PALYNOLOGY OF TERTIARY ROCKS OF THE WHATCOM BASIN, SOUTHWESTERN BRITISH COLUMBIA AND NORTHWESTERN WASHINGTON

by

William Stephen Hopkins, Jr.

B. Sc., University of Washington, 1954
M. Sc., University of British Columbia, 1962

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Department of Geology

The University of British Columbia
Vancouver 8, Canada

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FACULTY OF GRADUATE STUDIES

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of

WILLIAM STEPHEN HOPKINS, JR.

B.Sc., University of Washington, 1954

M.Sc., The University of British Columbia, 1962

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Chairman: I. McT. Cowan

R. V. Best	G. E. Rouse
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V. J. Okulitch	A. J. Sinclair

Research Supervisor: G. E. Rouse

External Examiner: L. R. Wilson
Dept. of Geology
University of Oklahoma
Norman, Oklahoma

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ABSTRACT

Lower and Middle Tertiary continental sedimentary rocks comprise the fill in a large structural basin adjacent to the Georgia Depression in southwestern British Columbia and northwestern Washington. Upper Cretaceous continental sedimentary rocks apparently underlie the entire basin.

Outcrops of Tertiary rocks are restricted to the north, south and east margins where they are dipping into the basin and overlying older rocks rimming the basin. Relationships to the west are obscured by the Strait of Georgia, but apparently the Whatcom basin is part of, and contiguous with, the Georgia depression. Over most of the area, surface cover is Pleistocene and Recent sediments.

Investigations of plant microfossils from two deep basin wells indicate three distinct floras in pre-Pleistocene rocks. Basal portions contain a relatively small Upper Cretaceous floral assemblage. Above this are Middle and probably Upper Eocene assemblages. Upper parts of the section contain a predominantly dicotyledonous Miocene assemblage.

Palynological study of the outcrops indicates a Middle to Upper Eocene age for all except the Brothers Creek outcrop on the north side of Burrard Inlet, which appears to be Upper Cretaceous. Miocene rocks are found only in the wells, and apparently do not crop out.

Eocene assemblages contain Pistillipollenites and Platycarya together with significant numbers of Cactricosisporites and Anemia spores, and suggest a warm temperate to subtropical climate. Miocene assemblages are generally characterized by Glyptostrobus, Pterocarya, Ulmus-Zelkova and Fagus and several other dicotyledonous pollen. Miocene assemblages indicate a more temperate aspect than those of the Eocene.

GRADUATE STUDIES

Field of Study:

Paleobotany	G. E. Rouse
Advanced paleobotany	G. E. Rouse
Advanced invertebrate paleontology	V. J. Okulitch

Related Studies:

Advanced structural geology	W. H. White
Geology of North America	W. R. Danner
Advanced sedimentology	W. H. Mathews
Problems in sedimentology	W. H. Mathews
Permafrost and seasonally frozen ground	T. L. Péwé
Volcanology	R. Forbes
Petroleum geology of Northern Alaska	F. Weber

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INTRODUCTION

General Statement

In recent years the study of fossil plant spores and pollen has become a rapidly growing field of endeavor. From Mid-Paleozoic to the present time, terrestrial plants have been abundant and diversified, covering most of the land areas of the world. Plants produce enormous quantities of spores and pollen and with the coming of each flowering season these are widely dispersed by wind, water, insects, birds and occasionally mammals. Coupled with the tremendous production of spores and pollen is the fact that most spores and pollen are incredibly resistant to destruction. A hard cutinous coating aids in their preservation under a variety of depositional environments, and permits them to survive the rather rigorous treatment they undergo during maceration. Furthermore, they show a wide diversity in morphology including size, shape, and ornamentation which makes many of them readily identifiable. These three factors then, abundance, resistance to destruction, and morphologic diversity, make spores and pollen very valuable for study and re-interpreting the past record of plant life.

Most continental, and many marine sediments, contain fossil pollen and spores, a partial record of the flora extant at the time of deposition. From spores, pollen and other plant microfossils various data can be derived, such as information on the environment of deposition, suggestions as to plant evolution, and genetic relationships and age of the enclosing rock. And finally, correlations of time equivalent sedimentary rocks are possible, depending on the number of microfossils present, and their degree of preservation.

An aspect of particular interest to me is paleoecology. Information of this sort is largely available only from Cretaceous and Tertiary rocks, because only here can we relate many of the microfossils to extant genera. By analogy with requirements of modern day genera, conclusions can be drawn as to what the probable flora was and what its environmental and other ecological conditions might have been. Complications of interpretation arise, however, because of local climatic and edaphic factors, plant evolution, plant succession, and differential preservation. With care, however, much useful information can be deduced.

Purpose and Scope of the Investigation

This report presents the results of a Tertiary palynological study in the Whatcom sedimentary basin in northwestern Washington and southwestern British Columbia. The project involves an extensive section of Tertiary and Cretaceous sedimentary rocks in the Vancouver, British Columbia-Bellingham, Washington area.

At this point I should make it clear that I have not made a palynological study of the Paleocene Chuckanut Formation which crops out to the south and forms the southern boundary of the Whatcom basin. The geology of the Chuckanut Formation is briefly discussed in a later section so that comparisons can be drawn with the Middle Eocene and younger rocks that fill the Whatcom basin, as well as with the Upper Cretaceous rocks that underlie the basin.

The Tertiary section in the Whatcom basin, as well as the underlying Cretaceous, is an alternating sequence of conglomerates, sandstones, shales and coals that is almost totally lacking in vertebrate or invertebrate remains. Several possible vertebrate remains were found in the Kitsilano Formation but they will be discussed in a following section dealing with this formation. Plant macrofossils have been found locally, but with the exception of those found in the Burrard, Kitsilano and Chuckanut Formations, little of a systematic nature has been done with them. However, spores and pollen and other plant microfossils are present, and occasionally in large numbers. A study of this microflora would add significantly to our knowledge of Tertiary history and environments of this region, and provide a basis for correlating and also possibly dating the isolated microfossil-bearing outcrops.

This thesis presents as its focus a type section of plant microfossil assemblages based on the analysis of two deep wells. In addition, other Tertiary rocks of the area have been correlated with the type section on the basis of their contained microflora. Although a relative chronology has been established, it has not been possible to give absolute dates for the units of the section. The main reason is the dearth of plant microfossil information from the Pacific coastal areas of North America; but also lack of invertebrate fossil control and the absence of radiometrically datable ash beds or volcanic rocks has made it impossible to establish absolute ages. Nevertheless, a significant contribution is made here with the establishment of a floral succession to which other Tertiary rocks throughout the Pacific Northwest may be correlated in the future. As research continues, more absolute dates of some of the units considered here should become available. A third objective of the investigation was an attempt to interpret and discuss the environment as indicated by these plants.

To place the entire project in its geological setting, a brief discussion of the regional geology, and a more detailed description of the Tertiary sedimentary formations precedes the palynological analysis.

Geography

Location

The area under discussion is roughly triangular in shape, lying in northwestern Washington State and southwestern British

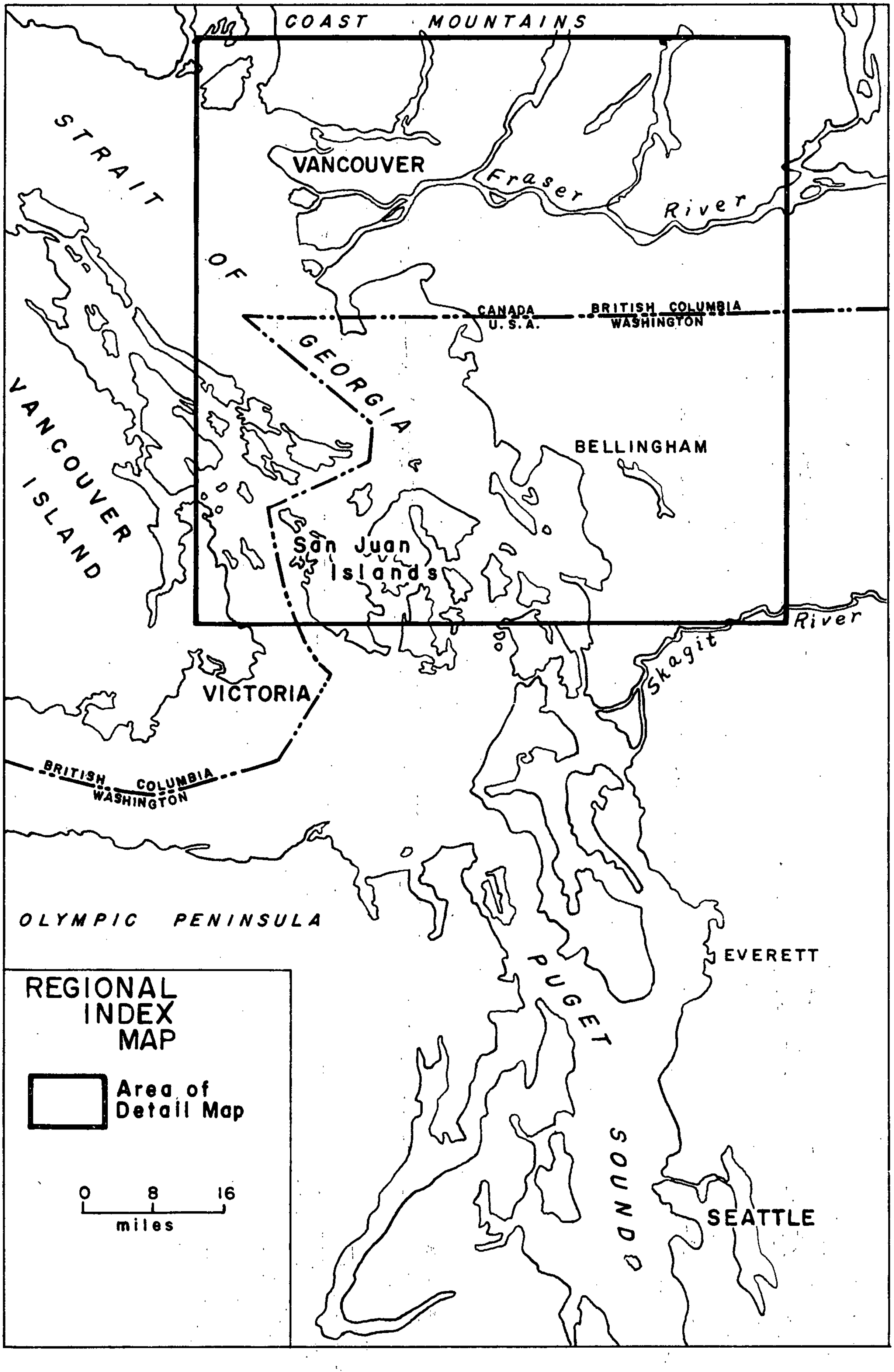
Columbia (see Index Map, Figure A; Geologic Map, Figure D). The northern boundary of the area is the southern end of the British Columbia Coast Mountains, the east margin is the Cascade Mountain foothills, the south margin is near Bellingham just north of the Chuckanut Hills, and to the west the study area is terminated by the waters of Georgia Strait. The sedimentary basin which includes the sedimentary sequence under study is indicated on Figure D by the dashed line. The entire land area encompassed in this study is approximately 1,200 square miles, but the area of Tertiary outcrop forms a minute fraction of this.

Topography

Elevations within the area range from sea level to 3,000 feet. At least 90 percent of the region lies below 300 feet and the surface is largely of Recent deposits of the Fraser and Nooksack Rivers or of Pleistocene till and outwash.

North of the International Boundary this lowland is termed the Fraser Lowland (Armstrong, 1960) and is largely an area of extensive low hills separated by broad flat-bottomed valleys. South of the International Boundary the land surface is mostly flat-terraced glacial outwash overlying the river alluvium which has been called the Bellingham-Sumas Coastal Plain (Miller and Misch, 1963). In subsequent sections the entire area is termed the Fraser Lowland; topography, like geology, does not necessarily change at International Boundaries.

FIGURE A


COAST MOUNTAINS
STRAIT OF GEORGIA
VANCOUVER
Fraser River
CANADA
U.S.A.
BRITISH COLUMBIA
WASHINGTON
VANCOUVER ISLAND
BELLINGHAM
San Juan Islands
Skagit River
VICTORIA
BRITISH COLUMBIA
WASHINGTON
OLYMPIC PENINSULA
EVERETT
PUGET SOUND
SEATTLE
REGIONAL INDEX MAP
Area of Detail Map
0 8 16
miles

Relief on the lowland is slight, ranging from 0 to 500 feet, although topographic changes can be abrupt against bluffs of Pleistocene outwash. Occasionally near the north, south, and east margins of the basin (see Geologic Map, Figure D) knobs of older rock penetrate the alluvium and/or Pleistocene outwash.

Rising abruptly at the margin of the basin are foothills, which to the north and east are composed of pre-Tertiary rocks. To the south the Whatcom basin is bordered by hills carved in the Paleocene Chuckanut Formation. The dashed line on Figure D approximately conforms to the basin margin and lies roughly along the line where the relief changes abruptly.

Drainage in the area is dominated by the sixth largest river in North America, the Fraser, which has an average discharge of 124,000 cubic feet per second, drains 92,000 square miles of interior British Columbia, and which on the Fraser Lowland flows across the northernmost part of the area. Of lesser importance is the much smaller Nooksack River which enters the Strait of Georgia near the city of Bellingham, Washington, and heads on the slopes of Mount Baker, a Pleistocene volcano located east of the basin. A number of smaller streams serve as tributaries to these master rivers, or enter the Strait of Georgia on their own. On the whole, the area is well-drained except near river mouths where bogs and swamps occur. Much of the land in these low-lying areas has been recovered for human use by diking both the rivers and parts of Georgia Strait.

Access and Culture

All portions of the area are readily and easily accessible, and three large metropolitan areas exist within the basin margins. Vancouver, British Columbia and adjacent New Westminster lie at the northwest corner, and Bellingham, Washington lies at the southwest tip. Numerous towns, villages, and farms throughout the lowland are served with a complete network of highways and railroads. Four railroads, the Great Northern, the Milwaukee Road, the Canadian Pacific, and Canadian National, all serve various parts of the area. A network of good paved roads encompasses all portions of the area, both in British Columbia and Washington, although a few of the more extreme marginal highlands can be reached only by logging or farm roads.

The lowland is intensively farmed, the bulk being utilized in dairying, truck farming, or the cultivation of various grain products. Areas marginal to the basin continue to produce timber, in most places on a sustained yield basis.

Vegetation

Except for local wood lots, all the native vegetation has been removed from the lowlands and replaced by agricultural crops. Prior to clearing by man, the lowland was covered by the western hemlock (Tsuga heterophylla) - red cedar (Thuja plicata) climax vegetation characteristic of the region. The surrounding hills support a forest consisting of douglas fir (Pseudotsuga menziesii), red cedar (Thuja plicata), western hemlock (Tsuga heterophylla), broad leaf maple (Acer macrophyllum), and red alder (Alnus rubra). At higher elevations, and farther back from the basin, the forest becomes characteristically mountain hemlock (Tsuga mertensiana), yellow cedar (or cypress) (Chamaecyparis nootkatensis) and alpine fir (Abies lasiocarpa). Ferns and salal are especially common in the ground cover. Further discussion of modern flora follows in a later section on paleoecological interpretations.

Climate

The climate within the area is classified as humid-temperate with cool, dry summers and moderate, wet winters (Trewartha, 1954). More recently Krajina (1959, 1965) has assigned the Whatcom basin area to his Coastal Douglas Fir Biogeoclimatic Zone which he considers to have a mediterranean subhumid to humid climate with a total annual precipitation of 26 to 60 inches. Summers are mostly warm, with July and August being essentially rainless. The winters tend to be mild, cloudy and wet.

At Bellingham the average precipitation is 32.6 inches, including an average snowfall of 10.7 inches. Most of the precipitation falls between October and March. The average July temperature is 60.6° and the average January temperature is 36.3°. Days above 90° or below 32° are uncommon (Smith, 1955).

Conditions at Vancouver are similar, although average annual precipitation is slightly higher with 40.5 inches, which includes 15.3 inches of snow (Meterological Division, 1961).

Climatic conditions across the lowlands vary only slightly from conditions at Bellingham and Vancouver. As one reaches the surrounding highlands, however, the average annual precipitation increases rapidly because of condensation in the rising moisture-laden east-moving air masses. Snowfall increases with increasing elevation, although nowhere in the map-area is there permanent snow.

Previous Work

Local areas within the region encompassed by this report have been examined geologically many times in the past, but to my knowledge no comprehensive discussion of the geology has ever been published. In the section on geology which follows, I will attempt to synthesize the work of a number of geologists and give a brief but general areal picture of the Whatcom basin, and insofar as possible, the rock units of pertinent interest.

Daly (1912) mapped through the center of the area along the International Boundary. Although he did little south of the International Boundary, he did examine briefly Canadian Sumas Mountain and the Tertiary rocks cropping out in the vicinity of Vancouver.

Johnston (1923) made a rather comprehensive study of the Fraser River Delta and vicinity but confined his efforts to the Canadian portion of the Whatcom basin.

Crickmay (1930) discussed the structural connection between the Coast Range of British Columbia and the Cascade Mountains of Washington. Later, Crickmay and Pocock (1963) expounded their views regarding the "Cretaceous" rocks of Vancouver.

South of the International Boundary little study has been undertaken on the Tertiary rocks of the Whatcom basin. Outcrops are relatively few and the assumption has been tacitly made that these are equivalent to the Tertiary Huntington Formation of British Columbia. In this connection Moen (1962) presents a valuable discussion of the structure and lithology of the continental Tertiary rocks composing the west side of American Sumas Mountain.

Miller and Misch (1963) demonstrated that these, and the Tertiary rocks cropping out near Bellingham, are a distinctly younger sequence than the Chuckanut Formation.

Little work has been published on the Tertiary floras of the Whatcom basin. Heer (1859) examined and identified some

Tertiary fossil plants from Vancouver and Bellingham; Lesquereux (1859) reported on fossil plants from the Bellingham Bay area. Newberry (1863) did further work with plant macrofossils from the Orcas Island-Bellingham Bay area. J. W. Dawson (1895) reported on a collection of plants from the Vancouver area. Berry (1923, quoted in Johnston) examined a collection from the south side of Burrard Inlet in Vancouver. Somewhat later Berry (1926) published a paper on the Tertiary floras of British Columbia in which he referred again to the Kitsilano and Burrard floras. Pabst (1962) presented a Ph.D. thesis on the Equisetales, Filicales, and the Coniferales from the Chuckanut Formation south of Bellingham.

Studies of the palynology are recent and incomplete. Rouse (1962) published the results of his investigations of the Burrard Formation cropping out at Vancouver. More recently, Griggs (1965) reported on a palynological study of the Chuckanut Formation with samples taken from the classical type section along Chuckanut Drive, south of Bellingham. To my knowledge, these are the only palynological studies that have been published for the Tertiary continental rocks of the Whatcom basin in northwestern Washington.

GENERAL GEOLOGY

The name Whatcom basin was first applied by Newcomb, et al (1949) and the name was again used by Moen (1962). Although

Miller and Misch (1963) refer to it as the "Bellingham Basin" the name "Whatcom" appears to have chronological priority in the literature, and I will use it throughout this thesis.

The term is here applied to a structural basin which apparently began to form during the Middle Eocene and intermittently subsided during the Early and Middle Tertiary. The Whatcom basin is underlain by Upper Cretaceous rocks but these are not considered part of the basin fill but probably represent a part of a once much larger basin of subsidence. The Chuckanut Formation, which bounds the basin to the south, and is possibly in fault contact with the younger basin rocks, is not part of the Whatcom basin.

The Whatcom basin lies in what has been termed the "western part of the 'Paleozoic-Mesozoic Cordilleran volcanic orogenic belt' or Pacific eugeosyncline" (Danner, 1960). In this region and extending north and south, a linear structural depression runs north from the Willamette Valley of Oregon, through western Washington and Puget Sound, and through the Georgia Depression (Bostock, 1948; Holland, 1964) that separates Vancouver Island from the mainland of British Columbia. South of Oregon this structural trough continues as the Great Valley of California, and finally into the Gulf of California (Bretz, 1913). Much of this linear trough is currently below sea level; the remaining portions are low and only slightly above sea level. The nature of this depression is not known, but it is both a topographic and structural low.

The Whatcom basin lies on the east side of the linear trough and is apparently part of it. The basin is closed to the north, south and east, but appears open to and contiguous with the Georgia Depression to the west. Unfortunately, however, little can be definitely said about this because of lack of information. The waters of Georgia Strait obscure relationships to the west, and virtually all of the lowland portions of the basin are covered with surficial material of Pleistocene and Recent age. To my knowledge, a dozen or so wells have penetrated the Tertiary sedimentary rocks into the underlying Cretaceous. Paleocene rocks, equivalent to the Chuckanut Formation, were not encountered within the wells, which presents a problem of interpretation. This problem is discussed more fully in a later section. To date, the well data have yielded no information concerning the underlying structure and basinal relationships within the Georgia Depression.

Tertiary rocks of the Whatcom basin, and the underlying Cretaceous rocks, lap up to the north on the granitic rocks of the Coast Mountains. This is a complex unit of multiple intrusions and metamorphic rocks formed over a long span of time, apparently beginning in the Jurassic and continuing into the Tertiary (White, 1960). A recent detailed study of the igneous and metamorphic rocks to the north of the Whatcom basin has been presented by Roddick (1965). At several places small relics of younger, post-granitic sedimentary rocks are preserved on the south slopes of the Coast Range, all dipping southward.

To the east, on Canadian and American Sumas Mountains, the Tertiary rocks lap upon the complex of pre-Tertiary metamorphic rocks and ultrabasic intrusions, and also upon the Paleocene Chuckanut Formation. These older rocks and their structural relations are described by Crickmay (1930), Misch (1952), Moen (1962) and Miller and Misch (1963).

On the south the relationships are obscured. Post-Chuckanut, Tertiary continental sedimentary rocks appear north and east of Bellingham, generally dipping north into the basin. South of Bellingham and to the east are the so-called Chuckanut Hills, a highland formed in the Chuckanut Formation. Although no contact is visible at the south end of the basin between the younger and older rocks, the contact is probably a fault relation of some type. A more detailed discussion of this will follow in a discussion of geologic history.

In summary, the Whatcom basin appears to be a structural and topographic low, connected to the Georgia Depression and rimmed by hills and mountains composed of older and diverse rock types. Active subsidence and concomitant deposition probably took place through most of the Early and Middle Tertiary period.

GEOLOGY OF THE LOWER TERTIARY ROCKS

General Remarks

Study of post-Chuckanut, Tertiary sedimentary outcrops is limited to only a narrow stratigraphic section for several reasons. The rocks, with minor and limited exceptions, all dip into the basin (see Figure D, in pocket). Outcrops are restricted to the extreme margins of the basin, and except to the north the dips are steep and width of outcrop narrow. Tertiary rock exposures within the basin and away from the margin are absent; Pleistocene and Recent deposits cover them all.

Although the thickness of the Quaternary and Pleistocene deposits is not everywhere known, wells in various places have penetrated the surficial material. At Pitt Meadows in British Columbia, the Pleistocene and Recent is 1,000 feet thick. At Steveston, 700 feet of Recent sediment overlies 160 feet of Pleistocene sediment (Johnston, 1923). A deep well near Point Roberts penetrated 800 feet of Pleistocene and Recent deposits; whereas a well north of Blaine encountered 1,200 feet of Quaternary deposits (Richfield Oil Company). The maximum thickness of the methane-bearing Pleistocene deposits in the Whatcom County gas field is 615 feet (Livingston, 1958).

In addition to the narrow width of outcrop, exposures are further concealed by a dense cover of vegetation. The high precipitation, especially on the hills rimming the basin, combined with mild temperatures, supports vegetation that is usually dense, and which covers all rock except that on very steep slopes, in deep stream cuts or along artificially excavated road cuts. The climate appears to hasten rock decay so that only those cuts made in the past few years provide exposures of fresh rock. When sampling for palynological purposes it is usually necessary to chip back into the outcrop a considerable distance to acquire relatively unweathered rock.

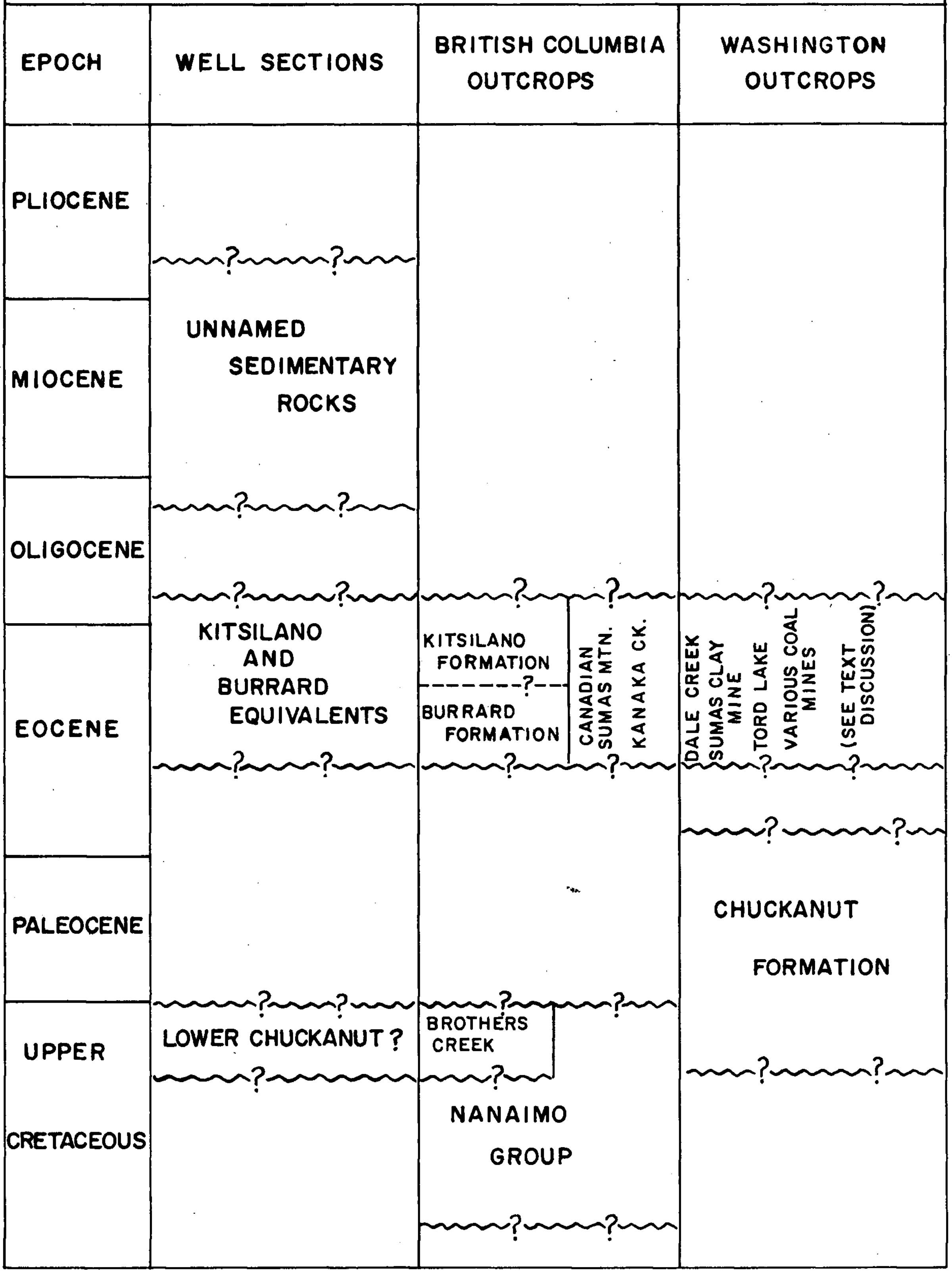
Finally, outcrop is restricted by the almost ubiquitous coating of Pleistocene till that is plastered on most surfaces. Even in the marginal uplands, till is abundant, covering large areas where Tertiary rocks should otherwise be abundantly exposed. Hence, outcrop study is limited by four factors: narrow width of outcrop, dense vegetation, Pleistocene till cover, and atmospherically decayed rock.

The only other place where Tertiary rocks can be directly observed is in well cuttings and cores. However, these are few, and little stratigraphy and less structure can be determined from them. As a consequence, knowledge of Tertiary rocks is based almost entirely on examination of limited exposures, both horizontally and vertically.

The paragraphs following give a brief discussion of each of the five formations. In a later section, following discussion of palynology, an attempt is made to place these formations in time, and to present a plausible historical account of their depositional environments and their present geological occurrence. Table A synoptically summarizes the relative position

TABLE A

STRATIGRAPHIC CORRELATION CHART OF THE NANAIMO GROUP, CHUCKANUT FORMATION, AND WHATCOM BASIN ROCKS



of the several stratigraphic units. The listing of outcrop samples indicates only that they are Eocene in age; not that one outcrop is necessarily younger or older than another.

Chuckanut Formation

While the present report does not deal specifically with the Chuckanut Formation, it is necessary to provide a brief description, so that a satisfactory distinction may be made when discussing the Tertiary continental sedimentary rocks. The Chuckanut Formation crops out south of Bellingham, to the west on Lummi Island, east on American Sumas Mountain, and sporadically southeast through the Cascade Mountains.

Glover (1935) and Weaver (1937) presented detailed stratigraphic descriptions from the type section along Chuckanut Drive, south of Bellingham. Glover states that there are at least 10,000 feet of continental clastic sediments here, but inferences drawn from drill hole data indicate a possible thickness of 16,000 feet. East of Sumas Mountain, 15,000 to 20,000 feet of Chuckanut Formation have been measured (Miller and Misch, 1963). The formation has been considered continental and consists predominently of arkose with considerable amounts of shale, siltstone, and conglomerate. According to Glover, the few coal seams present are mainly confined to the upper part of the section.

Structurally the Chuckanut Formation is rather intensely deformed. Folds, which are open to moderately tight, trend northwesterly south of Bellingham and northeasterly north of the Nooksack River. Locally there is evidence of minor reverse faulting or overthrusting. Crickmay (1930) and Moen (1962) have mapped a major west south-west fault east of American Sumas Mountain which cuts Chuckanut folds. Miller and Misch (1963) have indicated a displacement of greater than 5,000 feet on this fault, and find it is overlapped by post-Chuckanut Tertiary continental sedimentary rocks which show no offsetting. As a consequence, an unconformable relationship is inferred between the two formations.

Traditionally the Chuckanut Formation is reported as entirely continental and assumed to have been deposited in broad alluvial valleys. However, according to W. H. Mathews (written communication), Marie Pabst observed probable vertebrate remains (Ichthyosaur?) at the southern end of Chuckanut Bay, but apparently these have never been collected. If this report is correct, the lowermost Chuckanut is marine and probably Upper Cretaceous.

