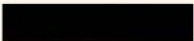


POLLEN AND SPORES FROM THE MIOCENE SARDINE
FORMATION: TAXONOMY AND PALEOECOLOGY


by

MAMTAZ SHIREEN

A THESIS

Presented to the Department of Biology
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Master of Science

December 1983

APPROVED

Jane Gray

At the Department of Biology
An Abstract of the Thesis of
Mamtaz Shireen for the degree of Master of Science
in the Department of Biology to be taken December 1983
Title: POLLEN AND SPORES FROM THE MIOCENE SARDINE
FORMATION: TAXONOMY AND PALEOECOLOGY

Approved: _____

Jane Gray

This study was undertaken to identify fossil pollen and spores recovered from the Sardine Formation, a late Tertiary rock unit from northwestern Oregon that also contains plant megafossils. Fifteen rock samples were collected spanning some 4.66 meters of the formation. About 30 families and 31 genera were identified, many of which are represented by co-occurring megafossils, others of which are new to the late Tertiary vegetation of northwestern Oregon. The vegetation represented by microspores and megafossils is indicative of a mixed Taxodiaceous-deciduous hardwood forest similar to warm temperature, summer-wet forests of eastern and southeastern North America and eastern Asia. Relative frequency counts, assembled as a pollen diagram, suggest no vegetation or climatic changes throughout the depositional time denoted by the samples which may represent a period of 50 years or less. Fluctuations on the diagram are seen

rather to reflect random aerodynamic or hydrodynamic factors at the depositional site.

NAME OF SUBJECT: *Basilar Chiroptera*

PLACE OF BIRTH: Chittagong, Bangladesh

DATE OF BIRTH: October 17, 1951

EDUCATION: B.S. in Zoology, University of Dhaka, 1973

EDUCATION: M.S. in Zoology, University of Dhaka, 1975

EDUCATION: Ph.D. in Zoology, University of Oregon, 1978

EDUCATION: Postdoctoral Fellow, University of Oregon, 1978-1979

EDUCATION: M.A. in Zoology

EDUCATION: Bachelor of Science, 1973, University of Dhaka

EDUCATION: Master of Science, 1975, University of Dhaka

AREAS OF SPECIAL INTEREST:

Palynology

Palaeogeography

AWARDS AND HONORS:

Scholarship, University of Dhaka, 1970

Foreign Student Scholarship, University of Oregon,

1976-1978

VITA

NAME OF AUTHOR: Mamtaz Shireen

PLACE OF BIRTH: Chittagong, Bangladesh

DATE OF BIRTH: October 17, 1953

UNDERGRADUATE AND GRADUATE SCHOOLS ATTENDED:

University of Dacca

University of Oregon

DEGREES AWARDED:

Bachelor of Science, 1975, University of Dacca

Master of Science, 1977, University of Dacca

AREAS OF SPECIAL INTEREST:

Palynology

Paleobiogeography

AWARDS AND HONORS:

Scholarship, University of Dacca, 1976

Foreign student scholarship, University of Oregon,
1978-1981

ACKNOWLEDGMENTS

I wish to thank Dr. Jane Gray for giving me the opportunity to work under her supervision, for the training she gave me, and the innumerable hours spent teaching me the techniques of pollen analysis. I also wish to thank Dr. Boucot and Dr. Wagner for serving on my advisory committee and for their helpful suggestions about the manuscript.

I wish to convey my special thanks to Kent Colbath, Patricia Sanford and Frances Duryee for their support and varied help in many ways. I would also like to thank Carol Cogswell for helping with the photomicrography.

I would also like to extend my appreciation to Raisuddin Ahmad, who encouraged me throughout the period of study and for his patience, co-operation and suggestions. My special thanks to him for helping me during the field trip and his excellent cartographic work.

V. RESULTS

Description of the Pollen Diagram	88
Vegetational Interpretation of	
Co-Occurring Mega- and Microfossils	124
Discussion and Conclusion	131

BIBLIOGRAPHY

139

TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Summary of Tertiary Geologic, Climatic and Vegetational Changes in the Pacific Northwest	3
Modern Climate and Vegetation of the Pacific Northwest	10
Previous Work on Fossil Plants from the Faraday Dam Area	12
II. PROVENANCE OF THE SAMPLES	13
Locality and Accessibility	13
Geologic Setting and Age of the Fossiliferous Rocks at Faraday Dam . . .	13
III. RESEARCH METHODS	19
Field and Laboratory Methods	19
Microscopic Examination	22
IV. TAXONOMY AND BIOGEOGRAPHIC RELATIONS OF THE FARADAY DAM FLORA	23
Systematic List of the Identified Pollen and Spores	23
Description of the Pollen and Spores . . .	27
Modern Biogeographic Relations of the Identified Taxa	84
V. RESULTS	93
Description of the Pollen Diagram	93
Vegetational Interpretation of Co-Occurring Mega- and Microfossils . . .	106
Discussion and Conclusion	121
BIBLIOGRAPHY	129

LIST OF TABLES

Table	Page
1. TAXONOMIC LIST OF THE FARADAY DAM FLORA . . .	24
2. COMPARATIVE ABUNDANCE OF MEGA- AND MICROFOSSILS FROM FARADAY DAM, PRESENT GEOGRAPHICAL DISTRIBUTION AND MODE OF POLLINATION	85
3. POLLEN PERCENTAGES NOT SHOWN IN THE POLLEN DIAGRAM	96
4. CLIMATIC DATA FOR LOCATIONS WHOSE VEGETATION IS COMPARABLE TO THE FARADAY DAM FOSSIL FLORA	127

LIST OF FIGURES

Figure	Page
1.--Location map of the Faraday Dam area	4
2.--Lithology of the studied section	15
3.--Pollen diagram	94

CHAPTER I

INTRODUCTION

Palynology generally deals with the study of fossil pollen and spores, which are reproductive parts of plants and microscopic in size. This type of study is important for the reconstruction of past vegetation and climate. Although palynological investigation in different countries began in the early part of the 20th century, such studies only became extensive during the last two decades.

The use of pollen and spores in reconstructing past vegetation and climate has some advantages compared with plant megafossils, because the former are more resistant to various types of physico-chemical changes in sediments and remain well preserved. Moreover, pollen and spores are widely available in a variety of different types of rocks where megafossils are not preserved. There is a major disadvantage using pollen in the reconstruction of past vegetation, because pollen and spores are hard to identify and compare with modern plant species. In that case, generic assignments that include different species growing in completely different climatic and geographical conditions could be misleading in interpreting paleoclimate.

Almost all studies of fossil plants in the Pacific Northwest are based on megafossils, especially leaf fossils

of Tertiary age. Important work has been done by Chaney (1920, 1922, 1924, 1925, 1938, 1939, 1940, 1944, 1953, 1956, 1959), Axelrod (1937, 1939, 1944, 1945), Arnold (1935, 1936, 1937), Berry (1929, 1931, 1934) and Brown (1934, 1935, 1937).

So far, few Tertiary pollen studies have been made throughout the Pacific Northwest, especially in northwestern Oregon. The first pollen examination of Tertiary rocks in the Pacific Northwest was made by Gray (1958 and Gray in Martin and Gray, 1962). Hers was an extensive study of the Miocene pollen floras of the Columbia Plateau, eastern Oregon. Later Tertiary pollen floras have also been investigated by Gray (1964) from the Oligocene to Pliocene age rocks of Oregon, Washington, Idaho, northern California, and Nevada, including some 25 localities where megafossil remains had previously been described. Recently, Gray (in press) has also investigated a flora of the Miocene age from Clarkia, western Idaho. Pollen studies of several Miocene floras in the northwestern Cascades region, Oregon including the Faraday Dam flora, were made by Wolfe (1962, 1969) and a taxonomic list was published. Unfortunately, the list amalgamated the pollen record from eight different floras and did not discriminate which pollen came from the Faraday Dam locality. Thus, this study is inadequate for reconstructing detailed vegetational history and paleoclimate of the Faraday Dam area. Besides the above mentioned works only a few other pollen studies relate to

the Pacific Northwest: for example, studies of an Oligocene flora from the Coos Bay area, Oregon (Hopkins, 1967) and a Miocene flora from the Whatcom Basin, southwest British Columbia and northwestern Washington (Hopkins, 1968).

The present study deals with a pollen assemblage from the Faraday Dam site (Fig. 1). This is the first detailed study of a fossil pollen assemblage from northwestern Oregon. It will provide information about the Miocene vegetation and paleoclimate of the Faraday Dam area as well as elaborate previous interpretations of the flora and climate of western Oregon during the late Tertiary.

Summary of Tertiary Geologic, Climatic and
Vegetational Changes in the
Pacific Northwest

The Tertiary geologic history of the Pacific Northwest is complex. There were several major geologic events in this region which brought the Cascade Range to its present elevation, and profoundly altered the topography (Clark and Stearn, 1960). The major Tertiary events are summarized by McKee (1972), as follows: (1) Eocene to Early Miocene deposition of non-marine and volcanic strata; (2) Middle to Late Miocene eruption of the Columbia River Basalt; (3) Middle to Late Miocene folding, faulting, and granite intrusion; (4) Late Tertiary (Pliocene) volcanism and initiation of Cascade Range uplift. The uplift of the

Washington, D.C. (National Academy of Sciences, 1964) and the
 U.S. Geological Survey (1964).

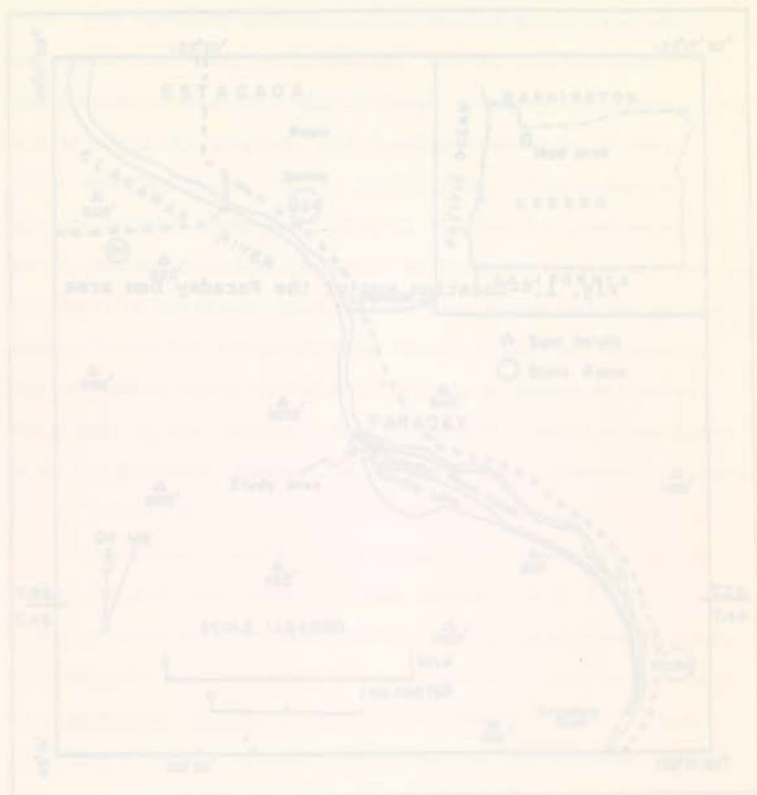
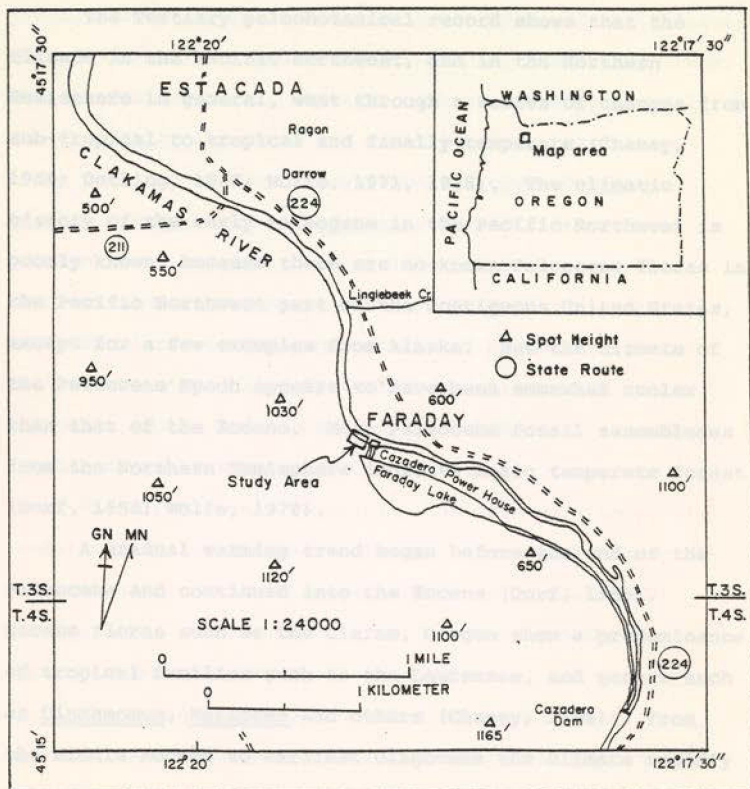


Fig. 1.--Location map of the Faraday Dam area



Cascades had a pronounced effect on the vegetation of the Pacific Northwest.

The Tertiary paleobotanical record shows that the climate in the Pacific Northwest, and in the Northern Hemisphere in general, went through a series of changes from sub-tropical to tropical and finally temperate (Chaney, 1956; Detling, 1968; Wolfe, 1971, 1978). The climatic history of the early Paleogene in the Pacific Northwest is poorly known, because there are no known Paleocene floras in the Pacific Northwest part of the contiguous United States, except for a few examples from Alaska. But the climate of the Paleocene Epoch appears to have been somewhat cooler than that of the Eocene. Most Paleocene fossil assemblages from the Northern Hemisphere indicate mesic temperate forest (Dorf, 1959; Wolfe, 1978).

A gradual warming trend began before the end of the Paleocene and continued into the Eocene (Dorf, 1959). Eocene floras such as the Clarno, Oregon show a predominance of tropical families such as the Lauraceae, and genera such as Cinnamomum, Meliosma and others (Chaney, 1956). From the Middle Eocene to earliest Oligocene the climate rapidly warmed. This tropical climatic trend reached as far north as Alaska, as confirmed by the presence of Sabalites, Ocotea, Hyperbaena and Microcos (Wolfe and Hopkins, 1967). Floras of this epoch from Oregon, Washington and Alaska record the warmest climate of the Tertiary (Chaney, 1956;

Dorf, 1959; Wolfe and Hopkins, 1967).

Most Oligocene floras indicate temperate climate. Families such as the Betulaceae, Aceraceae, and Juglandaceae were dominant in Oligocene floras such as the Bridge Creek, Oregon (Chaney, 1925). With the exception of Metasequoia and Cercidiphyllum which are now confined to Asia, many other genera of Oligocene age such as Fagus, Castanea, Betula, Quercus, and Liquidamber are still living in eastern North America (Chaney, 1956) as members of the deciduous hardwood forest. During the Middle Oligocene latitudinal zonation became pronounced between Alaska and the conterminous United States for the first time in the Paleogene (Wolfe and Hopkins, 1967). Temperate conditions continued into the Miocene.

Miocene floras, in general, indicate warm-temperate conditions in the Pacific Northwest. Even though subtropical genera such as Persea are found in the Middle Miocene Mascall flora, most other Miocene taxa were typically warm-temperate (Chaney, 1925).

The beginning of summer dry climate evidently took place in latest Miocene and earliest Pliocene time (Dorf, 1959; Wolfe and Hopkins, 1967). This resulted in a percentage increase of species with entire margined leaves. This change has been recognized by Wolfe and Hopkins (1967) in Late Miocene and Early Pliocene floras such as the Faraday and Troutdale of Oregon, on the western side of the

Cascades and the Lower and Middle Ellensburg of Washington on the eastern side of the Cascades. Although these pairs of floras are on opposite sides of the Cascades, the Pliocene floras show clear dominance of entire-leaved species over the Miocene floras (Wolfe and Hopkins, 1967: 70-71).

Using leaf characters as an index to climate, Wolfe (1971) plotted a temperature curve which, in general, summarizes the climatic trends deduced from floristic analysis of fossil leaf floras. This curve shows that there was a gradual cooling trend during the Paleocene, maximum warmth in the Late Eocene, a sharp temperature decline in the Oligocene and a second warming in the Middle Miocene. A cooling trend resumed at the end of the Miocene or early in the Pliocene, and continued throughout the Pliocene and into the Pleistocene (Dorf, 1959).

In the Tertiary floras of the Pacific Northwest, Chaney (1944:7) recognized several divergent types of vegetation which could be assigned to what he defined as Elements. According to him an "Element" is a group of fossil plants whose modern related species occupy a major geographic and climatic province. All together five Elements were recognized by Chaney (1944:7) from the Tertiary floras of western North America. In Miocene floras, especially Late Miocene floras of northwestern North America, three of these five elements can be recognized.

They are the West American Element, the East American Element and the East Asian Element. As identified by Chaney (1944:7), the main vegetational components, the living equivalent vegetation, and the principal climatic implication of these Elements are as follows:

The West American Element is "made up largely of conifers, with broad-leafed evergreens commonly present. The region which their most typical living equivalents now occupy is characterized by temperate climate, with winter rainfall and summer drought and with a moderate range of temperature."

The East American Element is "made up largely of broad-leafed deciduous genera, with conifers of minor importance. The region on the east side of North America now occupied by their living equivalents is characterized by temperate climate, with well distributed rainfall of which a considerable amount comes during the summer, and with seasonal extremes of temperature, most trees losing their leaves during the cold seasons."

The East Asian Element is "made up largely of genera now confined to eastern Asia, and including also genera occurring in other parts of the world. The climatic requirements of the living equivalents of this element are essentially the same as those outlined for the equivalents of the East American Element, except that the East Asian Element also includes genera which now range into the tropics.

The vegetational Elements described above are potentially recognizable from pollen taxa found in the Faraday Dam assemblage. In this flora the West American Element is probably represented by pollen of conifers such as: Abies, Tsuga, Pseudotsuga, Picea and Pinus; the East American Element is probably represented by Betula, Liquidamber, Fagus, Quercus, Carya and so on; the East Asian Element is represented by Pterocarya and Engelhardtia, and potentially by some members of the Taxodiaceae, that can also occur in the East American Element and the West American Element. However, because it is not always possible from fossil pollen to identify modern equivalent species, it is not possible in most cases to discriminate whether the pollen represents taxa found in one or more of the Elements. Thus, pollen of Abies may really represent all three Elements and Liquidamber the East American and/or the East Asian Element.

Modern Climate and Vegetation of the Pacific Northwest

The Cascade Range runs longitudinally through Oregon and Washington and exerts a profound influence on the climate and vegetation. It divides both states into distinct eastern and western climatic zones (Franklin and Dyrness, 1973). Climate to the west, where the study area is located, is generally mild, temperate, with prolonged cloudy periods

and long frost free seasons. Winters are mild, wet, and cool; summers are dry, and comparatively hot. Heavy precipitation, most of which occurs between October and March, falls as rain with occasional light snowfall. Elevation within the Cascades has a primary effect on local climate. Precipitation and snowfall increases and temperature decreases rapidly with an increase of elevation on the west slope of the Cascades.

The modern vegetation of the Pacific Northwest is predominantly coniferous. There are twenty-five conifer taxa which are dominant in the Pacific Northwest forests and many of them are endemic to this region or else most abundant and of largest size within it (Franklin and Dyrness, 1973:47; Cooper, 1957; Kirkwood, 1902). In the mesic temperate zone, deciduous hardwood or mixed hardwood-conifer forest is the typical vegetation type; but the wet mild climate with summer drought of the Pacific Northwest has reversed the normal pattern. In this region hardwoods are in a stressful situation (Franklin and Dyrness, 1973). In the northwestern Cascades region, the forest is characterized by the Tsuga heterophylla zone between 150 and 550 meters on the western slope of the Cascades. The study area belongs to this floristic zone. The dominant conifers are Pseudotsuga menziesii, Tsuga heterophylla and Thuja plicata. Abies grandis, Picea sitchensis, and Pinus monticola occur sporadically. Hardwoods are uncommon in this zone, and

almost always subordinant to the conifers. Alnus rubra, Acer macrophyllum and Castanopsis chrysophylla are most widespread. Populus trichocarpa and Fraxinus latifolia with Acer macrophyllum and Alnus rubra are found along the main water courses. Arbutus menzeisii and Quercus garryana may be found on the drier, lower elevation sites anywhere in the zone, but are not characteristic (Franklin and Dyrness, 1973:72).

