plate 2, Figures 4 and 5)

The botanical affinity of this species is not known. It is useful as a stratigraphic form, and is easily recognized by its conspicuously spinate exine.

Occurrence: Rare, although it occurs consistently in Zones B, C, and D.

Location: Pb 3872 3 ; 37.0 x 117.4

Pb 3874 4 ; 34.9 x 128.0

Code: C3sp-3

Tricolpites sp. 3

(Plate 9, Figure 19)

Several species of the genus Protoquercus Bolkhovitina are quite similar to the illustrated form, although the comparative material was not sufficient to allow placing this form with that genus. The botanical affinity is not known, but pollen of some species of modern Platanus is similar. It was included in the Platanus-Salix percentage counts of Figure 11, although it represents only a small portion of that group.

Occurrence: Rare to common, the species ranges throughout section, but its highest frequency occurs in the lignitic siltstone facies.

Location: Pb 3805 5 ; 51.3 x 125.9

Code: C3r-17

Tricolpites sp. 4

(Plate 4, Figures 5 and 6)

The botanical affinity of this species is unknown. Its large size (ca. 35-40) and heavy, reticulate exine make it very conspicuous. Some individuals show a tendency toward a porate condition, and Engelhardt (1964) figures a similar form, referring to it as Tricolporopollenites sp. 4.

Occurrence: Pb 3883 4 ; 40.2 x 124.9 (Fig. 5)

Pb 5616 1 ; 58.7 x 114.8 (Fig. 6)

Code: C3r-19

Genus TRICOLPOPOLLENITES Thom. and Pf., 1953

Tricolpopollenites cf. *retiformis* Pf. and Thom., 1953

(Plate 9, Figures 15 and 16)

This species is included in the counts of *Platanus-Salix* in Figure 11. The affinity with *Salix* is not certain, but the morphology suggests that relationship. The comparison of the illustrated form with T. *retiformis* is close, although the illustrated form has a slightly heavier reticulum.

Occurrence: Rare to common, especially in some marine siltstones in the middle part of the section (Zones C and D).

Location: Pb 3838 4 ; 40.0 x 114.9

Code: C3r-3

Genus RHOIPITES WODE., 1933

Rhoipites cf. *bradleyensis* Wode., 1933

(Plate 10, Figure 9)

The comparison with R. *bradleyensis* is close, although the original illustration is slightly vague. The botanical affinity is thought to be with the genus *Rhus*, family Anacardiaceae. The morphology of *Rhus typhina* pollen is similar.

Occurrence: Rare, occurs sporadically throughout section.

Location: Pb 5621 4 ; 48.9 x 115.0

Code: CP3st-4

Rhoipites pseudocingulum (Pot.) Pot., 1960

(Plate 10, Figures 14 and 16)

This species probably represents the family Anacardiaceae, and possibly the genus Rhus, although that is not certain. Potonie mentions Rhus as the likely affinity in the original description of the species. The species is frequently illustrated in studies of Tertiary microfloral assemblages.

Occurrence: Common in most samples, but the highest frequencies occur in nearshore marine or brackish water environments.

Location: Pb 3802 7 ; 44.5 x 120.8

Pb 3809 6 ; 41.1 x 126.4

Code: CP3sc-2

Rhoipites cf. pseudocingulum forma navicula (Pot.) Pot, 1960

(Plate 10, Figures 12 and 13)

The comparison with R. pseudocingulum forma navicula is tentative. Engelhardt (1964) illustrates a nearly identical form and refers to it as Tricolporopollenites sp. 1. He compares it with Acer mullensis Simpson from the Eocene of Great Britain. The botanical affinity is uncertain, but it is included in the counts of Figure 11 as Rhus, and probably represents the family Anacardiaceae, if not Rhus.

Occurrence: Rare to common, generally throughout the section, although it occurs most frequently in nearshore or brackish environments.

Location: Pb 3872 3 ; 47.8 x 110.1

Pb 3873 1 ; 47.2 x 119.8

Code: Cp3st-2

Rhoipites dolium (Pot.) Pot., 1960

(Plate 4, Figure 8)

Nuey-Stolz (1958) relates this species to the family Theaceae (as Tricolporopollenites dolium Thom. and Pf.). Potonie (1960) indicates that R. dolium is quite similar to R. bradleyi, and probably represents the genus Rhus. The figured specimen compares closely with Potonie's original illustrations, but the affinity with Rhus is not definite. It was not included in the counts of Figure 11 under Rhus.

Occurrence: Rare to common in samples in and above Zone D.

Location: Pb 3809 6 ; 51.8 x 112.2

Code: CP3g-6

Genus CYRILLACEAEPOLLENITES (Murr. and Pf.) Pot., 1960

Cyrillaceaepollenites cf. me gaexactus (Pot.) Pot., 1960

(Plate 11, Figure 11)

The comparison with C. megaexactus appears to be quite close, although the specimen found in this study are frequently slightly larger (25-30). Pollen of Cyrilla has been reported from other lower Tertiary localities, where sometimes it is abundant (Brandon Lignite, Traverse, 1955).

Occurrence: Generally rare in samples studied, except in some lignitic siltstones where it was common.

Location: Pb 6320 2 ; 44.0 x 117.7

Code: CP3sc-12

Genus FAGUSPOLLENITES Raatz, 1937

Faguspollenites cf. *versus* Raatz, 1937

(Plate 11, Figure 7)

The comparison with F. *versus* is tentative. It compares quite closely with modern *Fagus* pollen, and it comprises most of the percentage count under that heading in Figure 11.

Occurrence: Rare, although it occurs consistently throughout the section and is common in some nearshore siltstones.

Location: Pb 3805 6 ; 47.0 x 116.8

Code: CP3sc-7

Faguspollenites sp.

(Plate 11, Figure 3)

This species compares quite closely with some modern *Fagus* pollen (*Fagus sylvatica*). It is present in many samples, but in small numbers. It makes up a small portion of the *Fagus* percentage of Figure 11.

Occurrence: Rare, generally throughout the section.

Location: Pb 3838 6 ; 55.5 x 115.2

Code: CP3g-5

Genus TRICOLPOROPOLLENITES Thom. and Pf., 1953

Tricolporopollenites cf. helmstedtensis Pf. in Thom. and Pf., 1953

(Plate 3, Figure 9)

The comparison with T. helmstedtensis is quite close, although the figured species often has a slightly coarser reticulum in which the lumina are very angular. The botanical affinity is not established. Pflug (1953) indicates that this species is a common lower Tertiary element in Europe.

Occurrence: Rare to common, in and above Zone B, most frequent in Zone C and higher. Occurs consistently in nearly all sample types.

Location: Pb 3806 2 ; 93.5 x 40.5

Code: CP3r-7

Tricolporopollenites satzveyensis Pf., in Thom. and Pf., 1953

(Plate 10, Figure 11)

T. satzveyensis is regarded by Krutzsch (1957) as a key lower Tertiary form in central Europe. It is similar to Araliaceoipollenites edmundi, and may represent the family Araliaceae, although it is not certain. It was counted under the Araliaceae heading in Figure 11, although its contribution is small.

Occurrence: Rare to fairly common, occurs consistantly in samples from nearshore and brackish environments.

Location: Pb 5619 1 ; 57.8 x 114.0

Code: CP3fov-2

Tricolporopollenites cf. *macrodurensis* Pf. and Thom., 1953

(Plate 3, Figure 7)

The comparison with T. *macrodurensis* is quite close, although not certain. The botanical affinity is unknown. Thompson and Pflug (1953) suggest a possible relationship with genus *Parthenocissus*.

Occurrence: Pb 3802 7 ; 34.7 x 119.5

Code: CP3r-11

Tricolporopollenites sp. 1

(Plate 3, Figure 5)

The affinity of this species is unknown. Its small size and distinct reticulate exine may cause it to be confused with Platanus-like pollen if the grain is seen in polar view. In equatorial view, however, the small, round pore is conspicuous.

Occurrence: Rare, although it occurs consistently in and above Zone B, in all facies.

Location: Pb 3877 4 ; 32.1 x 121.4

Code: CP3r-2

Tricolporopollenites sp. 2

(Plate 3, Figure 6)

The botanical affinity of this type is unknown. The coarse reticulum composed of broad lumina and thin, high muri make this a distinctive form.

Occurence: Rare to common, especially in nearshore siltstones in the upper part of section.

Location: Pb 3805 6 ; 44.3 x 120.8

Code: CP3r-12

Tricolporopollenites sp. 3

(Plate 1, Figure 14)

The affinity of this species is not known. Its occurrence is fairly consistent in the lowermost part of the section, but its range is not definitely established. The very characteristic striate exine makes it readily identifiable, even though it is quite small (18-20μ).

Occurrence: Rare, a possible key form for Zone A.

Location: Pb 3828 6 ; 37.5 x 119.4

Code: CP3st-5

Genus ALANGIACEOIPOLLENITES (Traverse, 1955) n. comb.

Type species: Alangiaceoipollenites (as Alangium) barghoornianum (Traverse, 1955, page 65, Figure 12, photo 102; ca. 92) n. comb.

Alangiaceoipollenites barghoornianum (Traverse) n. comb.

(Plate 11, Figure 9)

The affinity of this species with the genus Alangium is almost certain. Specimens of Alangium chinense pollen in the reference collection at Michigan State University are very similar. It is the first known record of this genus in North America outside of the Oligocene Brandon Lignite, studied in detail by Traverse (1955). The family Alangaceae

is today distributed in the tropics and subtropics of the old world.