With this one exception, neither vertebrate nor invertebrate remains are known from the Chuckanut Formation, but plant micro- and macrofossils are locally abundant. On the basis of fossil plant remains, the Chuckanut has been dated as Cretaceous, Paleocene or Eocene (McLellan, 1927; Weaver, 1935; and Misch, 1952). After working with fossil plant collections from various localities, Pabst (1962) concluded that the Chuckanut Formation ranges in age from Late Cretaceous to Early

Oligocene. However, these workers did not recognize the existence of a younger Tertiary continental sedimentary sequence which unconformably overlies the Chuckanut Formation. The Tertiary continental sedimentary rocks which were defined by Moen (1962) and Misch (1963) and assigned by me to the Whatcom basin sequence were considered until 1962 as part of the Chuckanut Formation. This, of course, confused their interpretation and resulted in erroneous correlation. Griggs (1965) working with plant microfossils from the Chuckanut type section along Samish Bay, south of Bellingham, concluded the age of the Chuckanut is most likely Paleocene to Lower Eocene.

The correlation of the Chuckanut Formation with other rock units is generally known. Moen (1962) suggests that the Chuckanut Formation may, in part at least, be correlatable with the Marine Nanaimo group mapped by McLellan on the San Juan Islands. Others are more definitive: "On the basis of fossil evidence, lithologic similarity, outcrop patterns, structural continuity, and degree of deformation, the lower part of the Chuckanut Formation is correlated with the upper part of the Nanaimo Group" (Miller and Misch, 1963).

Burrard Formation

The Burrard Formation was named by Johnston (1923) for a series of conglomerates, sandstones, and shales that underlie the city of Vancouver and which sporadically crop out along the south shore of Burrard Inlet as far east as Burnaby Mountain. Several small outcrops occur on the north shore of Burrard Inlet along the lower reaches of Capilano Creek.

The Burrard Formation is about 2,000 feet thick, consisting of conglomerates, sandstones, and shales and a few thin interbedded lignitic seams (Johnston, 1923). The base of the formation rests unconformably upon the granitic rocks of the Coast Range Mountains and is exposed only on the lower canyon of the Capilano River. Beds higher up in the section are exposed at Prospect Point, then more or less continuously along the west side of Stanley Park. The general attitude of the formation appears to be a continuous south dip at 10 to 15°.

The base of the formation is marked by a basal conglomerate about 50 feet thick that is composed largely of subangular granodiorite boulders up to 6 inches in diameter, accompanied by minor amounts of diorite, greenstone, chert, quartzite, and schist boulders set in a sandy, ferruginous matrix (Johnston, 1923; Hughes, 1946). The upper portion of the Burrard Formation consists of a coarse-grained feldspathic sandstone interbedded with sandy shale. According to Johnston, a total of 1,300 feet of strata is exposed along the west shore of Stanley Park; of this thickness, 1,100 feet is sandstone and the remainder shale.

Johnston placed the top of the Burrard Formation beneath a "basal conglomerate" of the overlying Kitsilano Formation.

This conglomerate is not everywhere present and the similar lithologies of the two formations make distinctions difficult. A very real possibility exists that this may simply be an interbedded conglomerate and may have no particular time significance, i.e. a time break here may be inconsequential (Rouse, 1962).

A number of assemblages of fossil plants have been collected and examined from the Burrard Formation. J. W. Dawson (1895) studied a collection of plant remains from the Stanley Park area along the south shore of Burrard Inlet and concluded the beds were Eocene in age. E. W. Berry, after studying a plant collection made by Johnston from the same general site, reported that the rocks were Middle or Upper Eocene (reported in Johnston, 1923). Berry (1926) added: "There can be no question of the Eocene age of these plants, -- ." Rouse (1962), after a study of the plant microfossils, concluded that the Burrard Formation south of Burrard Inlet is Middle Eocene in age. He reported further that the "Burrard Formation" of the north shore in Capilano Canyon was considerably older, possibly Cretaceous and equivalent to part of the Upper Nanaimo Group. The nature of the contact between the north shore Burrard and the Burrard Formation to the south of the Inlet is unknown because it lies below the waters of Burrard Inlet. Crickmay and Pocock (1963) using palynological techniques, suggested that the Burrard Formation was Upper Cretaceous and correlated it with the plant-bearing portions of the Nanaimo Group on Vancouver Island.

According to Johnston (1923) the

> "Burrard Formation was deposited mostly in shallow water and in part sub-aerially on an alluvial plain under humid-warm climatic conditions and nearly at sea level. It is not a true delta deposit, at least in the landward part, but may pass into delta deposits."

He suggests the possibility that all of the Georgia Depression was an alluvial plain and that the sea did not extend into the region. Because some 2,000 feet of sedimentary rock is present in the Burrard Formation, subsidence probably was active during the period of deposition.

For the purposes of the discussion to follow I will continue to use Burrard Formation as defined by Johnston, excepting however, the outcrops on the north side of Burrard Inlet. As I will discuss more fully in a later section, these north shore rocks are probably equivalent to the Upper Cretaceous encountered in the well samples, and possibly equivalent to the lower Chuckanut Formation.

Kitsilano Formation

The Kitsilano is a rather inadequately delimited unit overlying the Burrard Formation, and underlying the Pleistocene sediments on which is built the city of Vancouver. It outcrops along Kitsilano Beach, at various places along the south shore of Burrard Inlet, and east to Burnaby Mountain. The Kanaka Creek sediments to the east, northwest of Whonock, apparently belong to the Kitsilano Formation, but the character of the sediments is not definitive and they may actually be Burrard equivalent (Johnston, 1923).

The bottom of the Kitsilano Formation has been placed more or less laterally continuous. As suggested above, the evidence for a prolonged time break between the Burrard and Kitsilano Formations is highly uncertain at best. Indeed, even Johnston (1923) observed "--- since both formations are in large part composed of material deposited on land or in shallow water, it is possible that the apparent break is due to contemporaneous erosion." Roddick (1965) no longer maintains the distinction between Kitsilano and Burrard Formations and considers them one unit. He adds that "Armstrong (report in preparation) indicates that the subdivision should be abandoned and a new name proposed for the assemblage."

For the purpose of the report, I shall continue to use the terms Burrard and Kitsilano Formations in the older sense of distinct rock units and in the sense they were defined by Johnston. Because the Kitsilano dips to the south and disappears beneath a mantle of Pleistocene outwash and till, the top of the formation is not visible. From several lines of evidence, Johnston considered a conservative estimate for the thickness of the Kitsilano Formation to be 1,500 feet. However, in the Highbury tunnel, which was not available to Johnston, there is a stratigraphic thickness of Kitsilano Formation of approximately 900 feet. From 5th and Highbury Streets due north to the northernmost outcrop mapped by Johnston on English Bay, the distance is 1¼ miles. Assuming an average dip of 10° due south, there is a total stratigraphic thickness in this latter interval of 1,225 feet. Because to the east, near Second Narrows, outcrops of Kitsilano Formation are known still farther north, it would appear that a minimum thickness of 2,500 feet is present. However, because outcrops are limited and because we are still uncertain as to the validity of the Kitsilano-Burrard contact, the actual thickness is still unknown.

The so-called basal conglomerate contains pebbles and boulders ranging from 1 to 10 inches in diameter. Near Second Narrows Johnston described imbricated gravels, suggesting deposition by a westerly flowing river. The rock fragments, according to Johnston, are mostly granitic and apparently derived from the Coast Mountains. Also present are schistose rocks and pebbles of shale, the latter presumably derived from the Burrard Formation.

Sandstones and shales make up most of the middle and upper parts of the Kitsilano Formation. The sandstones are coarse-grained, frequently cross-bedded on a small scale, and occasionally contain thin-lenses and irregular masses of lignitic coals. The sand grains are generally angular, contain an abundance of heavy minerals such as biotite, chlorite, hornblende, olivine, garnet and sphene (Thomson, 1958). Thomson also added that the fresh, angular nature of the sand grains "indicates that transportation has not been great, and that conditions of rock destruction were mechanical rather than chemical." The source rocks were apparently metamorphic and igneous, also suggesting a source in the Coast Range to the north.

The shale is often blue-grey and usually sandy. Locally both sands and shales contain remains of logs that have been altered to lignite. Stream channeling, similar to that of the Burrard Formation, is found throughout the middle and upper Kitsilano.

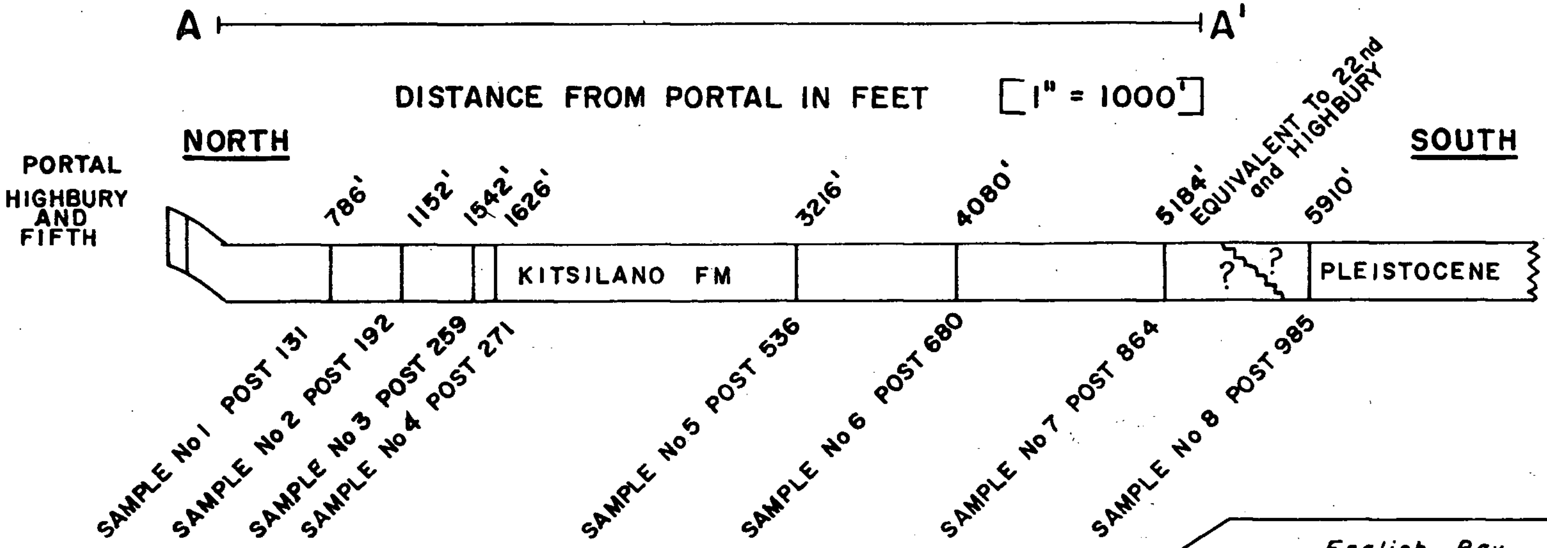
The Kitsilano Formation shows the same attitude as the underlying Burrard Formation and at Kitsilano Beach dips to the south at 6 to 9°. Attitudes measured south of the Kitsilano Beach outcrop, within the artifically excavated north-south Highbury Tunnel are 9 to 10°. (See Figures B and C.) To the south, for as far as direct measurements can be made, the southerly dip is reasonably constant. What happens deeper in the Whatcom basin can only be inferred from the study of plant microfossil assemblages in wells and outcrops. The results of this investigation follow in later sections of this report.

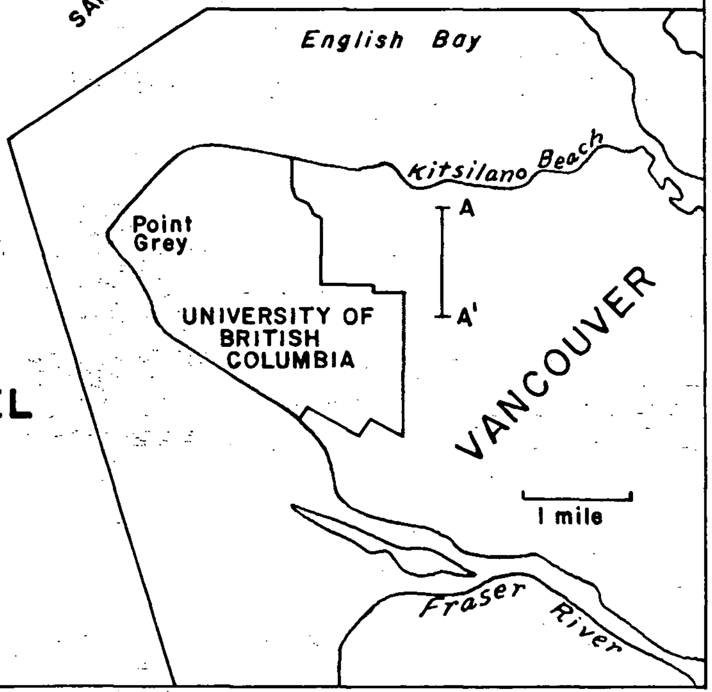
Plant macrofossils are abundant in the Kitsilano Formation. A collection of plants from rock exposures at Kitsilano Beach were identified and discussed by E. W. Berry. He concluded that "the general facies of the Kitsilano plants is, in my judgement, entirely Eocene and does not in the slightest degree suggest later Tertiary" (quoted by Johnston, 1923). Berry, in personal communication to Johnston, goes on to say "there is no objection to considering the Burrard Inlet plants as Middle or Upper Eocene, and Kitsilano plants as Upper Eocene or Lower Oligocene." Somewhat later Berry (1926) stated "the conclusion that the beds at Kitsilano are Eocene is strongly indicated --- Just what part of the Eocene is perhaps not determinable at the present time. I would regard it as late Eocene --- ."

Johnston, in referring to the origin of the Kitsilano sediments, suggests they are similar to the Burrard, i.e. an alluvial plain deposit which may pass into delta sediments westward and southward. In neither formation is there any evidence of marine deposition, nor are there any marine fossils. Channel structures, cut and fill structures, and imbricated gravels all imply an alluvial origin. Even the shales must have been deposited in shallow water because they contain abundant sand grains which probably could not have been carried far.

Huntington Formation

The Huntington Formation crops out on the southwest end of Canadian Sumas Mountain, just north of the International Boundary, at the northeast side of the Whatcom basin (see Figure D). Sumas Mountain is the most imposing topographic feature of the Lower Fraser Valley, rising abruptly from the flood plain to a maximum height of 3,000 feet. The upland consists of about 40 square miles, of which about five are underlain by Tertiary sedimentary rocks. The remainder consists of older volcanic rocks and intrusive rocks (Kerr, 1942).





NORTH-SOUTH SECTION OF HIGHBURY TUNNEL

VANCOUVER, BRITISH COLUMBIA

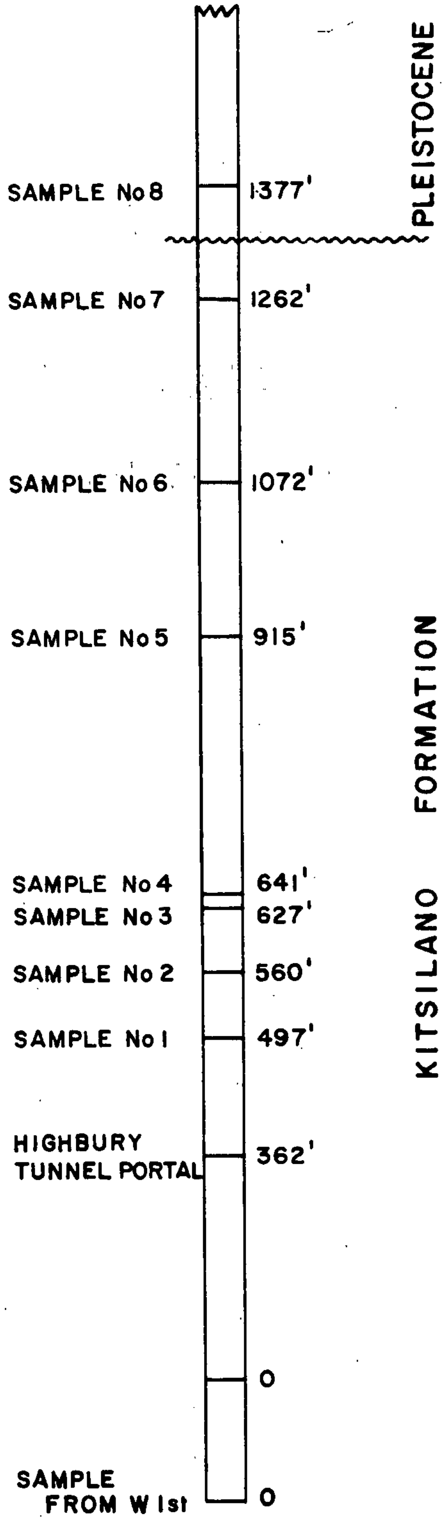
Scale 1" = 1000'

STRATA DIP SOUTH AT 8-10°

FIGURE B

FIGURE B

FIGURE C



STRATIGRAPHIC SECTION OF
KITSILANO IN HIGHBURY TUNNEL
SCALE 1" = 200'

Although Daly was not the first geologist to visit Sumas Mountain, he was the first to describe, with any degree of accuracy, the rocks cropping out there. During his 49th parallel study, Daly (1912) concluded that the sedimentary rocks of Sumas Mountain were Eocene in age and proposed the name "Huntington Formation" for them.

The first detailed study of the Tertiary rocks on Sumas Mountain was by Kerr (1942). Later the clay beds of the Huntington were examined and reported on by Cummings and McCammon (1952). The sediments comprising the Tertiary range from conglomerates with component pebbles up to 4 inches in diameter, to shales and lignites. Kerr, and Cummings and McCammon, both commented on the general tendency of the unit to become coarser stratigraphically upward. I observed the same characteristic during my collecting in the area.

As in the Kitsilano and Burrard Formations, lensing and pinching of sandstone is common. However, the conglomerates appear to be more constant. Likewise, channeling, cut and fill structures, and cross-bedding are commonplace features. On the contrary, however, the shales and lignites are fairly regular and may extend as much as 1,000 feet along strike without appreciable change in thickness or character. The latter uniformity was observed in mine drifts by Kerr (1942) but these drifts were no longer open in 1964 and 1965 when the present palynological collecting was being done.

The structural attitude of the Huntington Formation appears to be a more or less constant dip of 10 to 15° to the southwest with strikes averaging N 45° W. Many local variations occur in the Huntington, however, presumably as the result of sag and differential movement during uplift. The total thickness is not known because neither a top nor a bottom of the formation is exposed. However, Kerr managed to measure a stratigraphic thickness of 1,400 feet. He found that

> " --- about 300 feet consists of clayey shales, lignite seams, gray shales, indurated grit and sandstone. The remaining 1,100 feet are made up principally of pebbly conglomerate with interbedded sandy layers and they are found on the upper slopes of the hill." (Kerr, 1942)

The clasts in the conglomerate are principally of granite, diorite, quartzite, black argillite and greenstone. Unlike some of the Kitsilano rocks, they do not show imbrication, although limited cross-bedding suggests a source to the northeast. Contrary to the views of Kerr, Cummings and McCammon report on the lateral uniformity of the conglomerates, but the latter authors had the advantage of numerous drill holes. The sandstones are feldspathic, occasionally bearing primary biotite, and not as well consolidated as the conglomerates.

Cummings and McCammon (1952) discuss the clay and shale deposits of British Columbia, with considerable emphasis on the Sumas Mountain area. Here, they comment, occur the only true fire-clay deposits in British Columbia. Because of the glacial drift and thick brush, most of their structural interpretations are based on drill holes.

The basement rocks, both plutonic and volcanic, have an upper surface dipping generally to the southwest, but there are numerous hollows and depressions on this surface. It is in these that the fire-clay seams formed (Cummings and McCammon, 1952). Beneath the obviously clastic zone, and above the basement, lies a thick kaolinized zone, presumably the result of intense weathering of basement rocks prior to the deposition of the clastic sediment. The thickness of the clay zone varies, but reaches at least 70 feet in places. The lower portion of the clastic sequence, overlying the clay, is made up of alternating shales, lignites and sandstones, but higher up the section thick beds of conglomerate become numerous.

Kaolinite is almost pure, two-layered aluminum silicate, which here is apparently a result of laterization. Laterites are now forming only in areas of good drainage in humid-tropical and subtropical regions, so presumably these clays have an environmental significance.

The shales and lignites, overlying the clay, appear to have been deposited on flat swampy land with at least intermittently prolific plant growth. The inverse grading, or finer sediment becoming coarser stratigraphically upward, is typical of non-marine basins, and in most cases is the result of basin filling (Dr. R. V. Best, oral communication). Also possible is uplift in the source area, becoming more intense with time.

Leaf remains have been found in the Huntington, but they are characteristically poorly preserved and little has been done with them. Fossil plant specimens were collected by Daly and submitted to F. H. Knowlton, who reported that the collection was of little diagnostic value (Daly, 1912). Much later, R. W. Chaney collected at Sumas Mountain but stated in a communication to Kerr (1942) that the fossil leaves he collected were fragmentary and poorly preserved, and that he was unable to do anything with them.

It has been generally assumed, with little substantiating evidence, that the Huntington Formation is Eocene in age, and possibly correlated with the Burrard or Kitsilano Formations.

Other Tertiary Continental Rocks

Tertiary continental sedimentary rocks (excluding the Chuckanut Formation) crop out in a discontinuous belt from the southeastern end of Vedder Mountain, to the southern end of American Sumas Mountain, thence westward along Squalicum Mountain to King Mountain north of Bellingham. At various places this unit unconformably overlies pre-Cretaceous rocks. South of the Nooksack River it unconformably overlies the Chuckanut Formation.

The Tertiary continental sedimentary rocks are a sequence of conglomerates, sandstones, shales, and very minor coal seams. Because this unit dips westward into the Whatcom basin and is unconformably overlain by Pleistocene and Recent sediments, it is not possible to give its true original thickness. However, at the northern end of the outcrop belt, there are 3,000 feet of strata (Moen, 1963).

Conglomerates make up about 30 percent of the section and are composed of pebbles and cobbles 1 to 3 inches in diameter. These pebbles are mainly volcanic rocks, granitic and gneissic rocks, chert, white quartz, and argillite. The matrix is generally arkosic and moderately well indurated so that topographically the conglomerates form vertical cliffs as much as 200 feet high. The conglomerates are distributed throughout the section, and on Sumas Mountain occur also as a basal conglomerate which overlies Paleozoic rocks, and locally the Chuckanut Formation.

The sandstone is largely arkosic, massive and coarse-grained. It is composed of poorly-sorted angular particles and according to Moen (1962) may contain up to 50 percent feldspar as well as rock fragments and mica. Ordinarily the sandstone is poorly cemented by calcium carbonate or iron oxide and tends to be somewhat friable.

Shale is moderately common as interbeds throughout the section. These shales range from a silty clay to a refractory fire-clay very similar to that found at Canadian Sumas Mountain. All the shale beds are slightly carbonaceous but never highly so. Coal beds are thin and uncommon. In general, the carbonaceous material in the Tertiary continental sedimentary rocks is much less than that found in the Chuckanut Formation.

Although the refractory clays are similar to those of

Sumas Mountain, they are not *in situ* and are not lying on weathered basement rocks. The clays here lie in pockets at the southwestern end of Vedder Mountain, some 3 miles southeast of the town of Sumas, and 5 miles south of the clay occurrence at Canadian Sumas Mountain. The clays are separated by several hundred feet of clastic shales and sandstone, and the basement rocks show no sign of kaolinization. Because these clays were not formed in place, they are by definition allocthonous. The most likely place of origin was Canadian Sumas Mountain or some similar but unknown location.

Locally, on the west side of Sumas Mountain, a lateritic shale occurs at the base of the Tertiary continental sedimentary rocks, and was apparently developed as the result of weathering on a pre-Tertiary peridotite intrusion. The laterite is ferruginous and contains up to 48 percent iron, with the deposit ranging from 30 to 50 feet thick (Moen, 1963).

Structurally the rocks show little deformation besides tilting. On the west flank of American Sumas Mountain they have a general northward to north-northeast strike and dip 30 to 35° to the west. A small and local anticline-syncline at the south end of Sumas Mountain produces almost vertical dips. In the vicinity of Bellingham, the Tertiary continental rocks have an essentially east-west strike with dips up to 60° north.

A few isolated remnants of basal Tertiary continental rocks occur on the north end of American Sumas Mountain and on southeast Vedder Mountain. These are now mostly flat remnants of a once greater extent of Tertiary rocks. All the fire-clay deposits occur in these remnants.

As with all the other units discussed, these strata are continental and were deposited unconformably on an old erosion surface. The environment of deposition was probably similar to that of the Chuckanut Formation with local westward flowing drainage carrying material from rising highlands to the east, depositing the material on a near-sea level coastal plain. The composition of boulders within the conglomerate suggests that all were derived from the northern Cascade Mountain area to the east. The high proportion of conglomerate and sandstone, with the correspondingly low quantity of shale and coal suggests a rather unstable environment. More or less continual uplift of the source area to the east is indicated.

The presence of aluminum-rich fire clay on Canadian Sumas Mountain and ferruginous shales on American Sumas Mountain indicates a period of local stability in a humid subtropical to tropical climate. But in both cases these laterites are at or near the base of the section, and were formed prior to the deposition of the clastic sequence.

To my knowledge, only a few poorly preserved leaf fossils have ever been found in these rocks, on which no work has been done. Miller and Misch (1963) have considered the Tertiary continental sedimentary rocks equivalent to the Huntington Formation of British Columbia on the basis of lithologic similarity, degree of deformation and outcrop distribution. From this they assume a probable Middle Eocene age for the sequence.

AGE AND CORRELATIONS

Wells

Location and Descriptions

A number of wells have been drilled in the Whatcom basin with the first on record being a 30 foot hole drilled near Bellingham in 1893. Early wells included water wells, gas wells, and exploratory oil holes. Prior to 1940, drilling was generally on a haphazard and unscientific basis with little geologic control. As the oil potential of various Tertiary basins along the Pacific Coast became apparent, the Whatcom basin took on minor interest as a potential oil or gas bearing region.

Early in the century a well drilled near Ferndale, five miles northwest of Bellingham, encountered gas in modest quantities in the Pleistocene overburden. Additional wells revealed the presence of several gas horizons at depths of 170 to 500 feet (Livingston, 1958). Although this gas, with a high methane-nitrogen content, was not available in commercial quantities, it has been supplied to nearby homes and farm buildings. The maximum thickness of Pleistocene here is 615 feet, and the assumption is made that the gas has been generated in, and migrated from, coal seams in the underlying pre-Pleistocene rocks. Livingston (1958) has stated these are Chuckanut beds beneath the Pleistocene, but the results of the investigation reported here indicate a Miocene age.

In the 1930's and 1940's other deeper exploratory holes were sunk, penetrating the Pleistocene for a considerable distance into the underlying "Chuckanut", as the older sediments have been traditionally called. Companies involved in this exploration have been usually small and locally organized. Their operations have been random and without adequate geologic control. Drilling records were often kept in a haphazard method by the drillers. Samples were usually taken, but in many cases their whereabouts are no longer a matter of record.

I spent several days in Olympia, Washington, visiting the offices of the State Division of Mines and Geology, where available records and samples of wells drilled within the State are stored. Data are very incomplete, and in most cases add nothing to published material already available.

Results from four wells were scrutinized particularly because the data appeared comparatively good, and because the wells are located on sites which might have produced useful information. These are:

Russler No. 1, located about 4 miles west of the south end of American Sumas Mountain. This well was spudded in 1935, reached a depth of 4,175 feet with several reported gas shows.

Hillebrecht No. 1, located about 2½ miles south of Lynden, Washington. Spudding was in 1947 with a total depth of 3,492 feet. Gas shows were reported at 790 and 1,200 feet.

Lange No. 2, located in the earlier-mentioned Ferndale gas field. This well was spudded in 1931 and reached a total depth of 2,008 feet. Again, gas shows were recorded, one of sufficient quantity to be used locally.

Finally in 1945, the Standard Oil Company of California drilled the Ferndale Community well about 6 miles south of Blaine. Although it was completed as a dry hole, it reached a total depth of 6,231 feet and penetrated a considerable section of Tertiary rocks.

While in Olympia, I examined and sampled cuttings from these four wells. Unfortunately samples from the bottom 4,000 feet of the Ferndale Community well were missing. Cuttings on file were, for the most part, sand and hence unsuitable for palynological analysis. Some shale samples were chosen but the maceration results were disappointing. In almost every case microfossils were absent or so poorly preserved nothing could be done with them. The few adequately preserved forms were not diagnostic and of no value.

North of the International Boundary, in Canada, available well data are less complete, but a number of wells have been drilled, some of which penetrate the Pleistocene. Although an overall compilation of locations is available, there is no lithologic or testing information.

One interesting well is the Boundary Bay well No. 3, which was reported by Johnston (1923). The well, located near Boundary Bay, was drilled with rotary tools to a depth of 4,112 feet. Interpretations at the time suggest 2,300 feet of Pleistocene and Recent, but more recent drilling with more sophisticated equipment indicates this may be an excessive thickness. However, the bottom several thousand feet of the well are composed of poorly consolidated sands, shales and lignites. The well bottomed in what is interpreted as conglomerate or gravel. Fossils were absent, but Johnston suggested these rocks represent a formation similar to, but younger than the Kitsilano Formation which he had mapped and named to the north. On regional stratigraphic grounds he suggested that these rocks, which he termed the Boundary Bay Formation, are of Pliocene or possibly Miocene age. As a consequence, Johnston must have been the first to suspect that rocks younger than Kitsilano were present in the Whatcom basin.

More recently, the Richfield Oil Company and the Pure Oil Company together drilled two wells in the Whatcom basin, both in British Columbia. These two wells, because of their fundamental importance to the present investigation, are indicated on the geologic map in the pocket (Figure D).

The Point Roberts well is located near Tsawassen and was drilled during the last seven months of 1962. A total depth of 14,337 feet was reached. The Sunnyside well, located 14 miles to the east, and drilled during the first five months of 1962, reached a total depth of 10,899 feet. Although I have little of factual data concerning lithologic samples or specific logs run, I do have electric logs from both of these holes. Also, through the courtesy of the Richfield Oil Company, I have examined slides of macerated samples taken at approximately 100 foot intervals. I am also unofficially informed that key horizons were not encountered. Geologists at the well-site reported a continuous, non-diagnostic sequence of sandstones, shales, and coals from the base of the Pleistocene to total depth. I have attempted to correlate between wells on the basis of electric logs but with no provable success. Lithologic units are variable, characteristically pinching and lensing. However, some zones yielded plant microfossil assemblages, and these have been applied here in an attempt to provide some measure of correlation between wells.

Discussion of Well Data

Potentially, palynologic data from wells is very good for problems of correlation, dating and paleoecology. In the case of the two deep wells under discussion, a thick sequence of sedimentary rocks was penetrated. Accepting as valid the thesis that a microfloral assemblage is typical of the flora extant at the time, careful sampling and analysis of samples at regular intervals should produce a sequence of floras reflecting evolutionary and climatic change through time. Generally this appears to be true, although certain pollen grains, because of their fragile nature, (i.e. Thuja and Populus) or because they are easily destroyed by bacterial action, (i.e. Acer) may be under-represented. Others, because of their exceptionally durable nature (i.e. certain fungal spores) may be over-represented. However, if floras are taken as a whole, and if too much weight is not placed on relative proportions of microfossils, a fairly reliable analysis of surrounding vegetation is possible. Furthermore, because the Tertiary was a period of climatic and topographic change, floras did change and evolve. Analysis of the floral record should be, and often is, usable as an age dating method.