Previous Work on Fossil Plants from the Faraday Dam Area

Although northwestern Oregon is rich in fossil plant localities very little work has been done in this region. Wolfe (1962) studied mega- and microfossils from eight Miocene floras, including Faraday Dam, from the northwestern Cascades region and published a very brief paper that provided only a list of taxa without indicating the particular flora they represented. However, his illustrations of pollen grains in that report were labeled with localities. Later, a list of identified megafossils prepared by Wolfe and R. W. Brown from Faraday Dam was published in Peck, et al. (1964:34, Table 5). Both of the above lists are incomplete and do not provide much information about the past vegetation of the Faraday Dam area. Therefore, further study of this particular flora is necessary for understanding the past vegetation and paleoclimate.

CHAPTER II

PROVENANCE OF THE SAMPLES

Locality and Accessibility

The study area is located in the western foothills of the Cascade Range within the Estacada Quadrangle (SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec.33, T.3S., R.4E. at the Cazadero Power Station), Clackamas County, Oregon (Fig. 1). The nearest town is Faraday. Elevation at the site is about 550 feet (183.33 meters) above sea level. To reach the plant-bearing beds it is necessary to pass through the Power Station which requires official permission; otherwise, the spot is quite accessible. During fall and winter the section is partially covered by high water.

Geologic Setting and Age of the Fossiliferous

Rocks at Faraday Dam

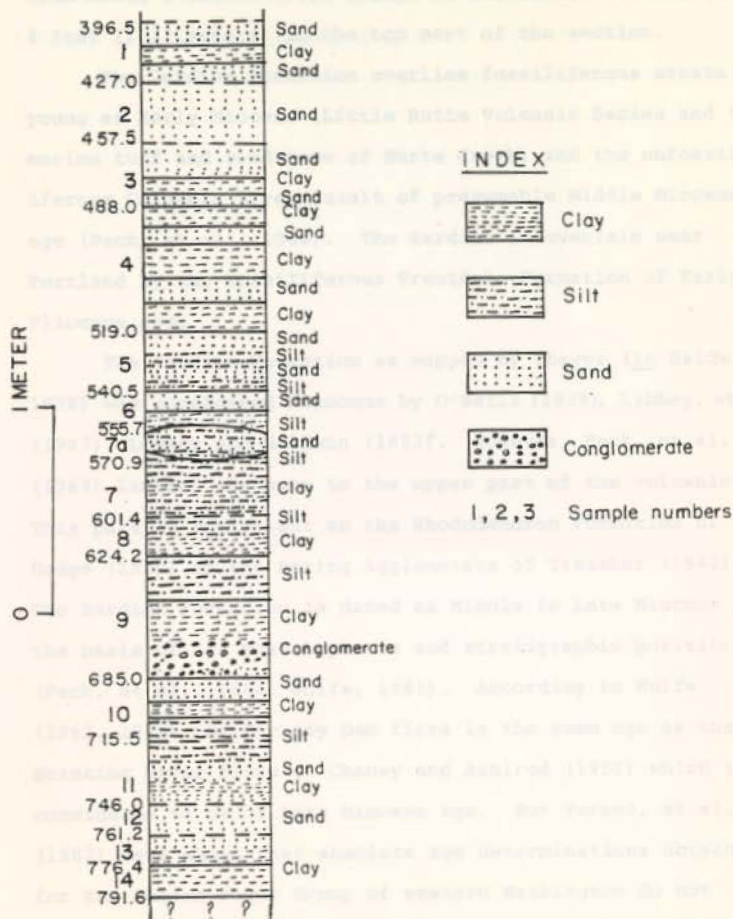
The Cascade Range of Oregon comprises two major rock sequences (Peck, et al., 1964). The older sequence, the volcanic rocks of the Western Cascade Range, make up most of the western slope of the Range. It consists of deformed and partially altered flows of Eocene to Late Miocene age. The younger sequence, the volcanic rocks of the High Cascade Range, form the crest and most of the eastern slope of the

Range. It consists predominantly of unaltered and undeformed andesitic and basaltic flows of Pliocene to Recent age.

The volcanic rocks of the Western Cascade Range have been divided into the following units: The Colestin Formation of Late Eocene age; the Little Butte Volcanic Series of Oligocene and Early Miocene; the Columbia River Basalt of Middle Miocene age and the Sardine Formation of Middle and Late Miocene age (Peck, et al., 1964; Wolfe, 1981).

The Faraday Dam mega- and microfossil assemblage comes from the Sardine Formation, which consists of volcanic flows, massive tuff-breccia, and mudflows and landslides deposited in the Sandy, Clackamas and Mollala drainage basins. At the study area the Sardine Formation is about 100 feet (33.33 meters) in vertical section, and the rocks are coarse grained upward (Fig. 2). The beds consist of alternating layers of thinly laminated siltstone, sandstone, conglomeratic sandstone and "varved" shale. There is precontemporaneous deformation in the thicker sandstone beds. Some sandstone lenses are 10 feet (3.33 meters) long; a few minor lignitic or carbonaceous lenses 4 feet (1.33 meters) long and 3 inches (.083 meter) thick are present. Micro-crossbedding is conspicuous in the sandstone beds; there is a fining upward trend of grains within the beds. The thickness of the sandstone beds increases upward in the section,

Fig. 2.--Lithology of the studied section



from about 2 inches (.055 meter) at the bottom to more than 4 feet (1.33 meters) in the top part of the section.

The Sardine Formation overlies fossiliferous strata as young as Early Miocene (Little Butte Volcanic Series and the marine tuff and sandstone of Butte Creek) and the unfossiliferous Columbia River Basalt of presumable Middle Miocene age (Peck, et al., 1964). The Sardine is overlain near Portland by the fossiliferous Troutdale Formation of Early Pliocene age.

The Sardine Formation as mapped by Thayer (in Baldwin, 1976) was considered Pliocene by O'Neill (1939), Libbey, et al. (1947), Lowrey and Baldwin (1952). However, Peck, et al. (1964) limited the name to the upper part of the volcanics. This part is equivalent to the Rhododendron Formation of Hodge (1938) or the Boring Agglomerate of Treasher (1942). The Sardine Formation is dated as Middle to Late Miocene on the basis of its fossil plants and stratigraphic position (Peck, et al., 1964; Wolfe, 1981). According to Wolfe (1962, 1981) the Faraday Dam flora is the same age as the Stinking Water flora of Chaney and Axelrod (1959) which is considered to be of Late Miocene age. But Turner, et al. (1983) have shown that absolute age determinations obtained for the Eocene Puget Group of western Washington do not entirely support previous paleobotanical age estimates or the paleobotanical stages defined within the section in western Washington. Until this type of conflict is resolved,

the use of paleobotanical stages as a basis for correlation should be treated circumspectly.

RESEARCH METHODS

Field and Laboratory Methods

I visited the field location on December 12th, 1935 in company with Dr. John Gray, Dr. A. J. Bouček, and Mr. Edmund Almond. We measured the exposed section and plotted the lithology (Fig. 2). The first sample was collected at approximately 11 feet (3.35 meters) below the spillway. Altogether fourteen samples were collected from distinct beds, at intervals from 2 inches (.05 meters) to 1 foot (.30 meter) depending on the lithology. A first sample (sample number 7A) represents a layer within the bed from which sample number 1 was collected. As they were collected, the samples were numbered and wrapped in newspaper.

I began collection of microfossils from the rocks on December 14th. The recovery of said insoluble pollen and spores from sedimentary and metamorphic rocks consists of four steps: (1) crushing, (2) sieving, (3) washing, and (4) mounting (Gray, 1931:238).

The size of pollen grains varied from 5 to 20 μ depending upon the lithology of the rock. Each grain was weighed, thoroughly cleaned with brush and a few cleaner,

CHAPTER III

RESEARCH METHODS

Field and Laboratory Methods

I visited the field location on December 12th, 1979 in company with Dr. Jane Gray, Dr. A. J. Boucot, and Mr. Raisuddin Ahmad. We measured the exposed section and plotted the lithology (Fig. 2). The first sample was collected at approximately 11 feet (3.96 meters) below the spillway. Altogether fourteen samples were collected from distinct beds, at intervals from 6 inches (.166 meter) to 2 feet (.66 meter) depending on the lithology. A fifteenth sample (sample number 7A) represents a lense within the bed from which sample number 7 was collected. As they were collected, the samples were numbered and wrapped in newspaper.

I began extraction of microfossils from the rocks on December 24th. The recovery of acid insoluble pollen and spores from sediments and sedimentary rocks consists of four steps: cleaning, disaggregation and dispersal, chemical extraction, and density separation (Gray, 1965:530).

The size of sample taken varied from 5 to 20 grams depending upon the lithology of the rock. Each sample was weighed, thoroughly cleaned with brush and ajax cleanser,

washed with distilled water and then disaggregated into small (pea size) fragments by gentle pounding. It was then transferred into a plastic beaker and covered with 48% to 50% HF acid overnight or for two to three days depending on the mineral content. Occasionally the sample was stirred. After it was no longer reactive with HF acid it was transferred from the beaker into a plastic tube using 10% HCl.

Treatment was necessary to eradicate silica gel. This was done by boiling each sample with HCl (10%) in a water bath for 30 minutes or more, depending upon the amount of gel. Samples were stirred from time to time during the boiling process. When all gel was dissolved, the sample was washed with distilled water until all acid was removed. The next step was to destroy extraneous organic matter. This was done by oxidation with 13% to 26% HNO_3 . This process was monitored very carefully to avoid destroying pollen and spores, which are also susceptible to oxidation. I generally started with 5 minutes of oxidation and gradually increased the time depending on the amount of organic matter present in the sample. After washing with distilled water, the sample was treated with 10% KOH, to make certain that the oxidation process had been completed. The sample was again washed 3 to 4 times with distilled water and sieved through 145 and 125 micron sieves to separate larger organic particles.

Flotation by which any remaining heavy minerals are separated from lighter organic particles and pollen and spores, was done by adding a saturated ZnCl_2 solution to the sample. This usually provides two clearcut layers of which the top layer contains organic materials including pollen and spores, and a bottom part which contains minerals. The organic layer was then pipeted out to another test tube. The bottom inorganic material was examined under the microscope for possible loss of pollen or spores before it was discarded.

Short time or controlled centrifugation was used for the differential removal of finely divided organic debris from the pollen-bearing organic part of the sample (Gray, 1965:571). Controlled centrifugation was done at increasingly shorter time intervals until pollen and spores began to remain in suspension. Completed samples were bottled with distilled water. To prevent fungal growth a few drops of phenol were added to each sample.

To get samples clean of organic and inorganic debris each sample was examined under the microscope after completing each step of the extraction process and when needed steps were repeated. To avoid loss of pollen and spores, and possible biasing of samples, all portions of samples to be discarded were also carefully examined as well. In extracting microfossils from rock, each step is very important and should be carefully done, and all

precautions should be taken to avoid contamination of any kind.

Microscopic Examination

Slides for optical examination were prepared with glycerin. For each sample 1000 pollen grains were counted. The grains were counted in vertical rows, skipping every two optical distances in a horizontal position. Both 40x and 100x (oil immersion) optics were used. Each grain was identified with the help of reference books (principally Wodehouse, 1935 and Erdtman, 1952, 1957, 1965), and under Dr. Gray's personal supervision. A systematic list was prepared after identifying the pollen and spores from all the samples.

Among the angiosperms, among the angiosperms, members of four families (Cyperaceae, Gramineae, Liliaceae and Typhaceae) are only herbaceous; 13 families include only woody plants. Among the 3 other families which contain both herbaceous and woody plants, 1 is represented possibly by a woody liana (Bignoniaceae-type, Caprifoliaceae); and 2 families could be represented by either herbaceous or woody plants (Rubiaceae, Geraniaceae-type (Chenopodiaceae), Polygonum and Compositae).

Of the families with more than 2 genera, Pinaceae leads with 5 genera, followed by Juglandaceae with 4 genera, and Fagaceae with 3 genera.

CHAPTER IV

TAXONOMY AND BIOGEOGRAPHIC RELATIONS OF
THE FARADAY DAM FLORASystematic List of Identified Pollen and Spores

Examination of the list of identified taxa of the Faraday Dam pollen flora shows that it contains at least 28 and possibly 30 families (depending on the disposition of pollen included in the arbitrary Taxodiaceae-Cupressaceae-Taxaceae group) and 31 genera (Table 1). Among these there are at least 1 bryophyte, 3 pteridophytes, at least 2 and possibly as many as 4 families of gymnosperms and 22 families of angiosperms. Among the angiosperms, members of four families (Cyperaceae, Gramineae, Lemnaceae? and Typhaceae) are only herbaceous; 13 families include only woody plants. Among the 5 other families which contain both herbaceous and woody plants, 1 is represented possibly by a woody liana (Lonicera-type, Caprifoliaceae), and 4 families could be represented by either herbaceous or woody plants [Ericaceae, Sarcobatus-type (Chenopodiaceae), Polygonum and Compositae].

Of the families with more than 2 genera, Pinaceae leads with 5 genera, followed by Juglandaceae with 4 genera, and Fagaceae with 3 genera.

The systematic list of the Faraday Dam pollen flora contains at least 13 genera which have been previously identified by Wolfe and Brown (in Peck, et al., 1964) from megafossils. These are identified on Table 1 by an asterisk. The list also includes genera and families of particular interest because they are new to the Faraday Dam flora and a source of further information.

TABLE 1

TAXONOMIC LIST OF THE FARADAY DAM POLLEN FLORA

(Systematic list is ordered according to G. M. Smith (1955); Hitchcock and Cronquist (1976); and J. P. Smith (1977))

Order: Anthocerotales

Family: Anthocerotaceae
Anthoceros

Order: Selaginellales

Family: Selaginellaceae
Selaginella
S. funiformis-type

Order: Eufilicales

Family: Osmundaceae
Osmunda

Family: Polypodiaceae

Order: Coniferales

Family: Pinaceae
*Abies
Cedrus
Picea
Pinus

TABLE 1--Continued

	<u>Pseudotsuga</u>
	<u>Tsuga</u>
	<u>T. heterophylla</u> -type
*Families	Taxodiaceae-Cupressaceae-Taxaceae
Order:	Glumiflorae
Family:	Cyperaceae
Family:	Gramineae
Order:	Typhales
Family:	Typhaceae
	<u>Typha</u>
	<u>T. angustifolia</u> -type
Order:	Spathiflorae
Family:	Lemnaceae?
Order:	Hamamelidales
Family:	Platanaceae
	<u>Platanus</u>
Family:	Hamamelidaceae
	* <u>Liquidamber</u>
Order:	Urticales
Family:	Ulmaceae
	<u>Celtis</u>
	<u>Ulmus/Zelkova</u>
Order:	Juglandales
Family:	Juglandaceae
	<u>Carya</u>
	<u>Engelhardtia</u>
	* <u>Juglans</u>
	* <u>Pterocarya</u>
Order:	Myricales
Family:	Myricaceae
	<u>Myrica</u>

TABLE 1--Continued

Order: Fagales

Family: Fagaceae

*Fagus*QuercusCastanea-type

Family: Betulaceae

*AlnusBetula

Order: Caryophyllales

Family: Chenopodiaceae

Sarcobatus-type

Order: Polygonales

Family: Polygonaceae Ulen and SporesPolygonum

Order: Salicales

Family: Salicaceae

*Salix-type

Order: Ericales

Family: Ericaceae

Order: Ebenales

Family: Symplocaceae

Symplocos

Order: Rosales

Family: Hydrangeaceae

Itea

Order: Myrtales

Family: Onagraceae

Order: Cornales

Family: Nyssaceae

Nyssa

Order: Celastrales

Family: Aquifoliaceae

Ilex

TABLE 1--Continued

Order: Euphorbiales

Family: Buxaceae

Pachysandra

Order: Dipsacales

Family: Caprifoliaceae

Lonicera-type

Order: Astrales

Family: Compositae

Description of the Pollen and Spores

Family: Anthoceroceae
Anthoceros L.

Diagnostic characters: The spores are distinguished by the trilete aperture and echinate surface pattern.

Description: Spores spherical, size range from 37.2 to 45.6 microns in diameter, wall about 3.6 microns thick, including the spines. Spores trilete. Surface pattern echinate, spines sharply pointed and about 1.2 microns long.

Discussion: This genus was identified from the description given by Erdtman (1965) and confirmed by Dr. Gray.

There are no known megafossil records from North America. Anthocerotaceae as well as many cryptogams do not preserve well because of the small size and delicate nature of their plant body (Schuster, 1966; Culberson, 1955).

There are also no other known spore records from North America or from the Pacific Northwest, but a few spores are

reported from the Tertiary of Europe (Lacey, 1969). The lack of fossil spores may also be because they are less resistant to decay than other spores.

This genus contains about 50 species (Wagner, personal communication) of cosmopolitan distribution; six of them grow in the Pacific Northwest (Clark and Frye, 1928; Sanborn, 1929).

Family: Osmundaceae
Osmunda L.

Diagnostic characters: The spores are distinguished by the trilete scar, and the presence of small, warty, irregular processes on the surface.

Description: Spore more or less spheroidal, size range from 34.2 to 49.4 microns. Wall about 1.2 microns thick. Scar rays 18.0 to 20.0 microns long, almost reach to the equatorial region. Surface pattern of conspicuously warty geometrically irregular processes.

Discussion: This genus was identified from the description given by Erdtman and Sorsa (1971) and confirmed by Dr. Gray.

There are megafossil records for Osmunda from the Paleocene and Eocene of North America, and Miocene records from the Pacific Northwest (LaMotte, 1952), including one from the Miocene of the northwestern Cascades (Wolfe, 1962).

Spores were identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958,

1975) from the Miocene of the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) also identified this genus from the Oligocene and Pliocene of Oregon, and the Miocene of Washington, Idaho, and California.

Osmunda has 10 species (Willis, 1973) scattered throughout the tropics and temperate regions. None of the species now grow in the Pacific Northwest.

Family: Selaginellaceae
Selaginella Beauv.
S. funiformis-type

Diagnostic characters: The microspores are characterized by their more or less spherical shape, trilete aperture system, and perispore.

Description: The spores are spherical, somewhat flattened in polar position. Grain size ranges from 44.4 to 67.6 microns (excluding the perispore). Wall thickness about 1.2 microns. A thin, granular and wrinkled perispore surrounds the exospore, and extends from 4.8 to 7.8 microns beyond the spore body. Spores trilete, scar arms approximately 10.8 microns long. Surface pattern coarsely scabrate to finely verrucate.

Discussion: This genus was identified from the description given by Erdman (1957) and by Erdtman and Sorsa (1971) and confirmed by Dr. Gray. The spores are morphologically similar to those of S. funiformis because of the character of the perispore.

There are very few megafossil records attributed to Selaginella in the Tertiary. Records are reported from the Paleocene of Colorado and Montana (LaMotte, 1952). So far, no Tertiary megafossils of Selaginella are known from the Pacific Northwest. The plants may not preserve well because of their soft vegetative parts.

Spores have been reported by Wolfe (1962) from the Miocene of the northwestern Cascades, Oregon and also by Gray (1958, 1964) from beds of the same age from the Columbia Plateau, Oregon and from Washington, Idaho and California.

The genus has 600 species, which are herbaceous and mostly tropical in distribution with a few temperate species. Selaginella often grows on boggy hillsides or damp places (Willis, 1973). The spores are wind borne.