Occurrence: Rare, although it occurs consistently in and above Zone D, in all facies.

Location: Pb 3805 5 ; 48.2 x 117.3

Code: CP3st-4

Alangiaceoipollenites sp. 1

(Plate 4, Figure 7)

This species is very similar to A. *barghoornianum*, and additional study may show that the two are really only one species. The illustrated specimen shows, however, the finer striate pattern of the exine and the more angular outline. The botanical affinity of this species is probably *Alangium*.

Occurrence: Rare, although fairly consistent in Zone D and above.

Location: Pb 3880 3 ; 43.7 x 124.5

Code: CP3st-5

Alangiaceoipollenites sp. 2

(Plate 3, Figure 11)

This species is very similar to *Pollenites ortholaesus* Pot., and it is clearly distinct from A. *barghoornianum* and A. sp. 1, having less well developed annular structure around the pores, thinner exine, and distinctly foveolate sculpture. The affinity is assumed to be with the family Alangiaceae, although it bears a strong resemblance to pollen of the closely related family, Nyssaceae.

Occurrence: Rare to common, especially in and above Zone B.

Location: Pb 5621 4 ; 40.0 x 126.9

Code: C3g-6

Genus NYSSAPOLLENITES Thierg., 1937

Nyssapollenites accessorius (Pot.) Pot., 1950

(Plate 3, Figure 10; Plate 11, Figure 4)

The botanical affinity appears to be Nyssa. This species comprises the major part of the Nyssa percentages of Figure 11. It frequently occurs in association with Taxodium-like pollen, and is assumed to indicate the presence of Taxodium-Nyssa swamp conditions during the time of deposition of some lignitic siltstones and coals.

Occurrence: Rare to common, occurs consistently in and above Zone B.

Location: Pb 3802 7 ; 39.6 x 114.1 (Pl. 3, Fig. 10)

Pb 3809 6 ; 52.6 x 115.1 (Pl. 11, Fig. 4)

Code: CP3g-7

Nyssapollenites cf. thompsoniana (Traverse) Pot., 1960

(Plate 11, Figure 5)

This comparison is only tentative. This species is very similar to pollen of modern Nyssa, and its botanical affinity is probably with that genus. It is included in counts of that species in Figure 11, although its contribution is small.

Occurrence: Rare, generally throughout the section.

Location: Pb 3841 2 ; 36.9 x 113.9

Code: CP3g-8

Nyssapollenites sp. 1

(Plate 11, Figure 8)

This species is tentatively referred to the genus *Nyssapollenites*. It resembles pollen of some members of the family Theaceae (*Gordonia*), but an affinity with that family is not certain.

Occurrence: Rare, generally throughout the section studied.

Location: Pb 5615 1 ; 51.0 x 111.5

Code: CP3r-13

Nyssapollenites sp. 2

(Plate 11, Figures 1 and 2)

This species is included in the percentages of the *Nyssa* group in Figure 11, although the affinity with that genus is not certain.

Occurrence: Rare, occurs only occasionally in lignitic siltstones in upper part of section.

Location: Pb 5615 1 ; 50.0 x 115.0

Code: CP3g-9

Genus GOTHANIPOLLIS Krutzsch, 1959

Gothanipollis sp.

This species bears some resemblance to specimens of G. *gothani* Krutzsch, although it appears to be distinct from that species. It appears to be a key form for lower Tertiary rocks in North America and Europe. The botanical affinity is unknown.

Occurrence: Rare, although it occurs conspicuously in most samples above Zone A.

Location: Pb 3832 2 ; 46.2 x 113.3

Code: Syn3g-4

Genus CUPANIEIDITES Cookson and Pike, 1954

Cupanieidites cf. *orthoteichus* Cookson and Pike, 1954

(Plate 3, Figure 4)

The figured species compares quite closely to C. *orthoteichus*, although is somewhat larger (ca. 30) and the exine is usually granular. The natural affinity may be with the family Sapindaceae, although that is not certain in this species.

Occurrence: Rare, although it is consistently present in Zones C and D.

Location: Pb 3837 6 ; 44.8 x 127.2

Code: Syn3g-1

Cupanieidites sp. 1

(Plate 3, Figure 8)

No comparative illustrations or descriptions for this species have been found. It appears to be an extremely useful stratigraphic form in the samples studied. The botanical affinity is as yet unknown, but it may well represent the family Sapindaceae, a nearly pan-tropical family.

Occurrence: Rare, but very consistent in Zones C and D.

Location: Pb 3883 6 ; 44.1 x 124.2

Code: Syn3r-1

Genus SYNCOLPORITES van der Hammen, 1954

Syncolporites sp. 1

This species is very distinctive and easily recognizable. The botanical affinity is unknown, and no similar forms have been illustrated from other Tertiary localities as far as is known. The species is characterized by the presence of a compound colpus, united at both poles (syncolpate) and enclosing an island at the poles. This island extends to the equatorial area, where it is interrupted by the pore structure. The grains are nearly always seen in polar view, and the pore is only rarely observed.

Occurrence: Rare, occurs very consistently, however, in and above Zone C.

Location: Pb 3803 5 ; 48.0 x 121.1

Code: Syn3g-2

Syncolporites sp. 2

(Plate 2, Figure 2)

This species appears to be closely related to Syncolporites sp. 1, differing only in that the colpi do not actually extend over both poles. The botanical affinity is not known.

Occurrence: Rare, appears to be a key form for Zone C.

Location: Pb 3839 5 ; 45.2 x 112.4

Code: Syn3g-2a

Genus SYMPLOCOIPOLLENITES Pot., 1951

Symplocoipollenites vestibulum (Pot.) Pot., 1951

(Plate 3, Figure 14; Plate 11, Figure 6)

This species has been frequently recorded Tertiary deposits of Europe and North America. The botanical affinity is thought to be with the genus Symplocos, a tropical to subtropical genus of wide distribution.

Occurrence: Rare to common, occurs consistently in samples from Zone C and above.

Location: Pb 3840 6 ; 54.0 x 117.6 (Pl. 3, Fig. 14)

Pb 3836 5 ; 41.6 x 113.0 (Pl. 11, Fig. 6)

Code: C3rug-1

Symplocoipollenites sp. 1

(Plate 4, Figure 10)

This species is vaguely similar to *Symplocos jacksonia* Traverse, described from the Oligocene Brandon Lignite. Its botanical affinity is very likely with the family Symplocaceae, although its generic reference to *Symplocos* is not certain.

Occurrence: Rare, although it occurs consistently in Zone D.

Location: Pb 5617 3 ; 49.7 x 126.8

Code: Prot-5

Symplocoipollenites sp. 2

(Plate 2, Figures 8, 9 and 10)

The assignment of this species to *Symplocoipollenites* is tentative. Krutzsch (1957) illustrates a similar type which he calls the "gesperlte vestibuloide formen," and indicates that the probable affinity is with the Symplocaceae.

Occurrence: Rare, although it occurs consistently in samples in Zone B and above.

Location: Pb 5621 4 ; 37.0 x 117.9 (Fig. 8)

Pb 3876 4 ; 48.4 x 110.9 (Figs. 9 & 10)

Code: CP3sp-4

Genus SAPOTACEOIDAEPOLLENITES Pot., Thom., and Thier., 1950

Sapotaceoidaepollenites cf. sapatoides (Tom. and Pf.) Pot., 1960

(Plate 11, Figures 11, 12 and 13)

The comparison with S. sapatoides is quite close, although in some examples (Figures 11 and 12) the pores appear more silt-like. This species is almost certainly related to the family Sapotaceae, but the generic affinity is not known. The Sapotaceae is a nearly pan-tropical family today with a distribution reaching highest latitudes in North America.

Occurrence: Rare, occurs consistently throughout the section.

Location: Pb 6320 2 ; 44.0 x 117.7
Pb 3805 5 ; 56.1 x 126.4
Pb 3873 1 ; 50.5 x 120.5

Code: CP4sc-1

Genus BETULACEOIPOLLENITES Pot., 1951

Betulaceoipollenites bituitus (Pot.) Pot., 1951

(Plate 12, Figures 3 and 4)

The morphology is very similar to that of the genus Betula, and this species was included in counts of that group in Figure 11. The family Betulaceae is, however, a difficult one to divide on the basis of pollen morphology alone, and the genus Betula is only a suggested affinity here.

Occurrence: Common to abundant, especially abundant in some lignitic siltstone samples.

Location: Pb 3875 4 ; 47.8 x 121.0

Pb 3809 6 ; 48.4 x 110.6

Code: P3sm-2

Genus TRIVESTIBULOPOLLENITES (Pf.) Thom. and Pf., 1953

Trivestibulopollenites cf. salebrosus Pf., 1953

(Plate 10, Figure 6)

The comparison with T. salebrosus is only tentative. The figured species is very similar to some members of the family Burseraceae, and in Figure 11 this type is shown as a percentage under that heading. The family Burseraceae is mainly subtropical in distribution.

Occurrence: Rare, although it occurs with great consistancy throughout the section, reaching its highest abundances in marine sediments.

Location: Pb 3840 6 ; 39.0 x 121.0

Code: P3st-1

Genus INTRATRIPOROPOLLENITES Thom. and Pf., 1953

Intratriporopollenites rizophorus (Pot.)