However, certain additional problems and pitfalls arise of which the palynologist must be cognizant, and make allowance for. The three basic problems involved in palynologic analyses of well samples are 1) reworking, 2) well-caving and 3) non-representative samples.

Many plant microfossils are exceptionally resistant and are often reworked from older to younger sediments. This is especially true if minute shale chips are being eroded and redeposited. The seriousness of this problem, of course, varies from area to area but may be critical in the Whatcom basin region where a microfossil-rich Chuckanut Formation presumably was at least a partial source for the younger basin sediments.

The extent of well-caving is usually unknown, but potentially poses problems. As the drill bit reaches increasingly greater depths, a tall cylinder of unsupported rock remains above. Mud pressure, of course, gives considerable support; nevertheless, motion of the rotating drill stem, coupled with mud moving upward at a relatively high velocity will induce caving from less well supported units, notably shale, up the hole. As a consequence, ditch samples taken at a specified depth may actually contain bits of shale or coal from different horizons up the hole. For this reason, the apparent stratigraphic range of certain floral elements may appear longer than it actually is. Cores, of course, eliminate this particular problem because we can be certain of the stratigraphic interval from which they were taken. However, cores are usually inconveniently located from the palynologist's view, and generally consist largely of sandstone.

The third problem of non-representative samples is always a cause for concern in palynological studies and the problem is accentuated with well samples. Samples taken at arbitrary intervals, in this case 100 feet, may not be totally representative of that interval. Several factors, such as lithology, edaphic conditions, and microclimate at the site of deposition could radically alter the type and proportion of microfossils.

All in all, the difficulties inherent in interpreting the floral record as revealed by pollen and spore analysis of wells are manifold. However, with judicious use of paleontologic techniques, with careful use of professional judgement, and above all with a strong sense of conservatism, conclusions of value can be drawn. With these reservations in mind, conclusions are drawn as to the probable age of rocks encountered in the wells.

Point Roberts Well

The interval from 847 feet to 4,800 feet, beneath the Pleistocene and Recent sediments, is characterized by mostly dicotyledonous pollen, largely from arboreal plants. The following genera, although not always abundant, are characteristic and conspicuous: Salix, Alnus, Carpinus, Castanea, Fagus, Quercus, Carya, Engelhardtia, Juglans, Pterocarya, Momipites, Ulmus-Zelkova, Tilia and Acer. Representatives of the Pinaceae such as Pinus and Picea do occur, but only in minor quantity. Several grains of Cedrus and Keteleeria were found, both coniferous genera now restricted to the eastern hemisphere. Glyptostrobus and Metasequoia occur rarely along with representatives of the Cupressaceae. The fern Osmunda is abundant; the only other spores of importance being several species of Laevigatosporites.

Unfortunately, most of the above dicotyledonous pollen range throughout the entire well section and are of little value in dating studies. Indeed, as Chaney (1940) has stated, "few phylogenetic trends are shown by Tertiary plants, most of whose arborescent genera have survived without change since the Eocene." As a result, many of the identified plants, especially at the generic level, are of little value in dating of the enclosing rocks. The data derived by counting were plotted in various ways, but for the most part did not materially increase the understanding of microfossil occurrence. However, reference to Table B indicates 10 palynomorphs which do appear to have a strong age significance. This chart indicates the relative percentage of microfossil types to the entire flora. In this well it is apparent that Pterocarya, Ulmus-Zelkova, Liquidambar and Glyptostrobus are restricted to, or are at least most abundant, in the upper 4,800 feet.

Attempts to establish an age for this stratigraphic section involved two approaches. The first involved plotting the ranges of those microfossils which seemed to be restricted to certain intervals of the well. The results of this are shown in the tabulations on Table B. This table was then compared with tabulations made by Krutzsch (1957) on the Upper Cretaceous and Tertiary of central Europe. Relative abundance and ranges which I derived from well samples tally quite closely with the Miocene of middle Europe, although there is a possibility Upper Oligocene may be included.

Next I compared the total flora with those published floral lists which are considered Tertiary in the circumpacific belt. The most significant list from this standpoint was that of Sato (1963) whose Miocene floras of Hokkaido (Japan) correspond very closely with those of the Whatcom basin. Comparison with Wolfe, _et al_ (1965) from the Oligocene (?) - Miocene of the Cook Inlet area of Alaska also suggests a Miocene age. Martin and Rouse (1966) interpreted the age of the flora of the Skonun Formation in the Queen Charlotte Islands of British Columbia as Upper Miocene and/or possibly Lower Pliocene. Generally the Whatcom and Skonun assemblages are similar, although the Skonun material contains a greater abundance of the Pinaceae. Finally, comparisons were made with the Miocene Sooke Formation as described by Cox (1962). Although not especially helpful, nothing was found to contradict earlier interpretations of a Miocene age. As a result of these comparisons, I have here considered this sequence of rocks to be of probable Miocene age.

Casual inspection of Table B indicates a marked change in the number and types of index fossils in the interval from 4,800 to 10,000 feet. Although many of the same anthophytes and coniferphytes are present, they occur in lower frequency. More common are the fern spores, including forms which do not occur farther up the hole, such as _Azolla_, _Anemia_ and _Cicatricosisporites_. _Pistillipollenites_, a presumed anthophyte and a characteristic fossil of the Middle Eocene (Rouse, Hills, and others) is locally abundant. _Platycarya_, which in North America appears restricted to the Eocene, is moderately common in the middle and lower parts of the section. _Ilex_, which is mainly characteristic of the Miocene, is restricted to the upper and middle portions of this section.

This interval (4,800 - 10,000 feet) was analyzed in the same way as the Miocene section. Comparison with Krutzsch (1957) was not nearly so helpful as in the Miocene interval. However, there is nothing to suggest an age younger than Eocene. Upper Cretaceous elements are missing. Comparison with known coastal Eocene floras is limited to the Burrard Formation (Rouse, 1962). The general similarity to the Burrard is high, as is the similarity to more inland Eocene floras such as that of Hills (1965) from the Princeton basin and Wodehouse (1933) from the Eocene Green River basin of Wyoming.

On the basis of these similarities and on the stratigraphic relations to be discussed later, I here consider this entire stratigraphic interval to represent Middle and Upper Eocene.

At about 9,600 feet the quality of samples deteriorates with little or nothing in the way of contained microfossils. A core of 10,100 feet contains very few microfossils, but its exact stratigraphic position is known. Only two microfossil species are present and only several specimens of each were found. However, these were Gleichenia and Proteacidites, both of which appear to be restricted to Upper Cretaceous rocks in northwestern North America. Macerations from 10,000 feet to total depth are not particularly helpful, as they contain very few microfossils. Occasionally they contain pollen or spores characteristic of the Miocene or Eocene sequences, but most of these occurrences are probably the result of caving or contamination further up the hole. The sporadic occurrence of Proteacidites and Gleichenia is sufficiently diagnostic to consider the sequence below 10,000 feet as Upper Cretaceous.

Sunnyside Well

The Sunnyside well was analyzed in a similar way to the Point Roberts well (see Table C). In overall aspect the pattern of microfossil distribution is similar to the Point Roberts well, but in details there are some variations.

Here the base of the Miocene has been placed at the last occurrence of Anemia and Cicatricosisporites. Although Ulmus-Zelkova, Liquidambar and Glyptostrobus are abundant elements in the Miocene, they extend down through most of the Tertiary section. Although one is tempted to consider this largely a result of contamination, it is not at all unreasonable, and in fact it is quite likely, that they would occur in the Eocene. In general, the microflora of the Miocene is dicotyledonous and identical to that described in the Point Roberts well.

From 4,900 feet to 8,950 feet the flora is similar to the Eocene sequence described in the Point Roberts well. Platycarya is consistently present in small amounts. Again Ilex is found in the upper and middle parts of the unit. Anemia is rare; Cicatricosisporites, although present, occurs in much reduced numbers. Pistillipollenites, a characteristic Middle Eocene fossil, shows maximum abundance in the same comparable position as in the Point Roberts well. *Sabal* does not appear to be present in the Eocene rocks in this well.

Although I have amplified this stratigraphic zoning in greater detail under paleoecology, it does not appear amiss to suggest that these minor floral differences are mainly a result of ecological conditions. The site of deposition at Point Roberts appears to have been an area of herbaceous plant and fern growth together with at least one arboreal palm. To the east, near Blaine, vegetation in general was more arboreal, and presumably somewhat less swampy. These variations in ecological conditions appear to have persisted throughout the Middle and Upper Eocene.

Conveniently, if anadvertently, a core was taken of the interval 8,938-60 feet. Chips from this core provide a small microfossil assemblage from a known stratigraphic zone. The upper portion of the core contains what I have considered a typical Middle Eocene flora, including *Lycopodium*, *Osmunda*, *Pinus*, Cupressaceae, Taxodiaceae, *Podocarpus*, *Salix*, *Alnus*, *Castanea*, *Quercus*, *Platycarya*, *Acer*, *Pistillipollenites*, *Typha*, and several trilete and monolete spores. The lower five feet of the core contain fewer of the above genera, but in addition contain several specimens of *Gleichenia* and *Proteacidites* which, as indicated, are Upper Cretaceous markers. The 9,000 foot ditch sample contains a rather extensive flora, characteristic of zones up the hole but it also contains *Proteacidites* and *Gleichenia*. In addition, a poorly preserved grain which appears to be *Triporina* was encountered. This particular form has been found only in the Lower Paleocene and Upper Cretaceous rocks of Russia. A core from 10,850 - 10,895 feet had a very small but characteristic Cretaceous assemblage, including *Gleichenia*, *Triletes solidus*, *Proteacidites*, *Extratriporopollenites*, *Sabal* and *Brochotriletes*.

Discussion of Well Results

On the basis of available data, which include ten significant microfossils, plus the appearance of the overall microfossil assemblage, I have subdivided the stratigraphic section in both wells into Miocene, Upper and Middle Eocene and Upper Cretaceous.

The study of Tertiary palynology has not progressed to the point where it can give absolute answers to the question of age. In fact, because of interpretive difficulties, some workers have assigned only Paleogene or Neogene age to certain floras. The problem of the Pacific Coast Tertiary is particularly difficult because only enough has been done to be tantalizing. Several of the Alaskan and B.C. floras are not pinned down by absolute dating, but are themselves dated by floral similarities and differences. Recently MacGinitie (1966), while discussing Eocene floras of the Middle Rocky Mountains, commented on the significant vegetative variation present in Wyoming floras of essentially the same age. He added (p. 40) that "such diverse vegetation types indicate that fossil floras cannot be used as accurate age indicators on the basis of floral composition alone, unless a sequence of vegetation types is established for each separate sedimentation basin." Of course in the Whatcom basin we have only two control wells, and these cannot be tied into any system of absolute age dating.

Further complications of interpretation are added in that definite Paleocene, Oligocene, and Pliocene floras have not been reported in the north Pacific area. In short, we really do not know what the typical microfossil or leaf assemblages are for these time intervals. However, interpretation of the available data suggest that Miocene, Upper and Middle Eocene and Upper Cretaceous rocks are present, and occupy approximately the stratigraphic intervals shown on Tables B and C.

Outcrops

Kitsilano Formation

The Kitsilano Formation, as mentioned previously, lies stratigraphically above the Burrard Formation in the northwest part of the Whatcom basin, where it underlies the city of Vancouver. Rouse (1962) suggested that the Burrard Formation is most probably Middle Eocene, which indicates that the Kitsilano is Middle Eocene or younger. Microfloral study of this unit was based on samples taken from Kitsilano Beach, and a series of samples taken from the north-south Highbury sewer tunnel on Point Grey (see Figures B and C and Table D). This tunnel, which was driven from 5th and Highbury Streets due south to Sea Island, penetrated about 1,000 feet of Kitsilano Formation dipping 8 to 10^{o} due south. In the vicinity of 22nd and Highbury Streets, the tunnel passed through the Kitsilano into the overlying Pleistocene outwash and till.

There is little indication of a fundamental change in either age or environment within the rocks of the Kitsilano Formation. As a result, I have considered the formation as a single unit. The microfossil assemblage is very similar to that of the underlying Burrard as described by Rouse (1962). Some of the more important genera are Osmunda, Anemia, Cicatricosisporites, Lygodium, Pinus, Taxodium, Podocarpus, Salix, Alnus, Carpinus, Corylus, Castanea, Fagus, Quercus, Carya, Engelhardtia, Pterocarya, Ulmus-Zelkova, Tilia, Myrica, and Liliaceae. A variety of fungal spores are also widely represented.

There are, however, several distinct and significant differences in the microfossil assemblages of the two units. Neither Sabal nor Tsuga are found in the Kitsilano but occur in low frequency in the Burrard Formation. However, Sabal leaves were found in the Kitsilano by Berry (1926). Ilex is absent in the Burrard, but is commonly present throughout the Kitsilano, becoming more abundant stratigraphically upwards. In the stratigraphically highest Kitsilano sample, which is a carbonaceous shale, Ilex reaches 27 percent of the total pollen count. Platycarya, while not common, is present in the upper half of the Kitsilano but was not reported from the Burrard. Finally, Pistillipollenites, which locally reaches several percent in the Burrard, is not present in the Kitsilano except for several grains found in the Kitsilano Beach sample.

The fact that Ilex is present suggests either a short time break between Burrard and Kitsilano times or the establishment of Ilex during the early stages of Kitsilano deposition. Platycarya appears in the upper part of the Kitsilano, suggesting that the plant migrated into the region during Kitsilano time. Rouse (1962 and personal communication) and Hills (1965) believe that Pistillipollenites is most representative of the Middle Eocene, but may occur in older rocks. Its presence in the Kitsilano, in the lowest part of the formation examined, suggests that at least the lowermost Kitsilano is Middle Eocene; although, the possibility of reworking Pistillipollenites into the Kitsilano from Burrard rocks undergoing erosion cannot be discounted. Because of the presence of Cicatricosisporites and Platycarya I have concluded that the Kitsilano is no younger than Eocene.

Geologic considerations also bear on the age of the Kitsilano. These were discussed earlier but I will summarize them here. The lithologies of the Burrard and Kitsilano are similar, and apparently were formed under the same depositional environment. The two formations are contiguous with no apparent angular unconformity of any sort between them, although Johnston suggests the presence of a disconformity. Indeed, no clear cut formational contact appears between them, except for a discontinuous conglomerate which has been assumed to be a basal conglomerate. No real evidence has been presented to show that this has more regional or temporal significance than any other local conglomeratic lens.

The lack of a conspicuous break between the formations, the lithologic and structural similarity, plus the floral similarities lead me to conclude that the Kitsilano is not really a distinct unit differentiated from the Burrard, but that both represent a long continued period of locally discontinuous deposition. Perhaps local diastems occur within the Burrard-Kitsilano, but they are not of sufficient magnitude to be called unconformities. If this is so, the formational names Burrard and Kitsilano should be discarded and an all-encompassing name applied to both.

The portion considered Kitsilano is interpreted as representing the upper part of the Middle Eocene. Possibly Upper Eocene rocks are included as well. The Burrard equivalent in the Sunnyside well, as interpreted by plant microfossils and stratigraphic relations, is the interval 7,300 to 8,955 feet. The stratigraphic portion of this well, thought to represent the Kitsilano Formation, is about 4,850 to 7,300 feet (see Table C).

Equivalent intervals in the Point Roberts well are: Burrard, 8,300 to 10,000 feet; Kitsilano about 5,300 to 8,300 feet. Because of poor sample control in the interval 5,000 to 6,000 feet, the upper limit of the Kitsilano equivalent is uncertain but stratigraphic thicknesses suggest it should be about 5,300 feet (see Table B).

Remaining Outcrop Correlation

A number of outcrops were carefully examined and sampled. In addition, the sites of three abandoned Whatcom County coal mines were visited. No fresh exposures are visible at any of these mines, but careful selection of shales and coal from the abandoned dumps were made, and these samples and those from outcrops were macerated and examined. A summary of significant tabulations is shown in Table D.

At the onset of this discussion I should say that the Kanaka Creek samples, which I worked on for a considerable period of time, have yielded a very limited microflora. Evidently microfossils were once present but have been rendered unidentifiable by bacterial action, by other biochemical reactions, or by rock diagenesis. The microfossils are largely fused and appear now to be only amorphous globules of wax. The few recognizable forms are not age diagnostic. Samples from Blue Mountain near Alouette Lake and from Silverdale proved to be barren of microfossils and are not discussed further. King Mountain, north of Bellingham, is made up largely of pebble conglomerates, but even the thin shale interbeds proved essentially barren and yielded no diagnostic fossils. This particular outcrop is not considered further here.

The remaining outcrop samples (locations on Figure D, microfossil content on Table D) are characterized by a high concentration of different types of fungal spores. In this respect they are more like Kitsilano-Burrard rocks than any other interval in either well. Most probably this is a function of environment rather than age.

On the basis of geographic location and physical attitude, it has been assumed (Moen, 1962; Miller and Misch, 1963) that outcrops from Canadian Sumas Mountain south, and those west to Bellingham, are equivalent to either the Burrard or Kitsilano Formations. Results of this study bear out this assumption.

With one exception, there are no typically Cretaceous pollen or spores such as Gleichenia or Proteacidites in these rocks. The one exception is on American Sumas Mountain where a thin, shaly lens interbedded between massive conglomerates was sampled. This yielded several proteaceous grains as well as other more typical Eocene microfossils. However, the rocks themselves suggest vigorous erosion in the headwaters, and I suspect the proteaceous grains are contaminants from the older rocks. Furthermore, these rocks are lying with strong angularity on folded, faulted, and eroded rocks of the Chuckanut Formation, which is considered most likely Paleocene in age.

Dicotyledonous pollen is present, but is not striking either in variety or numbers of individuals. Liquidambar and Glyptostrobus are conspicuous by their absence. Ulmus is absent from all outcrop samples, except Toad Lake, where it reaches about 4 percent of the total. The absence of a rich dicotyledonous flora as described earlier, and the absence of *Liquidambar* and *Glyptostrobus* and the virtual absence of *Ulmus* suggest the rocks are not as young as Miocene.

On the other hand, *Anemia* is present in one outcrop flora, *Cicatricosisporites* in three, *Pistillipollenites* in four, and *Platycarya* in four. As previously indicated, these genera are reasonable indicators of an Eocene age.

Although I believe there is no doubt that all the Tertiary outcrops are stratigraphic equivalents of the Burrard or Kitsilano Formations, a finer subdivision becomes more difficult and uncertain, largely because of the similarity of the Burrard and Kitsilano floras.

The Toad Lake outcrop, the Glen Echo Coal Mine, the Goshen Coal Mine, and probably the Bellingham Coal Mine appear generally to be Burrard equivalents. None contains *Ilex*, with the exception of a few percent in the Bellingham coal sample. Also, *Platycarya* is not present in any of these sites. With the exception of the Bellingham Coal Mine, all contain *Pistillipollenites*. These characteristics, while admittedly limited, suggest that these four outcrops are equivalent to the Burrard Formation and to the Burrard equivalent in the two wells. Data from the Bellingham Coal Mine is sketchy and non-conclusive, but it is close to and appears stratigraphically contiguous with the sediments of Toad Lake and the Goshen Coal Mine. However, the possibility exists that the Bellingham coal seam *might* actually be Miocene in age, although at the present time there is no way to prove or disprove the contention.

Microfossil assemblages from Canadian Sumas Mountain, the Whatcom Clay Mine, Dale Creek (American Sumas Mountain), and the Whatcom Quarry, suggest a Kitsilano age. Ilex characterizes two of the outcrops, Platycarya is found in three outcrops, Pistillipollenites is represented by only two grains in the Dale Creek (American Sumas Mountain) assemblage, and if these are not contaminents, their presence would suggest this section is equivalent to the Kitsilano beach portion of the Kitsilano Formation. However, as mentioned earlier, this might be erosional contamination from older rocks. Cicatricosisporites is abundant in three of the outcrops, but absent in the problematical Dale Creek sample. Anemia is abundant in the Canadian Sumas Mountain flora. From this evidence, I tentatively consider these four floras as equivalent to the Kitsilano Formation, and the Kitsilano-equivalent in the two wells.

The preceding discussion should not be construed as an argument for retaining the Burrard-Kitsilano subdivision. The overwhelming floral evidence suggests a close similarity between the two units, and the appearance or disappearance of several genera during a 16 million year period is not unexpected. However, this presence or absence may be useful in suggesting with what part of the Burrard-Kitsilano sequence one is dealing.

PALEOECOLOGICAL INTERPRETATIONS

General

Ideally, plants are the most sensitive of the terrestrial ecological indicators. Animals can roam and move about if climatic conditions become unfavorable, but plants are rooted to one spot and must tolerate the environment in which they grow. Furthermore, the tolerance in their environmental requirements is less than for most animals. Because the most critical stage in a plant's entire growth cycle is at germination, a changing environment will allow survival of the reproductive propagules only if they fall in a favorable site. Because of this, a changing climate can markedly alter the flora in comparatively few years. As a consequence, analysis of fossil floras should provide data on climatic conditions at the time of growth.

And indeed they do; but several problems loom large, one of which we have mentioned earlier. In palynology, as in all paleontology, a generally accepted truism is the old saw, "the present is the key to the past." In paleoecologic interpretations one must assume that organisms, whether plant or animal, reacted to a given environment in much the same way as their modern counterparts do. In other words, an alder or elm would have had the same ecologic requirements in the Miocene as they do today. The problem with this assumption is that we are not really familiar with the complete ecological requirements and the range of tolerance of most genera and species of plants. This is true with temperate species, and is even more so for tropical and subtropical species. Furthermore, within any given genus the range of variability may (and usually is) high with each species requiring slightly different conditions. However, in virtually all studies where plant microfossils are used to interpret paleoecology we are not dealing with natural species but only with natural genera. The species of microfossils or other plant parts are artificial, at least in rocks older than Pliocene, and are based on various morphological differences which may or may not have significance in reflecting natural (or phylogenetic) relationships. In any event, in very few cases can they be equated to modern species. Palynologists usually take the total range of variables within a genus, and utilize as many genera as possible to interpret paleoecology. Hopefully, a large microfossil assemblage will give a qualitative estimate of the climatic conditions at the site of deposition while the particular flora was in existence.

The other problem is whether a given sample is truly representative of the extant flora at the time of deposition. As pointed out previously, differential preservation is always a factor -- some pollen grains survive bacterial and fungal attack, oxidation, hydrolysis and rock diagenesis more readily than others. Furthermore, pollen and spores are produced in vastly different quantities in different genera. For example, a ten year old branch system of beech has been estimated to produce 28 million pollen grains per year, while an equivalent branch system of pine may produce 350 million grains (Faegri and Iverson, 1964). This difference will obviously be reflected in the quantities of pollen grains obtained from maceration of rock samples and used in slide counts.

The method of pollen dispersal also reflects relative quantities. Wind pollinated species (i.e. Pinus) which usually produce pollen in enormous quantities, will be abundant in the fossil record, whereas insect pollinated plants (i.e. Acer) produce relatively few pollen grains. As a result, Acer may be under-represented in a microfossil spectrum and its importance in the assemblage will be under-rated. In the case of Acer, a pollen grain which is also easily destroyed, the combination of low relative productivity and comparative fragility may result in its absence entirely from the pollen record.

Factors such as these undoubtedly lead to complications of interpretation and must always be born in mind when arriving at ecological conclusions. Provided enough samples are collected, both laterally and vertically in a formation, a fairly satisfactory interpretation of some aspects of ecology should be possible. However, when using well samples which are taken only at arbitrarily selected intervals (in this case 100 feet), any conclusions of paleoecology must be regarded as tentative and can be presented only in general qualitative terms. This is what I have done in the following section, with brief interpretations of the overall floral picture through time. Reference can be made to Table E where generalized statements are made on both habitat and climatic requirements of the more common genera.

Upper Cretaceous

Interpretation of Upper Cretaceous environments are hampered by the small flora present in well samples of this age. However, examination of Table E indicates that all the genera are either tropical or subtropical. Microfossils found in the Cretaceous rocks, including *Gleichenia*, *Proteacidites*, and *Sabal* indicate a tropical to subtropical climate but with varying habitats. A subtropical climate is more likely, because as Brooks (1951) pointed out, the Late Cretaceous was a time of world wide cooling. Smiley (1966) working with Cretaceous megafloras in the Kuk River area of northern Alaska was able to document a cooling trend throughout the later Cretaceous. Modern genera of the Proteaceae commonly grow in areas where a prolonged annual dry season occurs. Possibly this was so in the Cretaceous because of the variety and abundance of the Proteaceae during the Late Cretaceous of the Northwest.

Because the Cretaceous rocks are not directly observable in the wells, little can be said directly about the depositional environment which they indicate. However, if they are equivalent to some part of the Chuckanut Formation, as seems likely, they would indicate intermittent continental deposition on a large

TABLE E

RANGE AND ECOLOGICAL REQUIREMENTS OF MODERN GENERA WHICH HAVE BEEN IDENTIFIED FROM THE WHATCOM BASIN

(Modified after Rouse (1962), Hills (1965), with additions from Bailey (1949), Lawrence (1951), Willis (1955), Graham (1965), and Smiley (1966).)

GENUS	HABITAT AND GEOGRAPHIC RANGE	CLIMATE
Isoetes	Moist areas to aquatic, cosmopolitan	Temperate to tropical
Lycopodium	Most are mesophytic, cosmopolitan	Temperate to tropical
Osmunda	Swamps, shaded moist woodlands, mainly Northern Hemisphere	Temperate to tropical
Anemia	Wet lowlands and rain-forests, particularly in tropical America	Subtropical to tropical
Gleichenia	Swamps, shaded moist areas, Southern Hemisphere	Tropical
Azolla	Quiet lake and pond waters	Warm temperate to tropical
Ginkgo	Open stands, well-drained areas, west China	Warm temperate, 40-60" precip-itation
Cedrus	Dense forests, northern Africa, southern Asia	Temperate to subtropical
Keteleeria	Dense forests, China	Warm temperate
Larix	Marshes to woodlands, mainly Northern Hemisphere	Cool temperate to boreal
Picea	Moist soils, mainly Northern Hemisphere	Cool temperate, generally high altitude

TABLE E

GENUS	HABITAT AND GEOGRAPHIC RANGE	CLIMATE
Pinus	Swamps to rocky highlands, predominantly dry sites, Northern Hemisphere	Variable
Glyptostrobus	Associated with evergreen oak forest, generally moist to swampy habitats, southeast China	Warm temperate to subtropical, 50-60" precipitation
Metasequoia	Wet ravines in mountains, central China	
Taxodium	Swamps and flood plains of southeastern United States and Mexico	Warm temperate to subtropical, 50-60" precipitation
Podocarpus	Moist woodlands and mountains of the Southern Hemisphere, Caribbean and South America	Warm temperate
Taxus	Northern Hemisphere, mostly small trees in woodlands	Temperate
Magnoliaceae	Trees and shrubs, some climbing, cosmopolitan	Warm temperate, subtropical to tropical
Liquidambar	Tree, component of oak-hickory forest, Northern Hemisphere	Warm temperate
Salix	Damp thickets, swamps, cool woods, cosmopolitan	Variable
Alnus	Swamps, wet woods, stream margins, cosmopolitan	Variable
Betula	Uplands to bog and wooded swamp, Northern Hemisphere	Cool temperate
Carpinus	Upland woodlands to coastal swamps, Northern Hemisphere	Cool temperate

TABLE E

GENUS	HABITAT AND GEOGRAPHIC RANGE	CLIMATE
Carylus	Thickets, woodlands, Northern Hemisphere	Temperate
Castanea	Dry woods, thickets, Northern Hemisphere	Cool to warm temperate
Fagus	Forms homogeneous, Northern Hemisphere	Temperate
Quercus	Wide range of habitats, Northern Hemisphere, mountains of the tropics	Variable
Carya	Variable habitats, China, southeast Asia, eastern North America	Cool temperate to subtropical
Engelhardtia	Asia	
Juglans	Woods and river terraces, southeastern United States, South America, southeastern Europe, Asia	Warm temperate to subtropical
Platycarya	Japan and northern China	
Pterocarya	Northern Hemisphere of old world	Temperate
Tilia	Low slopes and along streams, Northern Hemisphere	Temperate
Acer	Variable habitats, Northern Hemisphere	Cool to warm temperate
Aesculus	Woods, bottomlands and stream borders and thickets, Northern Hemisphere and South America	Temperate
Ilex	Bogs, moist depressions, cosmopolitan	Warm temperate to subtropical
Proteaceae	Mostly xerophytic, restricted to Southern Hemisphere	Most indicate long annual dry season

TABLE E

GENUS	HABITAT AND GEOGRAPHIC RANGE	CLIMATE
Myrica	Variable habitats, cosmopolitan	Temperate to subtropical
Sabal	Lowlands, river bottoms, coastal plains, southeastern United States, Caribbean, Columbia	Subtropical to tropical
Typha	Marshes, along river banks, cosmopolitan, except south of equator in Africa	Temperate to tropical
Potamogeton	Herbaceous in streams and ponds, a few along sea margin	Cool temperate to subtropical

flood plain with all its resultant variations in lithology.

Eocene

The Eocene flora is largely composed of genera whose modern components are warm temperate to subtropical. Most of the genera, such as Anemia, Taxodium, Salix, Alnus, Ilex, Sabal and Typha are now characteristic of a low, moist and poorly drained coastal area. The presence of Azolla and Potamogeton, which presently inhabit ponds and/or lakes, show that bodies of water existed on this lowland.

Other microfossils are present which suggest a more upland habitat. These include Pinus, Picea, Podocarpus, Carya, Corylus and Quercus. How far these trees were growing from the source of deposition is uncertain, but their low frequency of occurrence would suggest it was some distance away. Pinus, whose pollen is produced in prolific amounts, is not a common microfossil in any of the Whatcom basin rocks. Furthermore, bladdered conifer grains are seldom well preserved, are often physically broken and almost inevitably corroded. The implication is that their habitat was a considerable distance away, probably to the north, east and south but not to the west. Transport to the depositional site was probably largely by streams, which accounts for the poor physical preservation. Although we do not know the prevailing wind directions during the Eocene, it was porbably southeast to northwest, as at present. At the present time, during the fall and winter months, the prevailing winds are southeast; the spring and summer months are dominated by westerly to northwesterly winds (Vancouver Weather Office, oral communication). Because the flowering season is dominated by westerly winds there would be a further reduction in the number of pollen grains that would move westward to the site of deposition in the Whatcom basin.

The lithologies, insofar as they are visible in the Kitsilano and Burrard Formations, as well as in other Eocene outcrops, bear out this interpretation of a lowland environment. Sands and shales predominate, river and stream channels are common, thin coal seams are present, as are occasional cross-beds. Together these characteristics indicate the existence of lowlands and swamps. The picture that emerges is similar to that proposed by Johnston (1923) of a low, swampy coastal plain, spotted with small lakes, ponds and swamps, and traversed by generally slow-moving, meandering streams flowing westward an unknown distance to their junction with the sea.