Selaginella has 37 species distributed in North America. Three of them grow in the Pacific Northwest (Hitchcock and Cronquist, 1976) in arid regions (Wagner, personal communications).

Family: Polypodiaceae

A large number of fern spores were present in the samples whose classification is somewhat uncertain. Most probably belong to the family Polypodiaceae sensu lato.

Two major types of spores were identified:

(A) Monolete and (B) Trilete. Both monolete and trilete types have variations.

A. Monolete type: Among the monolete spores there are two basic types:

Type I: Spores kidney-bean shape in lateral view, elliptical in polar position. Grain size ranges in length from 25.2 to 48.0 microns and in width from 14.4 to 22.8 microns, commonly 31.2 by 15.6 microns. Wall about 1.2 microns thick. Scar 15.6 to 21.0 microns long, present on the concave side of the grain.

Type II: Spores commonly in lateral position and kidney-bean shape. Grain size ranges from 31.2 to 72.0 microns in length and from 20.0 to 52.8 microns in width. Because of the warty surface pattern the wall appears thick, about 2.4 to 3.6 microns. Scar on the flat or concave side. Surface warty, warts irregular in shape and size, gradually decreasing in size at the scar margin where they are almost scabrate.

B. Trilete type: Among the trilete spores there are three different kinds:

Type I: Spores spherical in polar view. Grain size 18.0 microns, wall about 1.2 microns thick. Spores trilete, scar wavy, exine scabrate.

Type II: Spores triangular in polar view, diameter ranges from 24.0 to 54.8 microns, commonly 28.0 microns. Wall thickness about 1.2 to 2.4 microns. Grain trilete,

scar ray straight, 10.8 to 15.0 microns long, in some cases almost extending to the equator. Surface psilate.

Type III: Spores spherical in polar view, diameter 31.2 microns. Trilete scar indistinct. Surface pattern warty, warts regular in arrangement.

Discussion: Spores of the Polypodiaceae were identified from the descriptions given by Erdtman and Sorsa (1971) and confirmed by Dr. Gray. There are a few megafossils attributed to the Polypodiaceae reported from the early Tertiary of California (LaMotte, 1952).

Polypodiaceae spores have been identified from the Miocene of the northwestern Cascades (Wolfe, 1962), from middle and late Tertiary age rocks of Oregon, Washington, Idaho, and California (Gray, 1958, 1964, 1975) and from the Miocene of the Queen Charlotte Island (Martin and Rouse, 1966).

The Polypodiaceae is a large family containing about 50 genera (Willis, 1973) with a cosmopolitan distribution. In the Pacific Northwest 21 genera and 41 species are presently found (Hitchcock and Cronquist, 1976).

Family: Pinaceae
Abies Mill.

Diagnostic characters: Pollen grains readily distinguished from other winged-grained pollen by their overall large size, small, pendulous bladders and thick,

coarse textured cap. *Exine have also been reported by Wolfe*

Description: Pollen grains very large, body always larger than bladders (approximately double bladder size).

Overall size of grains range from 108.9 to 132.0 microns in length and 60.0 to 84.0 microns in width. Body size length ranges from 81.0 to 91.0 microns and width from 65.0 to 78.8 microns. Bladder size length is from 44.2 to 53.0 microns; width from 52.0 to 70.8 microns. Exine cap thick, about 4.8 to 6.0 microns, thinner proximally at the middle of the body where it measures about 3.6 microns. Grains monocolpate, colpi not prominent, on the distal side of the body. Surface pattern varies between body and bladder; bladder larger and more irregular reticulum than body. Reticulum fine on the distal pole of body, almost psilate towards the colpi.

Discussion: This genus has been identified from the modern descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossils of fir have been reported from the Paleocene and Eocene of Alaska and Colorado (LaMotte, 1952). Most records from the Pacific Northwest are of Oligocene and later age. Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam and by Smiley (1975) from Clarkia, Idaho.

Abies pollen grains have also been reported by Wolfe (1962) from the Miocene of the northwestern Cascades, Oregon and by Gray (1958, 1975) from the Columbia Plateau and Clarkia, Idaho. Gray (1964) has also identified fir pollen from different late Tertiary localities of Oregon, Washington, Idaho, and California.

Abies contains 33 to 40 species (Sargent, 1949; Preston, 1976; Wodehouse, 1935) of large, wind-pollinated trees. They are scattered widely throughout North and Central America, Europe, Asia and North Africa. For the most part firs are restricted to cool, humid climate. There are nine species native to North America and seven of them grow in western North America (Hitchcock and Cronquist, 1976; Sargent, 1949).

Family: Pinaceae
Cedrus Link.

Diagnostic characters: Cedrus pollen is distinguished by its medium size, laterally broadly attached bladders, and sweeping curve of the grain in lateral position.

Description: Pollen grains medium size. Overall length ranges from 70.0 to 79.0 microns and width from 50.0 to 68.0 microns. Wall about 2.4 microns thick. Bladders small and inseparable from the body proper in lateral position, without reentrant angle at attachment to body. Surface pattern reticulate, reticulum uniform and moderately coarse on body area; coarser and more irregular on

the bladders.

Discussion: The genus was identified from the description given by Erdtman (1957) and confirmed by Dr. Gray.

The only megafossil records from North America are from the Oligocene of Oregon and Miocene of California (LaMotte, 1952).

Cedrus pollen has been identified from the Miocene of the Columbia Plateau, Oregon and Clarkia, Idaho by Gray (1958, 1975). Gray (1964) also identified cedar pollen from Oligocene through Miocene age rocks of the Pacific Northwest.

Cedrus has about 4 wind-pollinated species of large trees mostly distributed in Asia Minor, the Himalayan region and in North Africa. None grow in North America.

Family: Pinaceae
Pinus L.

Two basic types of pine grains were identified.

Haploxyylon-type

Diagnostic characters: Pollen grains are distinguished by bladders laterally attached broadly along the whole width of the body. Shape ovoid in polar view.

Description: Pollen grains small, overall size ranges from 70.0 to 80.4 microns in length and 42.0 to 60.0 microns in width. Body length (excluding bladder) ranges from 39.6 to 57.0 microns and from 41.0 to 43.2 microns in width.

Bladder length ranges from 39.2 to 45.0 microns; width from 37.2 to 48.8 microns. Body exine about 2.4 microns. Monocolpate, colpi very obscure, on distal side of grain. Body surface pattern reticulate becoming finer towards bladders and furrow but increasing in size on bladders.

Sylvestris-type

Diagnostic characters: Pollen grains are distinguished by their constricted bladder attachment with the body, which make the bladders very distinct from the body. Shape like three intersecting circles in polar view.

Description: Pollen grains small, overall size ranges from 78.0 to 96.6 microns in length and 70.0 to 92.0 microns in width. Body length (excluding bladders) ranges from 42.0 to 61.0 microns and from 25.2 to 49.0 microns in width. Bladder length ranges from 30.0 to 34.8 microns and from 34.8 to 46.8 microns in width. Monocolpate, colpi very obscure, present on the distal side of grain. Surface pattern reticulate, coarser on bladders than body.

Discussion: This genus and the Pinus sylvestris-type pollen were identified from the descriptions given by Wodehouse (1935). Pinus haploxyton-type was identified from the description and illustrations given by Boulter and Chaloner (1970). Both identifications were confirmed by Dr. Gray. Pinus haploxyton-type pollen cannot be compared with the pollen of any known species of living pine.

Fossil records indicate that pine was well represented throughout North America during the Tertiary. Megafossils were reported from the Paleocene of Alaska and from Iceland. The earliest Pacific Northwest report is from the Eocene of Washington (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Smiley (1975) from Clarkia, Idaho.

Pinus pollen grains have been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Pine pollen has also been identified from the Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California (Gray, 1964).

Pinus has 66 to 68 (Wodehouse, 1935; Preston, 1976) wind-pollinated species of trees or rarely shrubs. They are widely scattered over the Northern Hemisphere. About 35 species of Pinus are native to the United States and Canada and at least 18 species grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Pinaceae
Picea Dietr.

Diagnostic characters: Pollen grains characterized by large size and lateral, broadly attached bladders whose pattern merges with that of the body.

Description: Pollen grains large, overall size including the bladders ranges between 130.0 to 132.0 microns

in length and 78.0 to 87.0 microns in width. Exine about 3.6 microns thick. Bladders smaller than body; laterally broadly attached so that the overall appearance of the grain is kidney-bean shaped. Pollen grain monocolpate, furrow a shallow groove between the bladders. Surface pattern reticulate, coarser on the bladder than the body.

Discussion: This genus was identified from the description given by Wodehouse (1935) and confirmed by Dr. Gray.

Megafossil records of spruce indicate that this genus was widespread throughout North America during the Tertiary period. Megafossils are reported as early as the Paleocene and Eocene from Alaska, Montana, and British Columbia; records from the Pacific Northwest are of much younger age (LaMotte, 1952). Wolfe (1962) identified megafossils of Picea from the Miocene of the northwestern Cascades.

Picea pollen has also been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1964) from the Columbia Plateau, Oregon and from different localities of Oregon, Washington, Idaho, and California.

Picea includes 37 to 50 (Wodehouse, 1935; Preston, 1976; Willis, 1973) wind-pollinated species of large trees. Most of them are restricted to the cooler part of the Northern Hemisphere. In North America there are 7

indigenous species and 3 of them grow in the Pacific Northwest (Sargent, 1949; Hitchcock and Cronquist, 1976).

Family: Pinaceae
Pseudotsuga (Raf.) Sudw.

Diagnostic characters: Pollen grains characterized by their large size, absence of apertures and wings, and psilate surface pattern.

Description: Pollen grain spheroidal, size range from 60.0 to 96.0 microns. Inaperturate. Wall thickness about 1.2 microns. Surface pattern psilate.

Discussion: This genus was identified from the description given by Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that Douglas fir was mostly distributed in the western part of North America during the Tertiary period; megafossils are reported from the Paleocene of Alberta and British Columbia, and from Miocene and younger deposits of the Pacific Northwest (LaMotte, 1952).

Pseudotsuga pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1964) from the Columbia Plateau, and from the Oligocene through Pliocene of Oregon, Washington, and California.

Pseudotsuga includes 4 to 11 (Wodehouse, 1935; Sargent, 1949; Preston, 1976) wind-pollinated species of large trees. They are distributed in the hills and

mountains of the western United States and Canada, most abundantly in western Washington and Oregon. Douglas fir also occurs in southern Japan, southwestern China, and Taiwan (Wodehouse, 1935).

Family: Pinaceae
Tsuga (L) Carr.
T. heterophylla-type

Diagnostic characters: Pollen distinguished by their inaperturate, spheroidal grains, and rugulate surface pattern with microspines.

Description: Pollen circular in polar view with a saucer shaped body encompassed by slight fringed border, that may vary in width. Size range from 48.0 to 68.0 microns. Exine about 2.4 microns. Inaperturate. Surface pattern coarsely rugulate, sometimes extended to fringe-like wing at the equator. Spines about 1 micron long among the rugae.

Discussion: This genus was identified from the description given by Wodehouse (1935) and attributed to T. heterophylla-type on the basis of the spiny, rugulate surface. The identification was confirmed by Dr. Gray.

Most of the megafossil records of hemlock in North America and in the Pacific Northwest are from the later part of the Tertiary period, especially from the Pliocene. However, there is one Eocene megafossil reported from Colorado (LaMotte, 1952). Wolfe (1962) has identified

megafossils of hemlock from the Miocene of the northwestern Cascades, Oregon. Since most of the megafossil records are from the late Tertiary, it is evident that Tsuga was widespread during that time in the Pacific Northwest (LaMotte, 1952).

Tsuga pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho and by Martin and Rouse (1966) from Queen Charlotte Island, Canada. Gray (1964) also identified hemlock pollen from Oligocene throughout Pliocene age rocks of the Pacific Northwest.

Tsuga has 10 to 14 species (Wodehouse, 1935; Preston, 1976) of wind-pollinated trees. They are widely distributed throughout the temperate regions of North America and eastern Himalayas to Japan and Taiwan. In North America there are 4 native species, 2 eastern and 2 western (Preston, 1976). Two species now grow in the Pacific Northwest (Hitchcock and Cronquist, 1976), including Tsuga heterophylla whose pollen most closely matches that of the fossil specimens.

Family: Taxodiaceae Warming

Diagnostic characters: Pollen grains are distinguished by their spherical shape and presence of papillae.

Description: Pollen grains spherical, size range from 19.7 to 39.6 microns, wall thickness about 1.2 microns. Monoporate?, pore, if present, situated at the tip of a papillae. Size and shape of the papillae varies from a long neck to a slight protrusion; papillae straight or curved hook; size range from 2.4 to 6.0 microns. Surface with deciduous gemmae which often fall off leaving surface of psilate.

Discussion: This family was identified from descriptions given by Erdtman (1957) and Wodehouse (1935) and verified by Dr. Gray.

Variable size and shape of papillae indicates that there is more than one genus present in the samples. Otherwise pollen grains of this family are very homogenous in appearance and difficult to identify in routine counting with a light microscope.

Megafossil records indicate that several genera of the Taxodiaceae were widespread throughout North America during the Tertiary period including Taxodium, Sequoia, Glyptostrobus and Metasequoia. Megafossils of Paleocene age were reported from Greenland, Alaska, Canada, and Montana. The Pacific Northwest records belong to the Oligocene and younger epochs (LaMotte, 1952). Megafossil of this family have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962). Taxodium and Sequoia were identified by Wolfe and Brown (in Peck, et al., 1964)

from Faraday Dam and Taxodium, Metasequoia, and Glyptostrobus by Smiley (1975) from Clarkia, Idaho.

Pollen of Taxodiaceae has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho.

The Taxodiaceae includes 10 genera and 16 species of wind-pollinated trees and shrubs. They are distributed in eastern Asia and North America. Of the three genera growing in the United States, Taxodium only grows in the eastern region and Sequoia and Sequoiadendron only grow in the west principally in California.

NOTE: Grains whose affinities with the Taxodiaceae could not be determined because of preservation plus others that may belong to the Cupressaceae and/or Taxaceae, which have pollen of similar size and morphology, are included in the taxonomically artificial category T-C-T. Pollen of the Cupressaceae and Taxaceae do not have papillae but pollen of all three families very often splits open. In the case of the Taxodiaceae it is hard to recognize the papillae when it splits and difficult to separate Taxodiaceous pollen from that of the other two families.

Megafossils of all three families have been recognized from North America. Megafossils of Taxodiaceae (e.g. Taxodium), Taxaceae (Taxus) and Cupressaceae (Thuja, Libocedrus, Juniperus) are reported as early as the Paleocene from

Greenland and Alberta. Pacific Northwest records of these families are mostly from the Miocene (LaMotte, 1952).

Megafossils of Cupressaceae have been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Smiley (1975) from Clarkia, Idaho.

Pollen grain of Cupressaceae have been identified from the Miocene of the northwestern Cascades by Wolfe (1962); Gray (1958, 1975) has identified T-C-T pollen grains from the Miocene of the Columbia Plateau and Clarkia, Idaho. T-C-T pollen has also been identified from Oligocene through Pliocene age rocks from the Pacific Northwest (Gray, 1964).

The Cupressaceae has 15-16 genera and 140 species, and the Taxaceae has 3 genera and 13 species of wind-pollinated trees or shrubs (Lawrence, 1951). Two genera of Taxaceae and 5 genera of Cupressaceae grow in the United States, of which one taxaceous genus and four cupressaceous genera grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Cyperaceae Juss.

Diagnostic characters: The identified pollen grains of this family are distinguished by their pear-shape and the presence of lacunae.

Description: Pollen grains are pear-shaped and often folded. Size range from 51.6 to 60.0 microns in length and from 38.9 to 45.0 microns in width. Lacunae are very delicate, often indistinguishable from the grain surface but

sometimes small, irregular in outline and arrangement and marked by coarse texture. Number of lacunae variable in different grains from 3 to as many as 8. Grain surface scabrate.

Discussion: This family was identified from the pollen descriptions given by Erdtman (1952) and confirmed by Dr. Gray.

Although there are many variations among the pollen of the sedge family it is seldom possible to identify them to generic or specific levels. In the Faraday Dam assemblage this is partly because of inadequate reference material and partly because of the very few grains in the samples.

A large number of megafossil records indicate that this family was widely distributed throughout North America during the Tertiary period. The earliest megafossils are recorded from the Paleocene of Greenland, Montana, and Wyoming. Records in the Pacific Northwest are found as early as the Oligocene period (LaMotte, 1952). Megafossils attributed to the sedge family were also identified from the Miocene of the northwestern Cascades (Wolfe, 1962).

Sedge pollen has also been identified by Wolfe (1962) from the Miocene of the northwestern Cascades, and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) also identified pollen of this family from the Oligocene through Pliocene of Oregon, Washington, Idaho, and California.

This is a large family of monocotyledons. The family contains about 90 genera and 4,000 species (Willis, 1973) of wind-pollinated herbaceous plants. Sedges have cosmopolitan distribution and about 10 genera grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Gramineae Juss.

Diagnostic characters: Pollen grains of this family are distinguished by their single annulate aperture, and psilate surface pattern.

Description: Pollen grains spheroidal, diameters range from 18.0 to 33.0 microns, wall about 1.8 microns thick, Monoporate; pores slightly protruding, annulate, operculum present; pore diameter about 2.4 microns. Surface psilate-scabrate.

Discussion: This genus is identified from the pollen descriptions given by Erdtman (1952) and Wodehouse (1935), and confirmed by Dr. Gray.

The grains of the grass family are very uniform in appearance; it is therefore very difficult to identify them at the generic and specific levels. With large numbers of grains and with stereoscan techniques it might have been possible to assign them to genera. But for the few grains in the samples, and using only a light microscope for routine counting, it was not possible for me to identify the pollen grains below the family level.

Grass megafossils are not very abundant, most probably because herbaceous plants are not very resistant to decay. The earliest North American megafossil records for grasses are from the Paleocene of Alaska and Canada. There is a Pacific Northwest record from the Miocene of Washington (LaMotte, 1952).

Pollen grains of grasses have been identified from the Miocene of the northwestern Cascades (Wolfe, 1962) and by Gray (1958) from the Columbia Plateau. Gray (1964) also identified grass pollen from Oligocene through Pliocene age beds of Oregon, Washington, Idaho and California.

This is one of the largest families of flowering plants, comprising about 620 genera and 10,000 species of predominantly wind-pollinated herbaceous plants (Willis, 1973). Grasses are cosmopolitan in distribution and large numbers of genera and species grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Typhaceae

Typha L.

T. angustifolia-type

Diagnostic characters: The single identified pollen grain is distinguished by its one pore and reticulate surface pattern.

Description: Pollen spheroidal. Diameter of grain 31.2 microns; wall thickness 2.6 microns. Pollen monoporate. Surface pattern reticulate, with irregular reticulum.

Discussion: This genus was identified from the modern descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossil records indicate that this genus was widespread throughout North America during the Tertiary period. Megafossils are reported from the Paleocene of Alaska, Greenland and Canada and from the Miocene of the Pacific Northwest (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and from Clarkia, Idaho by Smiley (1975).

Typha pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Miocene of the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) also identified cattail pollen from varied Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California.

Typha contains 15 (Lawrence, 1951) to 20 (Willis, 1973) wind-pollinated herbaceous species. It is more or less cosmopolitan in distribution throughout the riparian and estuarine marshes of temperate and tropical regions of both hemispheres. At least 2 species of cattail grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Lemnaceae?

Diagnostic characters: Pollen distinguished by its single aperture, small size and echinate surface pattern.

Description: Pollen grain spheroidal. Size 21.0 microns. Wall about 1.2 microns thick. Monoporate, pore round. Surface pattern echinate, spines about 1.2 microns long.

Discussion: A single pollen grain possibly attributed to the family Lemnaceae was identified from the description given by Erdtman (1952) and confirmed by Dr. Gray.

Megafofossils of Spirodela are reported as early as the Paleocene from Alberta, Montana, and British Columbia (LaMotte, 1952). No fossils attributed to this family have been reported from the Pacific Northwest, either as mega-fossils or pollen.