(Plate 1, Figures 7 and 8)

The figured specimens match very closely illustrations of this species from Eocene brown coals in Germany. Krutzsch (1957) indicates that it is a typical lower Tertiary form. Pflug, in his recombination of the species, indicates that it may be related to the family Malvaceae.

Occurrence: Rare, occurs consistently only in the lower part of the section.

Location: Pb 3830 6 ; 47.0 x 110.5 (Fig. 7)

Pb 3867 5 ; 43.0 x 125.9 (Fig. 8)

Code: C3sp-4

Genus SUBTRIPOROPOLLENITES Pf. and Thom., 1953

Subtriporopollenites cf. constans Pf., 1953, in Thom. and Pf., 1953

(Plate 10, Figure 5)

The botanical affinity of this species is unknown. Pflug (1953) suggests a possible relationship with the Myricaceae, but many of the several hundred species of this large family have not studied as regards their pollen morphology, and the suggested affinity must be considered very tentative. The comparison with S. constans is very close, and Krutzsch (1957) indicates that it is a common type in the Tertiary of Europe. It is shown on Figure 11 as Pollenites constans.

Occurrence: Generally common, but becoming rare near top of section. The highest frequencies of this species occur in some lignitic siltstones of apparent estuary or lagoon environment.

Location: Pb 5622 - 1 ; 49.0 x 120.0

Code: C3g-1

Genus TRIATRIOPOLLENITES (Pf.) Thom. and Pf., 1953

Triatriopollenites rurensis Thom. and Pf., 1953

(Plate 12, Figure 2)

This species matches Myricipites dubius Wode. quite closely, and an affinity with the family Myricaceae is probable. The percentages of this species are shown in Figure 11 combined with pollen of other Myricaceous and Betuloid types, including also Corylus-like pollen.

Occurrence: Common, especially in association with Betula-like pollen in some coals and lignitic siltstones. The species occurs throughout the section.

Location: Pb 3883 4 ; 34.8 x 111.8

Code: P3sm-4

Genus MOMIPITES Wode., 1933

Momipites coryloides Wode., 1933

(Plate 6, Figure 7; Plate 12, Figure 9)

The percentages of Momipites shown in Figure 6 are combined values including pollen of Engelhardtia-type. The affinity of the species figured is not known for certain, but the morphology is similar to the pollen of Momisia of the family Ulmaceae. Figure 9, on plate 12, shows a slight tendency toward thickening of an annular area around the pores that is not present in pollen of Momisia, however.

Occurrence: Rare to common, throughout entire section, but the highest frequency occurs in carbonaceous siltstones of a nearshore marine environment.

Location: Pb 3877 4 ; 29.8 x 114.0 (Pl. 6, Fig. 7)

Pb 3832 5 ; 46.2 x 125.0 (Pl. 12, Fig. 9)

Code: P3sm-8

Genus ENGELHARDTIOIDITES Pot., Thom., and Thier., 1950

Engelhardtioidites microcoryphaeus (Pot.) Pot., 1950

(Plate 12, Figure 5)

This species is nearly identical to pollen of the genus *Platycarya* of the family Juglandaceae. It is commonly figured and referred to by that name in many reports dealing with Tertiary palynology.

Occurrence: Generally rare, but distributed consistently throughout the entire section.

Location: Pb 3895 4 ; 38.1 x 115.2

Code: P3sm-6

Engelhardioidites (as *Pollenites*) *quietus*
(Pot., 1933, p. 556, Figure 13;
Pot., 1934, p. 83, Plate 4, Figures 18 and 21) n. comb.

(Plate 12, Figure 10)

This species is here placed in the genus *Engelhardtioidites* in order to have a clear distinction between the small triatriate pollen grains with the characteristic grooves of the *Platycarya* type, and the entirely smooth grains of the *Engelhardtia* type. The species names *microcoryphaeus* and *quietus* were applied by Potonie (1931) to species of the large form genus *Pollenites*, and his original illustrations show the distinctive features mentioned. E. *quietus* is very similar

to pollen of *Engelhardtia*, and both E. *quietus* and E. *microcoryphaeus* probably are representatives of the family Juglandaceae, if not the genera *Platycarya* and *Engelhardtia*.

Occurrence: Generally rare, but very consistent throughout the section.

Location: Pb 3836 1 ; 91.1 x 33.0

Code: P3sm-9

Genus MYRICACEOIPOLLENITES Pot., 1951

Myricaceoipollenites cf. *megagranifer* (Pot.) Pot., 1951

(Plate 12, Figure 1)

The comparison with M. *megagranifer* is quite close, although the pores of the figured species appear to be slightly larger, and with a somewhat heavier annular thickening. The species probably has affinities with the family Myricaceae, and the morphology suggests a possible relationship with the genus *Myrica*. This species is combined with other Myricaceous and Betuloid types in the counts of Figure 11, and its contribution is relatively large.

Occurrence: Common to abundant, especially in lignitic and coaly facies throughout the section.

Location: Pb 6320 2 ; 49.8 x 113.0

Code: P3sm-2a

Genus TILIAPOLLENITES (Pot.) Pot. and Ven., 1934

Tiliapollenites instructus (Pot.) Pot. and Ven., 1934

(Plate 10, Figure 4)

The botanical affinity of this species is almost certainly with the genus *Tilia*, and it is frequently recorded from Tertiary deposits. This species is combined with other *Tilia*-like pollen types in the counts of Figure 11, but T. *instructus* comprises the bulk of the percentages shown.

Occurrence: Rare to fairly common, the species occurs consistently throughout the section.

Location: Pb 3837 1 ; 44.5 x 121.2

Code: Til-2

Tiliapollenites indubitabilis (Pot.) Pot. and Ven., 1934

(Plate 1, Figure 2)

This is a smaller species of *Tilia*-like pollen, and the affinity with the genus *Tilia* is not certain, although it certainly is related to the family Tiliaceae. Its contribution to the *Tilia* percentages on Figure 11 is relatively small.

Occurrence: Rare to fairly common, with the highest frequencies occurring in Zone A.

Location: Pb 3875 4 ; 39.0 x 121.0

Code: Til-7

Tiliapollenites (as Tilia) crassipites
(Wodehouse, 1933, page 510, Figure 48) n. comb.

(Plate 1, Figure 3)

This species, described by Wodehouse from the Green River formation, is probably related to the family Tiliaceae, but its affinity with the genus Tilia is not certain. Its coarse, even reticulum, and its relatively open apertures distinguish it from the other species of Tiliapollenites illustrated in this study.

Occurrence: Generally rare, restricted to lower half of section (Zones A and B).

Location: Pb 3875 - 1 ; 36.4 x 126.0

Code: Til-6

Genus PISTILLIPOLLENITES Rouse, 1962

Pistillipollenites mcgregorii Rouse, 1962

(Plate 1, Figure 4; Plate 5, Figures 2 and 3)

The botanical affinity of this species is not known for certain, although Rouse suggests a possible affinity with the genus Rusbyanthus, a genus of the family Gentianaceae. The size of the body and the club-shaped ornamental elements is quite variable, as is the number and distribution of the elements over the surface of the grain. The apertures appear to be short colpi with a raised margin surrounding them, the margin sometimes being covered with the pistilate projections.

Occurrence: Rare to common, the species is present in the lower and uppermost part of the section, but is absent

in the middle portion (Zones C and D).

Location: Pb 3831 6 ; 39.5 x 123.9

Pb 3867 5 ; 43.0 x 125.9

Pb 3811 1 ; 51.0 x 117.7

Code: P3gm-1

Genus BOMBACACIPITES Anderson, 1960

Bombacacipites cf. *nacimientoensis* Anderson, 1960

(Plate 10, Figure 8)

The comparison with this species is tentative. The botanical affinity of the illustrated form is thought to be with the family Bombacaceae, although the relationship is not certain. Other bombacaceous-like pollen is included in the percentages of the *Bombax* group in Figure 11, but this species is the dominant type.

Occurrence: Rare to fairly common, it occurs throughout the section, but its highest frequencies appear in carbonaceous siltstones in the upper part.

Location: Pb 3826 3 ; 46.8 x 111.1

Code: Bom-1

Genus BOMBACACIDITES Couper, 1960

Bombacacidites cf. *bombaxoides* Couper, 1960

(Plate 5, Figure 5)

The genera *Bombacacides* and *Bombacacipites*, both published in 1960, are probably not both valid, although no change is made here. This species is very similar to modern *Bombax* pollen, and affinity with the family

Bombacaeae if not Bombax is fairly certain. The family is tropical to subtropical in distribution today.

Occurrence: Rare, but it occurs conspicuously in Zone E.

Location: Pb 5621 4 ; 52.5 x 120.6

Code: Bom-4

Genus PROTEACIDITES Cookson, 1950

Proteacidites cf. marginus Rouse, 1962

(Plate 10, Figure 7)

The comparison with P. marginus is close, although, as Rouse points out, considerable variation exists and this species may be gradational with P. terrazus. The botanical affinity is probably the family Proteaceae.

Occurrence: Rare to common, especially in the lower part of the section.

Location: Pb 3828 5 ; 39.6 x 113.8

Code: Prot-1

Proteacidites terrazus Rouse, 1962

(Plate 6, Figure 12)

This species together with P. cf. marginus, comprise the total percentage of Proteacidites shown on Figure 6. Illustrations of similar types are common in studies of lower Tertiary sections, and it appears that this species is an excellent marker for Eocene rocks.