In summary, the Eocene in the area of the Whatcom basin appears to have been warmer and more humid than at present, but probably not truly subtropical. Highlands must have surrounded the basin of deposition, but relief was far less than at present. Precipitation was probably 50 to 60 inches annually and was more or less uniformly distributed throughout the year.

Miocene

Little can be interpreted from the rocks as to the probable environment of deposition, as the Miocene rocks are totally subsurface and well data are not particularly enlightening. Apparently, however, conditions similar to those of the Eocene prevailed, with deposition on a low, essentially flat, gradually subsiding coastal plain.

Available floral evidence suggests that the Miocene was slightly warmer than at present, with precipitation more equably distributed throughout the year. Three definite plant associations appear to have existed within the region, implying more topographic relief than during the Eocene.

The abundance of *Taxodium* and *Glyptostrobus* is an indication of large bodies of standing water in a warm temperate to subtropical climate. These two genera fill identical ecological niches, but at the present time *Glyptostrobus* is restricted to China whereas *Taxodium* is found only in the southeastern United States and northeastern Mexico. During the Tertiary, both of these genera were widespread over North America. At present, these genera require 50 to 60 inches of precipitation yearly and a temperature that rarely falls below 32° F. The abundance of *Potamogeton* attests to the apparently rather extensive bodies of standing water. *Typha* and *Ilex*, both abundant in warm swampy environments also inhabited these lowlands.

On slightly higher uplands, probably on the basin margins, stood a hardwood forest much like that currently present in the eastern United States and eastern Asia. Typical trees in this association were *Tilia*, *Fagus*, *Castanea*, *Ulmus*, *Carpinus*, *Liquidambar*, *Quercus*, and *Juglans*. Such trees have a modern distribution in moderately well drained sites where the annual precipitation is 40 to 60 inches (Chaney, 1940) with both winter and summer rains.

Still farther back from the basin were more pronounced uplands that supported at least some coniferous genera, such as *Pinus* and *Picea*. *Abies* has not been found in the Miocene rocks, so presumably any site of growth during this time was well removed from the basin. In modern floras, *Abies* generally grows at a considerably higher elevation than *Picea* so probably no highlands of sufficient height existed to support *Abies*.

In general, the floras of the Miocene ranged from warm temperate assemblages to those at slightly higher elevations consisting of deciduous hardwood trees. Temperate conditions must have existed at higher altitudes. As in the Eocene, precipitation was somewhat higher, and mean low temperatures not so extreme as at present. Generally, Miocene temperatures appear to be somewhat less than those of the Eocene. At the present time the precipitation is concentrated mainly in the winter months with a comparatively dry summer. Miocene precipitation was probably more equably distributed throughout the year.

GEOLOGIC HISTORY

This summary of geologic history of the Whatcom basin and immediate surroundings is concerned only with Late Cretaceous and Tertiary history, and hence no mention is made of the complex and involved Paleozoic and Mesozoic eugeosynclinal events that preceded the Tertiary. The present review begins with the deposition of the Chuckanut Formation of northwestern Washington.

Apparently during the Middle Cretaceous, deformation and low-grade metamorphism affected the entire area. In Late Cretaceous time subsidence began again in a long trough which extended from Bellingham southeast across the site of the Cascade Mountains, at least as far as Wenatchee, Washington. Within this trough, continental deposition took place, in some areas to greater thickness because of greater subsidence. Quite possibly subsidence and deposition took place in the Strait of Georgia which is a continuation of this trough. This sequence of continental rocks is now known as the Chuckanut Formation. The lowest part of the Chuckanut is perhaps equivalent to the upper part of the Nanaimo Group of Vancouver Island, but while the Nanaimo Group contains numerous marine sections, the Chuckanut Formation, with the one exception noted, appears to be entirely continental.

Deposition apparently continued in the elongated northwest-southeast trough through part or all of the Paleocene and possibly into the Lower Eocene until a maximum local thickness of 20,000 feet was reached. At this time, the entire sequence was deformed. As was pointed out in an earlier section, the Chuckanut was folded into northwesterly and northeasterly trending folds, some tight, some relatively open. Locally, minor reverse faulting and overthrusting has been observed.

At least one major fault, called the North Nooksack Fault by Moen (1962) and the Boulder Creek Fault by Miller and Misch (1963), has been mapped. Reportedly its displacement is at least 5,000 feet and must either terminate or post date deformation because Chuckanut folds have been displaced. This normal fault strikes essentially east-west with the south block down, and disappears beneath the Middle Eocene rocks without any evidence of offset or displacement. Evidently there has been no movement on this fault since the Middle Eocene.

The historical interpretation of what followed Chuckanut deformation is cloudy and difficult to interpret in detail. Basically there is no doubt that the Whatcom basin is a distinct entity -- well-data and outcrop information are incontrovertible. But the question is: how did the basin form, and when. Several interpretations are possible.

Middle Eocene rocks crop out in a discontinuous band around the entire basin. They are all clastic, with the exception of several small and local residual deposits. All dip into the basin and comparable Middle Eocene rocks are found in all the basin wells which penetrate deeply enough. In fact, Miller (in Miller and Misch, 1963) considered all the Tertiary rocks to be Eocene, including those which I have interpreted as Miocene. How extensive the Eocene deposits were originally is a question that cannot be given a definitive answer. However, they were probably never much more extensive than at present, because remnants are not found far outside the basin margin. Furthermore, at American Sumas Mountain, the Eocene is represented by a thick sequence of coarse conglomerates that suggest a nearby source. Component boulders are composed of rock types that could have been derived from active erosion of the area now comprising the northern Cascades.

Evidently, differential erosion of the Chuckanut Formation did take place prior to the formation of the Whatcom basin because Paleocene rocks are not recognized in the two deep wells. Griggs (1965) has considered the Chuckanut Drive sequence of rocks as mainly Paleocene, but nothing comparable to his flora occurs in the wells. However, as I earlier remarked, we do not really know what Paleocene in this area should look like, or whether the Chuckanut is truly Paleocene. Even if it is, it may not be the age of the lowermost Chuckanut, which as I have suggested earlier may be Upper Cretaceous. Also, a possibility exists that Paleocene rocks were not deposited on the site of the Whatcom basin, and that all that is equivalent to the Chuckanut, is Upper Cretaceous. Our interpretations here are confused by the fact the stratigraphy and paleobotany of the Chuckanut Formation is not known.

Evidently during the Middle Eocene, the Whatcom basin gradually subsided, accompanied by continual deposition of flood-plain and coastal-plain deposits. That subsidence never outstripped deposition is suggested by the absence of marine units which would have resulted had the sea transgressed the region. Eocene rocks are not known on the east side of Vancouver Island, hence they presumably wedge out westward beneath the waters of the Strait of Georgia. Presumably also, the Strait of Georgia, at least west of the Whatcom basin, but not as far west as Vancouver Island, was a subsiding area.

Source areas for the Eocene sediments were apparently highlands occupying the sites of the Coast Mountains and the Cascade Range. As indicated in earlier discussions, the floral evidence suggests much lower highlands than at present, probably not much more than low hills. Locally, to the east, more vigorous uplift must have occurred to provide a source for the conglomerates.

Near the end of the Eocene, or earliest Oligocene, deposition apparently came to an end. Quite probably, relief over the entire area was very low at this time with neither uplift nor subsidence taking place. The upper surface of the Eocene was near grade and probably little more than local reworking of the uppermost Eocene took place.

By the Miocene, orogenic activity had become pronounced over most of what is now western Washington and Oregon. In the area of western Washington, a series of pronounced northwest-southeast upwarps developed with the formation of a number of closed basins (Snavely, et al, 1963). The Whatcom basin became one of these closed areas again, on the north slope of an uplift centered south of Bellingham and passing through the San Juan Islands and presumably onto Vancouver Island. Uplift was probably mild in this particular area with the highlands subdued and showing none of the high relief characteristic of the region today. Probably, however, relief was considerably more than during the Eocene.

Gradual subsidence in the center of the Whatcom basin during part or all of the Miocene again resulted in infilling by continental sediments. Subsidence was more restricted and was not as extensive as during the Eocene. By the end of the Miocene, relief was again low and more stable conditions resumed with little subsidence or uplift. By Late Pliocene and Pleistocene the north-south Cascade Mountain uplift began with the resulting incision by drainage and with abundant clastic material carried westward to the Strait of Georgia.

Pleistocene glaciation resulted in mantling much of the region with outwash and till, covering all the lowlands except the post-Pleistocene deltas of the Fraser, Nooksack, Skagit and other rivers.

One additional point is the interesting topographic relations present at the south end of the basin. The Chuckanut Formation is topographically high south of Bellingham, locally reaching elevations in excess of 2,000 feet. The

Eocene rocks cropping out north of the Chuckanut Highlands are dipping steeply into the basin, more steeply than one would expect if it were simply an onlap relation.

Recently, intensive seismic investigations have been conducted in the Strait of Georgia from west of Vancouver to the area north of Orcas Island. Preliminary results of this work have indicated a very large and significant seismic discontinuity extending southeast along the southwest side of the Strait of Georgia off the eastern coast of the Gulf Islands (Dr. J. Murray, oral communication). This discontinuity is indicated on the generalized Geologic Map (Figure D, in pocket). North of Saturna Island the discontinuity swings to a more easterly bearing, passing well north of Orcas Island. Unfortunately, control is not extended beyond this point although ultimately additional work is planned. However, if one continues the projection of this discontinuity, it passes into the vegetatively covered area between the Chuckanut Formation and the Eocene rocks in the vicinity of Bellingham. It must be admitted that as far as I am aware there is no surface manifestation of this discontinuity on the mainland.

However, Dr. Murray believes that quite probably this discontinuity is a major fault, although the sense of movement is not clear. Preliminary examinations of the seismic profiles, however, suggest that this is a normal fault with the down block to the northeast and east. If this is so, and if this "fault" continues eastward into the mainland of Washington, it may account for the topographically high position of the Chuckanut Formation. It would also explain by drag the very steep dips which characterize the Eocene rocks at the south end of the basin.

Because this discontinuity affects the sea floor in the Strait of Georgia, it would appear to be a moderately recent feature, perhaps Pliocene or Pleistocene and in some way associated with the Cascade Mountain uplift.

Because the seismic data have not been completely evaluated, and because much work remains to be done, it would be unwarranted to speculate further. However, the potential significance of this discontinuity to explain the structural relations of Tertiary and Cretaceous rocks in this region should be born in mind.

Much remains to be done before a more complete understanding of the Tertiary geologic history of northwestern Washington and southwestern British Columbia is achieved. I hope that in a small way the results of this investigation have contributed to the ultimate understanding of this history.

PALYNOLOGY

Collecting and Laboratory Procedures

In the early stages of the investigation I found that the most productive rock samples, in terms of plant microfossil content, were fine-grained clastic rocks of clay size, and carbonaceous sediments, especially coal. In almost all cases, siltstones or sandstones yielded no microfossils; if they were ever present, physical damage or corrosion made them unrecognizable. As a general rule, the depositional environment of sand is one of considerable turbulence which almost certainly resulted in physical abrasion, destruction, or washing out of any contained microfossils. Furthermore, the higher permeability of sandstones, as contrasted with shales, would likely have permitted the entrance of atmospheric oxygen into the sands, with the concomitant growth of destructive fungi and bacteria. Although a number of silty and sandy shale samples were macerated, virtually all of the material on which floral conclusions are based was derived from shales and coals.

The sampling procedure was simple, with short channel samples taken from shales and coals within the rock units. With careful sampling at Kitsilano Beach and through the north-south Highbury Tunnel, stratigraphically located samples were taken through a partial stratigraphic section of the Kitsilano Formation. With the Huntington Formation and Tertiary continental sedimentary rocks, collecting on a complete stratigraphic basis was not possible because of the narrow width of outcrop, and the paucity of satisfactory fossil-bearing zones. Mostly ditch, but some core samples were used from the various wells examined.

The maceration procedure was essentially the same for all samples, with minor modifications to suit specific cases.

Approximately six grams of sample were selected and crushed until the maximum particle size was about 3 mm. The crushed sample was placed in 50 percent hydrochloric acid for about 24 hours to remove any carbonate present. All of the samples contained some carbonates; some of the shales were actually calcareous shales.

Following HCl treatment, the sample was thoroughly washed in tap water, then placed in 50 percent hydrofluoric acid to remove the silica. With occasional agitation the time required in HF ranged from 24 to 72 hours. Following this treatment, the sample was thoroughly washed and examined under the microscope. On occasion the microfossils were clear at this point and no further treatment was necessary. Usually, however, the microfossils were coated with a carbonaceous film which had to be removed before they could be mounted on slides.

To remove the carbonaceous film the residue was immersed in 30 percent nitric acid for periods ranging from 3 to 24 hours. As the carbon gradually oxidized the carbonaceous material turned red and transparent. At this point the sample was washed in water, then immersed in a 5 percent solution of potassium carbonate. This effectively removed the red film and left the microfossils clear and ready for staining.

Occasional samples were encountered in which the carbonaceous film was especially thick and tenacious. Originally an attempt was made to oxidize this using Schultzes solution (nitric acid, potassium chlorate and water). This solution is a very strong and rapid oxidizing reagent; thus it is difficult to use without excessive oxidation and eventual loss of the entire microfloral assemblage. I found it more satisfactory and less damaging to utilize several treatments with relatively weak nitric acid alternated with treatment with potassium carbonate.

Following immersion in potassium carbonate, regardless of whether the oxidation treatment was applied once or several times, the sample was thoroughly washed. A solution of safranin dye in water was applied and the sample allowed to stand for several minutes. This was followed by a rinse in alcohol to absorb any remaining water. Finally, the samples were stained in a safranin dye-alcohol solution and permanently mounted on glass slides with Gelva plastic dissolved in dioxane.

During the course of this project I macerated nearly 200 rock samples, although only about 140 of these contained suitable microfossils for permanent slide mounts. For each of the 140 samples, 3 to 6 slides were prepared, depending upon the microfossil concentration. Three hundred and twenty slides were obtained from the well samples, each from a different horizon. The value of these varied widely, some being completely barren, others bearing a rich microfloral assemblage.

An attempt was made to count at least 200 grains per slide, occasionally more than this. However, at times fewer than 200 were counted per preparation, simply because of the low concentration of grains on the slide.

Photomicography

Examination and counting of the microfossils was done with a Leitz Ortholux research microscope equipped with an automatic Leitz Orthomat camera. The film used was Ilford Pan F, processed in Acufine fine-grained developer. Enlargements were made on Kodak Kodabromide paper using Kodak Dektol developer.

Taxonomy

As every palynologist knows, the classification and description of plant microfossils is in a chaotic state with no uniform system acceptable to all workers. There are, however, two broad schemes in use, each with its advantages and disadvantages.

The first, originally championed by Potonié and other European palynologists, is a classification based on pollen and spore morphology. Here grains are assigned to distinctive groups on the basis of size, number and nature of pores, colpae and laesurae; and on the nature of sculpturing, i.e. warty, smooth, spiny, etc. This, of course, does not consider any botanical affiliation, and of consequence is of limited value in paleoecological interpretation. It is, however, a comparatively easy system to use and may provide useful information on correlation and age of various rock units. This so-called "artificial classification" is much in use by oil company palynological laboratories in their correlation and dating studies.

The second broad system of classification is the so-called "natural classification." Here the palynologist makes a determined effort to assign pollen grains to existing natural plant groups wherever possible. This procedure is only possible with Upper Cretaceous and Tertiary microfossils because during this period of time many of the extant plant genera made their first appearance. Throughout the Tertiary the floras of the world were taking on an ever more modern aspect, with most, if not all, of the modern genera appearing before the end of the Pliocene. By comparison with both the literature and modern reference material, many Tertiary pollen and spores can be assigned to modern genera. Species are a more difficult problem, and for the most part are created on the basis of minor morphological variations within grains of the established genus. These may or may not represent true species in the botanical sense. Some palynologists have assigned modern specific names to microfossils as old as Miocene (e.g. Macko, 1957; 1959; 1963), but this I consider to be misleading and incorrect procedure for several reasons. In the first place, it seems unlikely that a species would survive for 25 or more millions of years without change, especially during the Tertiary with its world wide climatic changes and constant tectonic instability. In the second place, pollen grains are seldom so perfectly preserved that they can be compared in every respect with modern material. In late Pliocene or Pleistocene rocks, perhaps the assignment of modern specific names has value, but I believe that in rocks older than Pliocene this is not valid. For rocks older than Upper Cretaceous, identification is very tenuous, assignment to modern genera is usually not possible, and the usage of an "artificial system" becomes mandatory.

In this work I have elected to use the system which is most commonly applied by Tertiary palynologists, i.e. a combination of these two broad systems. This involves identification to a natural genus wherever possible, and in some cases assignment to a form species in that genus. However, I have generally been conservative in my approach to subdividing a genus into species. It has often been the practice in paleontology to subdivide, or to split into ever smaller units, often on dubious grounds. If, within a given genus there are two or more forms which are clear cut, distinct, and easily recognized, a subdivision into form-species is more useful in stratigraphic studies. If, however, as appears to be more often the case, subdivisions are based on end products showing intergradations of form or on indefinite and vague criteria, little but confusion results and comparison between microfossil assemblages becomes difficult. Besides, this leads to unnecessary and meaningless proliferation of species names. As a result, if I have erred it is on the side of conservatism, or as it is sometimes called, "lumping."

For grains which cannot be assigned to modern genera I have used the form generic names which have been assigned by various other investigators. At times, I have suggested possible or probable botanical affiliations, but this is only an opinion and in some cases cannot be completely substantiated.

Because of the variation in application and definition of various textural and sculpturing terms, I have followed closely the terminology suggested by Faegri and Iverson (1964). This is not to suggest I feel their definitions are always the best, but it does provide some sort of consistency to the descriptions.

In the following section I have described approximately 100 palynomorphs from the Whatcom basin whose occurrence ranges from abundant in nearly all samples to very rare in one sample. The natural classification I have employed is the phylogenetic system as outlined in Scagel, *et al* (1965).

DIVISION EUMYCOTA

CLASS FUNGI IMPERFECTI

Dyadosporites$_1$ sp.

Pl. 1 Fig. 1

DIAGNOSIS: Spores bilocular, 35 to 74μ long, elliptical, aperature characteristics questionable but apical and presumably circular, central septum simple and 2-3μ thick. Wall psilate.

REMARKS: This fungal spore most closely resembles *D. ellipsus* Clark 1965, but is not definitely assigned to that species because of its somewhat larger size and because the aperature characteristics are not clear.

Similar fungal spores have been reported in Upper Cretaceous, Eocene, and Pliocene beds. As suggested by Martin and Rouse (1966) the spores are probably telispores of a rust.

OCCURRENCE: These spores were found in low frequency in several Kitsilano samples and in samples from the Sumas Clay Mine.

Dyadosporites$_2$ sp.

Pl. 1 Figs. 2-3

DIAGNOSIS: Spores elliptical, biporate, and bicellular, size 55 to 75μ. Pores large, circular, slightly aspidate, some sub-wall thickening. Large thickened septum through middle of grain, apparently dividing grain into two cells, each with an apical pore. Wall thick (ca. 2μ) and heavy.

REMARKS: This grain is referred to the genus *Dyadosporites* as redefined by Clark, 1965. It differs from *Dyadosporites*$_1$ sp. in having a heavier and less well defined septum as well as larger and more distinct apical pores.

OCCURRENCE: These spores were found in low frequency in several Kitsilano samples and from the Sumas Clay Mine.

Pluricellaesporites psilatus Clark 1965

Pl. 1 Figs. 4-6

DIAGNOSIS: Uniseriate fungal spores with individuals consisting of several to many cells. The width varies from 12 to

25μ and the length may be in excess of 100μ , depending upon the number of component cells, length of individual cells 6 to 12μ . A 0.5 to 1.0μ aperature occurs in each septum. Thickenings on one side of the septum appear as adjacent triangles with the aperature occurring between them. Cell walls psilate.

REMARKS: These spores are identical in all respects to those described by Clark (1965). They are particularly common in many Early Tertiary horizons of Arctic and western Canada and of northwestern Washington State.

OCCURRENCE: These fungal spores are very abundant in all the Kitsilano samples examined. They occur in lesser frequency in all the outcrop samples from the Whatcom basin. A cursory examination of samples from the Eocene and Oligocene rocks of the Olympic Peninsula of Washington State indicate they are also present there.

Pluricellaesporites sp.

Pl. 1 Fig. 7

DIAGNOSIS: Spores 35 to 50μ long with a length:width ratio of about 2:1, are multicellular, usually with three perforate cross walls. There is a suggestion of a pore at either end, but ruptured ends leave this unclear. The cross walls are triangular and are 1 to 3μ thick.

REMARKS: The pattern of thickened septa, which appear triangular, suggests strongly that this particular fungal spore should be assigned to the genus *Pluricellaesporites*. Possibly this form is identical to *P. psilatus* but is a more mature form, developed by constriction at every fourth cell. However, these forms always have four cells separated by three septa; furthermore, no intermediate stages were recognized. Consequently, assignment to a separate species is tentative.

OCCURRENCE: This species occurs in low frequency in all the coal samples from the south end of the Whatcom basin. It was not encountered in any well samples and was probably a fungus restricted to a local swamp-forming environment.

Fungal Hyphae

Pl. 1 Fig. 8

DIAGNOSIS: Segmented and germinating fungal hyphae, overall length 150μ, average thickness of hypha is 7μ.

REMARKS: Although of no known diagnostic value this is a common fossil in the Kitsilano Formation. Of particular interest are the young budding hypha and widely spaced and perforate septa shown on Plate 1, Figure 8.

OCCURRENCE: Fungal hypha are particularly abundant in the Kitsilano Formation but are also present in other outcrop samples, as well as various well samples.

DIVISION LYCOPODOPHYTA

ORDER ISOETALES?

FAMILY ISOETACEAE?

Isoetes? sp.

Pl. 1 Figs. 9-10

DIAGNOSIS: Small (17 to 23 μ) monolete spore (or pollen?). Characteristically the laesura extends about two/thirds length of grain, in some gaping slightly, in others tightly closed. Sculpture scabrate.

REMARKS: Assignment of this microfossil to Isoetes microspores remains tentative, but it closely resembles the illustrations and descriptions given by Erdtman (1943).

OCCURRENCE: This is an almost always present but never abundant microfossil from both the Sunnyside and Point Roberts wells. It is especially abundant in the Miocene section, but occurs also in the Eocene section. A few grains were also identified in the Kitsilano samples from the Highbury tunnel.

ORDER LYCOPODIALES

FAMILY LYCOPODIACEAE

Lycopodium annotiniodes Martin and Rouse 1966

Pl. 1 Fig. 11

DIAGNOSIS: Trilete spore, 30 to 35 μ, with moderately distinct laesurae reaching from pole to equator. Sub-circular in polar view, distal surface and near equatorial area of proximal surface covered with a reticulum of narrow muri and wide lumina. Reticulum 4 to 6μ between muri, muri up to 2μ high. Exine thin.

REMARKS: These specimens are identical with those found by Martin and Rouse (1966) from the Miocene or Pliocene Skonun Formation of the Queen Charlotte Islands, British Columbia. Their extremely thin exine makes them rather inconspicuous and difficult to photograph.

OCCURRENCE: Lycopodium is not common but occurs in the Sunnyside well in both Miocene and Eocene rocks. It was not found in the Point Roberts well, and with the exception of several specimens in the Kitsilano samples, it was not found in outcrop samples.

DIVISION PTEROPHYTA

ORDER FILICALES

FAMILY OSMUNDACEAE

Osmunda regalites Martin and Rouse 1966

Pl. 2 Fig. 12

DIAGNOSIS: "Trilete spores, spherical in outline. Laesurae simple, usually gaping slightly, and ranging from 18 to 22μ in length. A thin but distinct margo borders the commissure. The wall is about 1μ thick and appears to be rigid, as little folding has been observed. The ornamentation is characteristically rugulate with the rugulae short and thick, and packed close together. Individual rugulae range to 3μ in length but rarely exceed 0.5μ in height." (Martin and Rouse, 1966)

OCCURRENCE: This particular species appears throughout all the rocks of the Whatcom basin but is most abundant in the Kitsilano Formation.

Osmunda irregulites Martin and Rouse 1966

Pl. 2 Figs. 13-14

DIAGNOSIS: "Trilete spores, sub-circular in outline but usually folded or split open. Laesurae distinct, with a thin margo, and measuring about 17 to 22μ in length. The ornamentation consists of bacula 1.5 to 2.5μ long, 0.5 to 2μ wide and spaced 1 to 3μ apart. The bacula are usually straight, occasionally clavate. There are no rugulate thickenings subtending the bacula. The most diagnostic feature is the complete irregularity of the width of the bacula; delicate slender bacula are randomly mixed with stout, stump-like bacula, and with all grades inbetween. Size range: 41 to 57μ ." (Martin and Rouse, 1966)

OCCURRENCE: These are not common microfossils in the Whatcom basin. Only about ten specimens were encountered, and these were restricted to the continental Tertiary rock outcrops in Washington State. However, see remarks under *Osmunda*$_2$ sp.

Osmunda$_1$ sp.

Pl. 2 Figs. 15-17

DIAGNOSIS: Trilete spores showing considerable variation in shape. Trilete mark usually not distinct, but laesurae extend to equator. Ornamentation varies slightly from definitely baculate to weakly vermicula-baculate; baculae closely spaced, ranging from 1 to 3μ in height. The wall is comparatively thin which probably accounts for the wide variation in shape which ranges from prolate to spherical to irregular. Observed size range is 42 to 60μ .

REMARKS: These microfossils differ from O. irregulites in the smaller and more densely packed baculae. Generally this spore appears very much like spores of the modern O. claytonia.

OCCURRENCE: This particular form was comparatively abundant in all the well samples, in the Kitsilano Formation, and to a lesser extent in the outcrop samples.

Osmunda$_2$ sp.

Pl. 2 Figs. 18-20

DIAGNOSIS: Sub-spherical, echinate, trilete spore, laesurae sharp and distinct, tapering to a point at the equator; wall thin; covered with short spines less than 1μ high which are widely spaced over the entire surface. Size range 45 to 55μ .

REMARKS: This form differs from Osmunda$_1$ sp. in having much more widely spaced projections. Furthermore, the ornamentation appears to be much more spiny than is characteristic of the three preceding species. Occasional blunt baculae are observed but on the whole the ornamentation is echinate.

Although four different species of *Osmunda* are described here, these are in reality probably end products of what is a continuum. Attempts to count *Osmunda* were continually frustrated by uncertainty as to which of the four groups the particular species should be assigned. I feel that at this time it would be unwise to assume these grains represent four different natural species. All that can be said with certainty is that *Osmunda* was a common genus of fern throughout the Eocene and Miocene.

OCCURRENCE: This is never a common microfossil, but occurs throughout Miocene and Eocene rocks in the Sunnyside and Point Roberts wells. A few grains were also found in the Kitsilano Formation.

FAMILY SCHIZACEAE

Anemia poolensis Chandler 1955

Pl. 3 Figs. 21-23

DIAGNOSIS: These trilete spores are identical in all respects to those described by Chandler. The size range is 34 to 58μ with the majority approximately 52μ.

REMARKS: These specimens are identical to those described by Rouse (1962) from the Burrard Formation and by Hills (1965) from the Middle Eocene strata of interior British Columbia.

OCCURRENCE: This is a particularly common spore in the Kitsilano Formation. In much reduced numbers it is present in the Eocene of the Sunnyside and Point Roberts wells. It was not found in any of the other outcrop samples.

Cicatricosisporites intersectus Rouse 1962

Pl. 3 Figs. 24-27

DIAGNOSIS: "Trilete spore, with two sets of parallel ribs on the spore wall: the distal ribs are alligned in one direction, and the proximal ribs are oriented approximately 90° to the distal set. The proximal ribs encircle the equator and run obliquely across the proximal pole. Distance between ribs ca. 2.5μ. Size range 50 to 65μ." (Rouse, 1962)

Specimens from the Whatcom basin are identical to those described by Rouse, although a few specimens ranged down to 48μ in diameter.

REMARKS: Rouse has suggested (1962) that spores of *Cicatricosisporites intersectus* are more closely allied to those of the modern genus *Mohria* than to *Anemia*. However, overlap of the characters precludes classification of the generic alliance at this time.

Cicatricosisporites has not been found to date in the Middle Eocene beds from the interior of British Columbia. Apparently it is an Eocene form restricted to the coastal lowlands.

OCCURRENCE: This is a very common microfossil in the Kitsilano Formation, occasionally occurring in high frequency. It was also encountered in lower frequency in the Eocene sections of both the Point Roberts and Sunnyside wells. Several grains were found in the Sumas Clay Mine and the Whatcom Quarry.

Lygodium reticulosporites Rouse 1962

Pl. 4 Fig. 28

DIAGNOSIS: The grains of this species agree with those described by Rouse (1962) with an observed size range of 55 to 70 μ.

REMARKS: Rouse comments (1962, p.197) that "spores of this species resemble those of the living Lygodium japonicum Swartz and L. kerstenii Kuhn very closely."

OCCURRENCE: Lygodium, while never abundant, occurs in all the Kitsilano samples examined. Only a few grains were found in the Eocene rocks in the Point Roberts well.

FAMILY GLEICHENIACEAE

Gleichenia sp.

Pl. 4 Figs. 29-30

DIAGNOSIS: Sharply triangular, laevigate, trilete spores 25 to 30 μ in diameter. Rounded corners, weakly to strongly concave interradial areas. Wall thickens near poles in areas between laesurae; the thickenings extend toward the angles so that the trilete mark is enclosed by thickenings.

REMARKS: Very few forms were found and I could not, with confidence, place them in an established species. Gleichenia appears restricted, at least in North America, to uppermost Cretaceous or Paleocene and older rocks.

OCCURRENCE: Gleichenia is a rare microfossil and is found only in very low frequency in the Upper Cretaceous rocks of the

Sunnyside and Point Roberts wells.

FAMILY POLYPODIACEAE

Laevigatosporites discordatus Thompson and Pflug 1953

Pl. 4 Figs. 31-32

DIAGNOSIS: Spores generally bean-shaped; monolete, laesurae short, wall laevigate, although some appear to be nearly circular. Size range: 40 to 80 μ.

REMARKS: Rouse (1962) states "the closest affiliation appears to be with *Dryopteris*, particularly *D. latifons*."

OCCURRENCE: This is a moderately common microfossil in all the Eocene and Miocene rocks. It is especially abundant in the Kitsilano Formation

Laevigatosporites albertensis Rouse 1962

Pl. 4 Fig. 33

DIAGNOSIS: Kidney-shaped, monolete spores with a weakly defined suture, always occurring along the concave crest. Ornamentation weakly punctuate (Rouse, 1962). Size range: 32 to 36 μ.

REMARKS: Rouse (1962) described this specimen from the Burrard Formation, suggesting that it is most likely related to *Dryopteris* or *Asplenites*, both of which have been reported as leaves in the Burrard.

OCCURRENCE: This is an uncommon microfossil found only sporadically in the Kitsilano Formation. Several grains were found in the upper part of the Eocene sequence in the Point Roberts well.