The family Lemnaceae has 4 genera and 13 species of cosmopolitan hydrophytes (Lawrence, 1951). Among them three genera and five species of Lemnaceae grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Platanaceae
Platanus L.

Diagnostic characters: Pollen grains distinguished by their small size, short, broad colpi with textured membrane, and uniform reticulum.

Description: Pollen grains spheroidal, size range from 13.0 to 20.8 microns, commonly 15.6 microns. Wall about 0.6 microns thick. Tricolpate, colpi short and wide, with distinct scabrate sculptured membrane. Sculpture pattern finely and uniformly reticulate.

Discussion: This genus was identified from the descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that Platanus was widespread throughout North America during the Tertiary. There are megafossil records as early as the Paleocene from Alaska, Canada, Montana, and Colorado, and from the Eocene of the Pacific Northwest (LaMotte, 1952). Megafossils are also reported from the Miocene of the northwestern Cascades by Wolfe (1962), from Faraday Dam by Wolfe and Brown (in Peck, et al., 1964) and by Smiley (1975) from Clarkia, Idaho.

Platanus pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Pollen of this genus has also been identified from the Oligocene through Pliocene of the Pacific Northwest region (Gray, 1964).

Platanus has 4 (Wodehouse, 1935) to 6 or 7 (Preston, 1976) wind-pollinated species. They are distributed in eastern and western North America (Arizona, New Mexico, southern California), Mexico, Central America and southwestern Asia. Among the species, three are native to the United States.

Family: Hamamelidaceae
Liquidamber L.

Diagnostic characters: Pollen grains distinguished by irregular size and shape of pores, scabrate textured pore membrane and microreticulate surface pattern.

Description: Pollen grain spheroidal. Size range from 23.4 to 38.0 microns, wall thickness 2.4 microns. Periporate, pore number varies from 6 to 17, commonly 12. Pores irregularly arranged over the surface of the grain; shape and size variable: in some cases round, about 4.8 microns in diameter; in other cases elliptical with size range 6.2 to 9.4 microns in length and 3.2 to 6.0 microns in width. Pores covered with scabrate textured membrane. Surface pattern microreticulate.

Discussion: The genus was identified from the descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that Liquidamber was widespread throughout North America during the Tertiary. Megafossil as early as the Paleocene are reported from Alaska and Greenland, and from the Oligocene of the Pacific Northwest (LaMotte, 1952). Megafossil are also reported from the Miocene of the northwestern Cascades by Wolfe (1962), from Faraday Dam by Wolfe and Brown (in Peck, et al., 1964), and by Smiley (1975) from Clarkia, Idaho.

Pollen grains of Liquidamber have been identified by Wolfe (1962) from the Miocene of the northwestern Cascades, and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) also identified Liquidamber pollen from Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California.

This genus contains 4 species of wind-pollinated large trees (Wodehouse, 1935; Preston, 1976). Among the 4 species, one is spread from Connecticut to Texas, two are found in Asia and one in Mexico and Central America (Preston, 1976; Wodehouse, 1935).

Family: Ulmaceae
Celtis L.

Diagnostic characters: Pollen grains distinguished by their three operculate apertures, and coarsely scabrate surface pattern.

Description: Pollen spheroidal. Size range from 30.0 to 37.0 microns. Wall about 1.2 microns thick. Triporate, pores circular to elliptical and about 4.8 microns in diameter, operculate and equidistantly arranged at equator. Surface pattern coarsely scabrate.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that Celtis was widespread throughout North America during the Tertiary. Megafossils

of Paleocene age have been reported from Montana. The earliest Pacific Northwestern megafossils were reported from the Oligocene of Oregon (LaMotte, 1952).

Celtis pollen of Miocene age was identified by Gray (1958) from the Columbia Plateau, Oregon and from the Oligocene through Pliocene of Oregon, Washington, Idaho and California (Gray, 1964).

Celtis has 70 species of wind-pollinated small trees or shrubs (Preston, 1976). They are scattered throughout the north temperate and tropical regions. Five species of Celtis grow in North America; one species is found in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Ulmaceae

Ulmus L.

Diagnostic characters: Pollen grains distinguished by their spherical to slightly angular shape in polar view, equatorial pores and rugose surface pattern.

Description: Pollen grains are always in polar position, polar geometry round to semiangular; suboblate in equatorial view. Size range from 20.0 to 30.0 microns, commonly 26.4 microns. Periporate, 4 (few grains) to 7 pores; pores elliptical and arranged at irregular intervals at the equator. Surface pattern rugose.

Discussion: Pollen of this genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

The fossil record indicates that elm was widespread throughout North America during the Tertiary period. Megafossils have been identified as early as the Paleocene from Alaska, Canada, and Montana. The earliest reports from the Pacific Northwest are of Eocene age (LaMotte, 1952). Megafossils have been identified by Wolfe (1962) from the Miocene of the northwestern Cascades, by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Ulmus pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified elm pollen from Oligocene through Pliocene age rocks of the Pacific Northwest.

Ulmus has 20 to 25 (Preston, 1976; Willis, 1973) wind-pollinated species of trees. They are scattered throughout the Northern Hemisphere, Mexico, Indochina and Himalayan region. Six species are native to the United States. None now grow in the Pacific Northwest.

Family: Juglandaceae

Carya Nutt.

Diagnostic characters: The grains are characterized by spherical polar shape, 3 to 4 pores displaced off the equator and psilate surface pattern.

Description: Pollen grain spherical in polar position; flattened equatorially. Size range from 41.6 to 65.0

microns, commonly 46.8 microns. Wall about 1.2 microns thick. Triporate or tetraporate, rarely 5 pores, pores arranged equidistantly, slightly displaced off the equator. Surface pattern psilate.

Discussion: This genus was identified from pollen descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that hickory was widely distributed throughout North America during the Tertiary. Megafossil records are reported as early as the Paleocene from Alaska, Greenland, Canada, and Washington in the Pacific Northwest (LaMotte, 1952). Megafossils have also been identified by Wolfe (1962) from the Miocene of the northwestern Cascades, By Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Carya pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified this pollen from the Oligocene through Pliocene of Oregon, Washington, Idaho, and California.

Carya contains 12 species (Preston, 1976) of wind-pollinated trees. They are distributed largely in eastern North America, from the valley of the St. Lawrence River to the Highlands of Mexico, and in southern China.

Family: Juglandaceae
Engelhardtia Leschen.

Diagnostic characters: Pollen grains distinguished by their small size, triangular-rounded polar shape, triporate apertures and scabrate surface pattern.

Description: Pollen grain triangular in polar position and oblate to peroblate in equatorial view. Size range from 12.0 to 16.8 microns in polar diameter, commonly 13.2 microns. Wall about 1.2 microns thick. Triporate, pores circular to elliptical, pore diameter from 2.4 to 3.6 microns. Surface pattern scabrate.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossils attributed to Engelhardtia from as early as the Paleocene were identified from Alaska; Pacific Northwest records are from Oligocene and younger age rocks (LaMotte, 1952).

Engelhardtia pollen has been identified by Gray (1958) from the Miocene of the Columbia Plateau, Oregon and from Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California (Gray, 1964).

Engelhardtia contains 8 wind-pollinated species (Willis, 1973) of trees. Five species are distributed from the Himalayas to Taiwan throughout southeast Asia and Malaysia. Three species occur in Mexico and Central America.

Family: Juglandaceae
Juglans L.

Diagnostic characters: Pollen grains characterized by pores restricted to equator and one polar hemisphere, the subexinous thickening at the pore, and round polar shape.

Description: Pollen grains spherical in polar and oblate to suboblate in equatorial position. Polar size from 21.6 to 54.0 microns; wall about 1.2 microns thick. Periporate; pore number varies from 10 to 19, commonly 13, arranged on equator and/or in one polar hemisphere. Pores round to elliptical with subexinous thickening. Pore size from 2.4 to 3.6 microns. Surface pattern scabrate.

Discussion: Pollen grains of Juglans are very similar to those of Pterocarya in size, shape and pore geometry. There are no definite criteria to separate pollen of these two genera. However, it has been noted that Juglans tends to have a higher number of pores than Pterocarya (Wodehouse, 1935; Gray, personal communication), that the subexinous thickening surrounding the pore are more prominent in Juglans, and that Juglans pollen often has pores (or more pores) in one pole than pollen of Pterocarya.

The genus was identified from the descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that walnut was very widespread throughout North America during the Tertiary period.

Megafossil records from as early as the Paleocene are reported from Alaska, Greenland, Canada, Wyoming, and Colorado. The earliest Pacific Northwestern records are from Eocene rocks (LaMotte, 1952). Megafossils have been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Juglans pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified walnut pollen from Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California.

Juglans contains 15 wind-pollinated species (Willis, 1973) of trees. They are distributed in the Mediterranean region, eastern Asia, Indochina, North and Central America and the Andes. There are 6 species native to North America (Preston, 1976). On the West Coast two species grow in California (Sargent, 1949; Preston, 1976).

Gray (1964) has also identified pollen of this genus.
 Family: Juglandaceae
Pterocarya Nutt.

Diagnostic characters: Pollen grains distinguished by their more or less circular shape in polar view, and their 6 to 8 predominantly equatorial pores.

Description: Pollen grain circular in polar view and suboblate in equatorial view. Size range from 24.6 to 34.8

microns, commonly 26.4 microns. Exine 1.2 microns. Grain periporate, with pore numbers varying from 5 to 9, but the majority of the grains having between 6 to 8 pores. Surface psilate.

Discussion: Pollen of Pterocarya can be confused with that of Juglans. I used the characters given by Wodehouse (1935) which indicate that pollen of Pterocarya tends to have fewer pores and is slightly smaller in size than walnut pollen. My identification of the pollen of this genus was confirmed by Dr. Gray.

Megafossils are reported as early as the Paleocene from Alaska and Greenland. Pacific Northwestern records are mostly from the Miocene (LaMotte, 1952). Megafossils have been reported from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Pterocarya pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified pollen of this genus from Oligocene through Pliocene age rocks from the Pacific Northwest.

Pterocarya has 10 (Lawrence, 1951; Willis, 1973) wind-pollinated species of trees found in the Transcaucasian region, China, and Japan (Willis, 1973; Wodehouse, 1935).

Family: Myricaceae
Myrica L.

Diagnostic characters: Pollen grain distinguished by its subtriangular polar shape, three pores, presence of vestibulum and microscabrate surface pattern.

Description: Pollen grain subtriangular in polar view and oblate in equatorial position. Size 20.8 microns in polar diameter. Wall about 2.4 microns thick. Triporate, pores lie on the equator, equidistantly arranged, vestibulum present. Surface pattern psilate to microscabrate.

Discussion: A single grain of this genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray. Myrica pollen is very similar to Betula. The principle difference between the two is in the appearance of the vestibulum. In the case of Myrica the inner wall of the vestibulum is toothed instead of knob-like as in Betula.

Megafossils of Myrica were reported as early as the Paleocene from Alaska and Greenland. There are Eocene and Miocene records from Oregon and Idaho (LaMotte, 1952).

Myrica pollen has been identified from the Miocene of the Columbia Plateau by Gray (1958) and from Washington and Oregon (Gray, 1964).

Myrica contains 25 (Willis, 1973) to 40 (Lawrence, 1951) species of wind-pollinated shrubs or trees, which occur in xerophytic or swampy areas over much of the Northern

Hemisphere. Two species now grow in the Pacific Northwest near the coast in boggy sites (Hitchcock and Cronquist, 1976).

Family: Fagaceae
 Castanea Hill.
 Castanea-type

Diagnostic characters: Pollen grains distinguished by their prolate shape, small size and tricolporate aperture with "square" pores.

Description: Pollen grains prolate in equatorial view, the position in which most grains were identified. Size range from 12.2 to 18.0 microns in length and 7.2 to 14.4 microns in width, average size 12.2 by 7.2 microns. Wall thickness about 1.2 microns. Tricolporate, colpi very long, extend almost to the poles; pores square and situated at the middle of the colpi. Surface pattern psilate.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray. A similar pollen type is found in Lithocarpus and Castanopsis as well as in unrelated taxa hence the uncertainty in the identification. Castanea has, however, been identified from leaf remains at the Faraday Dam site.

Megafossil records indicate that chestnut was widespread throughout North America during the Tertiary. The earliest megafossil records are from the Paleocene of Alaska,

Greenland, Colorado, and Montana. The earliest Pacific Northwest megafossils attributed to Castanea were reported from the Oligocene of Oregon (LaMotte, 1952). Megafossils of Miocene age have been identified by Wolfe (1962) from the northwestern Cascades, by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam and by Smiley (1975) from Clarkia, Idaho. Castanea pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958) from the Columbia Plateau. Gray (1964) later identified Castanea pollen from the Oligocene through Pliocene age rocks of the Pacific Northwest.

Castanea contains 7 to 10 (Sargent, 1949; Lawrence, 1951) species of insect-pollinated trees which produce, however, large amounts of pollen. Castanea was (prior to chestnut blight) widely distributed throughout eastern North America, southern Europe, northern Africa, southeastern Asia, and central and northern China, Korea, and Japan. Three to four species grew in eastern North America (Sargent, 1949; Preston, 1976).

Family: Fagaceae

Fagus L.

Diagnostic characters: Fagus pollen is distinguished by the tricolporate aperture system and the coarsely scabrate sculpture pattern.

Description: Pollen grains spheroidal in equatorial position, sub-triangular to spherical in polar position. Size ranges from 36.4 to 54.6 microns in equatorial length, and averages 44.2 microns in diameter. Exine about 1.8 microns thick. Tricolporate, very large pores, length from 7.2 to 9.6 microns and width from 4.8 to 8.4 microns, average 8.4 by 7.2 microns. Pores meridionally elongate and situated at the middle of the colpi, which is moderately long. Surface pattern coarsely scabrate.

Discussion: Beech pollen was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossil records indicate that beech was widespread in North America during the Tertiary period. The earliest megafossil reports are from the Paleocene of Alaska, Greenland, Colorado, Montana, and Wyoming. The earliest Pacific Northwest record is reported from the Oligocene of Oregon (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964), from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Fagus pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau and Clarkia, Idaho. Gray (1964) has also identified beech pollen from the Oligocene through Pliocene of Oregon, Washington, Idaho and California.

Fagus contains about 10 wind-pollinated species of trees (Lawrence, 1951; Preston, 1976). They are confined to the Northern Hemisphere (Willis, 1973). One species is widely distributed throughout Europe, another is found in the Caucasus, and others are confined to eastern temperate Asia (Sargent, 1949). In North America one species is confined to the eastern region (Sargent, 1949).

Family: Fagaceae

Quercus L.

Diagnostic characters: Pollen grains distinguished by their tricolpate apertures and the verrucate surface pattern.

Description: Pollen grain spherical in polar view and subprolate to prolate in equatorial view. Size range from 15.6 to 26.0 microns in width and 18.2 to 36.4 microns in length. Thickness of the wall about 1.2 microns. Tricolpate, colpi long and tapering towards the pole. Surface irregularly verrucate.

Discussion: This genus was identified from the descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

From the fossil records it is evident that oak was widespread throughout North America during the Tertiary. The earliest North American record comes from the Cretaceous of Utah (LaMotte, 1952). The earliest Tertiary records come from the Paleocene of Alaska, Greenland, Canada, Montana, Colorado, and Washington (LaMotte, 1952). The majority of

the Pacific Northwest remains are Oligocene age and younger. Megafossils have been identified by Wolfe (1962) from the Miocene of the northwestern Cascades, by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Quercus pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified this genus from the Oligocene through Pliocene of Oregon, Washington, Idaho, and California.

Quercus contains about 275 to 450 species (Sargent, 1949; Willis, 1973) of wind-pollinated trees. They are distributed in temperate regions of the Northern Hemisphere and at high altitudes within the tropics; from the New World southward to the mountains of Colombia and in the Old World to the Indian Archipelago (Willis, 1973). Some 54 (Sargent, 1949) to 58 (Preston, 1976) species of oak are native to North America; two species grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Betulaceae
Alnus (Tourn) Hill.

Diagnostic characters: Pollen grains distinguished by their definite rectangular, pentagonal, or hexagonal polar shape related to pore number, and the presence of arci.

Description: Polar geometry varies from rectangular, pentagonal to hexagonal, depending on number of apertures. Size ranges from 15.6 to 26.9 microns. Wall thickness about 1.2 microns. Number of pores varies from 4 to 6 (rare), pores equatorially arranged and equidistant. Arci (a band-like thickening) run over the polar area between adjacent pores. Surface pattern psilate to micro-scabrate.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that alder was widely distributed throughout North America during the Tertiary period. The earliest North American megafossils are reported from the Paleocene of Alaska, Colorado and Wyoming; the earliest records from the Pacific Northwest are from the Oligocene of Oregon and Idaho (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Alnus pollen was identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from Clarkia, Idaho. Pollen grains have also been identified from the Oligocene through Pliocene of Oregon, Washington, Idaho, and California (Gray, 1964).

Alnus has 30 wind-pollinated species (Lawrence, 1951; Preston, 1976) of trees and shrubs. They are scattered throughout the cooler parts of the Northern Hemisphere and extend into the mountains of South America. There are also species growing in China, Burma, and the Himalayas in valleys and streamside sites (Wodehouse, 1935). Among the eight native species, four grow in the Pacific Northwest (Preston, 1976; Hitchcock and Cronquist, 1976).

Family: Betulaceae

Betula L.

Diagnostic characters: Pollen grains distinguished by their triangular to sub-triangular polar shape, three equatorial vestibulate pores, and small size.

Description: Pollen grain sub-triangular in polar position and peroblate in equatorial position. Size range from 15.6 to 25.2 microns, commonly 20.4. Wall about 2.4 microns thick. Triporate, pores round, vestibulate, diameter about 3.6 microns, equatorial and equidistant. Surface pattern psilate.

Discussion: The genus was identified from the modern descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records suggest that birch was widespread throughout North America during the Tertiary. Megafossils were reported from as early as the Paleocene from Alaska and Montana; the earliest Pacific Northwest megafossils are from

the Oligocene of Oregon (LaMotte, 1952). Leaf remains are reported from the Miocene of the northwestern Cascades by Wolfe and from Clarkia, Idaho by Smiley (1975).

Betula pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified birch pollen from Oligocene through Pliocene age rocks from Oregon, Washington, Idaho, and California.

Betula has 40 to 60 (Preston, 1976; Willis, 1973) species of wind-pollinated shrubs and trees. They are scattered throughout the Northern Hemisphere. Among the eleven or twelve native species of North America, four species of Betula presently grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Chenopodiaceae
Sarcobatus Neer.
Sarcobatus-type

Diagnostic characters: Pollen distinguished by small size, small number of irregularly arranged pores which are both annulate and operculate.

Description: Pollen grain spheroidal. Size range from 27.2 to 28.0 microns. Wall about 2.4 microns thick. Periporate, 8 to 12 pores, commonly 12. Pores circular, irregularly arranged, 2.4 to 3.6 microns in diameter, annulate and operculate. Surface pattern psilate to scabrate.

Discussion: Pollen of this family was identified from descriptions given by Erdtman (1952) and Wodehouse (1935); the genus Sarcobatus was suggested by Dr. Gray.

Although most Chenopodiaceae pollen is morphologically very similar, that of Sarcobatus appears to be distinguished by the relatively small number of pores and their irregular arrangement. Other taxa in the Chenopodiaceae with which I am not familiar may have similar pollen, hence the tentative identification.

There are no megafossil records of this family or the genus from the Tertiary of North America. One record has been reported from the Pleistocene of the east coast (LaMotte, 1952). Megafossils are not preserved, probably because most members of this family are herbaceous and have distributions which preclude their occurrence in depositional basins.

Chenopodiaceae pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho.