Occurrence: Rare to common, generally throughout the section, but with decreasing frequency in Zones D and E.

Location: Pb 3843 2 ; 43.3 x 112.0

Code: Prot-2

Genus CARYAPOLLENITES Raatz 1937

Caryapollenites simplex (Pot.) Raatz, 1937

(Plate 12, Figure 8)

The botanical affinity of this species is probably the family Juglandaceae, and possibly the genus Carya, although C. simplex is considerably smaller than pollen of most modern species of Carya. This species comprises the total shown under Carya in Figure 11.

Occurrence: Common to abundant, occurs throughout the section; its highest frequencies occur in carbonaceous siltstones apparently deposited in brackish lagoons or bays.

Location: Pb 3829 5 ; 41.6 x 113.8

Code: Car-1

Caryapollenites spackmanius (Traverse) Pot., 1960

(Plate 5, Figure 4)

This species is about twice as large as C. simplex. It appears that the larger C. spackmanius type may be the product of an evolutionary trend to larger pollen from the smaller C. simplex type. C. spackmanius occurs only in a few samples in the uppermost part of the section, and though C. simplex is still present in those samples, its abundance is considerably reduced. This species compares closely with modern Carya pollen, and an affinity with that genus is probable.

Occurrence: Rare, the species occurs only in Zone E.

Location: Pb 3897 4 ; 50.3 x 121.0

Code: Car-2

Genus ALNIPOLLENITES Pot., 1931

Alnipollenites versus (Pot.) Pot., 1934

(Plate 12, Figure 6; Plate 4, Figure 9)

The botanical affinity of this species is almost certainly with the genus *Alnus*, family Betulaceae. It is a commonly identified form in Tertiary deposits. This species comprises most of the percentages shown under *Alnus* in Figure 11.

Occurrence: Common in most samples throughout the section, although its relative abundance decreases generally in most coal samples. A six pored form of this species (Plate 4, Figure 9) occurs only in Zones D and E.

Location: Pb 3838 4 ; 43.4 x 120.8 (Pl. 12, Fig. 6)
Pb 3897 4 ; 46.5 x 116.5 (Pl. 4, Fig. 9)

Code: Al-1

Alnipollenites sp.

(Plate 12, Figure 7)

This species may be referable to the species A. *versus*, although the pores appear to be consistently oriented slightly off the equator, and the pore annulus is generally less well developed. Only four pored forms of this type were observed, while four and five pored A. *versus* were present in nearly equal numbers. The affinity with the

genus *Alnus* is less certain for this species, although it was included in counts under that heading in Figure 11.

Occurrence: Rare, the species ranges throughout the section.

Location: Pb 3883 4 ; 47.5 x 128.0

Code: A1-2

Genus ULMIPOLLENITES Wolfe, 1934

Ulmipollenites undulosus Wolfe, 1934

(Plate 2, Figure 11; Plate 12, Figure 11)

Anderson (1960) used the name *Ulmoidipites* for grains very similar to the types illustrated here. The botanical affinity appears to be with the family Ulmaceae, although the generic affinity is not certain. Four and five pored forms of this species are present, and both types are included in counts of *Ulmus* in Figure 11.

Occurrence: Generally common throughout the section, although the five pored form occurs only in samples from Zone B and above.

Location: Pb 5615 1 ; 52.2 x 113.8 (Pl. 2, Fig. 11)
Pb 3883 4 ; 36.2 x 125.1 (Pl. 12, Fig. 11)

Code: P_{∞}rug-1

Ulmipollenites sp.

(Plate 1, Figure 13)

This is a smaller, three pored pollen which is in other respects similar to U. *undulosus*. Anderson (1960) illustrates a similar type referring to it as *Ulmoideipites* *krempi*. It appears that an evolutionary sequence from three pored to polyporate aperture condition is present in this group of pollen, which are probably related to the family Ulmaceae.

Occurrence: Rare to common, this species does not range above Zone D.

Location: Pb 3831 6 ; 47.5 x 117.2

Code: P3rug-1

Genus PTEROCARYAPOLLENITES Thierg., 1937

Pterocaryapollenites stellatus (Pot.) Raatz, 1937

(Plate 6, Figure 10; Plate 12, Figure 15)

The botanical affinity of this species appears to be with *Pterocarya*. The percentages of *Pterocarya* shown in Figure 11, and of *Pterocaryapollenites* in Figure 6, are comprised entirely of this species. The sporadic occurrence of extremely high abundances of this species in particular swamp or brackish environments reduces its stratigraphic value, although it provides some indication of the ecological setting of the parent plant.

Occurrence: Rare to abundant, the species occurs throughout the section with the highest abundances occurring in some coals and lignitic siltstones in the upper part of the section.

Location: Pb 3872 3 ; 49.0 x 122.0 (Pl. 6, Fig. 10)

Pb 3801 5 ; 35.0 x 125.3 (Pl. 12, Fig. 15)

Code: P_{∞}p-1

Genus LIQUIDAMBARPOLLENITES Raatz, 1937

Liquidambarpollenites stigmosus (Pot.) Raatz, 1937

(Plate 4, Figure 11)

The botanical affinity of this species appears to be with the genus *Liquidambar* of the family Hemamelidaceae. It is a frequently identified form from Tertiary deposits. This species comprises about half of the counts shown under *Liquidambar* in Figure 11.

Occurrence: Rare to common, this species occurs in Zones D and E and the highest frequencies appear in some lignitic siltstone samples.

Location: Pb 3802 2 ; 50.3 x 120.2

Code: P_{∞}r-1

Liquidambarpollenites cf. *mangelsdorfiana* (Traverse) Pot., 1960

(Plate 3, Figure 15; Plate 12, Figures 12 and 13)

The illustrated species compares quite closely with L. *mangelsdorfiana* from the Oligocene Brandon Lignite. The pores are slightly more elongate and the exine somewhat thicker in the illustrated species than in the original illustration of L. *mangelsdorfiana*. It is included in the percentages of *Liquidambar* in Figure 11.

Occurrence: Generally rare, but it is consistently present in and above Zone B.

Location: Pb 3827 5 ; 38.0 x 125.1 (Pl. 3, Fig. 15)
Pb 3872 3 ; 48.2 x 123.3 (Pl. 12, Figs.12,13)

Code: P_{∞}r-3

Genus MULTIPOROPOLLENITES Pf., in Thom. and Pf., 1953

Multiporopollenites ludlowensis Stanley, 1960

(Plate 12, Figures 17 and 18)

This identification is based on a thesis description, and it is therefore not a valid name. The species almost certainly represents the genus *Pachysandra* of the family Buxaceae. This pollen species has been identified from a number of Tertiary localities in North America.

Occurrence: Rare, although it occurs with some consistency throughout the section.

Location: Pb 3873 1 ; 45.5 x 121.9

Code: Pac-1

Genus JUGLANSPOLLENITES Raatz, 1937

Juglanspollenites versus Raatz, 1937

(Plate 12, Figure 16)

The botanical affinity of this species appears to be with the genus *Juglans*. The pollen possesses the characteristic feature of pores arranged equatorially with one to three pores in one hemisphere, off the equator.

Occurrence: Rare, the species occurs very consistently in nearshore marine sediments, especially in the upper part of the section.

Location: Pb 3806 2 ; 34.3 x 111.7

Code: P sm-3

Genus POLLENITES H. Pot., 1893

Pollenites *oculus-noctis* Thierg., 1940

(Plate 1, Figure 10; Plate 11, Figures 14 and 15)

Couper (1960) has illustrated very similar forms and referred them to the genus *Epilobium*. The two pored form illustrated in this paper (Plate 11, Figure 15) is identified as *Fuchsia* by Couper (1960). Traverse (1955) illustrates a nearly identical form and refers it to the modern genus *Jussaea*. The botanical affinity of P. *oculus-noctis* is almost certainly with the family Onagraceae.

Occurrence: Rare, although it occurs consistently throughout the section with the highest frequencies appearing in the lower half of the section.

Location: Pb 3831 6 ; 51.3 x 113.7 (Pl. 1, Fig. 10)
Pb 5622 1 ; 61.0 x 122.8 (Pl. 11, Fig. 14)
57.8 x 111.3 (Pl. 11, Fig. 15)

Code: P3sm-4

Pollenites cf. *ventosus* Pot., 1931

(Plate 3, Figure 3)

The comparison of the illustrated specimen with Potonies original drawing is only suggestive of an identity. The form present in the samples studied is tricolpate with a suggestion of pore development at the equator. It is nearly always seen in polar view, with the colpi narrow and slit-like. It is a frequently occurring Eocene form in the German brown coals.

Occurrence: Common to rare, the species occurs throughout the section.

Location: Pb 3809 6 ; 45.9 x 110.9

Code: C3g-4

Pollenites genuinus Pot., 1934

(Plate 2, Figure 1)

The illustrated species usually shows a slight constriction or pore-like development within the colpi at the equator, much as Potonie describes as a genuculus in P. *genuinus*. It is common in some Eocene sediments of Europe. The botanical affinity is not known.

Occurrence: Rare to common, in and above Zone C.