Laevigatosporites ovatus Wilson and Webster 1946

Not Illustrated

DIAGNOSIS: Monolete, bean-shaped spores, length 33 to 37μ, smooth wall, simple monolete suture.

REMARKS: These forms are identical to those described by Wilson and Webster (1946).

OCCURRENCE: This is a common microfossil throughout the Eocene and Miocene rocks.

Laevigatosporites gracilis Wilson and Webster 1946

Not Illustrated

DIAGNOSIS: Bean-shaped monolete spores, laevigate, simple monolete suture on concave side, length 25 to 32μ.

REMARKS: Wilson and Webster (1946) remark that *L. gracilis* and *L. ovatus* probably belong to *Thelypteris*, *Asplenium*, *Athyrium*, *Aspidium* or *Blechnum*.

OCCURRENCE: This is a very uncommon microfossil which occurs sporadically throughout the Eocene and Miocene rocks.

FAMILY DENNSTAEDTIACEAE - POLYPODIACEAE

Pls. 4-5 Figs. 34-39

REMARKS: Martin and Rouse (1966) have discussed the difficulties in classifying the large reticulate-verrucatewarty monolete spores which are abundant in the Miocene or Pliocene Skonun Formation. This spore pattern occurs in several different fern genera in at least two families; viz. the Polypodiaceae and Dennstaedtiaceae, and sufficient gradation of ornamentation exists as to defy generic identification. Potonié (1956) established three form genera to include these three spore types, i.e. *Polypodisporites*, *Polypodiites* and *Verrucatosporites*. However, the fossil spores encountered in the Skonun Formation could not be assigned, even to form genera. As a result, Martin and Rouse elected to use "non-committal form designates" for the three main forms.

In my work with the Tertiary rocks of the Whatcom basin I encountered identical problems of classifying these monolete spores. As a result, I have utilized the same system suggested by Martin and Rouse. Forms 1, 2 and 3 are illustrated but not described. They are identical in all respects to the descriptions given by Martin and Rouse (1962, p. 187-188).

OCCURRENCE: Although these microfossils are nowhere abundant, they are sporadically present in low frequency throughout the Eocene and Miocene rocks of the Point Roberts and Sunnyside wells. They occur also in the Kitsilano Formation and other outcrops. One, two or three of the forms may occur in the same sample.

ORDER SALVINIALES

FAMILY SALVINIACEAE

Genus *Azolla* sp.

Pl. 5 Fig. 40

DIAGNOSIS: Only isolated anchor-shaped glochidia of *Azolla* were found in this study. The massulae and microspores were not encountered; the reason for their absence is not known. The glochidia are about 20 μ long, and 8 μ across the barbs.

REMARKS: *Azolla* appears to be especially common in Eocene rocks in the interior of British Columbia (Hills, 1965) but has also been reported from Upper Cretaceous and rocks of other Tertiary epochs.

OCCURRENCE: *Azolla* has been found in the Eocene and Upper Cretaceous rocks in both the Point Roberts and Sunnyside wells. It was not encountered in any outcrop samples.

DIVISION GINKGOPHYTA

ORDER GINKGOALES

FAMILY GINKGOACEAE

Ginkgo sp.

Pl. 5 Figs. 41-43

DIAGNOSIS: Pollen monosulcate, shape oblate to peroblate, sulcus broad, generally closed in the middle and gaping at the ends. Sculpture psilate to slightly scabrate. Length 28 to 34 μ .

REMARKS: Comparison with modern *Ginkgo biloba* strongly suggests affiliation with *Ginkgo*. Similar grains have been reported as *Cycadopites* Wodehouse 1933, and *Cycadopites follicularis* Wilson and Webster 1946.

OCCURRENCE: *Ginkgo* is a very uncommon grain but has been found in both Eocene and Miocene rocks. It appears most commonly, and in a better state of preservation, in the upper part of the Miocene sequence in both the Sunnyside and Point Roberts wells.

DIVISION CONIFEROPHYTA

ORDER CONIFERALES

FAMILY PINACEAE

Cedrus sp.

Pl. 5 Fig. 44

DIAGNOSIS: The few grains that appear to be those of *Cedrus* are about 65μ in diameter. The bladders are moderately large and tend to enclose the body, except at the leptoma which separates the bladders.

The circular cap is thick and grades without perceptible discontinuity into the wall of the bladders. Sculpture of the body is finely reticulate whereas the bladders are somewhat more coarsely reticulate.

REMARKS: Only three of these grains were found, all high in the Sunnyside well, within the Miocene sequence of rocks. Preservation is not particularly good and the finer details are not clear. As a consequence, these grains are only tentatively assigned to Cedrus. There have been very few reports of Cedrus in North American Tertiary rocks, the most recent well-documented occurrence being in the Miocene of the Queen Charlotte Islands (Martin and Rouse, 1966).

OCCURRENCE: Three grains were found within the Miocene sequence of strata in the Sunnyside well. The low frequency and indifferent preservation indicate the source area was probably some distance away.

cf. *Keteleeria*

Pl. 6 Figs. 45-46

DIAGNOSIS: Bisaccate grains, large, body oval, 85 by 65μ ; bladders nearly sub-spherical, 55 by 45μ . The body appears to be scabrate to minutely punctate, cap thin. Bladders are finely reticulate, attached discretely to body and directed distally. Structure and dimensions of leptoma obscured by bladders.

REMARKS: The character of this grain fits closely those of *Keteleeria davidana* as illustrated in Erdtman (1943) and Macko (1957). However, Macko gives overall dimensions of up to 200μ while Erdtman gives dimensions of 102-161μ . Because only a few of these grains were found, I have no satisfactory range of sizes and it may well be the average size is higher.

The only other grain which resembles this is *Pseudolarix* which is considerably smaller. According to Wodehouse (1935), *Pseudolarix* ranges from 51 to 53 μ.

At the present time, *Keteleeria* is restricted to central China where it grows in damp lowland forests and lower belts of mountain forest up to 2,500 meters above sea level.

OCCURRENCE: Only a few grains were found in the Upper Eocene and Miocene rocks of the Sunnyside well.

Larix plicatipollenites Rouse 1962

Pl. 6 Figs. 47-48

DIAGNOSIS: These grains appear to be identical with those reported by Rouse (1962) from the Burrard Formation. However, a number are smaller with the observed size range for the present specimens being 50 to 70 μ.

REMARKS: These specimens closely agree in size with those of *Larix plicatipollenites* reported by Hills (1962) from the Princeton basin. Their small size suggests affiliation with *Larix* rather than *Pseudotsuga*.

OCCURRENCE: Nowhere is this particular microfossil abundant, although it occurs most commonly in the Kitsilano Formation. It is sparsely present, however, within the Eocene and Miocene sequences in both the Point Roberts and Sunnyside wells.

Picea grandivescipites Wodehouse 1933

Pl. 6 Figs. 49-50

DIAGNOSIS: This bisaccate pollen grain appears to be essentially identical with that described by Wodehouse (1933) and Rouse (1957; 1962). The observed range of body size is 75 to 80 μ.

REMARKS: Pollen of P. grandivescipites is rare in the Whatcom basin and is usually not well preserved. This suggests that the trees originally producing the pollen were some distance away from the sedimentary site.

OCCURRENCE: This form occurs very sparsely throughout all the rocks of the Whatcom basin. It is invariably poorly preserved and often physically broken, suggesting a considerable distance of transport.

Pinus strobipites Wodehouse 1933

Pl. 6 Figs. 51-52

DIAGNOSIS: There is little doubt that this is the same specimen described by Wodehouse (1933) from the Eocene Green River Formation. It has also been reported from the Eocene Burrard Formation by Rouse (1962).

REMARKS: Preservation of this species is almost invariably poor.

OCCURRENCE: Although this particular species is more common than any other bladdered conifer, it is by no means abundant. It occurs most commonly in the Kitsilano Formation and other outcrop samples but is found in both the Point Roberts and Sunnyside wells.

and Rouse (1957; 1962). The observed range of body size is 75 to 80 μ.

REMARKS: Pollen of P. grandivescipites is rare in the Whatcom basin and is usually not well preserved. This suggests that the trees originally producing the pollen were some distance away from the sedimentary site.

OCCURRENCE: This form occurs very sparsely throughout all the rocks of the Whatcom basin. It is invariably poorly preserved and often physically broken, suggesting a considerable distance of transport.

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OCCURRENCE: Although this particular species is more common than any other bladdered conifer, it is by no means abundant. It occurs most commonly in the Kitsilano Formation and other outcrop samples but is found in both the Point Roberts and Sunnyside wells.

Pinus sp. *haploxylon*-type

Pl. 7 Figs. 53-54

DIAGNOSIS: Disaccate pollen grain with bladders attached to lateral equatorial extremeties of body, bladders larger than body, body circular and finely reticulate, bladders moderately coarsely reticulate, becoming finer toward bladder roots. Leptoma broad, straight margined and finely granular. Body ranges from 40 to 50 μ, bladders slightly larger.

REMARKS: Thompson and Pflug refer this species to the form species *Pityosporites microalatus* which they say belongs to the *Pinus haploxylon* group of Rudolph.

OCCURRENCE: This particular species is present in low frequency throughout the Point Roberts and Sunnyside wells. It is also represented by a few grains in the Kitsilano Formation.

Pinus sp.

Pl. 7 Fig. 55

DIAGNOSIS: Bisaccate pollen grain with bladders about equal in size to body, the body is essentially spherical with exine coarsely granular proximally. Lightly reticulate sculpture on both bladders and distal portion of body. Cap thick. The bladder connection at the poximal root well defined, at distal root the contact is sharp and distinct. Leptoma indistinct, but smooth to fine granulate. Observed body diameter 50 to 55 μ.

REMARKS: This grain is very similar to pollen of extant *Pinus strobus*.

OCCURRENCE: Only a few grains of this form were found, all in the Miocene portion of the Sunnyside well.

FAMILY CUPRESSACEAE

Pl. 7 Figs. 56-57

DIAGNOSIS: Pollen grains sub-spherical, although in some cases deformed by folding. Inaperaturate, size range 20 to 40 μ . Exine thin, transparent, invariably with surface folds, occasionally ruptured. Surface of exine covered with small flecks that are slightly more stained than exine. No evidence of pores, colpae or papillae. Irregular area of thinning is commonly present which may represent a leptoma.

REMARKS: This pollen appears to be that of *Juniperus*. However, other genera of the Cupressaceae have similar pollen, and differentiation is difficult to impossible. As a result, I have placed grains of this morphology and size in the family Cupressaceae, recognizing that one or more genera may be represented.

OCCURRENCE: This is a moderately abundant grain found throughout all the rocks of the Whatcom basin. It is especially abundant in the Miocene sequence of rocks in both the Sunnyside and Point Roberts wells.

FAMILIES CUPRESSACEAE, TAXODIACEAE or PINACEAE

Pl. 7 Figs. 58-59

DIAGNOSIS: Usually sub-circular, inaperaturate, laevigate pollen grains, identical to Larix, except smaller. Observed size range 22 to 42 μ.

REMARKS: These grains would be assignable to Larix except for their small size. They also bear a marked resemblance in size and form to modern species of Thuja. At this time, it is not possible to classify them closer than probably affiliated to one or more of the above families.

OCCURRENCE: Grains of this description are moderately common throughout the Sunnyside and Point Roberts well sections. They are present, but in lesser amount, in the Kitsilano Formation and other outcrop samples.

FAMILY TAXODIACEAE

Glyptostrobus vacuipites Wodehouse 1933

Pl. 7 Figs. 60-61

DIAGNOSIS: According to Wodehouse (1933) "the case skins of pollen grains split into two approximately equal halves. Exine in life apparently stiff and under mechanical strain so that in separating, the two halves buckle with the formation of longitudinal folds. Outer surface dotted with small flecks openly and irregularly spaced. Length of halves 37.6 μ."

Martin and Rouse (1966) add that the "pollen grains usually split into two halves, with the wall folded parallel to the split edges. Size range 27 to 30μ, wall thickness about 0.5μ and the ornamentation decidedly scabrate."

The specimens in this study correspond closely to the above descriptions except that the length of the split halves ranges from 30 to 33μ.

REMARKS: Although Glyptostrobus is now confined to central China it appears to have been widespread in the Tertiary of western North America.

OCCURRENCE: Although Glyptostrobus has been reported from rocks as old as Eocene in North America it appears restricted to the Miocene in this study. Glyptostrobus has been identified only in the Miocene of both the Point Roberts and Sunnyside wells. It was not seen in the Kitsilano or other outcrop samples.

Metasequoia papillapollenites Rouse 1962

Pl. 7 Fig. 62

DIAGNOSIS: The few grains of Metasequoia encountered appear to be identical with those described by Rouse (1962) from the Burrard Formation and by Hills (1962) from the Princeton coal fields.

However, the observed size range of the present grains is 22 to 26μ which extends the 20 to 26μ range suggested by Hills (1962).

OCCURRENCE: Metasequoia is frequently difficult to distinguish from Taxodium and so the apparent frequency may be less than it is in reality. Definitely identifiable Metasequoia is uncommon, but is most frequently seen in the Miocene section of the Sunnyside well. A few grains were found in the Kitsilano Formation.

Sciadopitys sp.

Pl. 7 Figs. 63-64

DIAGNOSIS: Pollen grains large (68 to 75μ), spherical, covered with large warts, 3 to 6μ in diameter, usually lower than broad. Although a distinct apperature is not visible, there is a distinct leptoma, that is usually psilate to granulate, but covered with warty projections in some specimens.

REMARKS: Although this grain closely resembles the single extant species Sciadopitys verticellata, as figured and described by Erdtman (1943) and Van Campo (1951), it is considerably larger. S. verticellata, both in modern reference slides and in the above literature, appears to have a size range of 28 to 44μ with most being 35 to 40μ. Morphologically this grain is similar to S. serratus as described by Martin and Rouse (1966) but again is much larger. S. serratus has an observed size range of 29 to 41μ.

Because of the size discrepancy this grain is not assigned to any particular species of Sciadopitys.

OCCURRENCE: Sciadopitys is a very uncommon microfossil with only a few grains found within the Miocene section of the Sunnyside well.

Taxodium hiatipites Wodehouse 1933

Pl. 8 Figs. 65-66

DIAGNOSIS: The specimen here appears to be identical with those described by Wodehouse 1933, Wilson and Webster 1946, Rouse 1962, and Hills 1962.

REMARKS: It is quite possible that some of these grains are *Metasequoia* because of the frequent difficulty in distinguishing the two species except under conditions of exceptional preservation.

OCCURRENCE: *Taxodium* is a moderately abundant microfossil throughout the Whatcom basin rocks.

FAMILY PODOCARPACEAE

Podocarpus sp.

Pl. 8 Figs. 67-68

DIAGNOSIS: Bisaccate grain, body circular, 28 to 33 μ in diameter. Bladders large and irregular. Body sculpture scabrate, bladders finely reticulate.

REMARKS: Only a few grains referable to *Podocarpus* were found in this study and all are poorly preserved. As a result, no attempt has been made to assign the grains to particular species.

Superficially these grains appear similar to *Podocarpidites microreticuloidatus* Cookson as reported by Martin and Rouse (1966) from the Miocene or Pliocene Skonun Formation. Hills (1962, 1965) reported *Podocarpus* from the Eocene rocks of interior British Columbia. Rouse (1962) found a single grain of *Podocarpus* from the Middle Eocene Burrard Formation.

OCCURRENCE: *Podocarpus* is nowhere common in the Whatcom basin but it is present in both the Miocene and Eocene sequences in the Point Roberts and Sunnyside wells. Several grains were found in the Kitsilano Formation but it is only doubtfully present in outcrop samples.

FAMILY TAXACEAE

Taxus? sp.

Pl. 8 Figs. 69-70

DIAGNOSIS: Spherical pollen grains 18 to 21μ in diameter. In most specimens a leptoma appears to have ruptured to form a large irregular opening. Exine psilate to faintly scabrate.

REMARKS: Lack of definitive and diagnostic features makes assignment of this grain to *Taxus* somewhat tenuous. However, morphologically it is identical with grains of the western yew, *Taxus brevifolia*. However, the present grains average about 5μ smaller than extant pollen.

OCCURRENCE: *Taxus* was found only in two samples from the Miocene sequence in the Sunnyside well.

DIVISION GNETOPHYTA

ORDER EPHEDRALES

FAMILY GNETACEAE

Ephedra? sp.

Pl. 8 Fig. 71

DIAGNOSIS: Large (80μ), elliptical pollen grains. Exine thick, heavy and provided with broad, low and irregular ridges that are sub-parallel to the long axis of the grain. Ridges appear to bifurcate and anastomose in an irregular pattern. No furrows or pores are apparent.

REMARKS: It is with the greatest uncertainty that I assign this grain to Ephedra, which in extant forms ranges from 35 to 55μ in length. It is much larger than modern members of this genus, but is similar in morphology to Ephedripites Bokhowitina (1953) as illustrated in Potonié (1958).

OCCURRENCE: Only three grains of this particular form were found, all in the Goshan and Glen Echo Coal Mines samples.

DIVISION ANTHOPHYTA

CLASS DICOTYLEDONAE

ORDER MAGNOLIALES

FAMILY MAGNOLIACEAE

Pl. 8 Fig. 72

DIAGNOSIS: Ellipsoidal, monocolpate grains ranging from 46 to 56μ in polar length. A single furrow extends from end to end of the grain, usually gaping slightly at the ends.

Margins of the furrow are closed and slightly wavy, and are not thickened along margins. Exine moderately thick and slightly roughened.

REMARKS: Except for the roughened exine this pollen is identical with that of *Liriodendron psilopites* reported by Wodehouse (1933) from the Eocene Green River Formation.

OCCURRENCE: This pollen grain occurs in very low frequency in the Eocene and Miocene rocks of the Sunnyside and Point Roberts wells. Several specimens were found in the upper part of the Kitsilano Formation.

ORDER ARALIALES

FAMILY CORNACEAE

Nyssa? sp.

Pl. 8 Fig. 73

DIAGNOSIS: Large (45 to 50μ equatorial diameter) tricolporate pollen grains. Outline essentially circular, colpae long and tapering, becoming wider at the equator. Each colpus contains a deeply sunken, pronounced, slightly elliptical pore. Exine finely but distinctly granulate.

REMARKS: Morphologically these grains appear to be affiliated with *Nyssa* but are generally larger than extant pollen. Also, the shoulders of the wall surrounding the colpae are sloping rather than right-angled as in extant pollen of *Nyssa*.

OCCURRENCE: Only three grains of this type were found, all in the Kitsilano Formation.

ORDER HAMAMELIDALES

FAMILY HAMAMELIDACEAE

Liquidambar sp.

Pl. 8 Figs. 74-75

DIAGNOSIS: Spherical to irregular, polyporate pollen grains. Pores large, up to 4 by 8μ in size; generally 8 to 12 pores per grain. Weak annuli surrounding each pore. Exine very minutely reticulate to punctate. Pore membranes weakly scabrate. Extexine and endexine sharply distinct.

REMARKS: *Liquidambar* was widely distributed throughout Tertiary floras in North America and is even reported from the Upper Cretaceous Frontier Formation of Wyoming (Axelrod, 1950). Representative Tertiary occurrences in North America include the Eocene Wilcox Formation, the Oligocene Brandon lignite, the Oligocene Bridge Creek flora, the Oligocene (?) - Miocene of the Cook Inlet area of Alaska, and the Miocene Latah Formation. Gradual cooling during the Pliocene destroyed *Liquidambar* in the western United States but it still persists in the warm temperate part of the eastern United States. It is also a common element in portions of the east Asiatic floras at the present time. Sato (1963) and others describe *Liquidambar* from the Miocene of Japan.

In short, during the Tertiary, *Liquidambar* was widespread throughout North America, Europe and eastern Asia.

OCCURRENCE: *Liquidambar* is relatively common in the Miocene rocks of the Sunnyside and Point Roberts wells. In the

Sunnyside well there are several occurrences in the Eocene part of the section. Liquidambar was not observed in either the Kitsilano Formation or any of the other outcrop samples.

ORDER SALICALES

FAMILY SALICACEAE

Salix discoloripites Wodehouse 1933

Pl. 8 Figs. 76-77

DIAGNOSIS: The grains found in this investigation are identical with those described by Wodehouse except for a more restricted size range of 15 to 19μ.

OCCURRENCE: Salix is never abundant, but occasionally occurs up to several percent in the Miocene rocks in the Sunnyside and Point Roberts wells. It is rare in the Kitsilano Formation.

Salix? sp.

Pl. 8 Figs. 78-79

DIAGNOSIS: Tricolpate grains, mostly oblate with colpae extending almost from pole to pole. Furrows closed, show a slight internal marginal thickening.

Sculpture minutely reticulate to punctate, maintained right up to the margins of the colpae. Length 25 to 30μ, width 15 to 20μ.

REMARKS: This grain is only tentatively assigned to Salix because of the lack of conclusive and diagnostic features.

Tricolpate, reticulate pollen grains are abundant in various families and their identification is always an uncertain procedure.

OCCURRENCE: These particular forms are only sparingly present in the Miocene section of the Sunnyside and Point Roberts wells. They infrequently occur in the Eocene sections as well as the Kitsilano Formation. They were not encountered in the other outcrop samples.

ORDER FAGALES

FAMILY BETULACEAE

Alnus quadrapollenites Rouse 1962

Pl. 8 Figs. 80-82

DIAGNOSIS: According to Rouse (1962) these "pollen grains are typically square in outline, with four pores situated at the angles. Bands of the wall connecting the pores are obvious. The exine around the pores is not greatly thickened, so that no prominent protrusions are in evidence. Exine laevigate. Size range 25 to 27μ."

The _Alnus_ grains found in the Kitsilano Formation match this description, but the minimum size range is 20μ, with the majority measuring about 23μ.

REMARKS: Alder grains are common throughout the Tertiary section represented in the well samples. However, the older forms generally appear more aspidate, with heavier lips around the pores. There is no doubt, however, that these are _Alnus_ grains. In this study all four-pored Alnus grains have been included in the species A. quadrapollenites. See further discussion under "Remarks" of A. hexapollenites.

OCCURRENCE: Four-pored alder is extremely common in all the well samples. It is present, in much reduced numbers, in the Kitsilano Formation and in most of the outcrop samples.

Alnus quinquepollenites Rouse 1962

Pls. 8-9 Figs. 83-86

DIAGNOSIS: Rouse (1962) states "pollen grains broadly pentagonal in outline, with five pores situated at the angles. The pores are distinct, with a prominent thickening of the exine immediately surrounding the pore. Thickened bands between the pores are sometimes present, but generally lacking. Size range 20 to 22μ."

I can add little to this except to state the thickened bands are invariably present but in some specimens are weakly developed.

REMARKS: All five-pored Alnus grains are placed in this species. As in A. quadrapollenites the pores appear more aspidate in older grains. See further discussion under "Remarks", A. hexapollenites.

OCCURRENCE: Five-pored alder is extremely common in all the well samples. It is present in much reduced numbers in the Kitsilano Formation and in most of the outcrop samples.

Alnus hexapollenites n. sp.

Pl. 9 Figs. 87-88

DIAGNOSIS: Sub-circular to broadly hexagonal with six pores situated at the angles. The pores are always distinct with prominent thickenings of exine around the pores. Pores moderately aspidate. Thickened bands between the pores almost always prominent. Size range is 21 to 24μ.

REMARKS: All six-pored *Alnus* grains are placed in this species. Probably *A. quadrapollenites*, *A. quinquepollenites* and *A. hexapollenites* would fall within *A. speciipites* (Wodehouse, 1933). Wodehouse gave an all-encompassing description that included three to six-pored forms with a size range of 20 to 30.4μ. Thus, as Rouse (1962) points out, there is justification for establishing different species to encompass these three distinct types of *Alnus* pollen.

There is no implication here that these three species represent distinct natural species. Modern reference material indicate that the same anther may paroduce pollen grains with different pore numbers.

Finally, Martin and Rouse (1966) have included all fossil *Alnus* as *Alnus verus* R. Potonié 1931 because there is no essential difference in morphology between the various forms. However, I prefer maintaining separate specific names for the different morphological types because of the possibility of each having stratigraphic significance.

HOLOTYPE: 2,100 ft. slide, Sunnyside well, coordinates

38.8-108.0.

OCCURRENCE: Six-pored pollen grains are never as common as the four- and five-pored types. However, they often occur associated with them, and occasionally comprise several percent of the total alder count. In a general way, they appear more common in the Miocene sequences within the wells, than they do in the Eocene sequences. They are rarely present in the Kitsilano Formation and were not observed in other outcrop samples.

If more control were available in the Whatcom basin, it might become possible to use Alnus pore numbers in zoning. However, at the present time this is only speculative.

Betula, cf. B. Claripites Wodehouse 1933

Pl. 9 Figs. 89-90

DIAGNOSIS: Pollen grains assignable to Betula are very rare in rocks from this area. The several grains found fit the description of B. claripites as given by Wodehouse (1933).

REMARKS: Betula is a widespread and common element in Tertiary rocks throughout North America. It has been found in the Eocene Green River Formation, the Eocene of interior British Columbia, in the Paleocene Fort Union Formation, the Miocene Florissant Formation and in the Miocene Latah Formation. Betula is characteristic of cool and humid conditions which probably accounts for its rarity in the Whatcom basin rocks.

OCCURRENCE: Only three or four grains were found which could be assigned to *Betula* with certainty, and those were all in the Miocene section of the Sunnyside well. It was not encountered in the Kitsilano Formation nor in any of the outcrop samples.

cf. *Carpinus* sp.

Pl. 9 Figs. 91-92

DIAGNOSIS: A number of grains were found which suggest definite affinities with *Carpinus*. Generally they fit the description of *Carpinus ancipites* Wodehouse 1933 but many are considerably smaller. The size range of the present specimens are 25 to 37μ, whereas Wodehouse reports a range of 27.4 to 44.5μ. The only modern *Carpinus* available for reference is *C. betulus* with a size averaging 35μ.

REMARKS: *Carpinus* was once much more widespread than it is at present, and appears to have been a common element in many of the North American floras during the Tertiary.

OCCURRENCE: Although *Carpinus* is never abundant, it is almost invariably present, even if represented on a slide by a single specimen. It has been observed throughout the section in both wells and in the Kitsilano Formation. It was also recorded in Dale Creek (American Sumas Mountain) and the Toad Lake outcrop.

Corylus tripollenites Rouse 1962

Pl. 9 Figs. 93-94

DIAGNOSIS: "Pollen grains subtriangular in outline. Three-pored with the pores elliptical in outline and subtended by slight bulbous expansions of the wall (see Wodehouse, 1933, text-figure 39, *Corylus* pattern). The wall is typically folded between the pores, but the pattern is irregular. Ornamentation laevigate to weakly punctate. Size range 25 to 27 μ."

Specimens from the Whatcom basin are morphologically identical, but tend to be smaller with a minimum size of 18 and an average of about 24 μ.

REMARKS: *Corylus* has been reported locally from the Burrard Formation (Rouse, 1962) and the Miocene or Pliocene Skonun Formation (Martin and Rouse, 1966).

OCCURRENCE: *Corylus*, like *Carpinus*, is never abundant but it is commonly present. It was encountered in the Miocene and Eocene sequences in both the Point Roberts and Sunnyside wells. A few grains were found in the Kitsilano Formation but it was not observed in the other outcrop samples.

FAMILY FAGACEAE

Castanea? sp.

Pl. 9 Figs. 95-96

DIAGNOSIS: Grains small (16 to 19 μ), tricolpate with colpae extending from pole to pole. Small circular pore, situated in short transverse furrow, lies in the center of each colpus. The exine is psilate to very faintly granular.

REMARKS: These specimens look very much like pollen of the modern species Castanea dentata but are slightly larger. However, according to Wodehouse (1935) pollen of the genus Castanopsis looks much like that of Castanea. In fact, Castanopsis chrysophylla is identical to Castanea dentata. For this reason the assignment to Castanea is questionable.

Castanea-type pollen has been described from numerous Tertiary rocks ranging in age from Eocene to Pliocene. Rouse (1957) and Couper (1965) have also reported Castanea-type pollen from Upper Cretaceous rocks.

OCCURRENCE: Castanea-type pollen is fairly common in all the samples examined. It was found through the entire stratigraphic sections represented in the Point Roberts and Sunnyside wells, as well as in the Kitsilano Formation and other outcrop samples.

Fagus granulata Martin and Rouse 1966

Pl. 9 Figs. 97-99

DIAGNOSIS: "Pollen tricolporate, 27-38 X 20-30 μ, circular in polar-view, broadly elliptical in equatorial view. Colpae with narrow borders, about 20-23 μ long, with large elliptical pores about 7-9 μ in diameter. The wall, about 0.5 to 1.5 μ thick, is distinctly divided into endexine and ectexine that supports a coarse- to fine-granulate ornamentation. The endexine forms distinct costae around the pores" (Martin and

Rouse, 1966).

REMARKS: The Whatcom basin specimens appear identical to those described by Martin and Rouse. They go on to say that this species probably represents "either an extinct or extant Asiatic species."

OCCURRENCE: *Fagus granulata* has been observed principally in the Miocene rocks, but is also present in much of the Eocene sequence in the Sunnyside and Point Roberts well. A few grains were found in the Kitsilano Formation.

Fagus$_1$ sp.

Pl. 9 Figs. 100-101

DIAGNOSIS: Sub-spherical tricolpate grain, 30 to 34μ in diameter. Colpae one-half to two-thirds total grain length. Conspicuous margo bordering colpae; small, slightly elliptical pores in center of each colpus. Exine finely scabrate, becoming much finer on the margo.

REMARKS: This grain differs from *F. granulata* mainly in having shorter colpae, but also appears to have consistently smaller pores. This probably represents an undescribed species, but there is little doubt that it is *Fagus*, possibly an extinct form.

OCCURRENCE: This particular form is present in small quantity in the Miocene rocks of the Point Roberts and Sunnyside wells.

Fagus$_2$? sp.

Pl. 9 Fig. 102

DIAGNOSIS: A single, sub-spherical tricolporate grain, 30μ in diameter. Colpae extend almost from end to end of grain. Conspicuous margo bordering colpae, expanding in width at equator. Small circular pore located in center of each colpus. Exine finely scabrate, becoming finer on margo.

REMARKS: Assignment of this grain to *Fagus* is questionable, but it is closer to pollen of this genus than any other known to me.

OCCURRENCE: Only one grain was found and that was in the Miocene of the Sunnyside well at a depth of 4,100 feet.

Quercus explanata Anderson 1960

Pl. 9 Figs. 103-104

DIAGNOSIS: "Prolate tricolpate pollen with long furrows extending far into the polar area; furrows usually of unequal length and often with a margo, a definite pore not present, but the middle of the furrow sometimes slightly gaping; grains tend to be slightly rhomboidal in equatorial view; exine clearly differentiated and thicker at the poles; tectate-columellate exine gives the appearance of scabrate sculpture.

"Length (polar axis) 33 to 48μ, mostly greater than 40μ; width 23 to 37μ, exine as much as 2μ thick at poles." (Anderson, 1960)

REMARKS: Anderson's specimens occur in the lowermost Pliocene, but in the present study area they are probably somewhat older.