The family has 75 to 102 genera and 550 to 1400 (Wodehouse, 1935; Willis, 1973) species of wind-pollinated annual or perennial herbs, shrubs or rarely trees of world-wide distribution. Among the 22 genera of Chenopodiaceae represented in the United States, 18 grow in the western region. The genus Sarcobatus is represented by 1 or 2

species of shrubs in North America, one of which grows in the Pacific Northwest (Hitchcock and Cronquist, 1976) from the Great Basin section of eastern Oregon to Saskatchewan, Montana, Arizona, and California (Peck, 1961).

Family: Polygonaceae
Polygonum (Tourn) L.

Diagnostic characters: Pollen grains characterized by small size, tricolporate aperture with transverse furrows which encircle the grain.

Description: Pollen grain subprolate to prolate in equatorial position. Size range from 21.6 to 25.2 microns in length and from 13.2 to 16.8 microns in width. Exine thickness varies from 2.4 to 3.6 microns on the pole to 1.2 microns in the equatorial region. Tricolporate, colpi moderately long and tapered at the poles, crossed equatorially by transverse furrows which coalesce and appear to encircle the grain as a single equatorial furrow. Surface pattern uniformly reticulate; elements baculate.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossils have been reported as early as the Oligocene from Colorado (LaMotte, 1952), but most records are from the Quaternary.

Pollen grains of Polygonum have been identified from the Miocene of the Columbia Plateau by Gray (1958).

Polygonum has 300 species of insect-pollinated herbs or shrubs of cosmopolitan distribution (Willis, 1973).

About 9 species grow in eastern North America and more than 20 species grow in the Pacific Northwest (Robinson and Fernald, 1908; Hitchcock and Cronquist, 1976).

Family: Salicaceae

Salix (Tourn) L.

Salix-type

Diagnostic character: Pollen grains distinguished by their tricolpate apertures, coarsely reticulate surface pattern, and presence of margo.

Description: Pollen grain subprolate to prolate in equatorial position. Size range from 7.8 to 20.6 microns in width, and 18.2 to 41.6 microns in length, commonly 6.0 by 18.4 microns. Wall about 1.2 microns thick. Tricolpate, colpi very long, about 12.2 to 18.0 microns in length, extending almost to pole and tapering towards the pole. Surface pattern coarsely reticulate, mesh generally smaller towards the pole and along the margin of the furrow (margo).

Discussion: This genus was identified from the descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray. A similar type pollen is found in some unrelated taxa hence the uncertainty in the identification.

Megafossil records indicate that willow was widely distributed throughout North America during the Tertiary.

Megafossils were reported as early as the Paleocene from Alaska, Greenland, Colorado, and California. Most of the Pacific Northwest megafossil records are from Oligocene and younger age rocks (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Wolfe and Brown (in Peck, et al., 1964) from Faraday Dam, and by Smiley (1975) from Clarkia, Idaho.

Salix pollen was identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) also identified Salix pollen from Oligocene through Pliocene age rocks of the Pacific Northwest.

Salix contains about 150 to 170 (Wodehouse, 1935; Preston, 1976) predominantly insect-pollinated trees or shrubs. They are distributed in nearly all moist temperate regions well up into the Arctic circle. About 100 species are native to North America and grow in almost all parts of the United States. At least 34 species of Salix grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Ericaceae Juss.

Diagnostic characters: Pollen grains of this family are recognized by their tetrad form and the tricolporate aperture shared by adjacent grains in the tetrad.

Description: Pollen grains in tight tetrahedral tetrad configuration, tetrad outline circular. Tetrad size ranges from 30.0 to 37.0 microns. Wall about 1.2 microns thick. Tricolporate, slight thickening (costae) margining the colpi, which run across the juncture of adjacent grains in the tetrad. Surface pattern scabrate.

Discussion: Pollen grains of the family Ericaceae were identified from the description given by Erdtman (1952) and confirmed by Dr. Gray.

The pollen grains of this family are very homogeneous in appearance, and difficult to identify, with some exceptions, below the family level. In my samples the individual grains in the tetrad may be either round or sub-triangular in shape, although the tetrads themselves do not differ in shape. That difference may not be taxonomically significant.

Megafossil records of a few genera of Ericaceae have been reported from as early as the Paleocene from Alaska and Greenland. Pacific Northwest records are mostly from Oligocene and later epochs (LaMotte, 1952). Megafossils of members of this family have been identified from the Miocene of the northwestern Cascades by Wolfe (1962). Wolfe and Brown (in Peck, et al., 1964) identified Arbutus from Faraday Dam.

Ericaceous pollen grains have been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by

Gray (1958) from the Columbia Plateau. Pollen of this family have also been identified from Oligocene through Pliocene age rocks of the Pacific Northwest (Gray, 1964).

The family has about 50 genera (Lawrence, 1951; Willis, 1973) and 1350 to 1900 insect-pollinated species (Willis, 1973; Lawrence, 1951). Ericaceae plants are usually confined to high altitude regions in tropics. The members of the family form important ecological communities in many parts of the world, especially in moors, swamps and on peaty soil. The family contains herbs, shrubs and small trees. A large number of genera and species now grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Symplocaceae
Symplocos Jacq.

Diagnostic characters: Pollen grains distinguished by their triangular shape in polar view, tricolporate aperture system and coarsely scabrate surface pattern.

Description: Pollen triangular shape in polar position, oblate in equatorial position. Size about 49.4 microns in polar diameter. Wall 1.2 microns thick. Tricolporate, pore round with 5.2 microns in diameter, colpi short about 7.8 microns in length. Surface pattern coarsely scabrate.

Discussion: This genus was identified from the description given by Erdtman (1952) and confirmed by Dr. Gray.

Megafossil records from North America are limited to finds from the Eocene and Miocene of Oregon (LaMotte, 1952; Wolfe, 1962), including a record from Faraday Dam (Wolfe and Brown in Peck, et al., 1964).

Symplocos pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Pollen of Symplocos has also been identified by Gray (1964) from Oligocene through Pliocene age rocks of the Pacific Northwest.

This genus contains 240 (Willis, 1973) species of shrubs or small trees of predominantly tropical and subtropical distribution. One species of Symplocos grows from Delaware to Florida, west to Tennessee, Arkansas, and in Texas (Sargent, 1949; Preston, 1976). None now grow in the Pacific Northwest.

Family: Hydrangeaceae
Itea L.

Diagnostic characters: Pollen distinguished by their biconvex shape and biaperturate grains.

Description: Pollen grain subisopolar, one side more convex than the other. Size range from 22.8 to 24.0 microns in length and from 12.0 to 14.2 microns in width. Wall thickness about 1.2 microns. Biaperturate, pores on the two narrow ends of the grain; costate, intruding. Surface pattern psilate.

Discussion: This genus was identified from the modern description given by Erdtman (1952) and confirmed by Dr. Gray. *Ginkgo* were identified at the family level.

There are no megafossil records of this genus known from North America. Pollen grains attributed to *Itea* have, however, been identified from the Miocene of the Columbia Plateau, Oregon (Gray, 1958) and from Washington, Idaho, and California (Gray, 1964). One record has been reported from the Miocene of the Columbia Plateau.

This genus contains 15 (Willis, 1973) species of shrubs and trees. They are pollinated most probably by organisms. *Itea* is distributed from the Himalayas to Japan and the western Malaysia region, and in Atlantic North America. *Itea* was identified from the Miocene of the Columbia Plateau by Willis (1973) and by Gray (1964).

Family: Onagraceae Juss.

Diagnostic characters: Pollen grains are distinguished by their large size, triangular polar shape, three large, vestibulate pores and scabrate surface pattern.

Description: Pollen grains triangular in polar view and peroblate in equatorial position. Polar diameter from 49.2 to 63.6 microns. Wall thickness about 1.2 microns. Triplicate with large circular pores approximately 8.4 microns in diameter. A modified vestibulum is developed around the pores, where the inner wall is thickened and pouched out slightly. Surface pattern scabrate.

Discussion: Pollen grains of this family were identified from the description given by Erdtman (1952) and confirmed by Dr. Gray. Grains were identified at the family level because pollen of this family is similar and hard to distinguish at the generic level, especially when specimens are limited.

There are no Tertiary megafossil records of this family from North America. One record has been reported from the Pleistocene of Nevada (LaMotte, 1952). Because members of this family are herbaceous, they are less resistant to decay.

Onagraceae pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958) from the Columbia Plateau. Pollen of this family has also been identified from Oligocene through Pliocene age rocks of Oregon, Washington, Idaho, and California (Gray, 1964).

The Onagraceae family has 20 genera and 650 species of worldwide distribution (Lawrence, 1951) although Onagraceae taxa are abundant in temperate regions of the New World. This family contains herbs, rarely shrubs or trees pollinated by a variety of organisms. Nine genera of Onagraceae grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Nyssaceae
Nyssa Gronov. (L).

Diagnostic characters: The spheroidal shape, large pores, costae margining the furrow and pore and the scabrate surface pattern are diagnostic for Nyssa.

Description: Pollen grain spheroidal. Size 28.8 microns. Wall about 2.4 microns thick. Tricolporate, pores round, large and positioned at the middle of the furrow; colpi very long extending almost to the poles, bordered by a conspicuous thickening at the margin and surrounding the pore. Surface pattern scabrate.

Discussion: This genus was identified from the description given by Erdtman (1952) and confirmed by Dr. Gray. Only one Nyssa pollen grain was found.

Fossil records indicate that Nyssa was widely distributed throughout North America during the Tertiary period. Paleocene megafossils have been reported from Colorado and Eocene records are known from the Pacific Northwest (LaMotte, 1952). Megafossils have also been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Smiley (1975) from Clarkia, Idaho.

Nyssa pollen has been identified by Wolfe (1962) from the Miocene of the northwestern Cascades and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. This genus has also been identified from the Oligocene and Miocene of Oregon, Washington, Idaho, and California (Gray, 1964).

Nyssa has 6 (Lawrence, 1951) to 10 (Willis, 1973) primarily insect-pollinated species of trees. They are now confined to eastern North America and to southern and eastern Asia.

Family: Aquifoliaceae
Ilex L.

Diagnostic characters: Pollen grains distinguished by prolate shape in equatorial view and clavate-baculate-gemmate surface pattern.

Description: Pollen prolate in equatorial view. Size range from 22.8 to 24.0 microns in length. Wall thickness about 1.2 microns (excluding elements). Tricolpate, furrow membranous, tapered at poles, with margo. Pores small, present equatorially at the middle of the furrow. Surface clavate-baculate-gemmate, elements about 2.4 microns in length.

Discussion: This genus was identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Fossil records indicate that holly was fairly widespread throughout North America during the Tertiary. Megafossils are reported from as early as the Paleocene in Alaska, Greenland, and Colorado, and from the Eocene of Oregon (LaMotte, 1952). Megafossils are also identified from the Miocene of the northwestern Cascades by Wolfe (1962).

Ilex pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958, 1975) from the Columbia Plateau, Oregon and Clarkia, Idaho. Gray (1964) has also identified holly pollen from Oligocene through Pliocene age rocks of the Pacific Northwest.

Ilex contains 280 (Wodehouse, 1935) to 400 (Willis, 1973) insect-pollinated shrubs and small trees, of cosmopolitan distribution but with main centers in Central and South America (Willis, 1973). About 14 species of Ilex are native to eastern and southeastern North America (Sargent, 1949; Preston, 1976).

Family: Buxaceae
Pachysandra Michx.

Diagnostic characters: Pollen distinguished by its large number of pores and distinctive exine sculpture, where two kinds of elements (wedge-shape and rectangular) alternate to make the pattern.

Description: Pollen spheroidal. Size about 30.0 microns. Periporate, 31 pores, pores circular to elliptical in shape. Surface pattern made up of two distinct types of elements having different surface geometry; some are wedge-shape and others are rectangular. Elements are arranged alternately to form a reticulum.

Discussion: One poorly preserved grain was identified as Pachysandra by Dr. Gray from her previous experience with pollen of this genus.

Megafofossils are identified from the Miocene of the northwestern Cascades by Wolfe (1962). This is the only megafofossil record of Pachysandra in North America.

Pachysandra pollen has been identified from the Miocene of the northwestern Cascades by Wolfe (1962), by Gray and Sohma (1964) from Oregon, Washington, Idaho, and California, and by Martin and Rouse (1966) from the Queen Charlotte Islands, Canada.

Pachysandra has 4 species (Gray and Sohma, 1964; Willis, 1973) of perennial herbs. Among them one species grows in eastern North America and three are distributed in Asia.

Family: Caprifoliaceae

Lonicera L.

Lonicera-type

Diagnostic characters: Pollen grains distinguished by large pores and short colpi, and microechinate surface pattern.

Description: Pollen grain spherical in polar view; flattened equatorially. Size range from 36.6 to 48.0 microns. Wall about 1.2 microns thick. Tricolporate, colpi very short and pores large, about 12.0 microns in diameter. Surface pattern microechinate, spines about 1.2 microns in length.

Discussion: Pollen of Lonicera was identified from the description given by Erdtman (1952) and confirmed by

Dr. Gray. The pollen is comparable to that of Lonicera on the basis of its size, aperture system and surface pattern. Grains of Symphoricarpos and Diervilla are, however, very similar.

There are no megafossil records of the Caprifoliaceae or of genus Lonicera from the Tertiary of North America. Pollen grains have been identified, however, from the Miocene of the Columbia Plateau, Oregon and from other localities in Oregon, Washington, and California (Gray, 1958, 1964).

The family Caprifoliaceae has 18 genera (Lawrence, 1951) and Lonicera includes 180 to 200 species (Lawrence, 1951; Willis, 1973) of bird and organism pollinated species of lianous plants, distributed in North America and Eurasia. Eight species of Lonicera are now growing in the Pacific Northwest (Hitchcock and Cronquist, 1976).

Family: Compositae Giseke

Diagnostic characters: Pollen of the Compositae are distinguished by their echinate sculpture thick exine, and tricolporate aperture system.

Description: Pollen grains spheroidal. Size range from 16.8 to 19.0 microns. Wall 3.0 microns thick including the spines, tectate, thinner near the furrows. Tricolporate, colpi very long, extending almost to the poles, pore large equatorial, constricted at the middle where it crosses the furrow. Surface echinate, spines moderately long about 1.0

micron in length, regularly arranged, tip solid.

Discussion: Pollen grains of this family have been identified from descriptions given by Erdtman (1952) and Wodehouse (1935) and confirmed by Dr. Gray.

Megafossils of Compositae are very rare, probably because plants of this family are mostly herbaceous, rarely shrubs. Three genera are reported from the fossil record. They are Bidens from the Paleocene of Greenland, Aster from the Oligocene of Colorado, and Taraxacum from the Pleistocene of Alaska (LaMotte, 1952). Records prior to the late Oligocene-early Miocene are probably erroneously identified (Gray, personal communication).

Pollen grains of Compositae have been identified from the Miocene of the northwestern Cascades by Wolfe (1962) and by Gray (1958) from the Columbia Plateau, and from Miocene and Pliocene age rocks of Oregon, Washington, Idaho, and California (Gray, 1964).

The Compositae is one of the largest families of dicotyledons. It includes about 900 genera and 13,000 species (Willis, 1973) of predominantly insect-pollinated annual, biennial, or perennial herbs or less often woody plants of cosmopolitan distribution. A large number of genera and species grow in the Pacific Northwest (Hitchcock and Cronquist, 1976).

NOTE: Beside the pollen grains attributed to taxa there are a number of grains which I could not identify as belonging to any genus or family. These taxonomically unidentified pollen grains represent about 10.0% or less of the pollen sum. Most of these were in the tricolporate category; a few were triporate or tricolpate.

Modern Biogeographical Relations of
the Identified Taxa

The Faraday Dam pollen flora includes taxa which indicate a completely different vegetation than presently exists in northwest Oregon. To help understand the overall vegetation type and the paleoclimate of this area, I have indicated (Table 2) the present geographic occurrence of the genera, and in some instances families, identified from the pollen. Since the pollen grains were identified only at the generic, and in some cases only at the familial level, the biogeographic relations are more general than they would have been were it possible to compare the fossil pollen at the specific level, because species are more restricted in their distribution. It is clear nevertheless that most of the genera can be found in two regions of the world, namely eastern North America and eastern Asia, although few are confined to either area.

Taxa identified from their pollen fall into the following broad groups.

TABLE 2

COMPARATIVE RECORD OF MEGA- AND MICROFOSSILS FROM FARADAY DAM,
THE PRESENT GEOGRAPHICAL DISTRIBUTION OF THE TAXA,
AND MODE OF POLLINATION*

Genera	Megafofossils at Faraday Dam	Mode of Pollination	Geographical Distribution											
			C	Te	Tr	1	2	3	4	5	6	7	8	9
<u>Anthoceros</u>	-	WP	x	x	x									
<u>Selaginella</u>	-	WP	x	x	x									
<u>Osmunda</u>	-	WP	x	x	x									
<u>Polypodiaceae</u>	-	WP	x	x	x									
<u>Abies</u>	x	WP		x		x	x		x	x	x	x		x
<u>Cedrus</u>	-	WP		x						x	x	x		
<u>Picea</u>	-	WP		x		x	x			x	x			x
<u>Pinus</u>	-	WP		x		x	x		x	x	x	x		x

TABLE 2--Continued

Genera	Megaossil at Faraday Dam	Mode of Pollination	Geographical Distribution											
			C	Te	Tr	1	2	3	4	5	6	7	8	9
<u>Pseudotsuga</u>	-	WP		x		x				x				
<u>Tsuga</u>	-	WP		x		x	x			x				
Taxodiaceae	x	WP		x		x	x			x			x	
Cupressaceae	-	WP	x	x										
Taxaceae	-	WP		x	x	x	x		x	x		x		x
Cypteraceae	-	WP	x	x	x									
Gramineae	-	WP	x	x	x									
<u>Typha</u>	-	WP	x	x	x									
Lemnaceae?	-	Hydrophily	x	x	x									
<u>Platanus</u>	-	WP		x		x	x		x	x	x			
<u>Liquidamber</u>	x	WP		x		x			x	x	x			
<u>Celtis</u>	-	WP		x	x	x	x			x		x		
<u>Ulmus</u>	-	WP		x	x	x				x				x
<u>Zelkova</u>	-	WP		x						x	x			

TABLE 2--Continued

Genera	Megafossil at Faraday Dam	Mode of Pollination	Geographical Distribution										8	9
			C	Te	Tr	1	2	3	4	5	6	7		
<u>Carya</u>	x	WP		x		x				x				
<u>Engelhardtia</u>	-	WP		x	x	x			x	x				
<u>Juglans</u>	x	WP		x		x	x	x	x	x	x			
<u>Pterocarya</u>	x	WP		x						x	x			
<u>Myrica</u>	-	WP		x		x	x		x	x	x	x		x
<u>Fagus</u>	x	WP		x		x				x	x			x
<u>Quercus</u>	x	WP		x	x	x	x	x		x	x	x		x
<u>Castanea-</u> <u>type</u>	-	IP		x		x				x	x	x		x
<u>Alnus</u>	x	WP		x	x	x	x	x	x	x		x		x
<u>Betula</u>	-	WP		x		x	x		x	x		x		x
<u>Sarcobatus-</u> <u>type</u>	-	WP		x			x							
<u>Polygonum</u>	-	IP	x	x	x									
<u>Salix-type</u>	x	IP		x		x	x	x	x	x		x		x

TABLE 2--Continued

Genera	Megafossil at Faraday Dam	Mode of Pollination	Geographical Distribution											
			C	Te	Tr	1	2	3	4	5	6	7	8	9
Ericaceae	x	IP	x	x	x									
<u>Symplocos</u>	x	IP		x	x	x				x			x	
<u>Itea</u>	-	IP		x	x	x				x				
Onagraceae	-	IP	x	x	x									
<u>Nyssa</u>	-	IP		x	x	x				x				
<u>Ilex</u>	-	IP	x	x	x									
<u>Pachysandra</u>	-	IP		x		x				x				
<u>Lonicera</u>	-	Zoophilous		x	x	x	x			x	x	x		
Compositae	-	WP, IP	x	x	x									
Total			14	44	23	25	17	4	10	29	14	11	2	12

*Note: WP - wind-pollinated; IP - insect-pollinated, (x) - present; (-) - absent;
 C - cosmopolitan; Te - temperate; Tr - tropical, 1 - eastern North America;
 2 - western North America; 3 - South America; 4 - Central America; 5 - eastern
 Asia; 6 - western Asia; 7 - Africa; 8 - Australia; 9 - Europe.