Location: Pb 3895 2 ; 48.2 x 110.0

Code: C3r-18

Pollenites anulus (Pot.) Pot. and Ven., 1934

(Plate 12, Figure 14)

This species possibly represents the genus *Celtis*, although that is not certain. The number of pores is variable from three to six, but most commonly there are five. This is a frequently identified lower Tertiary species.

Occurrence: Generally rare, however it is very consistent in the upper part of the section.

Location: Pb 3806 2 ; 44.5 x 116.3

Code: P_{∞}sm-5

Genus SPORITES H. Pot., 1893

Sporites cf. *vegetus* Pot., 1934

(Plate 1, Figure 5)

Despite the misleading name, this species is a tricolpate pollen, as pointed out by Krutzsch (1957). The botanical affinity is unknown. The comparison of the illustrated form with S. *vegetus* is close.

Occurrence: Rare to fairly common, especially in the lower part of the section.

Location: Pb 3839 1 ; 45.7 x 127.3

Code: C3r-9

FUNGI

FAMILY MICROTHYRIACEAE

(Plate 7, Figures 4, 8 and 9)

A great variety of fungi are present in nearly all of the samples examined. The illustrated specimens represent only an example of the most abundant types. The family Microthyriaceae is today a tropical-subtropical group of ectoparasites commonly found on ferns, broadleaf trees and cenifers.

Occurrence: Common to abundant, especially abundant in some lignitic siltstones and coals. The fungi as a whole show an inverse relationship in abundance with the microplankton.

Location: Pb 5607 1 ; 38.2 x 119.0
Pb 3805 5 ; 41.0 x 114.7
Pb 3805 5 ; 52.4 x 124.9

ALGAE

Genus CYCLONEPHELIUM (Deflandre and Cookson) Cookson and Eisenack, 1962

Cyclonephelium sp.

(Plate 7, Figure 1)

The genus *Cyclonephelium* is a commonly identified Mesozoic to lower Tertiary form. It is a significant contributor to the percentages of microplankton in Figure 6.

Occurrence: Rare to common in samples of marine origin, especially those away from the swampy shoreline.

Location: Pb 3836 5 ; 41.0 x 110.3

Code: Hyx-2

Genus WETZELIELLA Eisenack, 1938

Wetzeliella glabra Cookson, 1956

(Plate 7, Figures 2 and 7)

This species has been described from the Eocene in Australia, and it is likely that it will prove to be an excellent stratigraphic marker for lower Tertiary rocks.

Occurrence: Rare, apparently in open marine environments.

Location: Pb 5616 2 ; 38.5 x 127.1 (Fig. 2)

Pb 5617 3 ; 36.4 x 115.3 (Fig. 7)

Code: Dino-5

Wetzeliella sp.

(Plate 7, Figure 5)

Occurrence: Rare to common, especially in samples from upper part of the section.

Location: Pb 5618 4 ; 50.8 x 118.1

Code: Dino-6

Genus DEFLANDREA Eisenack, 1938

Deflandrea cf. *spinulosa*

(Plate 7, Figure 6)

This species is commonly seen in lower Tertiary sediments. It exhibits a considerable range of morphological features, but the illustrated specimen is by far the most common type seen in the samples studied.

Occurrence: Common to abundant, occurring in large numbers in some apparently nearshore or even brackish environments.

Location: Pb 5616 2 ; 32.3 x 123.6

Code: Dino-2

Deflandrea sp.

(Plate 2, Figure 12)

Occurrence: Rare to common, mostly in middle part of section (Zone C).

Location: Pb 3838 1 ; 35.5 x 115.3

Code: Dino-1

Genus CYMATIOSPHAERA (wetzel) Deflandre, 1954

Cymatiosphaera sp.

(Plate 1, Figure 9)

This genus is comprised of species most of which are Paleozoic to Mesozoic in age. The figured specimen appears to be referable to the genus, however, although no specific comparisons were found.

Occurrence: Generally rare, it occurs most frequently in the lower part of the section, especially in Zone A.

Location: Pb 5603 1 ; 46.3 x 114.9

Code: Hyx-8

Genus CANNOSPHAEROPSIS Wetzel, 1932

Cannosphaeropsis sp.

(Plate 2, Figure 13)

This genus is composed mostly of Mesozoic species, and has not been recognized from North America.

Occurrence: Rare to common, it is restricted to Zone C and appears to be an excellent marker for that zone in marine rocks.

Location: Pb 3874 4 ; 46.2 x 122.0

Code: Hyx-4

Genus TYTTHODISCUS Norem, 1955

Tytthodiscus sp.

(Plate 5, Figure 8)

Occurrence: Rare to common, it occurs with highest frequency in the upper part of the section, especially Zone E.

Location: Pb 3896 2 ; 52.5 x 115.2

Code: Tyth-1

INCERTAE CEDIS

(Plate 1, Figure 12; Plate 5, Figure 7)

This specimen may be an encystment or budding state of a brown edge alga (Phaeophyta) (Prescott, G. W. personal communication). It bears some resemblance to the genus *Halogoras* Cookson, 1956 which is also assumed to be an algal cyst by that author.

Occurrence: Rare to common, it occurs in the lowermost and uppermost part of the section and is totally absent in between.

Location: Pb 3828 5 ; 39.5 x 127.5 (Pl. 1, Fig. 12)
Pb 3830 6 ; 42.7 x 124.2 (Pl. 5, Fig. 7)

Code: Alga-1

INCERTAE CEDIS

(Plate 5, Figures 6 and 9)

This specimen appears to be a marine microplankton species, probably a member of the Dinoflagellatae. It appears in abundance in Zone E, and may be an excellent marine marker for latest Eocene and/or earliest Oligocene.

Location: Pb 3896 2 ; 54.0 x 109.0 (Fig. 6)

Pb 3896 2 ; 36.3 x 115.0 (Fig. 9)

Code: Hyx-9

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APPENDIX A

The location of the sections collected and studied are presented in this section. The position and lithologic description for each sample is also provided. The lithologic descriptions are based on field examination only, and are not intended as accurate petrographic analyses. The sample numbers correspond to those mentioned in the text and shown in the illustrations.

Skookumchuck River Section 64-DS-XII
Sec. 33, T15N, R2W

Sample Number	Position in Section	Lithology
4	590 ft.	dark gray, soft, fissile, carbonaceous shale, some molluscan fossils
3	500 ft.	12" coal seam, with underclay where roots are in place
2	360 ft.	lignitic siltstone and thin coal, many leaf fossils
1	base of exposed section	thick coal and parting clay sequence, some logs and stumps appear to be in growth position

Willapa River Section 64-DS-XIII and 65-DS-XI
Secs. 3, 11, 14, 24, 25, 36, T13N, R8W, Pacific County, Wash.

Sample Number	Position in Section	Lithology
7	900 ft.	hard, dark gray, fissile, micaceous siltstone
6	800 ft.	same lithology as above
5	700 ft.	dark gray, massive, poorly sorted, micaceous siltstone, possibly graded
4	600 ft.	gray, concretionary shale, with associated coarse agglomerate zone
3	200 ft.	dark gray, carbonaceous, concretionary, sandy siltstone
2	150 ft.	dark gray, poorly sorted, coarse sandstone
1	50 ft.	dark gray, fissile siltstone, with associated coarse volcanic sandstone

Rock Creek Section 65-DS-XIV
T4N, R5W; T5N, R5W; T5N, R4W, Columbia County, Oregon

Sample Number	Position in Section	Lithology
50	850 ft.	soft, tuffaceous, dark gray, well bedded, silty shale
49	750 ft.	soft, massive, concretionary siltstone
48	700 ft.	same lithology as above, with calcareous horizons
47	600 ft.	dark gray, tuffaceous, sandy, siltstone, with CaCOs stringers
46	450 ft.	gray, well bedded, slightly fissile, silty sandstone
45	350 ft.	hard, dark gray, fissile, well bedded siltstone and shale
44	250 ft.	same lithology as above
43	125 ft.	dark gray, fissile, carbonaceous siltstone
42	50 ft.	gray, very carbonaceous, micaceous siltstone with plant fossils and associated bluish sandstone

Chehalis River Section 65-DS-X
Sec. 12, 13, T12N, R5W, Lewis County, Washington

Sample Number	Position in Section	Lithology
6	4000 ft.	lignitic, micaceous, siltstone with associated channel sandstone
5	3900 ft.	brownish-gray, well bedded, carbonaceous shale
4	3700 ft.	dark gray, poorly sorted, concretionary siltstone
3	3000 ft.	hard, dark gray, fissile, concretionary shale
2	2500 ft.	dark gray, micaceous siltstone with carbonaceous stringers possibly graded bedding
1	1000 ft.	hard, dark gray, fissile, silty shale with associated volcanic sandstones

McIntosh Lake Section 64-DS-XI
Sec. 14, T16N, R1W, Thurston County, Washington

Sample Number	Position in Section	Lithology
2	100 ft.	hard, dark gray, thin bedded, fissile, concretionary shale and siltstone
1	base of exposed section	same lithology as above

Stillwater-Olequa Creek Section
64-DS-XIV, 64-DS-XV and 65-DS-VIII
Secs. 4, 5, 6, T10N, R3W; Secs. 25, 26, 34 T11N, R3W,
Lewis and Cowlitz Counties, Washington