OCCURRENCE: These microfossils are locally moderately abundant in the Miocene sections of the Point Roberts and Sunnyside wells.

Quercus$_1$ sp.

Pl. 9 Figs. 105-106

DIAGNOSIS: Prolate, tricolpate pollen grains with furrows extending nearly from pole to pole, occasionally weak margo along colpae, no pores but the middle of the furrow may gape slightly, a tectace-columellate exine suggests a reticulate pattern; appears slightly coarser at the poles. Polar axis varies from 33 to 40μ, width 23 to 30μ.

REMARKS: This grain resembles *Quercus longicanalis* Traverse 1955. See remarks under Quercus$_4$ sp.

OCCURRENCE: This microfossil occurs locally in low frequency throughout the Miocene and Eocene sequences of the Point Roberts and Sunnyside wells. Two specimens were found in the Kitsilano Formation.

Quercus$_2$ sp.

Pl. 10 Figs. 107-108

DIAGNOSIS: Fairly large (29 to 35μ polar diameter) tricolpate grains, nearly circular in polar and equatorial views.

Colpae two-thirds to three-fourths length of grain, usually tightly closed. No sub-exinous thickenings along colpae. Sculpture scabrate.

REMARKS: See remarks under *Quercus*$_4$ sp.

OCCURRENCE: This grain occurs only sporadically throughout the Miocene and Eocene well sections, and in the Kitsilano Formation.

Quercus$_3$ sp.

Pl. 10 Figs. 109-110

DIAGNOSIS: Tricolpate grains, 20 to 24μ long, prolate. Closed colpae extending from end to end of grain. Weak sub-exinous thickening beneath colpae margins. Sculpture faintly scabrate.

REMARKS: This grain, although somewhat smaller, superficially resembles *Quercus virginiana* Mill as described by Macko, 1957. See remarks under *Quercus*$_4$ sp.

OCCURRENCE: This grain is found throughout the Whatcom basin rocks but is somewhat more common in the Miocene section of the Point Roberts and Sunnyside wells.

Quercus$_4$ sp.

Pl. 10 Fig. 111

DIAGNOSIS: Tricolpate grain with the same size and same morphology as *Quercus*$_3$ sp. The sculpture, however, is psilate rather than scabrate.

REMARKS: *Quercus* is a widespread genus consisting of over 300 species at the present time. During post-Eocene times *Quercus* appears to have been a main element of northern hemisphere floras. In the Whatcom basin, Miocene rocks have a conspicuously large percentage of *Quercus* pollen which undoubtedly represent more than 4 species. However, on the basis of pollen, *Quercus* is very difficult to subdivide into species. All are tricolpate with few distinguishing features. Some previous workers (esp. Macko, 1957; Traverse, 1955) have assigned these grains to numerous species. I feel this is meaningless and that a valid species subdivision of the types encountered here is not possible on the basis of palynological features. As a result I have shown the four distinct *Quercus* groups present in the Whatcom basin but have not attempted to assign a species name to any.

OCCURRENCE: This form occurs in limited quantity throughout the rocks of the Whatcom basin, but is more common in the Miocene rocks of both wells.

ORDER JUGLANDALES

FAMILY JUGLANDACEAE

Carya juxtaporites (Wodehouse 1933) Rouse 1962

Pl. 10 Figs. 112-115

DIAGNOSIS: Circular to sub-triangular triporate grains, 24 to 36μ in diameter. Pores usually circular, $1\frac{1}{2}$ to 2μ in diameter, occasionally slightly oval. Pores on one hemisphere slightly offset from equator. Ornamentation ranges widely from psilate to distinctly granulate.

REMARKS: The Whatcom basin specimens appear identical with the *Hicoria juxtaporites* Wodehouse 1933 and to *Carya juxtaporites* (Wodehouse 1933) Rouse 1962. The size range given by Rouse (23 to 29μ) is slightly less than given above but in all other respects they appear identical. The average size of the specimens encountered in this study is 30μ and the range in ornamentation is pronounced. Possibly more than one species is included under this designation but the gradational nature of the ornamentation makes it difficult to draw definite conclusions. Wodehouse (1933) in his original description of this species included psilate to granular forms, and I have followed the same procedure in this study.

OCCURRENCE: *Carya* is an almost omnipresent element in all specimens from the Whatcom basin including the Miocene and Eocene rocks in both wells, the Kitsilano Formation and most of the outcrop samples examined.

Engelhardtia cf. *E. granulata* Simpson 1961

Pl. 10 Figs. 116-117

DIAGNOSIS: Pollen grains 22 to 26μ in diameter, profile in polar view triarcuate; three pores, close to circular, slightly aspidate; on most specimens there is a narrow and often inconspicuous collar, sculpture slightly scabrate. On proximal hemisphere, between pores, there are three sub-circular areas of exine thinning; a broad indefinite triradiate mark is present on proximal surface.

REMARKS: These forms appear very similar to those described by Simpson (1961) from Lower Tertiary rocks of Scotland. See remarks under *Engelhardtia* sp.

OCCURRENCE: These particular forms were found only in the lower part of the Eocene sequences and the Cretaceous within both wells. They occur only in very low quantity.

Engelhardtia sp.

Pl. 10 Figs. 118-119

DIAGNOSIS: Pollen grains in this group are similar to those of *E. granulata* but differ in two respects: 1) there is no area of thinning in the interpolar areas and 2) the exine is laevigate to faintly scabrate.

REMARKS: This grain appears similar to *Engelhardtia corylipites* Wodehouse 1933.

It is only with some uncertainty that I assign the grains encountered here to two fossil species of *Engelhardtia*. Modern *Engelhardtia* pollen can be distinguished from *Myrica* and *Corylus* mainly on the basis of size but it is only supposition that this relationship held throughout the Tertiary. Because these forms are smaller than typical *Myrica* and because the pores are not set precisely on the equator, which is a characteristic of the Juglandaceae, I have concluded that these grains are those of *Engelhardtia* species.

OCCURRENCE: These forms never occur in high frequency but are present in the Miocene and Eocene sequences in the two wells as well as most of the outcrop samples.

Platycarya sp.

Pl. 10 Figs. 120-122

DIAGNOSIS: Small (14 to 17μ), triporate pollen grains. More or less distinctly triangular; sharp, slit-like pores at each angle. Pores are reported by several authors (Wodehouse, 1935; Thiergart, 1940) to have a characteristic *Corylus*-pattern. Pores are characteristically slightly offset from the equator in the Juglandaceous fashion. Exine is faintly scabrate and always crossed by at least two crossed folds.

REMARKS: Although it is not in print to my knowledge, the unofficial feeling among Tertiary palynologists is that *Platycarya* is restricted to Eocene rocks. However, as a number of writers have mentioned, the distinction between *Platycarya* and *Engelhardtia* and certain members of the Betulaceae can at times be difficult. I have not had access to the modern *Platycarya* or *Engelhardtia* but have compared descriptions and illustrations and can see how difficulties of differentiation might occur. As a result of this potential confusion, it seems possible to me that *Platycarya* might be more long ranging than commonly thought, simply because it has not been identified.

I have assigned these grains with some confidence because of their small size, their slit-like pores and characteristic cross-folds.

OCCURRENCE: Platycarya is never abundant but is a common element in the Eocene sections of both the Point Roberts and Sunnyside wells. It is also present in low frequency in the upper part of the Kitsilano Formation, at Kilgard Quarry on Canadian Sumas Mountain, at Dale Creek on American Sumas Mountain, at the Whatcom Quarry and at the Glen Echo Coal Mine.

Juglans periporites Martin and Rouse 1966

Pl. 10 Figs. 123-124

DIAGNOSIS: These forms are essentially morphologically identical to those described by Martin and Rouse. However, the size range can be expanded because forms from the Whatcom basin range from 26 to 35μ. Martin and Rouse give an annulus diameter of 8 to 10μ which is somewhat higher than shown in their illustrations. The annulus of the present specimens ranges from 5 to 6μ with pore diameters, in different specimens, varying from 1.5 to 4μ.

REMARKS: Juglans has been found in numerous Tertiary floras, including the Eocene Green River Formation, the Oligocene (?) - Miocene of Alaska, the Miocene of Nevada and the Miocene of Japan. Wodehouse (1933, p. 504) states: "Juglans is an ancient group, with a history dating back to the Upper Cretaceous. In the Tertiary it was represented by many different species and is a conspicuous feature of most of the

Tertiary floras, particularly those of the more northerly and colder climates --- ."

OCCURRENCE: This particular microfossil, while never abundant, occurs in all the rocks of the Whatcom basin.

Juglans sp.

Pl. 10 Fig. 125-127

DIAGNOSIS: Polyporate pollen grain, 28 to 35μ , subrounded. Number of pores highly variable but usually around twelve. Most located near the equator, the remainder located on one hemisphere. Pores generally small (1 to 2μ in diameter) circular to slightly elliptical, annulus weak or absent altogether. Sculpture weakly scabrate.

REMARKS: The closest species appears to be *Juglans periporites* Martin and Rouse 1966, but these have a more pronounced annulus. This type of *Juglans* pollen from the Whatcom basin is similar to that of the modern *J. nigra*.

OCCURRENCE: This particular form appears to be restricted to the Miocene sequence of rocks in the Point Roberts and Sunnyside wells.

Pterocarya stellatus Martin and Rouse 1966

Pl. 11 Figs. 128-130

DIAGNOSIS: Polyporate grain with 5 to 8 subcircular to circular pores, located at or near the equator. Pores vary from 5 to 7μ with the majority having six pores. Grains definitely angular with the number of sides dependent on the number of pores. Sub-exinous thickenings beneath the pores shallow. Almost invariably the surface is folded into one or more folds. Surface sculpture ranges from psilate to faintly scabrate. Size range 28 to 37μ .

REMARKS: These grains appear identical to *Pterocarya stellatus* Martin and Rouse 1966. No real difference seems to exist between fossil and extant *Pterocarya* pollen.

OCCURRENCE: *Pterocarya* is particularly common in the Miocene sections of the Point Roberts and Sunnyside wells. However, it is also present in lesser quantity in the Eocene sections and in various outcrops.

FAMILY JUGLANDACEAE?

Momipites tenuipolus Anderson 1960

Pl. 11 Figs. 131-133

DIAGNOSIS: These grains are identical to those described by Anderson (1960). Size range 14 to 17μ .

REMARKS: Stanley (1965) describes what appears to be *M. tenuipolus* from the Paleocene of South Dakota, and calls it *Engelhardtia microfoveolata*. He does not refer to Anderson's species, nor does he comment on polar exine thinning which characterizes *Momipites tenuipolus*, but his illustrations appear to show this thinning.

Probably this grain belongs to the family Juglandaceae; possibly closely related to *Engelhardtia* or *Platycarya*.

OCCURRENCE: This is a common grain throughout the Point Roberts and Sunnyside wells. It was also observed in the Dale Creek sample on American Sumas Mountain.

ORDER UTRICALES

FAMILY ULMACEAE

Ulmus or *Zelkova* sp.

Pl. 11 Figs. 134-135

DIAGNOSIS: Square to sub-rectangular pollen grain; 28 to 37μ in diameter. Four pores are the rule, although three and five have been observed; they are generally somewhat elliptical, 3 to 4μ in length. As a rule, pores are located on the angles of the grain, but as in modern *Ulmus* they may be all on one hemisphere, adjacent to the equator. Slight, sub-exinous thickenings do occur. Exine characteristically laevigate with a rugulate to reticulate pattern impressed into it. Wodehouse (1935) has remarked that these undulations are due to "internal thickenings."

REMARKS: *Ulmus* and *Zelkova* cannot be distinguished on the basis of pollen, even in modern pollen grains, so I have not attempted to separate them here. I have not seen an *Ulmus-Zelkova* of this type described before. It is quite different from the *U. granopollenites* described by Rouse from the Burrard Formation. It looks much like *U. americana* but according to Wodehouse (1935), *U. americana* characteristically has five pores. The *Ulmus* described here is dominently four pored.

OCCURRENCE: Common in the Miocene sections of both wells. A few specimens occasionally present in Eocene well samples.

Planera sp.

Pl. 11 Fig. 136

DIAGNOSIS: Morphologically, *Planera* is identical with the *Ulmus*-*Zelkova* already described, but has the addition of arci or curved linear thickenings reaching from pore to pore. A description of *Planera* given by Simpson (1961) fits these grains almost exactly. Wodehouse (1935), commenting on the arci of *Planera*, states that arci are more than adequate to differentiate *Planera* from *Ulmus*.

REMARKS: I feel there is little doubt these are truly *Planera*. The difference in these grains to those referred to as *Ulmus*-*Zelkova* is striking and consistent. Leaves of *Planera* have been found in the Burrard and Kitsilano Formations (Rouse, 1962), although it has not been commonly identified before in Tertiary floras on the basis of microfossils.

OCCURRENCE: *Planera* is not common, with only about 15 grains identified. However, they have been found in both the Miocene and Eocene sections of the Point Roberts and Sunnyside wells. Several grains were also found in the Kitsilano Formation.

ORDER TILIALES

FAMILY TILIACEAE

Tilia vescipites Wodehouse 1933

Pl. 11 Figs. 137-139

DIAGNOSIS: These specimens appear identical with those described by Wodehouse. They range in polar diameter from 24 to 34 μ. Except for the slightly smaller size, these specimens are similar to the modern *T. americana* as suggested by Wodehouse (1933).

OCCURRENCE: This microfossil is locally rather abundant and is found throughout the Eocene and Miocene of the two wells as well as in most of the outcrop samples.

Tilia sp.

Pl. 11 Fig. 140

DIAGNOSIS: Small (21 to 24 μ), triporate grain, invariably subcircular. Pores circular and deeply sunken forming pits. Sub-exinous thickening around pores is considerable, and always conspicuous. Exine is pitted to minutely reticulate.

REMARKS: This grain differs from *Tilia vescipites* in its smaller size; in the punctate rather than coarsely reticulate sculpture; and in the pronounced thickenings around the pores.

OCCURRENCE: This is a relatively uncommon microfossil found principally in the Miocene section of the Point Roberts and Sunnyside wells. However, a few grains were found in the Kitsilano Formation

FAMILY TILIACEAE?

Pl. 11 Fig. 141

DIAGNOSIS: Elliptical pollen grain, 22 to 26μ, markedly pointed end. Tricolporate, colpae extending from end to end of grain. Marked sub-exinous thickening. Small circular pore located in short, shallow transverse furrow. Exine is fine granular with a suggestion that allignment of ornamentation is parallel to long axis of grain.

REMARKS: Assignment to the Tilliaceae is tentative, and done only on the basis of the resemblance of this grain to "Grewia-type" as illustrated in Erdtman (1952).

OCCURRENCE: Not a common microfossil, occurring very rarely in the Miocene rocks of the Point Roberts and Sunnyside wells.

ORDER SAPINDALES

FAMILY ACERACEAE

Acer sp.

Pl. 11 Figs. 142-143

DIAGNOSIS: Grains predominantly oblate, 24 to 30μ long, 10 to 20μ in width. Colpae extend from pole to pole, usually closed, but where gaping slightly, are faintly granular. No thickening at colpae margins. The exine is always distinctly granulate; almost always the granules are alligned in rows, giving a striate appearance, although at times the striations are weakly developed.

REMARKS: Wodehouse (1935) and Simpson (1961) remark on the diagnostic value of these granular striations. Among modern forms, only *Acer negundo* fails to show this striate characteristic. As a consequence I have identified as *Acer* only those grains which show this feature. Tricolpate grains are common in many diverse groups in the Dicotyledonae, and I am convinced that many misidentifications are found in the literature. As a result, I have decided to err on the conservative side and assign to *Acer* only those forms which show the characteristic striations. This may have resulted in *Acer* appearing in lesser percentage than it did in reality.

OCCURRENCE: Rare, but omnipresent in all Whatcom basin rocks.

FAMILY HIPPOCASTANACEAE

Aesculus sp.

Pl. 11 Fig. 144

DIAGNOSIS: Prolate, tricolpate grains, 20 to 26μ in polar diameter. Colpae short, each containing a weak elliptical pore in center. Exine faintly scabrate.

OCCURRENCE: A very uncommon microfossil, identified definitely only in several samples from the Miocene of the Sunnyside well.

ORDER CHENOPODIALES?

FAMILY CHENOPODIACEAE?

Pl. 11 Fig. 145

DIAGNOSIS: Pollen grains small (17 to 19μ), spheroidal, cribellate. Twelve or more circular pores covered by a thin, flecked membrane; exine thick and faintly scabrate.

REMARKS: Although I have assigned these pollen grains to the Chenopodiaceae, there remains the possibility they may be in the family Caryophyllaceae. Erdtman (1943) points out the similarity of pollen from the two families, and that many are difficult to differentiate. Because there are over 550 genera in the Chenopodiaceae and 80 genera in the Caryophyllaceae, with a combined total of about 2,000 species, all with similar pollen, it is impossible to refine identification to any lower level.

OCCURRENCE: Only four grains of this type were observed, and they all occurred in the Miocene section of the Sunnyside well.

ORDER CONTORTAE

FAMILY GENTIANACEAE

Pistillipollenites mcgregorii Rouse 1962

Pl. 12 Figs. 146-149

DIAGNOSIS: The description given by Rouse for the genus is as follows: "Pollen grains circular to broadly sub-triangular in outline. Triporate (?tricolpate) with the three openings generally obscured by the club or pistil-shaped elements of ornamentation. The wall is about 2μ thick, with no obvious division into ektexine and endexine; the presence of costae has not been confirmed because no clear view of the pores has been available. Size range 20 to 30μ ."

For the description of Pistillipollenites mcgregorii, Rouse adds the following to the generic description: "The pistil-shaped ornaments resemble young mushrooms emerging from the soil, i.e. they are circular to oval in shape, --- pores or (colpae?) which are hidden between and under the projections. --- the projections are not generally evenly distributed on the surface of the wall but tend to be concentrated on one surface. The size range is 20 to 30μ ."

REMARKS: There is no doubt these forms are identical to those described by Rouse, although a wider range of ornament variation is present. The exine may have as few as six pistils or the entire surface may be densely covered. According to Hills (1965) the range of Pistillipollenites mcgregorii is, in British Columbia, Middle Eocene. However, the total range may be Paleocene to Middle Eocene (Rouse, personal communication).

OCCURRENCES: Pistillipollenites has a restricted occurrence in the Whatcom basin. In the Sunnyside and Point Roberts wells it occurs only, and sometimes in high percentage, in the middle and lower parts of the Eocene section. It was also encountered in the lower part of the Kitsilano Formation and in several outcrops in Washington State. Distribution of this microfossil is indicated on Tables B, C and D.

FAMILY AQUIFOLIACEAE

Ilex sp.

Pl. 12 Figs. 150-155

DIAGNOSIS: Tricolpate pollen grain, subprolate to prolate. Some grains show the colpae distinctly, others with the colpae barely visible. All specimens show a clavate sculptured ektexine. Clavae vary from 1.5 to 3.5μ in diameter, markedly expanded and rounded on distal ends. Most specimens have equal-sized clavae, others have slight variations. No clavae present on furrows. Size range (excluding ornaments) 25 to 37μ in polar length.

REMARKS: At the present time there are over 180 species of *Ilex* (Willis, 1955) and these presumably all have very slight variation in pollen morphology. Presumably this multiplicity of species was present in the Tertiary, as several different forms of *Ilex* are reported from Tertiary floras. Differences in the fossil *Ilex* of the Whatcom basin are slight and do not lend themselves to meaningful subdivision. Considerable overlap of forms exists, and it is difficult and arbitrary to assign most of the grains to any particular species. Traverse (1955) has created five fossil species, but to my mind this has very little validity. As a result I have simply placed all forms of *Ilex* sp. and illustrated some of the minor variations present.

OCCURRENCE: Ilex is common, and sometimes abundant, in the Miocene and upper part of the Eocene sequence in both the Point Roberts and Sunnyside wells. It is also present in the Kitsilano Formation and some of the other outcrop samples. Distribution of Ilex is indicated on Tables B, C and D.

ORDER PROTEALES

FAMILY PROTEACEAE

Proteacidites thalmanni Anderson 1960

Pl. 12 Figs. 156-158

DIAGNOSIS: Triporate, triangular pollen grain about 22 to 30μ in diameter. Rounded corners, slightly convex interradial areas. Pores at angles, somewhat variable in character. Pores generally appear elliptical, and notch-like. Annulus usually pronounced around pores. Exine is rather coarsely reticulate near equator, becoming finer toward poles.

REMARKS: Proteacidites pollen is difficult to break into species because of the transitional nature of the pollen grain morphology. However, the present specimens appear identical with P. thalmanii Anderson 1960.

Available evidence indicates that Proteacidites is restricted to Upper Cretaceous in New Mexico. Stanley (1960) found Proteacidites retusus Anderson 1960 restricted to Upper Cretaceous in northwestern South Dakota. Rouse (1962) stated that two species, P. terrazus Rouse 1962 and P. marginus Rouse

1962, is restricted to Upper Cretaceous rocks in British Columbia. Informal discussion with oil company palynologists has indicated to me that most workers accept proteaceous grains as indicators of Upper Cretaceous age in North America.

OCCURRENCE: Several of these grains were found in the Dale Creek (American Sumas Mountain) sample, but as explained in the text, I feel these are contamination from older rocks. They were found in the Upper Cretaceous rocks in both the Sunnyside and Point Roberts wells. Distribution of proteaceous grains is given on Tables B and C.

Proteacidites sp.

Pl. 12 Fig. 159

DIAGNOSIS: Rather sharply triangular grain, abruptly rounded angles, straight to slightly concave sides. Size about 28μ. Pores indistinct but appear notch-like, no particular thickening of exine around pores. Sculpture is wart-like at equator grading to reticulate and punctate at poles.

REMARKS: This grain appears similar to *Proteacidites terrazus* Rouse 1962, but is rather poorly preserved and can't be identified any closer to species.

OCCURRENCE: Only three of these particular microfossils were found, all in the Upper Cretaceous of the Sunnyside well.

ORDER MYRICALES

FAMILY MYRICADEAE

Myrica annulites Martin and Rouse 1966

Pl. 13 Figs. 160-161

DIAGNOSIS: Triporate grains, 26 to 33 μ in diameter. Specimens from the Whatcom basin appear very similar to those described by Martin and Rouse so I have assigned them to this species.

REMARKS: Wodehouse (1933) has stated "(*Myrica*) is one of the most abundant and widely distributed genera of the Tertiary occurring in practically all of the floras of the epoch. It was also present in the Upper Cretaceous period and is still widely distributed though greatly reduced in numbers of species."

Myrica is reported from the Miocene or early Pliocene Skonun Formation of the Queen Charlotte Islands (Martin and Rouse, 1966) but has not been found in either the Eocene Burrard Formation (Rouse, 1962) nor in the Eocene of interior British Columbia (Hills, 1965).

OCCURRENCE: This is a very uncommon microfossil in the Whatcom basin with only a few grains encountered in the Miocene section of the Point Roberts and Sunnyside wells.

CLASS DICOTYLEDONAE

Form genus *Extratriporopollenites* sp.

Pl. 13 Fig. 162

DIAGNOSIS: Strongly triangular grain, with strongly protruding pores. Size about 22μ. Annulus prominent, vestibulum appears present but difficult to define its nature. Sculpture appears rough, almost beaded.

REMARKS: This form compares most closely with *E. Fractus* Pflug in Thomson and Pflug (1953).

A number of species of *Extratriporopollenites* have been described. However, there appears to be considerable overlap of features, and I prefer not to commit myself to the species level. *Extratriporopollenites* appears to be a good indicator of Upper Cretaceous and Paleocene rocks. Thomson and Pflug (1953) find it abundant in Upper Cretaceous, rarely present in the Paleocene, and absent in younger rocks. Samolovitch, *et al* (1961) found *Extratriporopollenites* in both Upper Cretaceous and Paleocene rocks in Russia.

OCCURRENCE: Several grains of this form were found within the Upper Cretaceous part of the Point Roberts and Sunnyside wells.

CLASS MONOCOTYLEDONAE

ORDER LILIALES

FAMILY LILIACEAE?

cf. *Liliacidites* sp.

Pl. 13 Figs. 163-164

DIAGNOSIS: Monocolpate pollen grains, prolate to perprolate, 14 to 45μ in polar length. Furrow extending to extremities of grain, usually not gaping but well defined; some grains show a slight margo. Sculpture reticulate, becoming finer toward the furrow and end of grain. Lumina irregular and angular in shape.

REMARKS: These grains are morphologically similar to those of *Liliacidites leei* Anderson 1960, but many are 5 to 10μ shorter in polar diameter. They are also similar to *Aponogeton* as described by Simpson (1961) but because this latter is strictly an African genus it seems unlikely it was ever native to North America. Because of the considerable doubt surrounding their botanical affiliation, I have tentatively assigned them to the form-genus *Liliacidites*, though they may well be affiliated with a family other than Liliaceae.

OCCURRENCE: This is a very uncommon microfossil found only in a few places in the section in both the Point Roberts and Sunnyside wells. It also was encountered in several of the Kitsilano Formation samples.

ORDER PALMALES

FAMILY PALMAE

Sabal granopollenites Rouse 1962

Pl. 13 Figs. 165-166

DIAGNOSIS: "Pollen monocolpate, fusiform in outline, coarsely granulate to weakly reticulate. The single colpae is long and narrow with weak margins. Size range 28 to 32μ " (Rouse, 1962).

REMARKS: *Sabal granopollenites* has been reported from the Eocene Burrard Formation (Rouse, 1962), the Middle Eocene Allenby Formation (Hills, 1965) and the Paleocene (?) Chuckanut Formation (Griggs, 1965).

OCCURRENCE: *Sabal* is relatively abundant in the lower part of the Eocene section and in the Cretaceous of both the Point Roberts and Sunnyside wells.

ORDER PANDANALES

FAMILY TYPHACEAE

Typha sp.

Pl. 13 Figs. 167-168

DIAGNOSIS: Pollen grains small (18 to 25μ), irregularly spheroidal. Single germ pore, which is often not distinct, but usually occurs as a rather irregular hole. Exine is thin and covered with a fine foam-like reticulation.

REMARKS: These grains appear identical to those of the extant *Typha latifolia* which grows in marshes throughout temperate North America, sometimes abundantly.

OCCURRENCE: Typha has been found in low frequency throughout the stratigraphic section represented in the Point Roberts and Sunnyside wells. It is especially abundant in several Miocene samples from the Sunnyside well.

ORDER NAJADALES

FAMILY POTAMOGETONACEAE

Potamogeton hollickipites Wodehouse 1933

Pl. 13 Fig. 169

DIAGNOSIS: According to Wodehouse these grains are "spheroidal, somewhat ellipsoidal or variously irregular, 16 to 27.4μ in diameter. Exine rather thin and conspicuously reticulate with a coarse network of beaded ridges. Without pores or furrows or vestiges of them."

REMARKS: The specimens here are similar to those described by Wodehouse except the upper size limit is 32μ. My specimens are identical to those described by Hills (1965) from the Eocene Allenby Formation, Princeton basin, interior British Columbia.

Wodehouse (1933) remarked: "It is not known for certain whether they (Potamogeton pollen) have a germ pore or not, the absence of which is the only character which distinguishes these grains from those of Sparganium and some species of Typha." However, detailed examination of the reticulate ornamentation indicates that the muri of modern Sparganium grains are not always closed, while *Potamogeton* appears to always have closed muri. Furthermore, *Typha* has a much finer and more delicate reticulum than either *Sparganium* or *Potamogeton* and usually has a conspicuous germ pore. Because a germ pore is never present and the muri are always closed, I have assigned these grains to the genus *Potamogeton*.

Potamogeton has been described from a number of Tertiary Formations including the Eocene Green River, the Middle Eocene Allenby of interior British Columbia and the Miocene Latah of the Columbia Plateau.

OCCURRENCE: Locally this is an abundant microfossil and is found in both Miocene and Eocene rocks.

INCERTAE SEDIS

Triletes solidus Krutzsch 1959

Pl. 13 Figs. 170-171

DIAGNOSIS: Moderate sized (35 to 50μ) trilete spore, sub-angular, rounded angles. Slightly concave to slightly convex interradial areas. Trilete mark distinct, extending from pole almost to equator. Ornamentation coarsely warty-rugulate.

REMARKS: Krutzsch states this spore occurs in the Eocene of Germany, but its overall stratigraphic range is unknown. Its botanical affiliation is unknown.

OCCURRENCE: Only four specimens of this grain were found, two in the Kitsilano Formation and two at the Sumas Clay Mine.

Trilete spore (unidentified)

Pl. 13 Fig. 172

DIAGNOSIS: Trilete spore, subtriangular, 36μ, laesurae extend almost to equator; coarsely reticulate, lumina essentially round instead of angular.

REMARKS: This grain looks much like _Brochotriletes fovealatus_ as described by Naumova (Potonié, 1958) from the Upper Devonian of Russia. It is also similar to _Foveasporis_ Krutzsch 1959 but is smaller than any of the species described for this genus. However, _Foveasporis_ is found in the Cretaceous of Germany.

Descriptions for both of these genera are ambiguous and there is apparently overlap of morphological character. Serious restudy of these genera may result in an all-inclusive term but this is beyond the scope of this work. The botanical affiliation of this grain is unknown but it may belong to the Lycopodophyta.

OCCURRENCE: Only one grain was found, and that from a core at 10,873 feet (Cretaceous) of the Sunnyside well.

Deltoidospora $_1$ sp.

Pl. 13 Fig. 173

DIAGNOSIS: Small (22 to 28μ), trilete spore. Subtriangular, broadly rounded angles, straight to slightly concave interradial areas. Trilete mark weakly developed, extending about two-thirds of distance toward equator. Exine very weakly and minutely punctate.

REMARKS: This spore is similar to *Deltoidospora microforma* Rouse 1962 but these forms do not have the generally gaping laesurae which Rouse describes. In size and shape it is more like *D. rhytisma* but does not often have the concave interradial areas which characterize Rouse's illustrations.

OCCURRENCE: Only a few of these microfossils were found in the Miocene and Eocene rocks of the two wells.

Deltoidospora $_2$ sp.

Pl. 13 Fig. 174

DIAGNOSIS: Small (20 to 22μ) trilete spore. Subtriangular in shape, broadly rounded angles, straight to weakly concave interradial areas. Trilete mark weak, extends to spore equator. Sculpture scabrate.

REMARKS: This grain is similar to *Deltoidospora taenia* Rouse 1962, but is somewhat smaller. Rouse gives a size range for this species of 26 to 35μ . No botanical affiliation can be suggested for this grain.

OCCURRENCE: Only two specimens of this microfossil were found, both in the Toad Lake outcrop.

Monoporate A

Pl. 13 Figs. 175-176

DIAGNOSIS: Almost spherical spore, 16 to 17μ , with one very slightly aspidate pore. Exine about 3μ thick, with no thickening about the pore. Exine psilate.

REMARKS: This is almost certainly a fungal spore, but no clue as to its affiliation can be presented at this time.

OCCURRENCE: This is not a common grain but it is rather widespread. It is particularly abundant in the Whatcom Quarry and Dale Creek samples, but has been found in the Miocene section of the Sunnyside well.