I. Genera distributed in North America and in eastern Asia: North America and eastern Asia are the two major geographical areas represented by the Faraday Dam pollen flora (Table 2). These two regions show the largest number of taxa, a total of 23 genera and two families whose pollen was not identified below the family level. However, the distribution pattern of these genera and families are neither uniform within these two regions or confined to these two regions. Their distribution patterns within these regions and elsewhere are discussed below.

a. A few genera such as Carya, Nyssa, Itea, and Pachysandra, although they fall under this broad group, have distributions restricted to eastern North America and eastern Asia. On the other hand, Pseudotsuga occurs only in western North America and eastern Asia.

b. There are other genera which have distribution patterns in North America and eastern Asia as well as in other regions, notably Europe, as well as in Central and/or South America and to some extent in Africa and Australia. Two groups of genera are in this category.

(i) Genera with occurrences in eastern North America and Asia which also grow elsewhere, such as Fagus in Europe and western Asia; Ulmus in Europe; Castanea in Africa, Europe and western Asia; Engelhardtia in Central America; Liquidambar in Central America and western Asia; and Symplocos in Australia.

(ii) Taxa with distributions in both eastern and western North America and Asia which are also found elsewhere such as Salix in South America, Africa and Europe; Quercus in Africa, western Asia, South America and Europe; Betula in Europe; Alnus in Europe, Africa, Central and South America; Myrica in Central America, western Asia, Africa and Europe; members of the Taxaceae in Central America, Africa and Europe; Platanus in western Asia and Central America; Pinus and Abies in western Asia, Africa, Europe and Central America; Picea in western Asia and Europe; members of the Taxodiaceae in Australia (Tasmania); Juglans in western Asia, Central and South America; and Celtis in Africa.

II. Genera with cosmopolitan distribution: A total of 14 taxa identified from the Faraday Dam pollen assemblage have worldwide distribution. The cosmopolitan genera are Anthoceros, Selaginella, Osmunda, Typha, Polygonum, and Ilex, and the families are Polypodiaceae, Cupressaceae, Cyperaceae, Gramineae, Lemnaceae?, Ericaceae, Onagraceae, and Compositae.

III. Genera distributed mainly in Asia: Three genera, Cedrus, Pterocarya, and Zelkova have their common distribution within the geographical boundaries of Asia (Table 2). However, Cedrus does not grow east of the Himalayan region and also occurs in North Africa. Pterocarya has its principle occurrence in China, Japan, and the Caucasus; Zelkova grows in most of temperate eastern Asia

as well as in western Asia around the Mediterranean regions.

IV. There is one genus which does not fit in the above mentioned groups. This is Sarcobatus, which grows exclusively in western North America.

Fossil plants and their living counterparts are assumed to have similar ecological requirements (Martin and Gray, 1962). Thus it is assumed that the genera represented in the Faraday Dam flora also had similar ecological requirements to their extant counterparts and comprised a similar vegetation type to that found in the two principal regions of the modern world where most of these genera are found.

From the geographical distribution (Table 2) it is evident that the genera which survived in the Pacific Northwest since the late Miocene have a much wider distribution pattern, except for one or two, e.g., Pseudotsuga and Sarcobatus, than most of those now found in eastern North America and eastern Asia. In addition, there are some taxa no longer present in the North American flora with more restricted distribution patterns. Table 2 shows that the East Asian Element was most prominent in the late Miocene flora of northwestern Oregon followed by the East American Element. The genera distributed in those two major areas (eastern North America and eastern Asia) live in regions that are ecologically and climatologically similar. Thus it seems clear that during the late Miocene the climate in the Pacific Northwest was more like that of present day

eastern North America and eastern Asia than that of north-western Oregon.

CHAPTER V

RESULTS

Description of the Pollen Diagram

The pollen diagram from Parady Oak 1 is presented in Figure 3. The diagram represents genera and other taxa with percentage values higher than 2%. Genera with low percentage values (below 2%) are listed in Table 2. For convenience in discussion and interpretation, the pollen diagram has been divided into three pollen zones based on overall pollen/spore characteristics. Characteristics of the zones, starting with the oldest (stratigraphically lowest) are outlined below:

- F-1: Maximum alder, high conulate spores, common umbifers, low oak.
- F-2: Maximum chestnut-type, saccate, symmetrical high oak, pine (haploxylon-type), and I-C-F; alder generally low.
- F-3: Maximum Taxodiaceae, oak and beech.

Zone F-1: This zone is characterized by the highest overall frequency of alder and homolete polypodiaceae spores, and by common umbifers. Although alder has maximum frequency in zone F-1 it also shows very low frequencies. Homolete spores maintain their highest frequency throughout

CHAPTER V

RESULTS

Description of the Pollen Diagram

The pollen diagram from Faraday Dam is presented in Figure 3. The diagram represents genera and other taxa with percentage values higher than 2%. Genera with low percentage values (below 2%) are listed in Table 3. For convenience in discussion and interpretation, the pollen diagram has been divided into three pollen zones based on overall pollen/spore characteristics. Characteristics of the zones, starting with the oldest (stratigraphically lowest) are outlined below:

F-1: Maximum alder, high monoolete spores, common conifers, low oak.

F-2: Maximum chestnut-type, sweetgum, sycamore; high oak, pine (haploxylon-type), and T-C-T; alder generally low.

F-3: Maximum Taxodiaceae, oak and beech.

Zone F-1: This zone is characterized by the highest overall frequency of alder and monoolete polypodiaceous spores, and by common conifers. Although alder has maximum frequency in zone F-1 it also shows very low frequencies. Monoolete spores maintain their highest frequency throughout

Fig. 3.--Pollen diagram

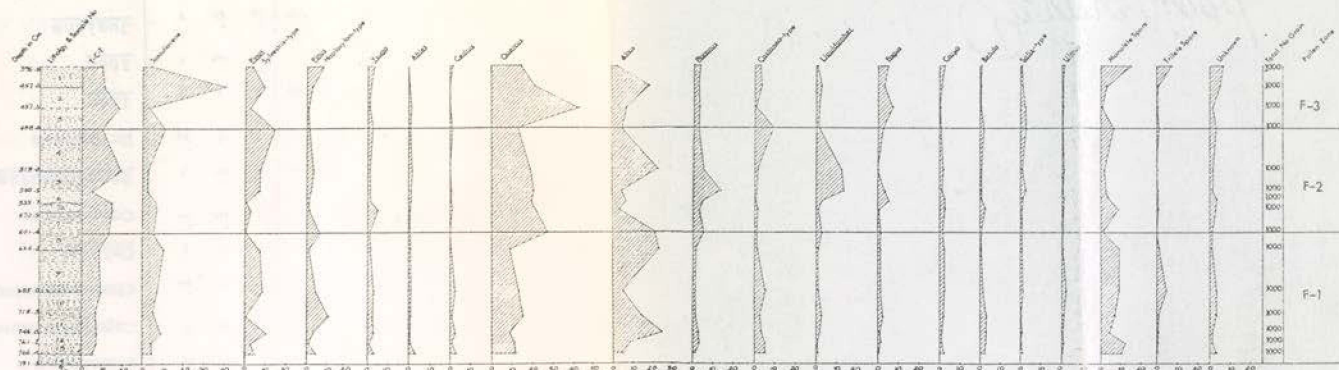


TABLE 3

POLLEN PERCENTAGES NOT SHOWN IN THE POLLEN DIAGRAM
(P = present)

Depth in Cm	<u>Anthoceros</u>	<u>Selaginella</u>	<u>Osmunda</u>	<u>Picea</u>	<u>Pseudotsuga</u>	<u>Gramineae</u>	<u>Caprifoliaceae</u>	<u>Chenopodiaceae</u>	<u>Celtis</u>	<u>Compositae</u>	<u>Engelhardtia</u>	<u>Ericaceae</u>	<u>Ilex</u>	<u>Itea</u>	<u>Juglans</u>	<u>Lemnaceae?</u>	<u>Onagraceae</u>	<u>Pterocarya</u>	<u>Symplocos</u>	Pollen Zone
396.5-427.0	-	P	.1	-	.8	.2	-	.1	-	.1	-	.2	-	-	-	-	-	.5	.1	F-3
427.0-457.0	P	-	-	1.5	-	.1	.2	-	-	.5	.1	-	-	.3	.6	-	.1	.3	.1	
457.0-488.0	-	P	-	1.2	-	-	-	-	-	-	-	-	-	.1	.3	-	-	.4	-	
488.0-519.0	.2	.1	.3	.4	.1	-	-	-	-	.1	-	-	.2	-	.5	-	-	1.0	-	F-2
519.0-540.5	-	-	.4	-	-	-	-	-	-	-	-	.1	.3	-	-	-	.2	.3	-	
540.5-555.7	-	-	.3	.6	.3	.2	-	-	-	.4	-	-	-	-	.1	-	-	.9	-	
555.7-570.9	-	-	-	1.1	-	-	-	-	-	.1	-	.1	-	-	-	-	.6	1.1	-	
570.9-601.4	-	-	.3	.2	.5	.2	.1	.1	.1	-	-	.4	.1	-	.2	-	.1	.7	-	

TABLE 3--Continued

Depth in Cm	<u>Anthroceros</u>	<u>Selaginella</u>	<u>Osmunda</u>	<u>Picea</u>	<u>Pseudotsuga</u>	<u>Gramineae</u>	<u>Caprifoliaceae</u>	<u>Chenopodiaceae</u>	<u>Celtis</u>	<u>Compositae</u>	<u>Engelhardtia</u>	<u>Ericaceae</u>	<u>Ilex</u>	<u>Itea</u>	<u>Juglans</u>	<u>Lemnaceae?</u>	<u>Onagraceae</u>	<u>Pterocarya</u>	<u>Symplocos</u>	Pollen Zone
601.4-624.2	-	-	.2	-	.1	-	-	-	-	-	-	-	-	-	.3	.1	-	.5	-	F-1
624.2-685.0	.1	-	-	.4	.5	.4	-	-	-	-	-	.2	.1	-	.1	-	.1	.4	-	
685.0-715.5	-	-	.3	.4	.4	-	-	-	-	-	.2	-	.3	-	.1	-	-	1.5	.1	
715.5-746.0	.1	.2	.1	.2	.5	.1	-	-	-	.1	-	.2	.1	.3	.2	-	.1	1.3	.1	
746.0-761.2	.1	.2	.3	.1	.2	.1	-	-	-	.1	-	-	.3	-	.2	-	-	1.8	-	
761.2-776.4	.1	.1	-	.7	.5	.2	.1	.1	.1	-	.3	.1	.1	.4	.4	-	-	1.8	-	
776.4-791.6	.1	.1	.1	.6	.2	.4	-	.1	-	-	.1	.2	-	-	-	-	.1	1.3	-	

the zone. Conifers show an overall high percentage throughout F-1 although individually some are better represented in other zones. Oak has its lowest frequency in F-1 although it increases at the top of the zone. Sycamore and T-C-T pollen increase in the upper part of the zone.

Zone F-2: Pine (haploxylon-type) and T-C-T grains reach their highest frequency in F-2 and the combined T-C-T and Taxodiaceae percentages are somewhat higher than in F-1. Other conifers have continuing low frequencies (Tsuga and Cedrus are lower in F-2 than in F-1 or F-3). Chestnut-type pollen, sweetgum, and sycamore reach their highest frequency in F-2; chestnut toward the top of the zone, sweetgum and sycamore in the middle of the zone. Beech also reaches its highest frequency in F-2 in the middle of the zone. Oak shows an overall decline in F-2 although its overall frequency is higher than in F-1. Alder fluctuates randomly throughout zone F-2.

Zone F-3: Taxodiaceae is highest (42%) in F-3 where it shows a sudden increase in frequency. Oak (43%) and beech (7.9%) also reach their highest percentages in F-3, followed by a precipitous decline of oak higher in the zone. Alder increases in F-3 from a decline at the top of F-2 and in the lower part of F-3 followed by a second decline. Polypodiaceous spores (monolete, 15% and trilete, 7.5%) reach their combined highest frequency at the top of F-3. All other taxa show either a slight decline or a slight

increase in F-3 compared to F-2.

Discussion: A pollen diagram directly reflects the vegetation and indirectly the climate of an area, but interpreting such a diagram is difficult for a number of reasons. Most problems in interpretation are discussed in detail by Martin and Gray (1964), Faegri and Iversen (1975), Moore and Webb (1978), and Birks and Birks (1980) who should be consulted for details. The major factors one must consider are outlined here.

1. Abundance of the parent plant in the local and regional vegetation. In general, the more abundant the source plant, the higher the probability of that pollen type being present in the sediment.

Abundance of any pollen type in sediment is also influenced by the density of the vegetation. In a dense forest, pollen from low undergrowth shrubs and herbs seldom gets airborne. As Tauber (1967) postulates most of these pollen types will be deposited near their source or filtered out on adjacent vegetation before reaching depositional basins.

2. The pollen production of taxa. This varies specifically and individually, in part, according to the conditions under which the plant grows. Pollen production depends among other things upon the frequency of the flowering season. Some plants flower freely every year, e.g., Alnus, Betula and Picea; some species of Fagus and

Quercus on the other hand have a distinct biennial rhythm (Faegri and Iversen, 1975; Andersen, 1974) with pollen long production in alternate years.

Pollen production also depends on the type of pollination mechanism of a taxa. Conventionally, insect-pollinated species produce smaller amounts of pollen than wind-pollinated species although there is considerable overlap. In the Tertiary, we assume a similar pollination ecology for taxa whose relationship to modern pollen producing species is unknown. This could make for obvious problems in interpretation. Pollen production may also depend on the morphological and physiological condition of the parent plant. If a plant has a means to propagate vegetatively, in severe condition it may do so rather than produce flowers. Some normally wind-pollinated taxa may also become cleistogamous under some severe environmental circumstances. The number of mature trees in the vegetation will also influence the pollen production.

3. The dispersal potential. This depends partly on the size and shape of a pollen grain and, in part, on pollination ecology. If a pollen grain is light and small it may travel a long distance and take a long time to settle; a large, heavy grain usually has less chance to cover long distances, and settles rapidly (Tauber, 1967; Krzywinski, 1977). and Cinq (1972) point out that because of the mathematical constraints of percentage data, "A change

Pollen of insect-pollinated plants which are frequently heavily armored or "sticky" do not disperse long distances in comparison with wind-pollinated species.

4. Variable preservation of pollen grains. Some pollen does not preserve well over time, e.g., Typha and Populus; other types do. The condition of preservation may hamper one's ability to identify pollen of some taxa.

Pachysandra, for example, frequently loses its diagnostic surface ornamentation and only prior experience with pollen of this taxon enables one to recognize its pollen in the fossil record. Pollen of the Taxodiaceae, Cupressaceae and Taxaceae often split open which makes it difficult to identify the pollen even at the family level. Also I, of course, do not have any information about the nature of the depositional basin, such as water chemistry, lake size, and so on, that might influence pollen preservation.

5. Limitations inherent in interpreting pollen diagrams. One attempts to understand the proportional representation of pollen in terms of a vegetation type. However, in a relative frequency diagram the relative abundances of pollen are interdependent. The fluctuations that one sees have limited meaning except within the context of a specific vegetation type. They cannot be used to directly determine the abundance of different taxa in the vegetation. Martin and Gray (1962:3) point out that because of the mathematical constraints of percentage data, "A change

in frequency of occurrence of one pollen type may not reflect a change in abundance or in pollen production or in local distribution for that particular plant species." One can have many spurious effects expressed in a pollen diagram which have little environmental significance. This uncertainty can be minimized by careful study of the relative fluctuations of all the important pollen types with the hope of separating "real" from statistical changes. Sometimes absolute data for the precise number of pollen grains falling per unit area per unit time can be calculated enabling one to overcome the problems imposed by relative frequency data. But these require knowledge of the sedimentation rate which is impossible to get at most Tertiary sites.

The Faraday Dam pollen diagram poses additional problems. Megafossil records only give information about the general climate and vegetational pattern of the Pacific Northwest from assemblages isolated in time and space. Although plants are slow to respond to climatic changes (Moore and Webb, 1978), a pollen diagram has the potential for showing more subtle changes than would the normal grab collection of megafossils. Megafossils are almost never collected centimeter-by-centimeter, and if so are too uncommon to provide the routinely large samples provided by pollen. The sheer order of magnitude difference in both size and abundance of megafossils and pollen puts

megafossils at a distinct disadvantage from a sampling point of view.

But since I also lack knowledge about the total time involved in deposition of the sedimentary rocks from which my pollen comes, I do not know their probability for reflecting short term environmental changes. Sediments can accumulate very rapidly by abnormal means such as floods, in which case little time is involved in the depositional record. Although there is no record from the sedimentary rocks at Faraday Dam that might indicate any anomalous depositional rates, there is also no basis for judging that the rate of deposition was sufficiently slow that the pollen diagram may reflect vegetational or climatic changes.

What does the diagram show? High pollen percentages of tree pollen evidently indicates a heavily forested region (Fig. 3). Pollen of herbaceous taxa, except ferns, are present in very limited frequency (Table 3). Ferns on the other hand as well as Selaginella and possibly bryophytes (Anthoceros) must have been important ground cover components. Although pollen of herbaceous taxa often indicates local presence of the parent plants, pollen of Cyperaceae, Gramineae, and Sarcobatus is windborne and has the potential to be transported long distances. There is no way to determine whether these plants lived in the vicinity of the depositional basin or not. Others, such as the zoogamously pollinated Polygonum, Pachysandra and Onagraceae,

were probably local. A more definite interpretation of the relative abundance of these genera in the vegetation is not possible.

The overall pollen diagram suggests that the frequencies for most genera do not show significant changes. Quercus and Taxodiaceae (including T-C-T) on the other hand show a trend toward increase over time that could indicate a real change in the vegetation. Both groups of taxa are lowest in zone F-1 (Fig. 3) and increase gradually. Both Quercus and Taxodiaceae show a precipitous increase in frequency in F-3.

Castanea-type, Fagus, Liquidamber, and Platanus show some changes in their spectra. Most reach their highest percentages in F-2. But the precipitous increase in frequency, such as occurs in Platanus and Liquidamber or in Taxodiaceae or Quercus in F-3, is difficult to interpret. It is difficult to conceive of vegetational changes that would permit the increase in some individual members of the flora, while other members show no or little change. Such taxa as Pinus, Tsuga, Cedrus, Abies, Carya, Betula, Salix-type and Ulmus show limited changes, with their spectra remaining almost the same throughout the section.

Alder, however, shows a number of sharp decreases and increases in its spectrum throughout the section without overall change in its trend. These appear to be simply random fluctuations. The fluctuations of Alnus pollen are

negatively correlated to some extent with those of oak, pine (haploxylon-type) and Taxodiaceae, and may simply be artifacts of the percentage frequency diagram.

If the fluctuations shown by the pollen diagram cannot be explained vegetationally, how can they be explained? Some of the precipitous changes shown in the diagram may be the result of the sampling distance chosen. I sampled mainly for changes in lithology in the section. The sampling distances vary from 6 inches (.166 meter) to 2 feet (.66 meter). Had I sampled continuously at 10 cm intervals, some of the precipitous fluctuations might have been seen to be more gradual. This does not, however, explain the apparent absence of significant vegetational trends. If the time actually represented in the section is very limited (possibly as little as 50 years or less, as suggested by Drs. Gray and Boucot), it seems most likely that the fluctuations may be caused by such things as depositional factors (size sorting correlated with lithologic variations in the section), input related to abnormal seasonal flowering, or shifts in wind direction and other factors that are related specifically to local pollination and depositional factors, rather than environmental changes that are normally reflected in pollen diagrams that represent extended periods of time.

later amalgamated into a single flora. Thus my pollen counts may be only partly comparable with the leaf assemblages. The local presence of any taxon established on the basis of

Vegetational Interpretation of Co-Occurring

Mega- and Microfossils

A small number of megafossils, mostly leaf remains, were identified from the Faraday Dam locality by Wolfe and Brown (in Peck, et al., 1964). In the present study I have identified a large number of pollen and spores from the same deposits. Though there is no information about the abundance of megafossils for each genus, the pollen diagram shows a number of fluctuations or changes, with some changes sharper than others.