Sample Number	Position in Section	Lithology
41	7925 ft.	lignitic, micaceous siltstone with much plant debris
40	7900 ft.	coarse channel sandstone with coalified logs and thin clay stringers
39	7840 ft.	interbedded coals and bluish shales, roots seen in place
38	7800 ft.	channel sandstone cutting through lignitic siltstone and coal
37	7600 ft.	bluish, micaceous, carbonaceous sandstone with coaly horizons
35 7	7250 ft.	gray, thinnly bedded, shale and siltstone, very carbonaceous
6	7240 ft.	same lithology
5	7230 ft.	same lithology
4	7220 ft.	same lithology
3	7215 ft.	same lithology
2	7210 ft.	same lithology
1	7200 ft.	same lithology
34	7000 ft.	gray, tuffaceous, concretionary siltstone with some sandy layers
33	6825 ft.	thinnly interbedded sandstone and siltstone, associated channel sandstone
32	6600 ft.	interbedded carbonaceous shales, sandstone and siltstone
31	6500 ft.	lignitic siltstone, interbedded with massive to crossbedded sandstone lenses
30	6450 ft.	gray, fairly well sorted, fissile siltstone with foraminifera
29	6400 ft.	same lithology, but containing molluscan fossils

Sample Number	Position in Section	Lithology
28	6250 ft.	same lithology
27	6150 ft.	gray siltstone, with molluscan fossils and associated fairly well sorted sandstones
26	6000 ft.	same lithology
25	5600 ft.	fossiliferous, poor to well sorted gray siltstone
24	5400 ft.	lignitic siltstone interbedded with gray siltstone and fossiliferous
23	5300 ft.	bluish massive sandstone with carbonaceous stringers
22	4900 ft.	gray, carbonaceous, micaceous, poorly sorted siltstone
21	4600 ft.	same lithology
20	4250 ft.	soft, bluish-gray, micaceous, fairly massive siltstone
19	4100 ft.	gray, micaceous, fine sandstone and siltstone
18	3950 ft.	dark gray, massive, poorly sorted siltstone
17	3900 ft.	hard, bluish, fissile shale with some concretions
16	3750 ft.	dark gray siltstone and bluish sandstone, some concretions
15	3650 ft.	dark gray, poorly sorted, well bedded siltstone with woody fragments
14	3600 ft.	same lithology as above
13	3500 ft.	dark gray, bedded siltstone and sandstone with carbonaceous fragments
12	3400 ft.	thinnly bedded, concretionary, micaceous siltstone
10	2600 ft.	gray, micaceous, carbonaceous, poorly sorted siltstone
9	2400 ft.	same as above
8	2300 ft.	dark gray, and well bedded, carbonaceous, fissile siltstone
7	2100 ft.	10 inch coal seam, with associated massive sandstone
5	1750 ft.	blue-gray, poorly sorted sandy siltstone
4	1700 ft.	concretionary, dark gray, sandy siltstone
3	1600 ft.	thinnly interbedded fine sandstone and siltstone, possibly graded
2	1500 ft.	hard, dark gray, poorly sorted, massive siltstone
1	800 ft.	hard, dark gray, poorly sorted siltstone

PLATES

PLATE 1

Figure	
1	Polypodiisporites sp. 1 x500
2	Tiliapollenites indubitabilis
3	Tiliapollenites crassipites
4	Pistillipollenites mcgregorii
5	Sporites cf. vegetus
6	Ilexpollenites iliacus
7	Intratriporopollenites rizophorus
8	Intratriporopollenites rizophorus
9	Cymatiosphaera x500
10	Pollenites oculus-noctis x500
11	Gothanipollis sp.
12	Incertae cedis, algal cyst?
13	Ulmipollenites sp.
14	Tricolporopollenites sp. 3

All illustrations x1000 unless otherwise indicated.

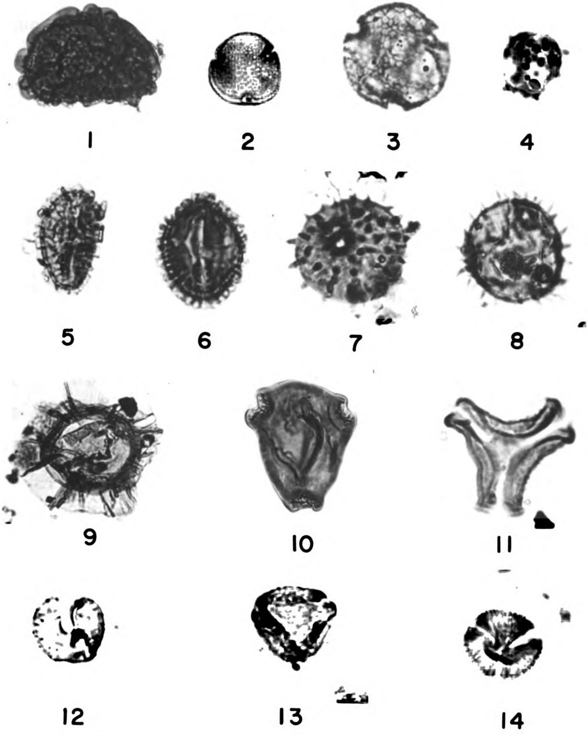

PLATE I

PLATE 2

Figure	
1	Pollenites genuinus
2	Syncolporites sp. 2
3	Syncolporites sp. 1
4	Tricolpites sp. 2
5	Tricolpites sp. 2
6	Rhoipites sp.
7	Rhoipites sp.
8	Symplocoipollenites sp. 2
9	Symplocoipollenites
10	Symplocoipollenites
11	Ulmidollenites undulosus
12	Deflandrea sp. x500
13	Cannosphaeropsis sp. x500

All illustrations x1000 unless otherwise indicated.

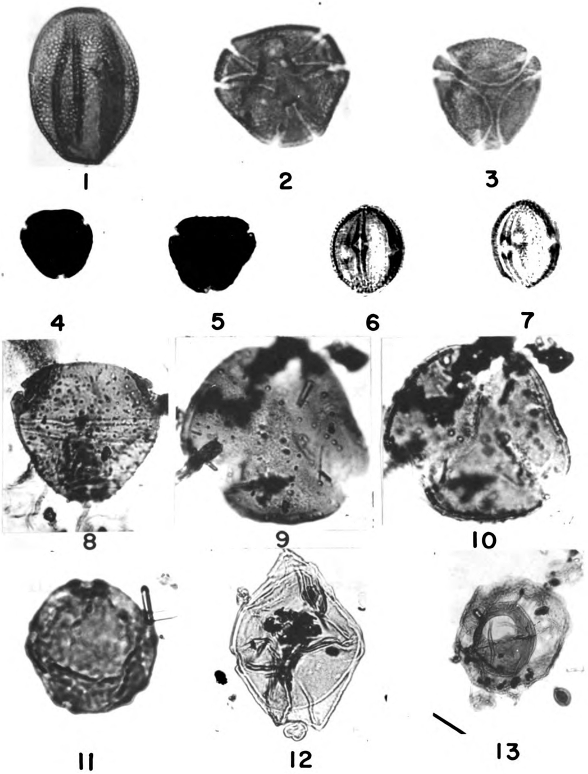

PLATE 2

PLATE 3

Figure	
1	Ilexpollenites cf. marginatus
2	Quercoidites henrici
3	Pollenites cf. ventosus
4	Cupanieidites cf. orthoteichus
5	Tricolporopollenites sp. 1
6	Tricolporopollenites sp. 2
7	Tricoloporopollenites cf. macrodurensis
8	Cupanieidites sp. 1
9	Tricolporopollenites cf. helmstedtensis
10	Nyssapollenites accessorius
11	Alangaceoipollenites sp. 2 x500
12	Ilexpollenites sp.
13	Ilexpollenites sp.
14	Symplocoipollenites vestibulum
15	Liquidambarpollenites cf. mangelsdorfiana

All illustrations x1000 unless otherwise indicated.

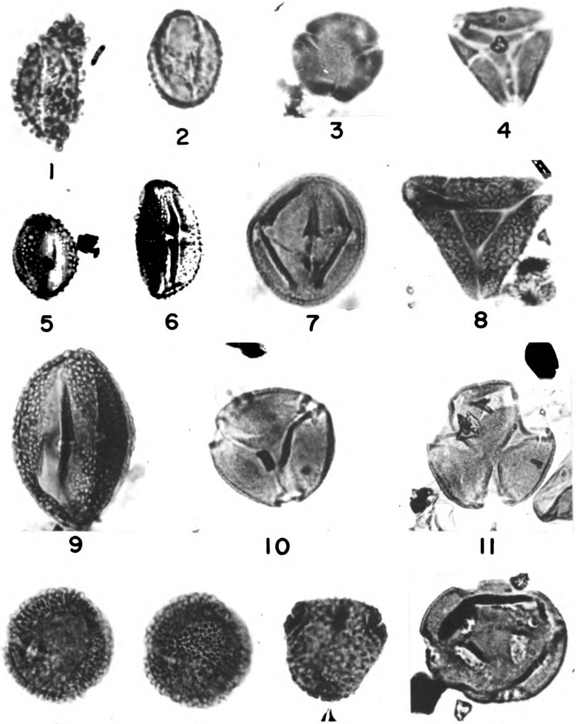

PLATE 3

PLATE 4

Figure	
1	Concavisporites minimus
2	Piceapollenites sp.
3	Tsugaepollenites viridifluminipites x500
4	Tricolpites cf. striatus
5	Tricolpites sp. 4
6	Tricolpites sp. 4
7	Alangaceoipollenites sp. 1 x500
8	Rhoipites dolium
9	Alnipollenitites versus
10	Symplocoipollenites sp. 1
11	Liquidambarpollenites stigmosus
12	Quercoidites sp. 2

All illustrations x1000 unless otherwise indicated.