Monoporate B

Pl. 13 Fig. 177

DIAGNOSIS: Spherical to oval, 17 to 20μ, monoporate spore. Pore very minute, surrounded by slight sub-exinous thickening, non-aspidate. Exine psilate.

REMARKS: This is undoubtedly a fungal spore, with no known affiliations.

OCCURRENCE: This spore was found only at the base of the Eocene section of the Sunnyside well.

Monoporate C

Pl. 13 Fig. 178

DIAGNOSIS: Small (15 to 16μ), oval, monoporate spore. Pore located at one end, circular, showing slight thickening of the exine at pore margins. Exine psilate.

REMARKS: This is undoubtedly a fungal spore, with no known affiliation.

OCCURRENCE: This spore was found only at the base of the Eocene section in the Sunnyside well.

Fusiformisporites microstriatus n. sp.

Pl. 13 Fig. 179

DIAGNOSIS: Oval spore, 42 to 49μ in length. Grain divided into two cells by a septum in the middle of the grain. Fine longitudinal ribs extend from the poles to the equatorial septum (which is very slightly constricted). Most of these ribs terminate at the equator, although occasionally several may be continuous across it. The wall is thick and appears granular.

REMARKS: This form is placed in the genus *Fusiformisporites* Rouse 1962 but has much finer grooves than *F. crabbii* Rouse 1962.

HOLOTYPE: Slide 14-5-65-3-1 (Whatcom Quarry), coordinates 25.2-118.0.

OCCURRENCE: Apparently restricted in small numbers to the Whatcom Quarry and Toad Lake samples.

Diporites granulatus Rouse 1962

Pl. 13 Figs. 180-181

DIAGNOSIS: "Pollen grains elongate, elliptical to fusiform in outline. Diporate with the pores diametrically opposed and protruding. Poral costae prominent, several microns below the pore; the projecting pore appears to be an extension of the ektexine only. Ornamentation coarsely and densely granulate. Size range 45 to 50μ" (Rouse, 1962).

Specimens from the Whatcom basin are identical to those described by Rouse except for their larger size. The size range here is 50 to 65μ.

REMARKS: Rouse has suggested that *Diporites granulatus* belongs to the Onagraceae, but this remains to be verified.

OCCURRENCE: This grain occurs in low frequency in the Kitsilano Formation and most of the outcrop samples.

Diporites psilatus n. sp.

Pl. 14 Fig. 182

DIAGNOSIS: Elongate spore or pollen grain, elliptical to fusiform in outline, 55 to 60μ in length. Biporate, pores opposed, slightly aspidate. Poral costae prominent with exine thinner toward pores. Exine is psilate.

REMARKS: This grain is almost identical with *Diporites granulatus* Rouse 1962 except for the character of the exine and the larger chambers subtending the pores. Rouse has tentatively suggested these grains belong to the Onagraceae, but no further clue on affiliation can be offered.

HOLOTYPE: Slide 14-5-65-6-1 (Goshen Coal Mine), coordinates 31.7-117.6.

OCCURRENCE: This microfossil has been found in low frequency in the Kitsilano Formation and other outcrops.

Diporate A

Pl. 14 Fig. 183

DIAGNOSIS: Large (63 to 68μ), irregularly oval pollen (?) grain. Diporate; pores are small, circular and surrounded by a narrow zone of sub-exinous thickening. Pores are always on the same surface but not always in the same place. Wall is thin and always creased with a number of folds. Sculpture minutely scabrate.

REMARKS: No suggestion can be given as to the probable botanical affiliation of this grain.

OCCURRENCE: Locally abundant within samples from the Sumas Clay Mine.

Diporate B

Pl. 14 Fig. 184

DIAGNOSIS: Large (45 to 55μ), diporate grain, oval. Pores at each end, markedly aspidate, exine flaring out to form lips which border the large, circular pore. No sub-exinous thickening or thinning around the pores. Plane of weakness cutting through pores. Although only a few grains of this type were observed, one pore is always ruptured along this plane. Exine laevigate to slightly irregular.

REMARKS: This is similar to *Diporites granulatus* but in this present form the prominent poral costae is absent. Furthermore, the exine in *D. granulatus* is "coarsely and densely" granulate. No botanical affiliation can be suggested for this grain.

OCCURRENCE: An uncommon grain occurring only in the Goshan Coal Mine samples.

Diporate C

Pl. 14 Fig. 185

DIAGNOSIS: Large (75 to 85μ), oval, diporate fossil. Circular, slightly aspidate pore at each end. Sub-exinous thickening around each pore. Grain divided into four cells by three moderately thick, but simple septa. No pores apparent in septa. Wall psilate.

REMARKS: No botanical affiliation can be suggested for this grain, although the general morphology resembles a fungal spore.

OCCURRENCE: Only several grains of this form were found at the Sumas Clay Mine.

Tricolpate A

Pl. 14 Figs. 186-187

DIAGNOSIS: Large (40 to 44μ) tricolpate pollen grain. Colpae about three-fourths total length of grain, somewhat wavy and tending to gape in middle. Exine coarsely reticulate, becoming slightly coarser at poles and finer toward the colpae.

REMARKS: No suggestion can be made as to the botanical affiliation of these grains, although they have been found in Tertiary rocks of southwestern Washington (T. Sparks, personal communication).

OCCURRENCE: These grains are found in very low occurrence throughout the Tertiary sequence in both the Point Roberts and Sunnyside wells.

Tricolpate B

Pl. 14 Fig. 188

DIAGNOSIS: Prolate, tricolpate pollen grain, 26 to 28μ in polar diameter. Colpae sharp and tightly closed, extending about three-fourths length of grain. Exine laevigate.

REMARKS: No botanical affiliation can be suggested for this pollen grain.

OCCURRENCE: Uncommon pollen grain, occurring only in the Miocene section of the Point Roberts and Sunnyside wells.

Tricolpate C

Pl. 14 Fig. 189

DIAGNOSIS: Small (15 to 19μ), prolate, tricolpate pollen grain. Colpae extending almost from end to end of grain, always tightly closed, and showing no sub-exinous thickening. Exine moderately thick, scabrate to minutely granular.

REMARKS: No botanical affiliation can be suggested for this grain.

OCCURRENCE: A moderately common grain throughout the Miocene and Eocene rocks of the Point Roberts and Sunnyside wells.

Tricolporate A

Pl. 14 Fig. 190

DIAGNOSIS: Tricolporate pollen grain, prolate, 23 to 28μ long. Three colpae extend almost from pole to pole. Circular protruding pore in center of each colpae. Weak subexinous thickening along margin colpae. Exine scabrate.

REMARKS: The affiliation of this grain is not known, but it resembles superficially some genera of the family Cornaceae.

OCCURRENCE: Not a common grain but does occur in the Miocene rocks and to a lesser extent in the Eocene rocks of both wells.

Triporate A

Pl. 14 Fig. 191

DIAGNOSIS: Triporate pollen grain, 28μ in diameter. Pores moderately aspidate but nature of exine around pores is not clear; there does not appear to be any thickening of exine around pores. Exine is finely and irregularly striate.

REMARKS: Only one specimen was found and its ornamentation in no way resembles anything I have seen.

OCCURRENCE: One specimen was found in the upper part of the Kitsilano Formation.

Acritarch, cf. Micrhystridium?

Pl. 14 Fig. 192

DIAGNOSIS: Fossil 23μ in diameter, no openings in body. Surface is warty and bears spiny appendages about 14μ long, about 3μ in diameter at base, tapering distally to a point.

OCCURRENCE: Only one specimen was found, in a core at 10,873 feet (Cretaceous) in the Sunnyside well.

Acritarch, cf. Micrhystridium?

Pl. 14 Fig. 193

DIAGNOSIS: More or less circular, sometimes irregularly folded. Size range from 22 to 28μ . Ornamented with spines, usually straight but occasionally curved, about 3μ long.

OCCURRENCE: Only one specimen was found in the Miocene section of rocks in the Sunnyside well.

cf. Asterina

Pl. 14 Fig. 194

DIAGNOSIS: These structures, which range from 65 to 85μ in diameter are identical to the cylindrical plates of cells described by Martin and Rouse (1966).

REMARKS: Dilchner (1963) described similar forms from the Eocene and placed them in the fungal family Microthyriaceae, genus Asterina. Similar structures are illustrated, but not described by Hills (1965) from the Eocene of interior British Columbia.

OCCURRENCE: These forms are found in low frequency in the Kitsilano Formation and other outcrop samples.

Unidentified

Pl. 14 Figs. 195-196

DIAGNOSIS: Large (75 to 80 μ), circular organic body of unknown origin.

OCCURRENCE: Found in very low quantity in the Kitsilano Formation.

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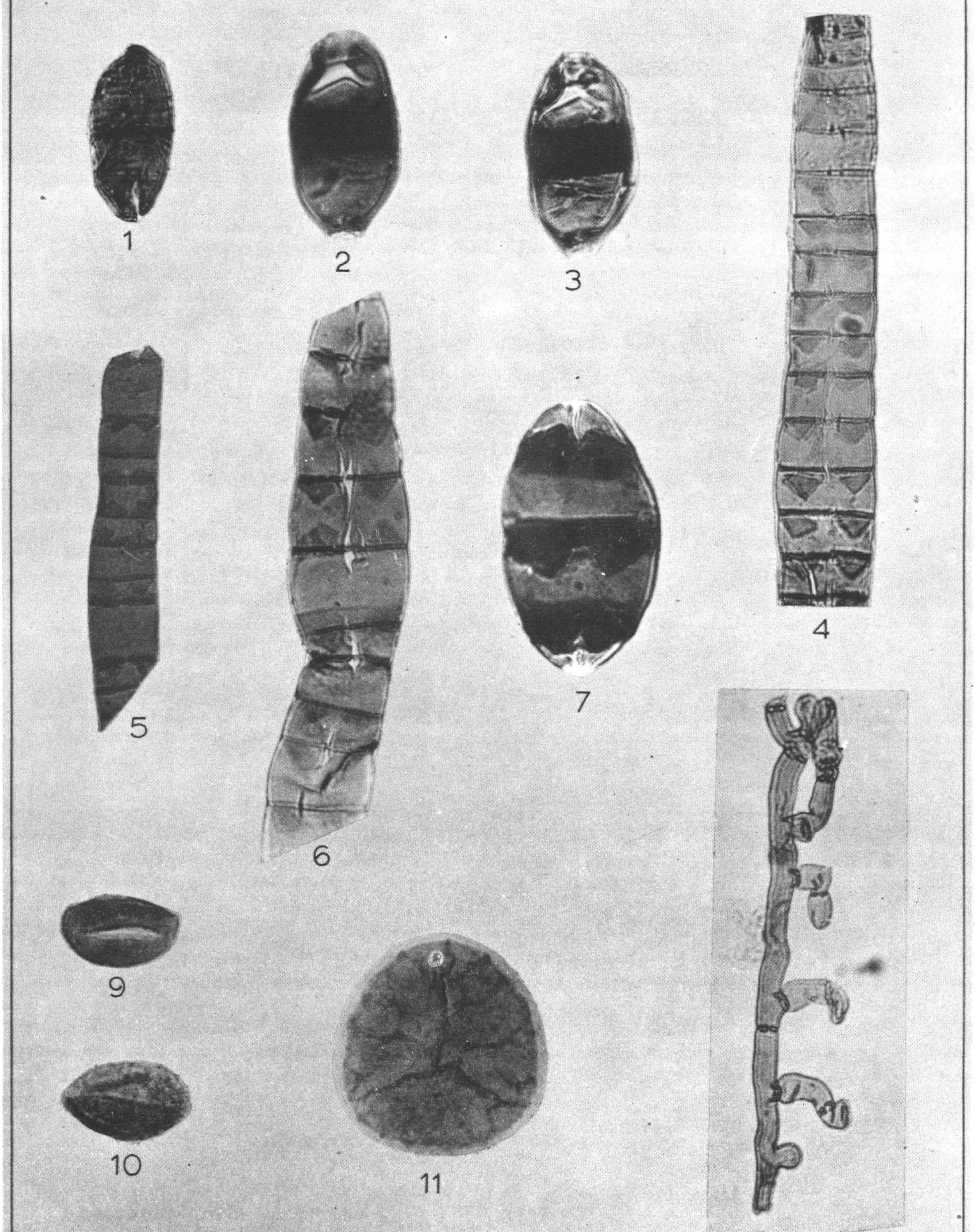
PLATE 1



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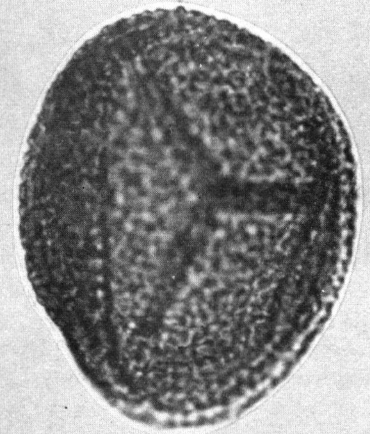

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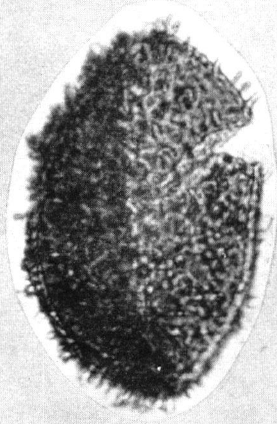

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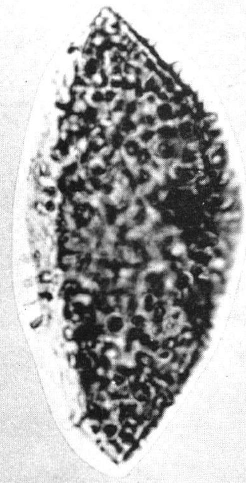

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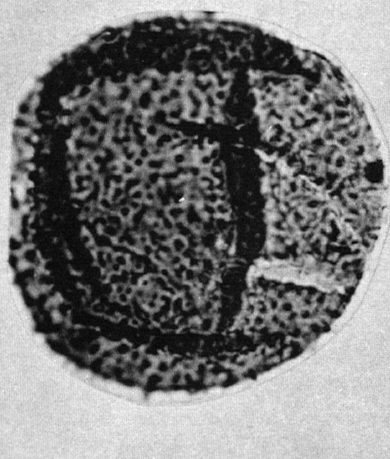

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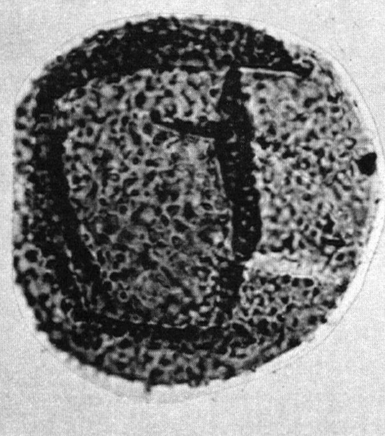

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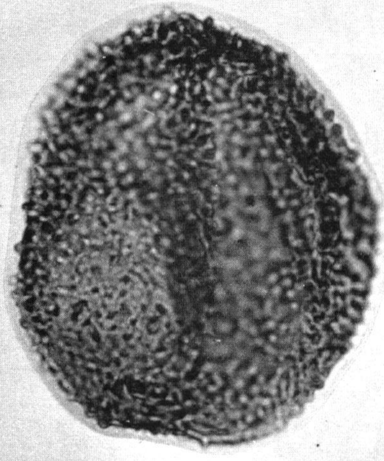

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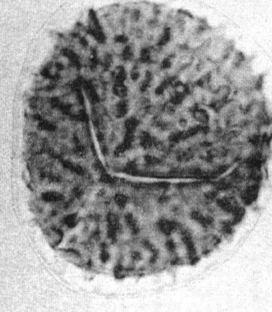

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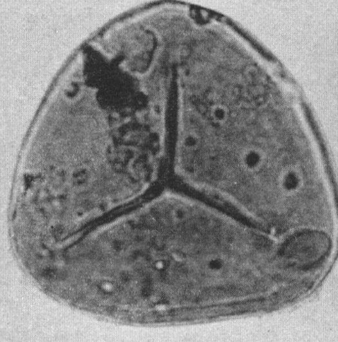

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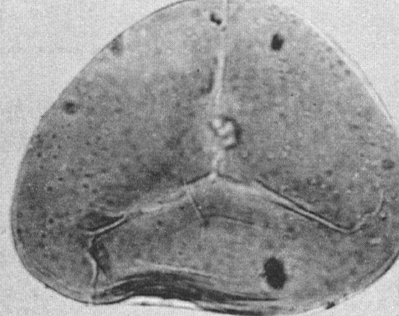

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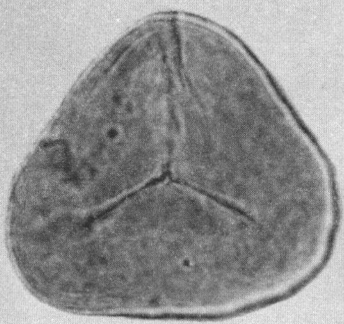

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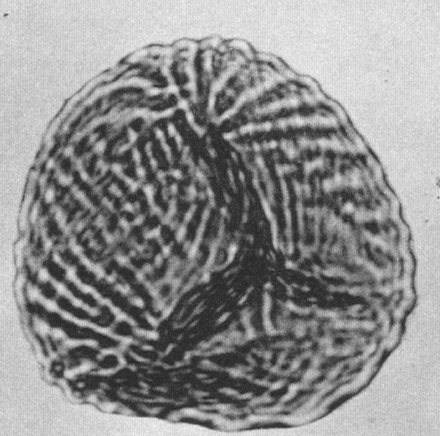

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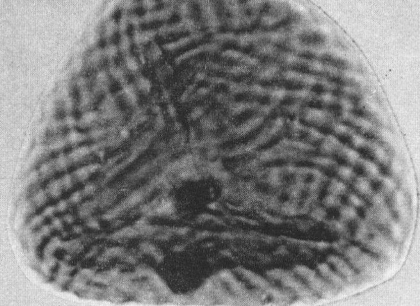

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PLATE 4

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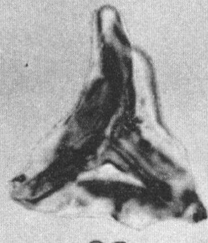

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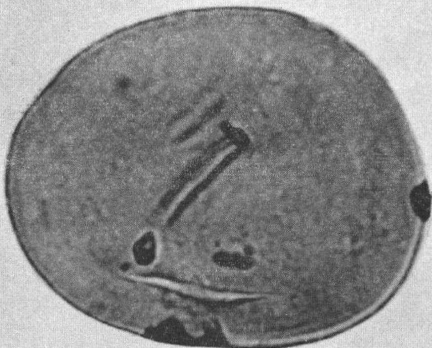

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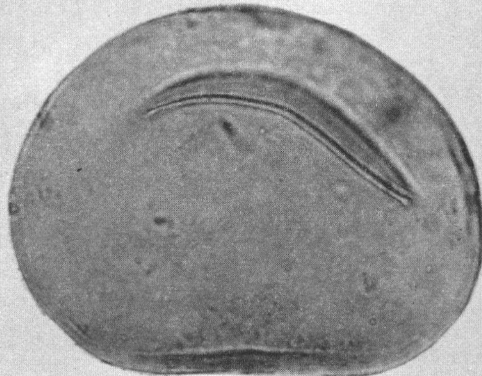

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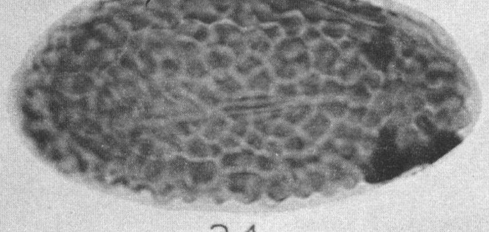

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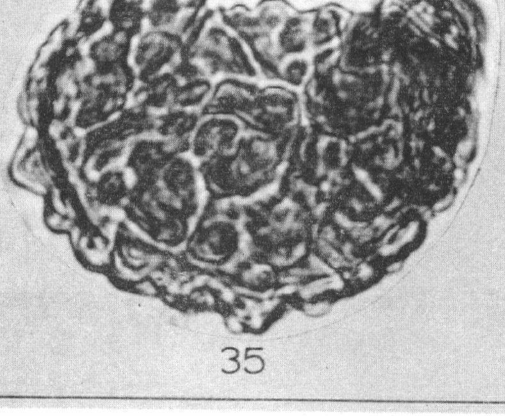

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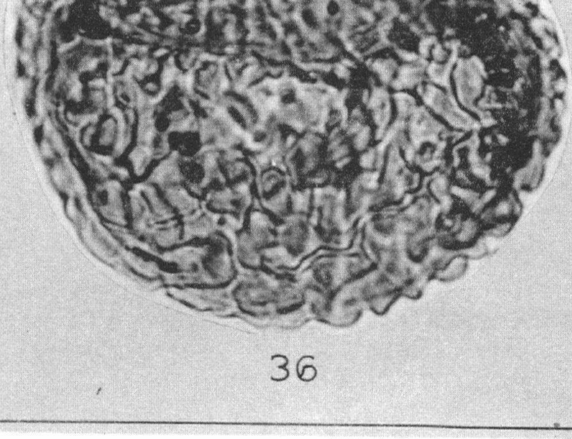

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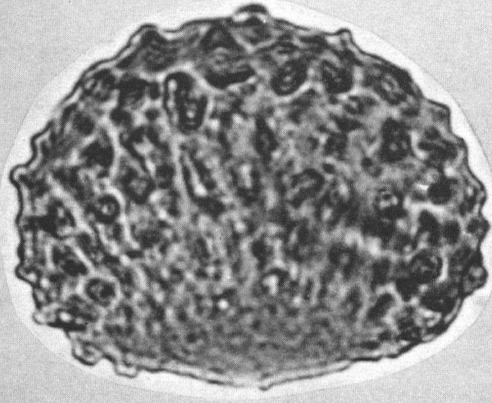

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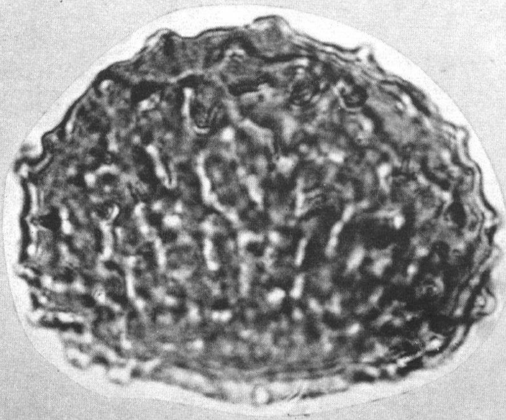

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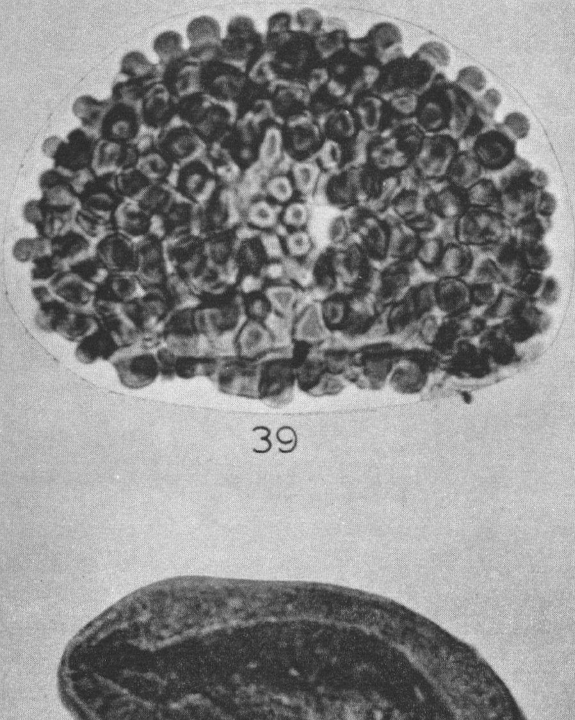

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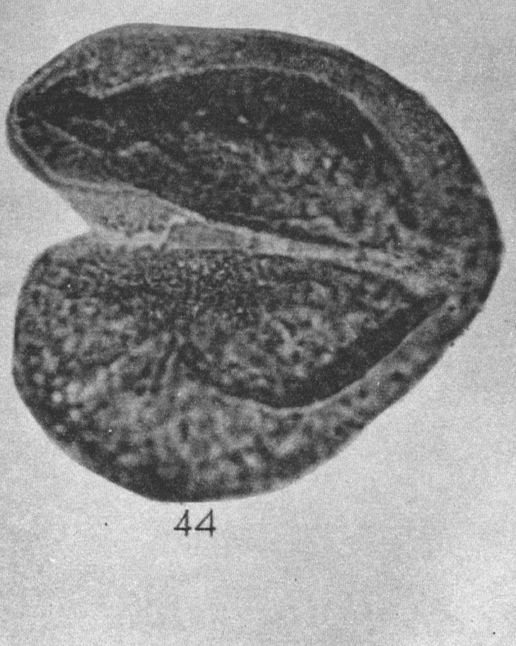

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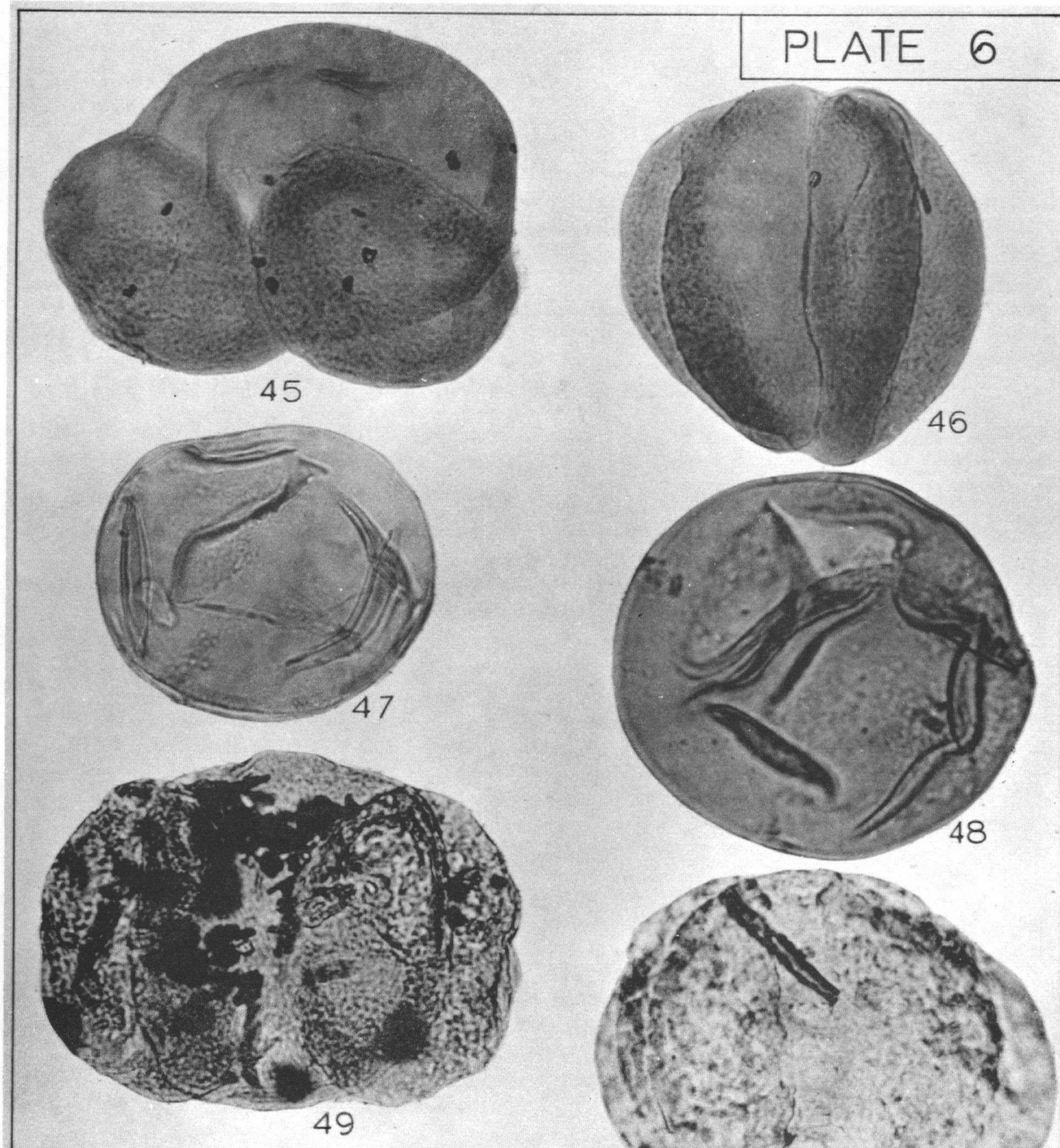

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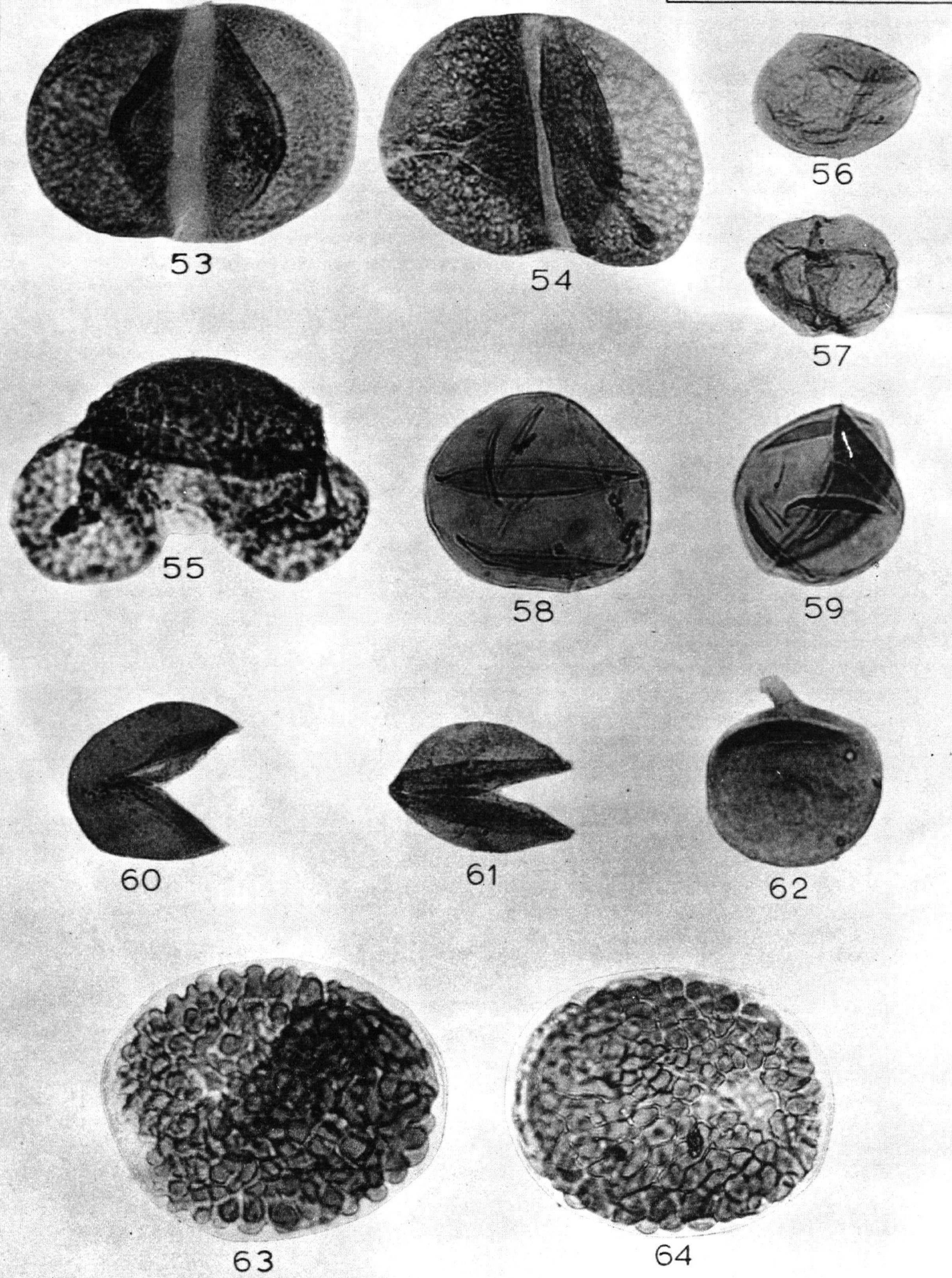