In the following paragraphs I have compared and contrasted the pollen and spore record with the megafossils previously identified by Wolfe and Brown (in Peck, et al., 1964) and have tried to use the relative frequency of the pollen as a basis for establishing significance of the parent plant in the local vegetation. There are some drawbacks I had to face in doing this kind of comparison between the megafossil and pollen records. (1) Although there are fragments of leaf impressions on all my samples, I do not know from which horizon (or horizons) the previous fossil leaf assemblage was collected. I do not know whether leaves were collected from one horizon or from several horizons and later amalgamated into a single flora. Thus my pollen counts may be only partly comparable with the leaf assemblage. The local presence of any taxon established on the basis of

its megafossil presence may not pertain to the entire sequence represented by the pollen diagram. (2) It was also difficult to compare and correlate the pollen data with the megafossils, because of insufficient information regarding the pollination ecology, pollen production and dispersal mechanism of many taxa. Low pollen percentages of some taxa are insufficient to draw conclusions regarding the presence and abundance of the parent plants. On the other hand, many genera are species specific in terms of their pollen production. In some cases one species may produce larger amounts of pollen than other species of the same genus. Since I was not able to identify the pollen at the specific level, it is uncertain whether the megafossils and pollen belong to the same species or to different species. Additionally, all studies on pollen production and dispersal deal, naturally, with modern species within a modern vegetation (Janssen, 1966; Davis and Goodlett, 1960; Potter and Rowley, 1960), whereas I may be dealing with fossil species. Lack of information about the vegetation structure or aerodynamic setting of the depositional site make it difficult to assess the importance of modern pollination studies in reference to my study. (3) Natural causes, such as seasonal shedding patterns, contribute to the abundance of leaves in an assemblage. Deciduous trees shed leaves annually, whereas evergreens do not in the same abundance, but they both could contribute pollen to the sediment equally.

Pollen may also be recycled throughout the year from other vegetation and other surfaces to depositional basins. In such cases absence of megafossils could be misleading with regard to the presence or absence of a taxon at the locality since megafossils and pollen do not have an equal opportunity to get into sediments.

There are three categories of leaf and pollen data:

(1) Genera which are represented by both megafossils and pollen. (2) Megafossils with no pollen record. (3) Pollen and spores without previous megafossil record. These three categories will be discussed in detail.

(1) Genera represented by both megafossils and pollen: Sequoia?, Taxodium?, Abies, Alnus, Carya, Fagus, Juglans, Liquidamber, Pterocarya, Platanus, Quercus, Salix-type and Symplocos.

Taxodiaceae (2.4%-42.1%) (Fig. 3). Although Wolfe and Brown (in Peck, et al., 1964) identified both Sequoia and Taxodium from the Faraday Dam leaf assemblage it is generally not possible with the light microscope doing routine counting to unequivocally distinguish pollen of Sequoia from Taxodium or these two from other papillate grains of the Taxodiaceae. Both genera may be represented by pollen since there are abundant papillate grains. These grains could also represent other members of the family, which were not identified on the basis of their needles. There are, in addition, a large number of "split" grains,

where the papilla has been torn apart that could be either Taxodium, Sequoia or other members of the Taxodiaceae. In conclusion it can be said that members of this family are locally present on the basis of their megafossil remains. The generally large number of Taxodiaceous pollen grains tends to confirm the presence and probable abundance of some members of the family in the vegetation.

Alnus (3%-24.6%) (Fig. 3) is often overrepresented because of local occurrence and high pollen production (Janssen, 1966; Tikhomirov in Potter and Rowley, 1960). Thus alder is not only a great pollen producer, it is often a dominant shrub in bogs, swamps, and riverine situations (Wodehouse, 1935). However data comparing alder pollen percentage with forest composition indicates that in some circumstances Alnus pollen may be slightly underrepresented (Bertsch in Potter and Rowley, 1960).

The pollen spectra of alder (Fig. 3) do not indicate uniformly high percentages, but considering all the pollen data (Fig. 3) and the presence of alder megafossils at Faraday Dam it can be concluded that alder was locally present and at least fairly common in the vegetation.

Quercus (8.7%-43.6%) (Fig. 3). Oak is usually reported as an overrepresented genus especially in America (Hansen, 1949; Davis and Goodlett, 1960). Iversen (in Potter and Rowley, 1960), however, categorized Quercus as a low pollen producer. Steinberg (in Potter and Rowley, 1960)

established a ratio between percentage of oak trees and pollen in sub-Recent deposits, which also indicated that oak pollen is slightly overrepresented compared to the abundance of trees in the vegetation. The conflicting evidence suggests that the amount of pollen produced may be species specific and whether a genus is over- or under-represented by its pollen may also depend on the particular vegetation assemblage in which the tree is growing. It is difficult to say whether oak pollen is over- or under-represented in the Faraday Dam pollen assemblage. One exceptionally high count may indicate local overrepresentation of oak pollen. The other counts are similar to each other, but high enough to indicate not only local presence for oak but that it was very abundant in the vegetation especially in zones F-2 and F-3 (Fig. 3).

Carya (.5%-3.3%), Fagus (.5%-7.9%), Liquidamber (.7%-12.9%), and Platanus (1.2%-13.6%) are represented by relatively moderate pollen percentages (Fig. 3). Carroll (1943) found that Carya and Liquidamber pollen can travel long distances. Carya, Liquidamber and Platanus also tend to be moderate pollen producers. The pollen spectra for Carya show uniformly low percentages (Fig. 3), which could indicate an external occurrence, although hickory megafossils confirm that the genus was locally present in the vegetation. The low percentages could be a result of morphology which restricts dispersal to limited distances.

Liquidamber also shows low percentages except for a high peak in zone F-2 (Fig. 3). These percentages could mean an external occurrence, but in the face of co-occurring megafossils may mean that Liquidamber was not a common component of the vegetation.

Platanus shows uniformly slightly higher percentages (Fig. 3) than either Carya or Liquidamber. The pollen data are similar throughout the section except for some deviations involving both higher and lower pollen percentages. Considering the overall pollen spectra for Faraday Dam it seems probable that Platanus was locally present throughout the section though possibly not equally common in the vegetation throughout the time represented by the diagram.

Fagus produces less pollen than many other anemophilous plants (Wodehouse, 1935; Iversen, in Potter and Rowley, 1960). Since Fagus pollen is a little larger, the grains tend to be slightly heavier than grains of many other anemophilous taxa (e.g. Alnus, Betula) and consequently dispersed over shorter distances (Tauber, 1967).

Pollen spectra of Fagus (Fig. 3) indicate both low and comparatively high pollen percentages for this taxon based on modern analogs. The relatively high pollen percentages along with the megafossil evidence probably indicates local presence. The low percentages could be a result of morphology which restricts dispersal to limited distances

or a limited number of beech trees in the vegetation.

Since all of these genera have leaf fossils from the study area, all of them were part of the Faraday Dam vegetation, but it should be noted that these genera probably were all minor constituents of the local flora.

Abies (.4%-3.2%), Pterocarya (.3%-1.8%) and Salix-type (.2%-2.5%) show low pollen percentages on the diagram (Fig. 3). Among these Abies has a conflicting record regarding its pollen dispersal potential. Some authors note it as an effective long distance transporter (Tikhomirov in Potter and Rowley, 1960); others found it to have inadequate dispersal because of its heavy pollen grains (Janssen, 1966; Davis and Goodlett, 1960; Bent and Wright, 1963; Bertsch in Potter and Rowley, 1960). Furthermore, in comparison with its occurrence in the vegetation, some studies show Abies to be equally represented (McAndrews, in Janssen, 1966; Steinberg in Potter and Rowley, 1960); others show it to be underrepresented (Carroll, 1943). But synthesizing all the references the majority support the opinion that Abies pollen tends to be underrepresented, and it probably is as well in my pollen diagram. Because megaremaines from Faraday Dam emphasize the local presence of Abies, the low pollen percentage could mean that fir was not common in the vegetation.

Pterocarya (.3%-1.8%) (Table 3). Although they are wind pollinated most members of the family Juglandaceae

produce less pollen (Wodehouse, 1935) than many anemophilous taxa. This may be one reason for the low frequency of Pterocarya pollen. It could also be the result of low pollen dispersal potential or a small number of trees in the vicinity. Although the pollen of Pterocarya is limited, it occurs throughout the section which could indicate its local presence throughout the time represented by the diagram. The presence of megafossils confirms its presence during at least part of the interval represented by sediments at Faraday Dam.

Salix-type (.2%-2.5%) (Fig. 3). A low pollen representation of willow is reasonable because it is entomophilous. The low pollen percentage may also reflect in part poor dispersal rather than low pollen production (Janssen, 1966). Janssen (1966) suggests that 3-4% of Salix pollen is adequate to indicate a local presence for willow; megafossils from the Faraday Dam area confirm its local presence even though the pollen percentages are below those suggested by Janssen. This genus may also be a minor element in the vegetation.

Among the genera which have megafossil records from Faraday Dam, Juglans and Symplocos show very low pollen percentages (Table 3). Juglans (.1%-.6%) like other members of the Juglandaceae produces a limited amount of pollen (Wodehouse, 1935). It has also been found that walnut pollen does not disperse well (Wright, 1952; Crane in Potter

and Rowley, 1960). Both these factors may be the main reason for its limited representation, although almost all the samples have some walnut pollen (Table 3). These data along with the megafossil record confirm the presence of walnut in the local vegetation of the area even though it may have been an uncommon member of the vegetation.

Symplocos (.1%) (Table 3), on the other hand, is a zoogamous plant. One might expect its megafossil records to be a better indicator of its local presence than the pollen.

Besides these genera there are a few ericaceous (.1%-.4%) (Table 3) pollen grains identified from the samples. It has not been possible to identify them at the generic level although Wolfe and Brown (in Peck, et al., 1964) identified Arbutus leaves at Faraday Dam. There is a possibility that some of the ericaceous pollen could belong to Arbutus although some variation suggests the presence of more than one taxon. Entomophilous pollination ecology doubtless accounts for the low representation of Ericaceae in the pollen assemblage.

(2) Genera represented only by megafossils: There are three genera for which no pollen was found from the Faraday Dam area. These are Populus, Acer and Paulownia.

Although Populus pollen travels long distances (Wright, in Potter and Rowley, 1960) its absence is probably due to poor preservation (Janssen, 1966) rather than low pollen

production. Populus pollen decomposes rather rapidly in some environments including some lakes (Sangster and Dale, 1961).

Acer, unlike the wind-pollinated poplar, is a low pollen producer with poor dispersal and it is, in addition, entomophilous (Tsukada in Potter and Rowley, 1960; Carroll, 1943). These factors probably are major causes for the absence of its pollen at Faraday Dam.

Paulownia is also an entomophilous genus, probably with a low pollen production. There are very few megafossil records for this genus from the Tertiary of North America or the Pacific Northwest (Smiley, 1961). Megafossil representation at Faraday Dam indicates that Paulownia must have been locally present but probably not in significant numbers.

Populus, Acer and Paulownia were undoubtedly part of the Faraday Dam vegetation in the Miocene. Absence of their pollen could be the result of low pollen production, inadequate dispersal, poor preservation, or all three. One or a few trees in each case could have made leaves available to the depositional basin. Because I do not have any information about the abundance of the fossil leaves of these three genera, it is difficult to draw any conclusions about their significance in the local vegetation.

(3) Genera represented only by pollen and spores:

A large number of pollen and spores were identified from Faraday Dam for which there are no reported megafossil

records. These microfossils include (1) spores, (2) pollen of both gymnosperms and arborescent angiosperms and (3) pollen of herbaceous taxa.

A large number of fern spores were identified from the Faraday Dam assemblage. Almost all of them appear to belong to the family Polypodiaceae (Fig. 3). These include both monolete (1.3%-15.0%) and trilete (.1%-7.5%) spores. The spectra of monolete spores show overall uniform, fairly high percentages; trilete grains by contrast are far less abundant for the most part. However, the spore producing plants were most probably local, because spores though dispersed by wind are released close to the ground and in a dense forest vegetation probably do not travel very far. The absence of megafossils may well be the result of poor preservation of the vegetative parts.

Besides the Polypodiaceae, there are a few other spores such as those of Osmunda (.1%-.4%), Selaginella (.1%-.2%) and Anthoceros (.1-.2%). All of these are present in the sample in very negligible amounts (Table 3).

In the second category, a large number of pollen of both gymnosperms and arborescent angiosperms were also identified that are without megafossil representation. These include Cedrus, Picea, Pinus, Tsuga, Pseudotsuga, Betula, Castanea-type, Celtis, Engelhardtia, Ilex, Itea, Lonicera, Nyssa and Ulmus. All of these genera have low pollen percentages (Table 3) (Fig. 3).

Among the five gymnosperms, Picea, Tsuga and Pseudotsuga are relatively low pollen producers (Tyldesley, 1973; Gregory, 1973; Wright, 1952; Wodehouse, 1935). But Picea and Tsuga have been reported to travel long distances (Whitehead and Tan, 1968; Janssen, 1966; Potter and Rowley, 1960; Carroll, 1943). Pseudotsuga, on the other, does not travel very far (Hansen in Potter and Rowley, 1960; Wright, 1952). However, low pollen percentages of all three genera and absence of any leaf fossils indicate their probable local absence from the vegetation. Since we do not have any information about the pollination ecology of Cedrus no conclusion can be made regarding its local presence or absence in the vegetation.

Although I have two morphologic types of pine pollen neither of them show high percentages (Fig. 3). Where the percentage of pine pollen is 10% or less, most pollen analysts would suspect an outside source. Because there are no megafossil records from the Faraday Dam deposits it seems evident that pine was most probably absent in the immediate vegetation.

Among the arborescent angiosperms, Betula, Castanea-type, and Ulmus are represented by over 2% of the pollen total and appear in the pollen diagram (Fig. 3). However, Betula (1.2%-3%) is one of the largest pollen producers with a record of long distance dispersal (Iversen in Potter and Rowley, 1960). All studies suggest that Betula is always

overrepresented (Potzger in Potter and Rowley, 1960; Janssen, 1966; Whitehead and Tan, 1968) when it is common in the local vegetation. Although birch pollen was identified throughout the section, the pollen percentages are low enough to suggest that it was very scarce or derived from an outside source (Fig. 3). The absence of megafossil evidence more or less confirms its absence.

Castanea-type (.6%-8.6%) (Fig. 3) pollen was also present throughout the section and also in some abundance. Chestnut sheds much less pollen than most anemophilous trees (Wodehouse, 1935) but more than many insect-pollinated taxa. According to Anderson (1974), pollen grain emission, dispersion, and deposition are greatest at localities in or adjacent to numerous chestnut trees. Although there is no megafossil evidence of chestnut locally the pollen is abundant enough to indicate that chestnut was indigenous to the site of deposition but not a common tree.

Ulmus (.2%-2.2%) (Fig. 3) is an anemophilous genus but produces relatively small amounts of pollen (Wodehouse, 1935; Potter and Rowley, 1960; Janssen, 1966). Uniformly low percentages of elm pollen and absence of megafossil evidence suggests an outside source for the pollen.

Celtis (.1%) (Table 3) is a profuse pollen producer with good potential for long distance transport. The extremely scarce grains and absence of megafossils suggests that hackberry was scarce or absent at Faraday Dam.

Engelhardtia (.1%-.3%) (Table 3). Like other members of Juglandaceae this genus is probably not a high pollen producer. However, the pollen record is probably too limited to indicate local presence; the absence of megafossil evidence suggests an outside source.

Ilex (.1%-.3%) and Itea (.1%-.4%) also have very limited pollen records (Table 3). Both are insect-pollinated. According to Whitehead and Tan (1968) a percentage of 0.4% for Ilex suggests that it is underrepresented whereas a percentage of 0.2% for Itea is a proportionate representation to its relative frequency in the vegetation. Considering these data it can be said that Ilex may or may not be present, but Itea was locally present at least as a minor element.

Lonicera-type (.1%-.2%) grains also have very low pollen frequency (Table 3). Since Lonicera is zoogamous (some species are pollinated by humming birds) it doubtless also has low pollen production. Honeysuckle was probably present in the local flora despite the absence of leaf remains.

Myrica and Nyssa were identified in the samples. But pollen of neither of them were found during routine counting. This information plus the absence of megafossil evidence for these genera from Faraday Dam suggests either their scarcity in the vegetation or an external source for the pollen.

In the third category is pollen of herbaceous plants. These are mainly identified at the family level, and include Cyperaceae, Gramineae, Lemnaceae?, Chenopodiaceae (Sarcobatus-type), Compositae, and Onagraceae. A few genera also belong to this category including Typha, Pachysandra and Polygonum.

All these specimens show low pollen frequencies. Pollen grains of herbaceous taxa are usually dispersed by local air movement near the ground and deposited near the parent plants (Davis and Goodlett, 1960). However, as a rule herbaceous pollen indicate local presence of the parent plant.

Among these, Cyperaceae, Gramineae, Chenopodiaceae and Typha are wind pollinated and produce large quantities of pollen which are very light and easily dispersed (Wodehouse, 1935; Faegri and Iversen, 1975). It is difficult to explain why they are not more common as fossil pollen. However, Typha, a common swamp plant, has pollen that is susceptible to degradation in some environments (Sangster and Dale, 1961) and may have low representation for that reason.

Pachysandra pollen was identified from the samples but was not found during routine counting. This genus produces much less pollen than many other herbaceous plants, and does not disperse very efficiently (Gray and Sohma, 1964).

The Lemnaceae? are hydrophytes and produce very negligible amounts of pollen. Because of their specialized pollination ecology (Proctor and Yeo, 1971) their pollen is seldom airborne.

Polygonum and members of the family Onagraceae are zoogamous and evidently produce small amounts of pollen (Wodehouse, 1935).

In conclusion, it can be stated that absence of previous megafossil records for these taxa may be because the vegetative parts are more susceptible to decomposition than pollen and spores, because of lack of recognition or identification of megafossils for the Faraday Dam flora, or because of limited opportunity for their remains to get into the fossil record.

Overall it should be noted that the leaf fossils with co-occurring pollen in the Faraday Dam also have high pollen percentages and are major constituents of the pollen diagram. From these data it can also be concluded that these genera probably were the dominant components of the Faraday Dam vegetation.

Discussion and Conclusions

The overall climatic and vegetational changes of the Pacific Northwest during the Tertiary have been discussed in detail by Chaney (1956, 1959), Dorf (1959), Wolfe (1969, 1971, 1978) and Wolfe and Hopkins (1967). These studies,

based almost exclusively on plant megafossils, reveal that the climate and vegetation were very different from the present climate and forest formations of the Pacific Northwest.

Pollen data generally support the limited megafossil data from Faraday Dam and are in agreement with the results of previous studies. The composition of the Faraday Dam flora represented by pollen and spores reflects a vegetation type similar to the deciduous forests of eastern North America and eastern Asia. Genera such as Quercus, Fagus, Carya, Castanea (Castanea-type pollen), Platanus and Liquidamber are recognized from both megafossils and pollen. These are among the dominant taxa of eastern Asian and eastern North American forests (Table 2). Conifers, including members of the Pinaceae, e.g. Pinus, and Tsuga, Taxodiaceae, e.g. Taxodium and possibly Cupressaceae and Taxaceae, also occur frequently in the deciduous forest formation (Braun, 1964). Evergreens such as Ilex and the perennial herb Pachysandra, recognized as minor elements from the pollen record, occur in the deciduous forest as secondary components.