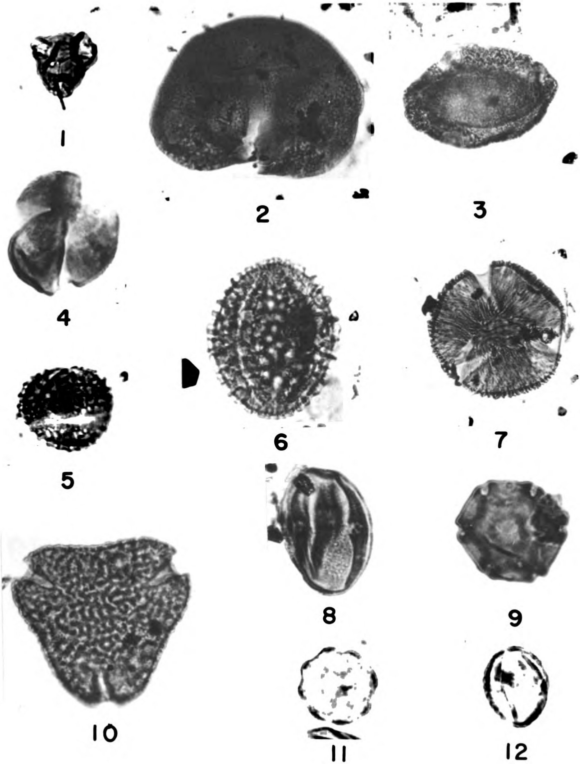

PLATE 4

PLATE 5

Figure	
1	Baculatisporis cf. baculatus
2	Pistillipollenites megregorii
3	Pistillipollenites megregorii
4	Caryapollenites spackmanianus
5	Bombacacidites cf. bombaxoides
6	microplankton, affinity uncertain x500
7	Incertae cedis, algal cyst?
8	Tytthodiscus sp. x500
9	microplankton, affinity uncertain x500

All illustrations x1000 unless otherwise indicated.

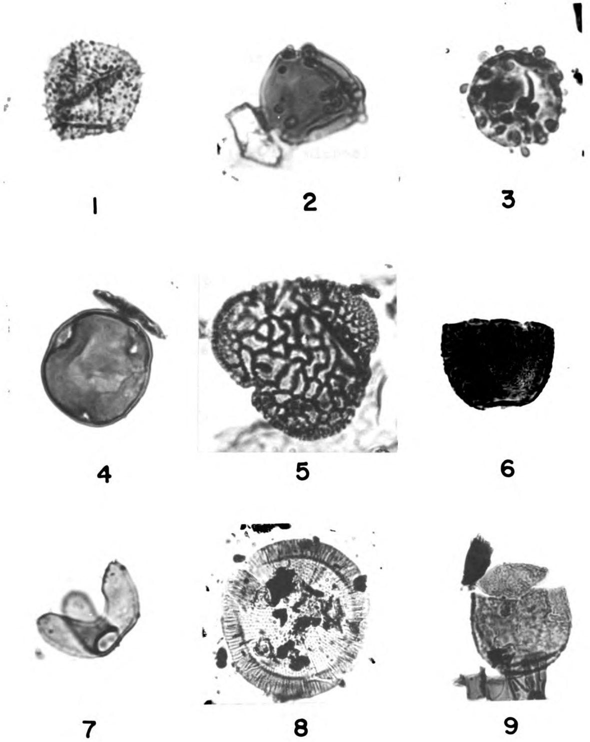

PLATE 5

PLATE 6

Figure

1	Osmundacites wellmanii x500
2	Trilites asolidus x500
3	Trilites asolidus x500
4	Podocarpidites x500
5	Abietineaepollenites microalatus x500
6	Cicatricosisporites cf. hallei x500
7	Momipites coryloides
8	Ilexpollenites inaequaliclaviata
9	Ilexpollenites inaequaliclaviata
10	Pterocaryapollenites stellatus
11	Liliacidites intermedius
12	Proteacidites terrazus
13	Ephedra cf. notensis

All illustrations x1000 unless otherwise indicated.

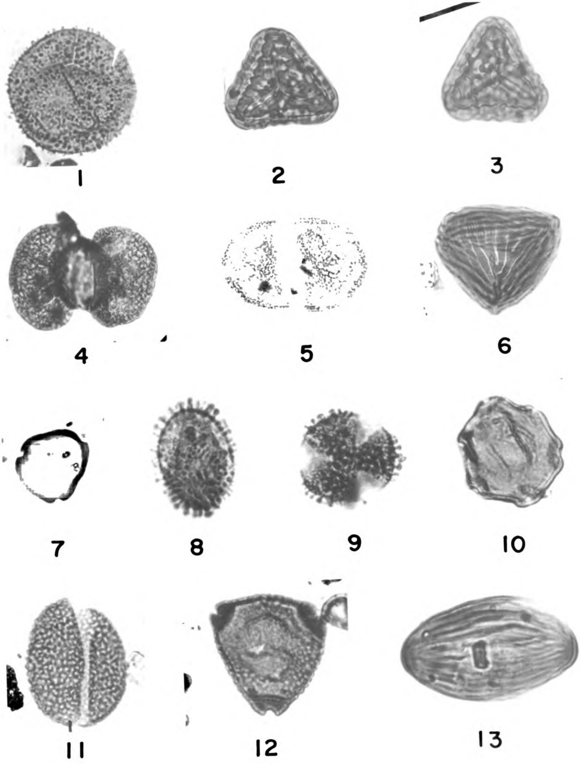

PLATE 6

PLATE 7

Figure	
1	Cyclonephelium sp. x500
2	Wetzellia glabra x250
3	Dinoflagellate x500
4	Microthyriaceae x1000
5	Wetzeliella sp. x500
6	Deflandrea cf. spinosa x500
7	Wetzeliella cf. glabra x250
8	Microthyriaceae x250
9	fungus x250
10	fungus x1000

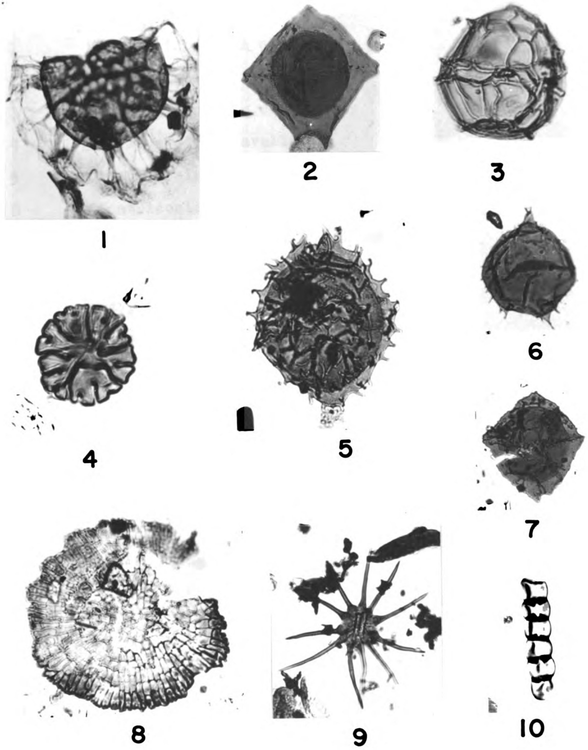

PLATE 7

PLATE 8

Figure	
1	Polypodiisporites sp. 1
2	Polypodiisporites cf. favus
3	Polypodiisporites cf. favus
4	Trilites cf. paravallatus
5	Cicatricosisporites cicatricosoides
6	Cicatricosisporites cicatricosoides
7	Laevigatisporites cf. pseudomaximus
8	Polypodiaceoisporites sp.
9	Polypodiaceoisporites sp.
10	Foveotriletes crassifovearis
11	Osmundicites wellmanii
12	Concavisporites minimodiversus
13	Concavisporites minimodiversus

All illustrations x500.

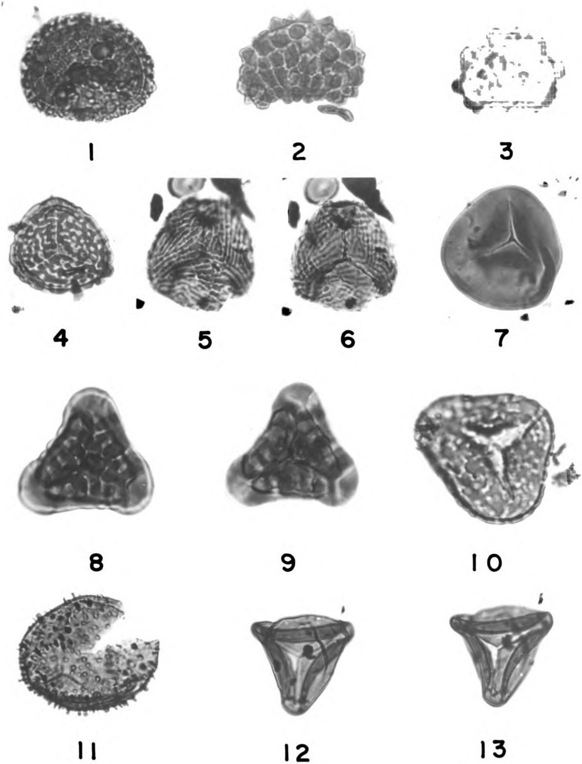

PLATE 8

PLATE 9

Figure

1	Abiespollenites cf. absolutus x500
2	Abiespollenites cf. absolutus x500
3	Abiespollenites cf. absolutus x500
4	Podocarpidites sp. x500
5	Tsugaepollenites viridifluminipites x500
6	Taxodiaceaepollenites hiatus
7	Quercoidites henrici
8	Sabalpollenites cf. convexus
9	Sequoiapollenites sp.
10	Taxodiaceaepollenites hiatus
11	Quercoidites henrici
12	Castaneoidites cf. exactus
13	Tricolpites sp. 3
14	Ilexpollenites iliacus
15	Tricolpopollenites cf. retiformis
16	Tricolpopollenites cf. retiformis
17	Platanoidites sp.
18	Platanoidites sp.
19	Tricolpites sp. 3

All illustrations x1000 unless otherwise indicated.

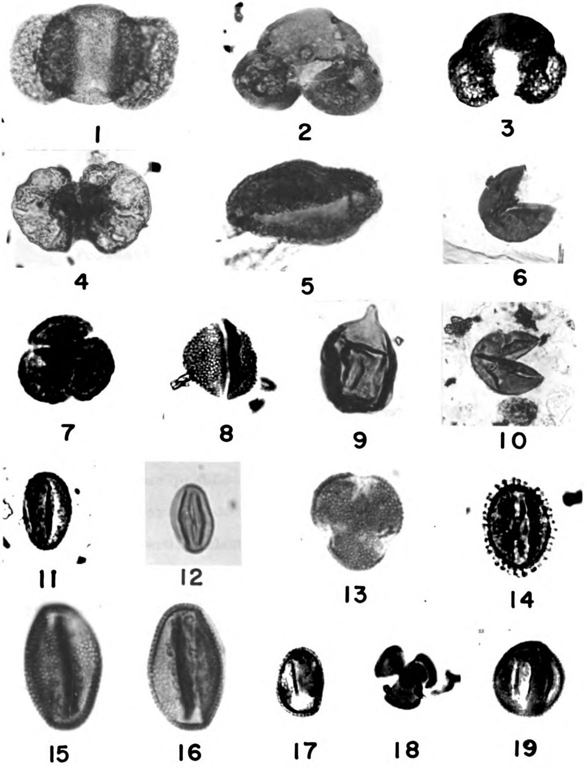

PLATE 9

PLATE 10

Figure

1	Tricolpites sp. 1
2	Tricolpites sp. 1
3	Tricolpites sp.
4	Tiliapollenites instructus
5	Subtriporopollenites cf. constans
6	Trivestibulopollenites cf. salebrosus
7	Proteacidites cf. marginus
8	Bombacacipites cf. nacimientoensis
9	Rhoipites cf. bradleyensis
10	Araliaceoipollenites cf. edmundi
11	Tricolporopollenites satzveyensis
12	Rhoipites cf. pseudocingulum forma navicula
13	Rhoipites cf. pseudocingulum forma navicula
14	Rhoipites pseudocingulum
16	Rhoipites pseudocingulum
17	Cupuliferoipollenites cf. pusillus

All illustrations x1000

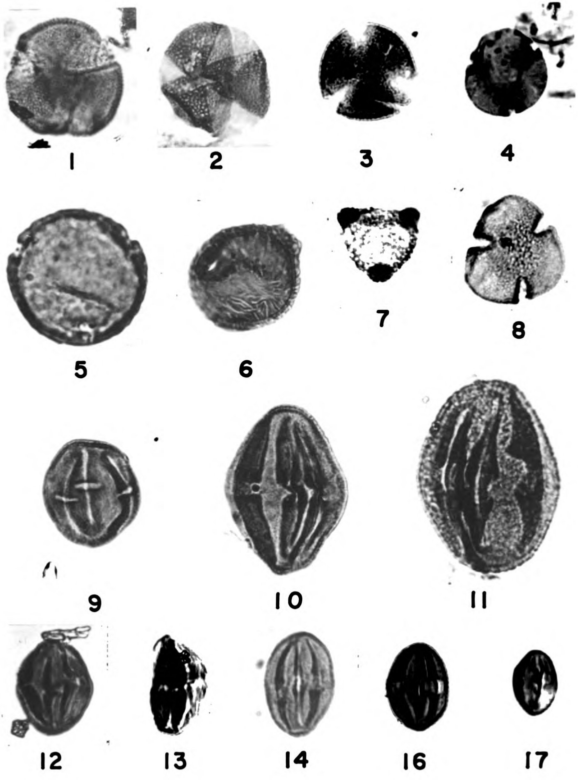

PLATE 10

PLATE 11

Figure

1	Nyssapollenites sp. 2
2	Nyssapollenites sp. 2
3	Faguspollenites sp.
4	Nyssapollenites accessorius
5	Nyssapollenites cf. Thompsoniana
6	Symplocoipollenites vestibulum
7	Faguspollenites cf. versus
8	Nyssapollenites sp. 1
9	Alangiaceoipollenites barhoornianum x500
10	Cyrillaceaepollenites cf. megaexactus
11	Sapotaceoidaepollenites cf. sapatoides
12	Sapotaceoidaepollenites cf. sapatoides
13	Sapotaceoidaepollenites cf. sapatoides
14	Pollenites oculus-noctis x500
15	Pollenites oculus-noctis x500

All illustrations x1000 unless otherwise indicated.

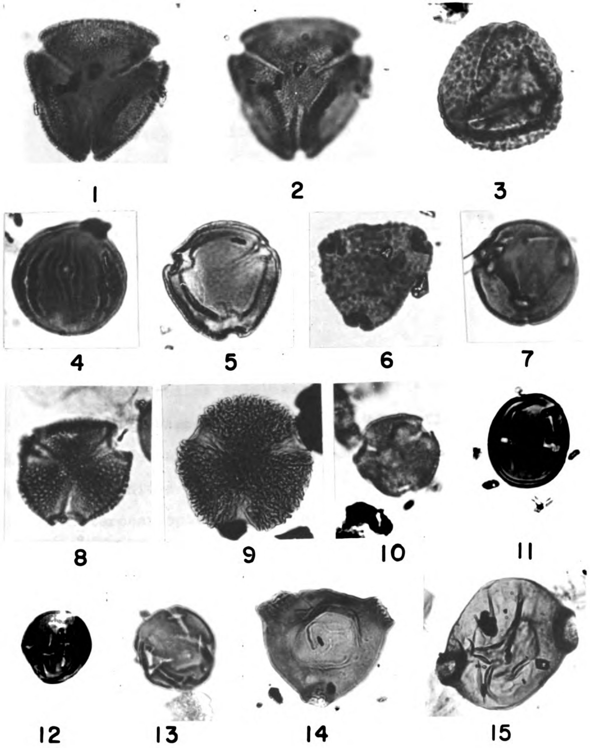

PLATE 11

PLATE 12

Figure	
1	Myricaceoipollenites cf. megagranifer
2	Triatriopollenites rurensis
3	Betulaceoipollenites bituitus
4	Betulaceoipollenites bituitus
5	Engelhardtioidites microcoryphaeus
6	Alnipollenites versus
7	Alnipollenites sp.
8	Caryapollenites simplex
9	Momipites coryloides
10	Engelhardtioidites quietus
11	Ulmipollenites undulosus
12	Liquidambarpollenites cf. mangelsdorfiana
13	Liquidambarpollenites cf. mangelsdorfiana
14	Pollenites anulus
15	Pterocaryapollenites stellatus
16	Juglanspollenites versus
17	Multiporopollenites ludlowensis
18	Multiporopollenites ludlowensis x1250

All illustrations x1000 unless otherwise indicated.

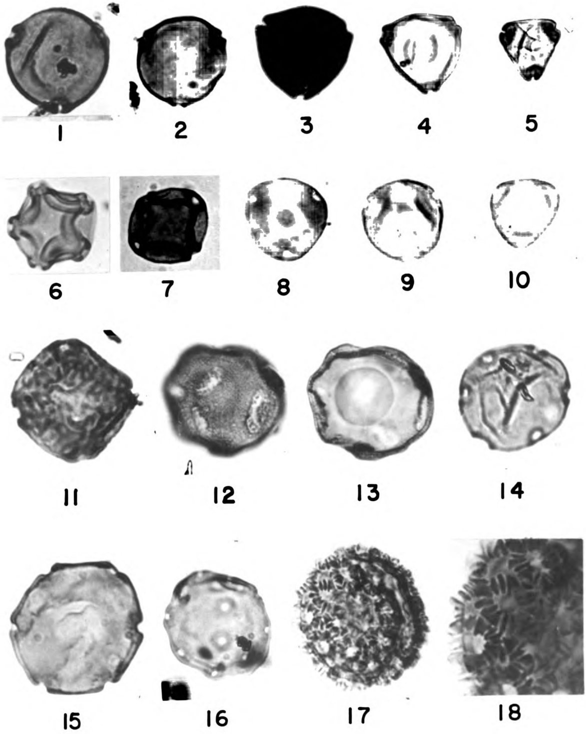

PLATE 12