The late Miocene deciduous forest of the Faraday Dam region is somewhat comparable to the modern Western Mesophytic Forest Region of the eastern North American deciduous forest (Braun, 1964). As described by Braun (1964) the Western Mesophytic Forest occupies the area from

the western escarpment of the Cumberland and Allegheny Plateaus on the east to the loess bluffs of the Mississippi River at the eastern limits of the Mississippi alluvial plain on the west. The region extends north from northern Alabama and Mississippi to the southern boundary of Wisconsin glaciation in Ohio and eastern Indiana, and the southern boundary of Illinoian glaciation farther west. In Illinois, it includes the Ozark Hills. This region is essentially the area known as the Interior Low Plateau, and includes in addition the area of Illinoian glaciation in southwestern Ohio and southwestern Indiana, and the area of coastal plain sediments in western Kentucky, western Tennessee, and northern Mississippi (Braun, 1964:122). The dominant genera of this region include Quercus, Carya, Castanea, Fagus, Platanus, Liquidamber, and Juglans which are among the common pollen taxa at Faraday Dam. Many genera represented by pollen at Faraday Dam are found specifically in the Mississippi Embayment section of the Western Mesophytic Forest Region (Braun, 1964:159), whose dominant genera include Quercus, Carya, Ulmus, Betula, Celtis, Liquidamber, Salix, Populus, Acer, Pinus, and Taxodium. All of these genera were identified from pollen, except Populus and Acer. Both these taxa have, however, been identified as megafossils (Wolfe and Brown in Peck, et al., 1964). Much of the Taxodiaceous pollen component can probably also be attributed to Taxodium. This particular section of the

deciduous forest is also relatively poor in herbaceous plants which may, in part, explain the limited abundance of some herbaceous elements in the Faraday Dam pollen assemblage although ferns were apparently common based on the spore records.

There are, however, some genera such as Juglans, Fagus, Castanea (Castanea-type pollen), Nyssa, Pachysandra, and Tsuga represented at Faraday Dam that are not present in the Mississippi Embayment section of the Western Mesophytic Forest Region although they are present in other sections of the Western Mesophytic Forest Region (Braun, 1964:122-161). There are also a few genera found at Faraday Dam such as Ilex, Symplocos, Itea, Lonicera, Abies and Picea that do not occur in any part of the Western Mesophytic Forest Region. All are found, however, in other deciduous forest regions of eastern North America. On the other hand, there are many genera now present in the modern deciduous forest such as Tilia, Magnolia, Fraxinus, Liriodendron, and Carpinus that are not found at Faraday Dam. There are several possibilities for explaining the absence of these and other genera common in the deciduous forest from the pollen record, such as inefficient dispersal of the pollen grains, limited abundance of the parent plants in the vegetation, distance of the parent plants relative to the depositional basin, or differences in topography in the Faraday Dam area in comparison with that in the modern deciduous forest that

might favor the presence of some taxa but not of others. One or more of these could contribute to the absence of pollen grains for some taxa. On the other hand, there may be real differences between the vegetational components of the late Miocene flora in the northwestern Oregon and the modern vegetation with which I have compared it.

Many attempts have been made to understand the late Miocene paleoclimate in the Pacific Northwest. It is hard to come up with specific environmental parameters because of the absence of adequate faunal and floral evidence. Previous studies conclude, however, that the late Miocene climate could be categorized as warm temperate (Chaney, 1956, 1959; Dorf, 1959; Axelrod, 1956, 1964; Wolfe, 1969, 1971, 1978; and Wolfe and Hopkins, 1967).

In general, the approximate temperature and rainfall pattern in the Pacific Northwest during the late Miocene can be deduced from the temperature and rainfall patterns that now pertain in regions where the vegetation is most like that of the fossil assemblage. That is, the modern vegetation provides an "index" to what environmental conditions were like for the fossil assemblage. A large number of taxa found in the Faraday Dam pollen assemblage no longer exist in northwest Oregon but are present in eastern and southeastern North America and in eastern Asia. The type of vegetation thus reveals that the Miocene climate was different in a number of essential ways from that of

western Oregon at this time.

Temperature and rainfall of some modern regions whose vegetation is more or less comparable to that at Faraday Dam along with modern climatic data for northwestern Oregon are presented in Table 4. From the table it is clear that the late Miocene climate in northwestern Oregon, in terms of mean annual temperature and precipitation, was most similar to that at latitudes as much as 10° to 15° south, although the mean annual temperature and precipitation at Estacada (the nearest climatic reference point to Faraday Dam) are not greatly different from those pertaining in parts of the modern deciduous forests of eastern North America and Asia (Table 4). Since many genera identified from the fossil flora still survive in eastern North America, in eastern Asia, or in both places, it can be concluded that the climate of northwestern Oregon during the late Miocene was also summer wet.

Despite the cooler trend of late Cenozoic climates globally, late Miocene climate in northwestern Oregon was still warmer than it is today. This can be supported not only by the overall floral assemblage but by the presence of such genera as Engelhardtia, Pachysandra, Symplocos, and Itea, taxa whose principle distribution is now in warm temperate and subtropical to tropical regions of the New World and Asia. At the same time the presence of conifers such as Abies and Picea along with the deciduous genera

TABLE 4
CLIMATIC DATA FOR LOCATIONS WHOSE VEGETATION IS COMPARABLE
TO THE FARADAY DAM FOSSIL FLORA*

Locality	Mean annual temperature (F°)	Mean annual precipitation (inches)	Season of maximum precipitation	Latitude
Estacada, NW OREG.	51.7	60.65	Winter	45°16'
Orleans, CALIF.	57.1	55.31	Winter	41°18'
Hillsboro, OHIO	52.4	42.84	Summer	39°12'
Mount Vernon, IND.	55.7	43.18	Summer	37°57'
Harrisburg, ILL.	57.6	43.28	Summer	37°44'
Nikko, JAPAN	51.0	90.00	Summer	37°
Mountain City, TENN.	53.0	47.00	Summer	36°
Covington, TENN.	59.7	49.97	Summer	35°34'
Boonville, MISS.	60.6	43.29	Summer	34°39'
Canton, MISS.	64.0	50.15	Summer	32°36'
Nanking, CHINA	59.5	39.10	Summer	32°03'
Engshih, CHINA	61.5	56.30	Summer	30°16'

*Compiled from: Chaney and Axelrod (1959); Wang (1961); and Ruffner (1980).

indicates that the climate was cool enough (or that there was sufficient topography) to allow these plants to grow in northwestern Oregon in the late Miocene, but that the temperature and possibly the season of maximum precipitation were not optimal for the existence of a coniferous forest of the type which presently exists in this region.

- _____. *As a time horizon in lake sediments in western North America. Canadian Journal of Earth Science* 11, 678-685.
- Aschard, R. J. (1956). *Mioc-Pliocene Floras from west-central Nevada. University of California Publications in Geological Sciences* 33, 321p.
- _____. (1958). *The Miocene Tappan Creek Flora of southern Idaho. University of California Publications in Geological Sciences* 35, 180p.
- Balchin, R. W. (1956). *Geology of Oregon. 2nd ed. University of Oregon Cooperative Bookstore, Eugene, Oregon. 168p.*
- Bart, A. W. and Wright, R. E. Jr. (1962). *Pollen analyses of surface materials and lake sediments from the Chuska Mountains, New Mexico. Geological Society of America Bulletin* 74, 451-460.
- Birks, H. J. B. and Birks, H. B. (1959). *Quaternary paleoecology. University Park Press, Baltimore, 299p.*
- Boulenger, M. C. and Chaloner, W. G. (1970). *Marquess fossil plants from Derbyshire (England). Review of Palaeobotany and Palynology* 10, 65-74.

BIBLIOGRAPHY

- Andersen, S. Th. (1974). Wind conditions and pollen deposition in a mixed deciduous forest. *Grana* 14, 64-77.
- Anderson, T. W. (1974). The chestnut pollen decline as a time horizon in lake sediments in eastern North America. *Canadian Journal of Earth Science* 11, 678-685.
- Axelrod, D. I. (1956). Mio-Pliocene floras from west-central Nevada. University of California Publications in Geological Sciences 33, 321p.
- _____ (1964). The Miocene Trapper Creek flora of southern Idaho. University of California Publications in Geological Sciences 51, 180p.
- Baldwin, E. M. (1964). *Geology of Oregon*, 2nd ed. University of Oregon Cooperative Bookstore, Eugene, Oregon, 165p.
- Bent, A. M. and Wright, H. E. Jr. (1963). Pollen analyses of surface materials and lake sediments from the Chuska Mountains, New Mexico. *Geological Society of America Bulletin* 74, 491-500.
- Birks, H. J. B. and Birks, H. H. (1980). Quaternary paleoecology. University Park Press, Baltimore, 289p.
- Boulter, M. C. and Chaloner, W. G. (1970). Neogene fossil plants from Derbyshire (England). *Review of Paleobotany and Palynology* 10, 61-78.

Braun, L. E. (1964). Deciduous forests of eastern North America. Hafner Publishing Company, New York and London, 596p.

Carroll, G. (1943). The use of bryophytic polsters and mats in the study of recent pollen deposition. American Journal of Botany 30, 361-366.

Chaney, R. W. (1925a). A comparative study of the Bridge Creek flora and the modern redwood forest. Carnegie Institution of Washington Publication 349I, 3-22.

_____ (1925b). The Mascall flora--its distribution and climatic relation. Carnegie Institution of Washington Publication 349II, 23-48.

_____ (1944). Introduction, In Chaney, R. W. (ed.), Pliocene floras of California and Oregon. Carnegie Institution of Washington Publication 553, 1-19.

_____ (1956). The ancient forests of Oregon. Condon Lectures (Oregon State System of Higher Education), 56p.

_____ (1959). Part I. Composition and interpretation, In Chaney, R. W. and Axelrod, D. I., Miocene floras of the Columbia Plateau. Carnegie Institution of Washington Publication 617, 1-133.

Clark, L. and Frye, T. C. (1928). The liverworts of the Northwest. Publications Puget Sound Biological

Clark, T. H. and Stearn, C. W. (1960). The geological evolution of North America. The Ronald Press Company, New York, 434p.

- Station, 194p.
- Cooper, W. S. (1957). Vegetation of the Northwest-American Province. Eighth Pacific Science Congress, Quezon City 1957, Proceedings 4, 133-138.
- Culberson, W. L. (1955). The fossil mosses of the Two Creeks forest bed of Wisconsin. American Midland Naturalist 54, 452-459.
- Davis, M. B. and Goodlett, J. C. (1960). Comparison of the present vegetation with pollen-spectra in surface samples from Browington pond, Vermont. Ecology 41, 347-357.
- Detling, L. E. (1968). Historical background of the flora of the Pacific Northwest. Museum of Natural History Bulletin 13 (University of Oregon), 57p.
- Dorf, E. (1959). Climatic changes of the past and present. Contributions from the Museum of Paleontology, University of Michigan, 131, 181-210.
- Erdtman, G. (1952). Pollen morphology and plant taxonomy I. Angiosperms. Almqvist and Wiksell, Stockholm, 539p.
- _____ (1957). Pollen and spore morphology/plant taxonomy II. Gymnospermae, Pteridophyta, Bryophyta. Almqvist and Wiksell, Stockholm, 151p.
- _____ (1965). Pollen and spore morphology/plant taxonomy III. Gymnospermae, Bryophyta. Almqvist and Wiksell, Stockholm, 191p.
- _____ and Sorsa, P. (1971). Pollen and spore morphology IV. Pteridophyta. Almqvist and Wiksell, Stockholm, 302p.

- Faegri, K. and Iversen, J. (1975). Textbook of pollen analysis. Hafner Press, New York, 295p.
- _____ and Pijl, L. van der. (1976). The principles of pollination ecology, 2nd ed. Pergamon Press, New York, 291p.
- Franklin, J. F. and Dyrness, C. T. (1973). Natural vegetation of Oregon and Washington. U.S.D.A. Forest Service General Technique Report PNW-8, 417p.
- Gray, J. (1958). Plant microfossils from the Miocene of the Columbia Plateau, Oregon. Ph.D. Dissertation, University of California, Berkeley.
- _____ (1964). Northwest American Tertiary palynology: the emerging picture. In Lucy M. Cranwell (ed.) Ancient Pacific floras. University of Hawaii Press (Tenth Pacific Science Congress Series), 21-30.
- _____ (1965). Extraction techniques, In Kummel, B. and Raup, D. (eds.), Handbook of paleontological techniques. W. H. Freeman, San Francisco, 530-587.
- _____ and Sohma, K. (1964). Fossil Pachysandra from western America with a comparative study of pollen in Pachysandra and Sarcococca. American Journal of Science 262, 1159-1197.
- Gregory, P. H. (1973). The microbiology of the atmosphere, 2nd ed. John Wiley and Sons, New York and Toronto, 377p.
- Hansen, H. P. (1949). Pollen content of moss polsters in relation to forest composition. American Midland

Naturalist 42, 473-479.

Hitchcock, C. L. and Cronquist, A. (1976). Flora of the Pacific Northwest, 3rd ed. University of Washington Press, Seattle and London, 730p.

Hodge, E. T. (1938). Geology of the lower Columbia River. Geological Society of America Bulletin 49, 831-930.

Hopkins, W. S. Jr. (1967). Palynology and its paleoecological application in the Coos Bay area, Oregon. The Oregon Bin 29, 161-184.

(1968). Subsurface Miocene rocks, British Columbia-Washington, a palynological investigation. Geological Society of America Bulletin 79, 763-768.

Janssen, C. R. (1966). Recent pollen spectra from the deciduous and coniferous-deciduous forests of north-eastern Minnesota: a study in pollen dispersal. Ecology 47, 804-825.

Kirkwood, J. E. (1902). The vegetation of northwestern Oregon. Torrey 2, 129-134.

Krzywinski, K. (1977). Different pollen deposition mechanism in forest: a simple model. Grana 16, 199-202.

Lacey, W. S. (1969). Fossil bryophytes. Biological Reviews 44, 189-205.

LaMotte, R. S. (1952). Catalogue of the Cenozoic plants of North America through 1950. Geological Society of America Memoir 51, 381p.

- Lawrence, G. H. M. (1951). Taxonomy of vascular plants.
The McMillan Company, New York, 823p.
- Libbey, F. W., Lowry, W. D., and Mason, R. S. (1947).
Ferruginous bauxite deposits in northwestern Oregon.
Oregon Department of Geological and Mineral Industries
Bulletin 29, 97p.
- Lowry, W. D. and Baldwin, E. M. (1952). Late Cenozoic
geology of the lower Columbia River valley, Oregon and
Washington. Geological Society of America Bulletin 63,
1-24.
- Martin, H. A. and Rouse, G. E. (1966). Palynology of late
Tertiary sediments from Queen Charlotte Islands, British
Columbia. Canadian Journal of Botany 44, 171-208.
- Martin, P. S. and Gray, J. (1962). Pollen analysis and the
Cenozoic. Science 137, 103-111.
- McKee, B. (1972). Cascadia: the geologic evolution of the
Pacific Northwest. McGraw-Hill Book Company, New York,
394p.
- Moore, P. D. and Webb, J. A. (1978). An illustrated guide
to pollen analysis. John Wiley and Sons, New York, 133p.
- O'Neill, T. F. (1939). The geology of the Stayton
Quadrangle, Oregon. Master's thesis, Oregon State
College, Corvallis.
- Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G.,
and Dole, H. M. (1964). Geology of the central and
northern parts of the western Cascade Range in Oregon.

- United States Geological Survey Professional Paper 449,
56p.
- Peck, M. E. (1961). A manual of the higher plants of
Oregon, 2nd ed. Binfords and Mort, Portland, Oregon,
936p.
- Potter, L. D. and Rowley, J. (1960). Pollen rain and
vegetation, San Augustin Plains, New Mexico. Botanical
Gazette 122, 1-25.
- Preston, R. J. Jr. (1976). North American trees, 3rd ed.
The Iowa State University Press, Ames, Iowa, 399p.
- Robinson, B. L. and Fernald, M. L. (1908). A handbook of
the flowering plants and ferns of the central and north-
eastern United States and adjacent Canada, 7th ed.
American Book Company, New York, Cincinnati and Chicago,
926p.
- Ruffner, J. A. (1980). Climates of the states, 2nd ed.
Vols. I and II. Gale Research Company, Book Tower,
Detroit, Michigan, 1-588; 589-1175p.
- Sanborn, E. I. (1929). Hepaticae and Anthocerotae of
western Oregon. University of Oregon Publication,
Eugene, 1, 111p.
- Sangster, A. G. and Dale, H. M. (1961). A preliminary study
of differential pollen grain preservation. Canadian
Journal of Botany 39, 35-43.
- Sargent, C. S. (1949). Manual of the trees of North America.
Vols. I and II. Dover Publications, Inc., New York,

- 1-433p; 434-910p.
- Schuster, R. M. (1966). The Hepaticae and Anthocerotae of North America east of the hundredth meridian. Vol. I, Columbia University Press, New York and London, 802p.
- Smiley, C. J. (1961). A record of Paulownia in the Tertiary of North America. American Journal of Botany 48, 175-179.
- _____, Gray J. and Huggins, L. M. (1975). Preservation of Miocene fossils in unoxidized lake deposits, Clarkia, Idaho. Journal of Paleontology 49, 833-844.
- Smith, G. M. (1938). Cryptogamic botany, Vol. II, Bryophytes and Pteridophytes. McGraw-Hill Book Company, Inc., New York and London, 399p.
- Smith, P. J. Jr. (1977). Vascular plant families. Mad River Press Inc., California, 320p.
- Tauber, H. (1967). Differential pollen dispersion and filtration, In Cushing, E. J. and Wright, H. E. Jr. (eds.), Quaternary paleoecology. Yale University Press, New Haven, 131-141.
- Treasher, R. C. (1942). Geology of the Portland area, Oregon, with text on back. Oregon Department of Geology and Mineral Industries.
- Turner, D. L., Frizzell, V. A., Triplehorn, D. M., Naeser, C. W. (1983). Radiometric dating of ash partings in coal of the Eocene Puget Group, Washington: implications for paleobotanical stages. Geology 11, 527-531.

- Tyldesley, J. B. (1973). Long range transmission of tree pollen to Shetland. *New Phytologist* 72, 175-181.
- Wang, Chi-Wu. (1961). The forests of China with a survey of grassland and desert vegetation. Harvard University Press, Cambridge, Massachusetts, 313p.
- Whitehead, D. R. and Tan, K. W. (1968). Modern vegetation and pollen rain in Bladen County, North Carolina. *North Ecology* 50, 235-248.
- Willis, J. C. (1973). A dictionary of the flowering plants and ferns, 8th ed. Cambridge University Press, Cambridge, 1245p.
- Wodehouse, R. P. (1935). Pollen grains. McGraw-Hill Book Company Inc., New York and London, 574p.
- Wolfe, J. A. (1962). A Miocene pollen sequence from the Cascade Range of northern Oregon. United States Geological Survey Professional Paper 450-C, Article 89, C81-C84.
- _____ (1969). Neogene floristic and vegetational history of the Pacific Northwest. *Madrone* 20, 83-110.
- _____ (1971). Tertiary climatic fluctuations and methods of analysis of Tertiary floras. *Palaeogeography, Palaeoclimatology, Palaeoecology* 9, 27-57.
- _____ (1978). A paleobotanical interpretation of Tertiary climates in the Northern Hemisphere. *American Scientist* 66, 694-703.

- _____ (1981). A chronologic framework for Cenozoic megafossil floras of northwestern North America and its relation to marine geochronology, In Armentrout, J. M. (ed.) Pacific Northwest Cenozoic Biostratigraphy. Geological Society of America Special Paper 184, 172p.
- _____ and Hopkins, D. M. (1967). Climatic changes recorded by Tertiary land floras in northwestern North America, In Hatai, K. (ed.) Tertiary correlations and climatic changes in the Pacific. Sasaki Printing and Publishing Company, Sendai, Japan, 67-76.
- Wright, J. W. (1952) Pollen dispersal of some forest trees. United States Forest Service, Northeastern Forest Experimental Station Paper 46.

Typed by:

Paula Brody Demong