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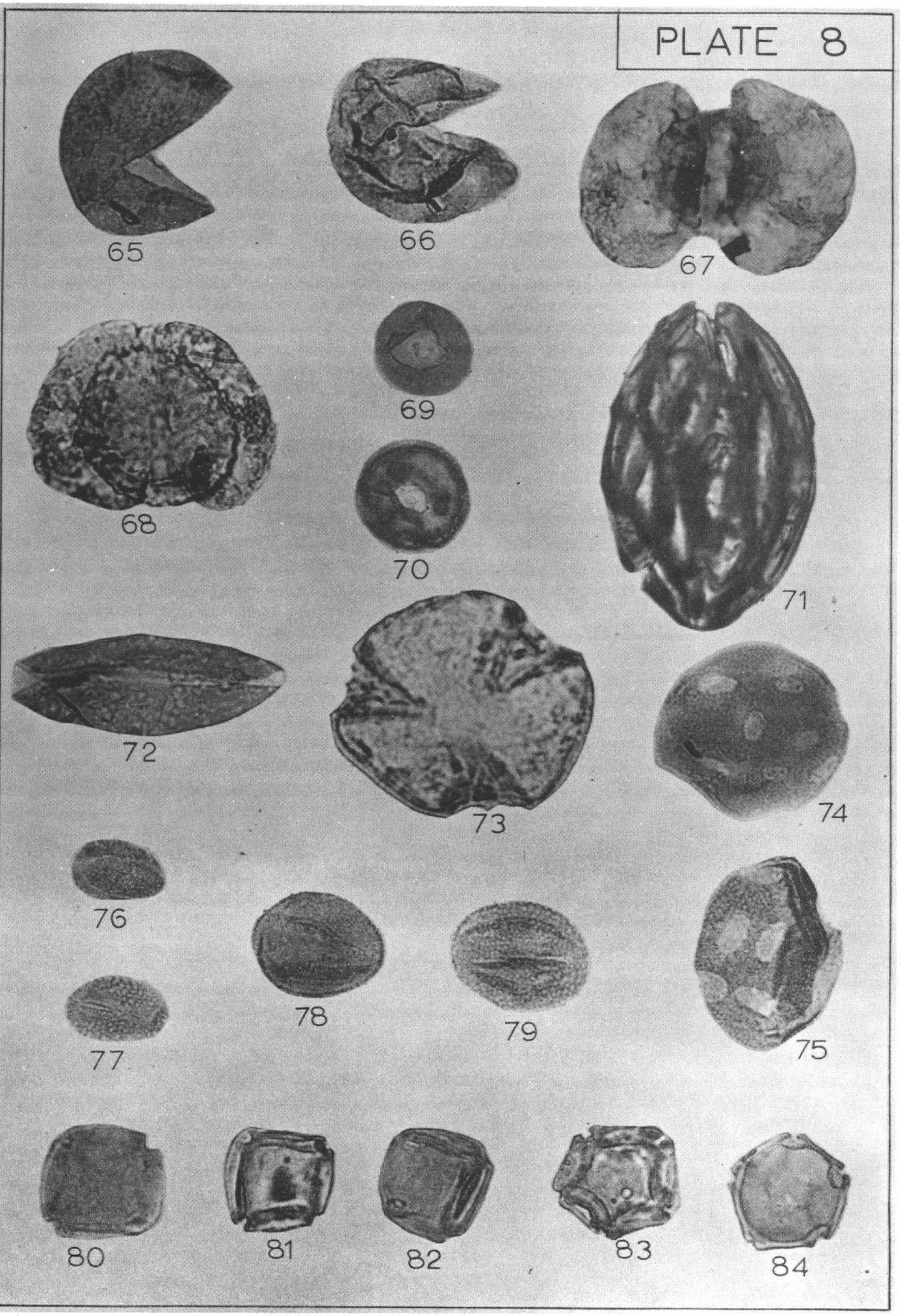

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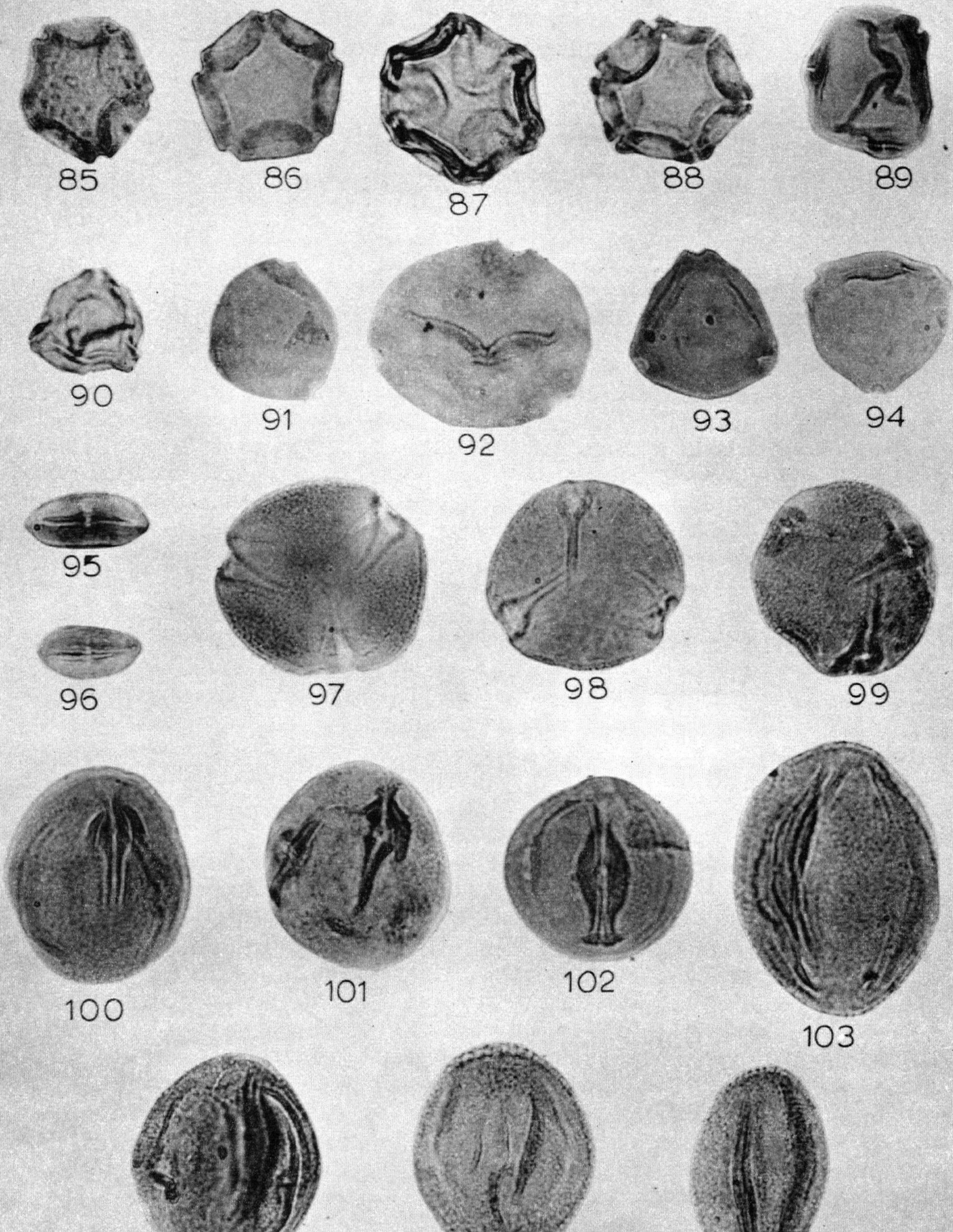
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PLATE 10

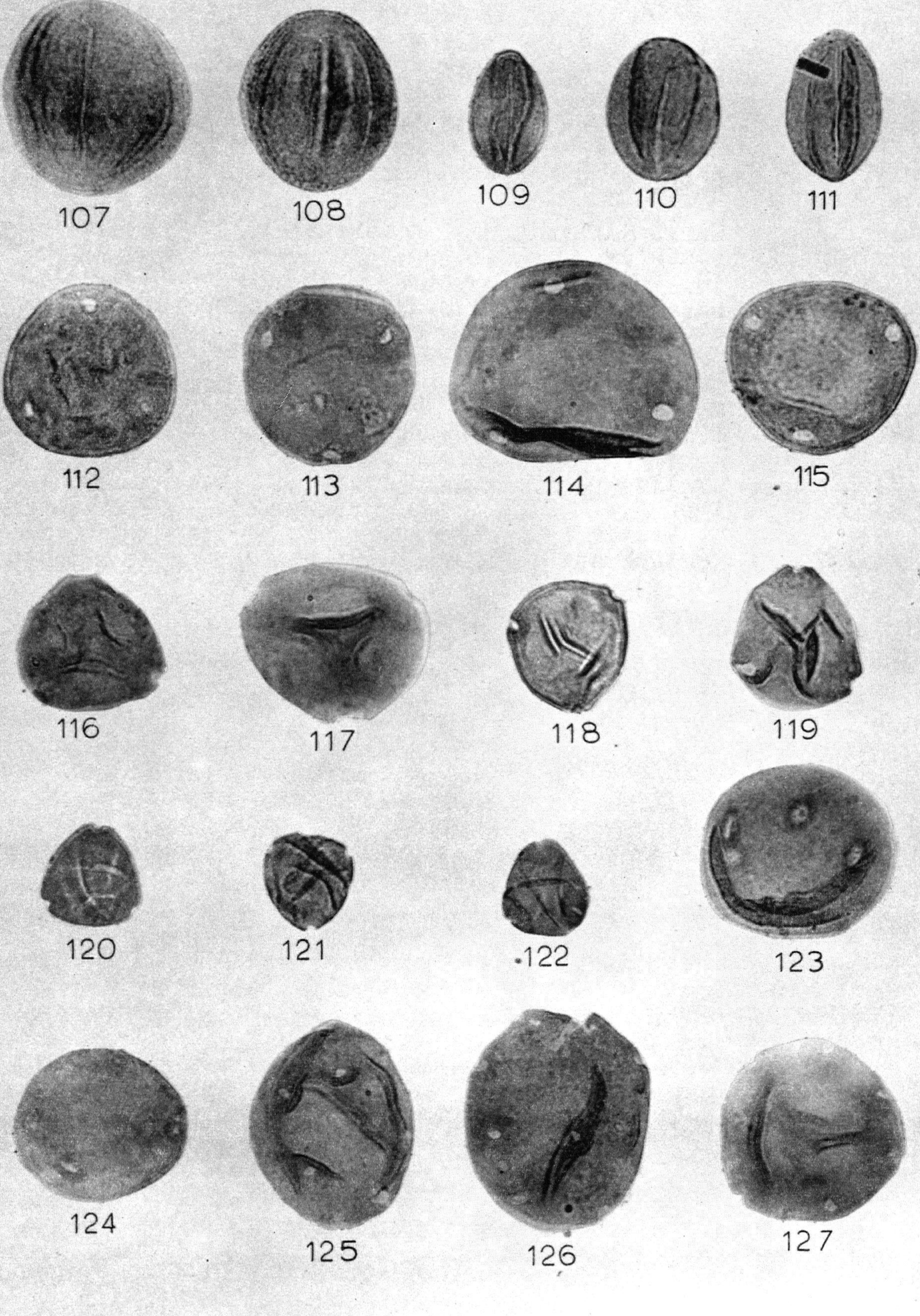
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PLATE 11

PLATE 11

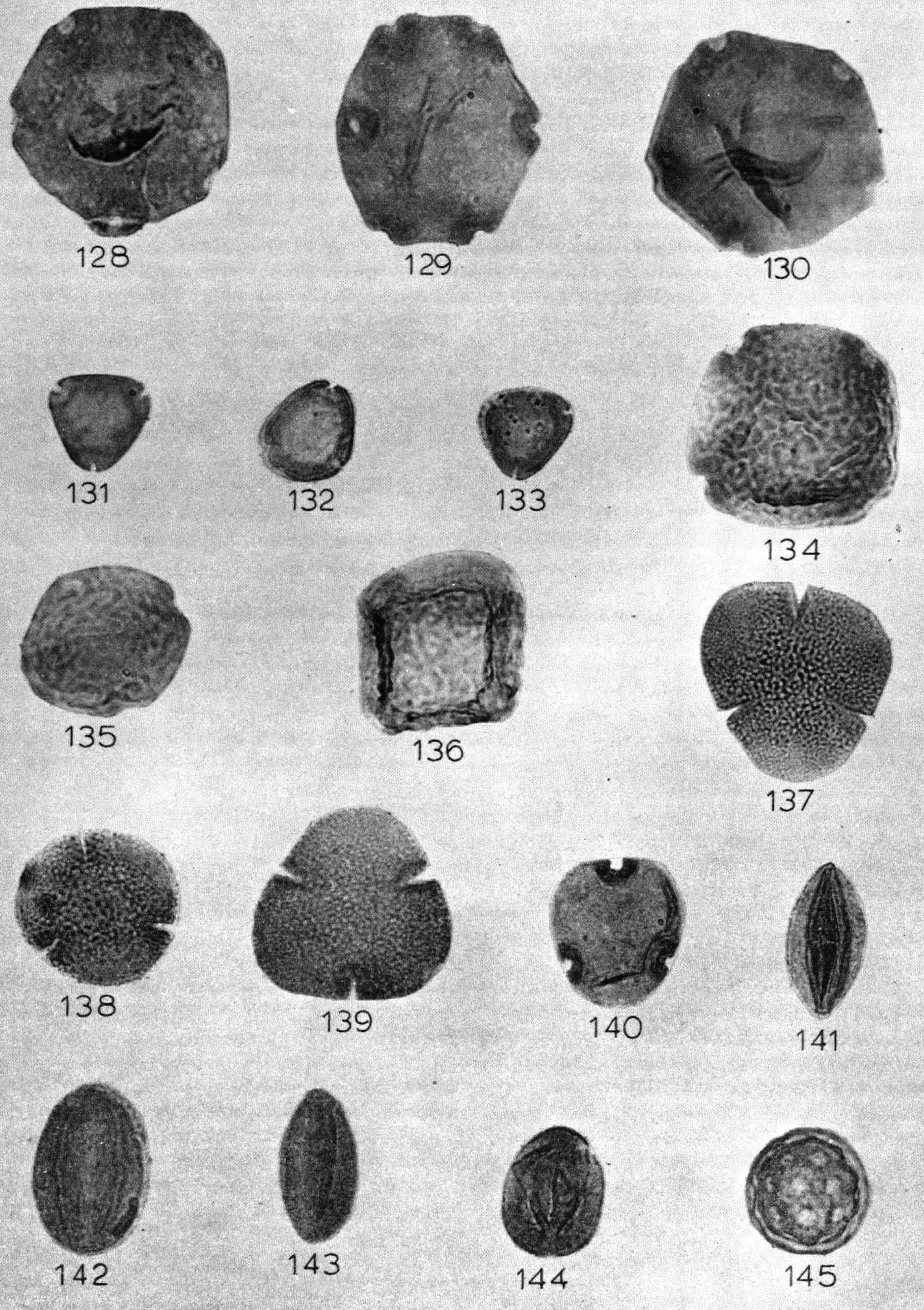
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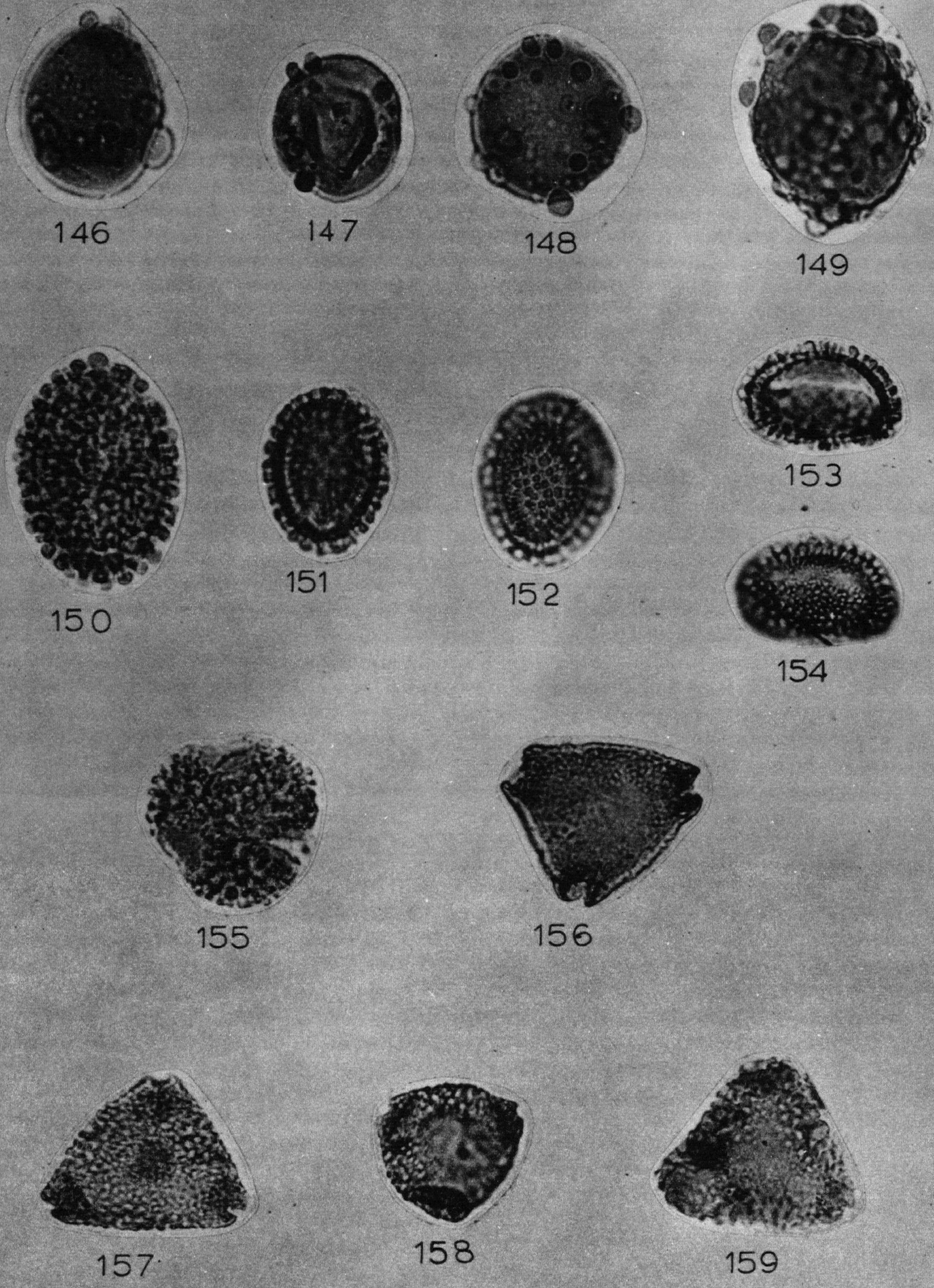
PLATE 12

PLATE 12



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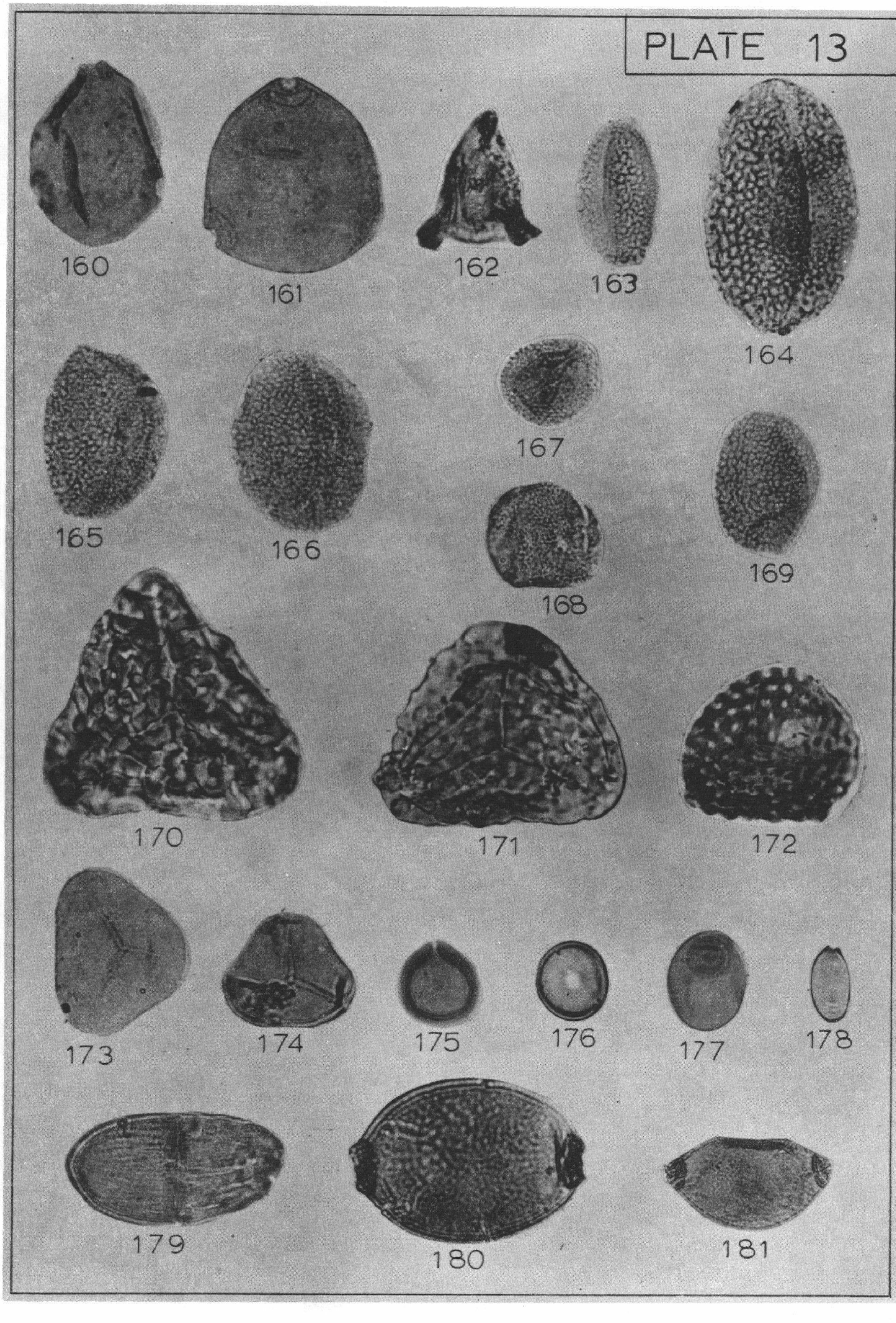
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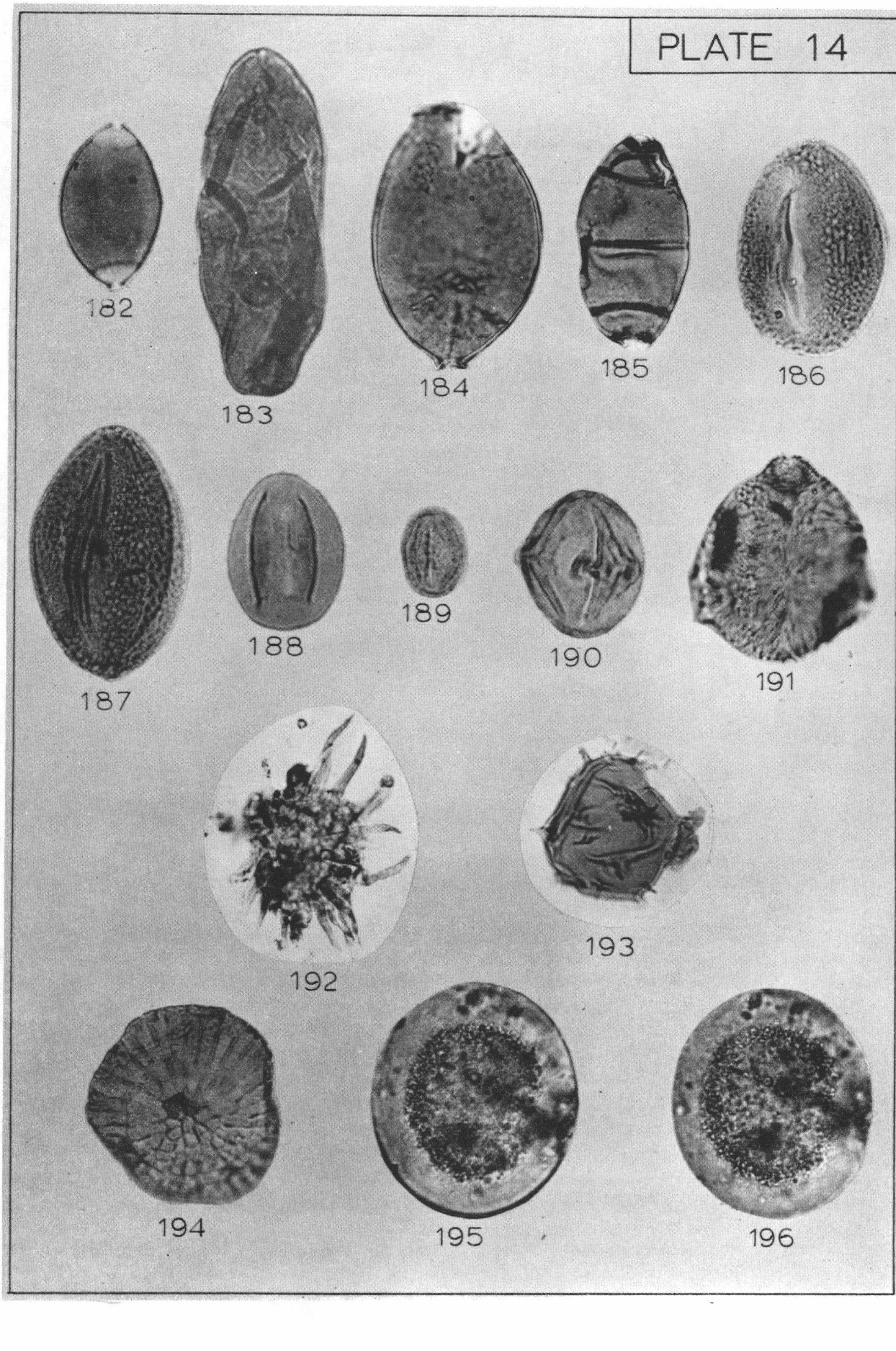
PLATE 13

PLATE 14

PLATE 14



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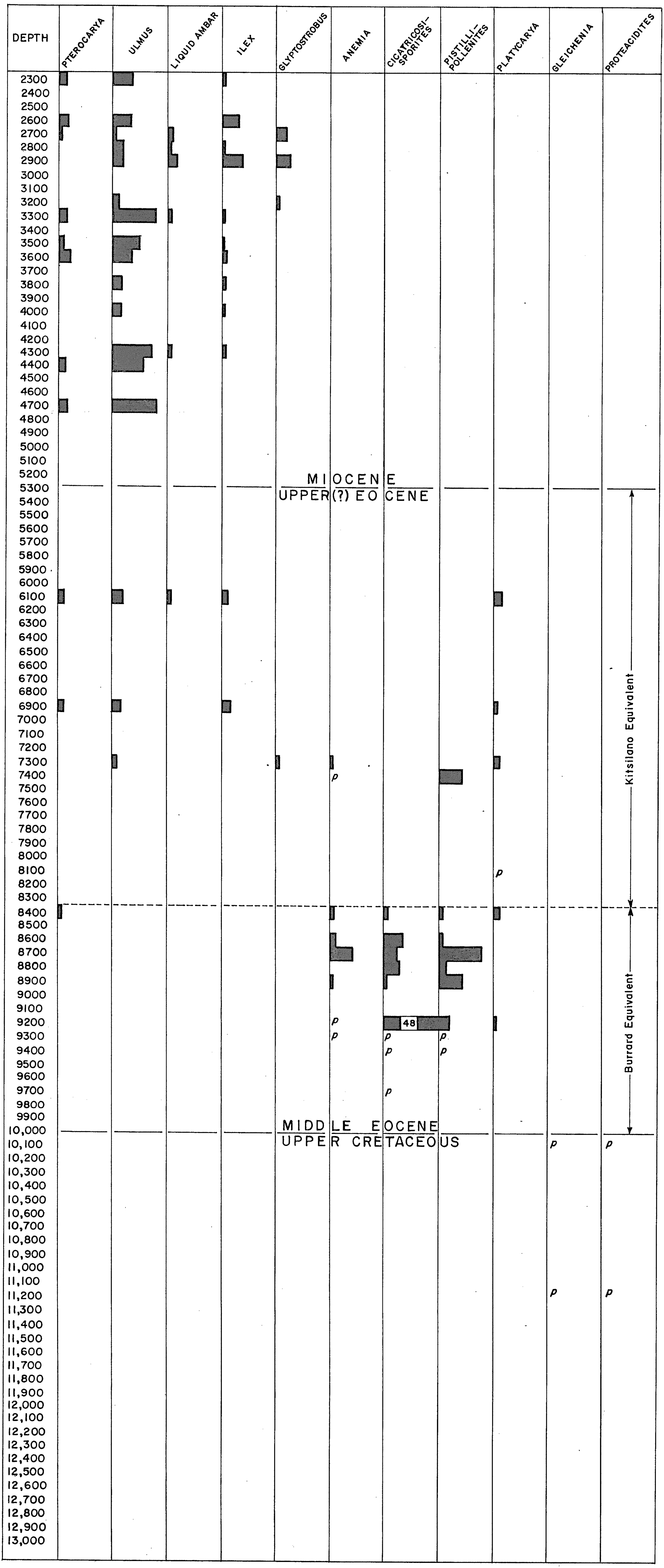


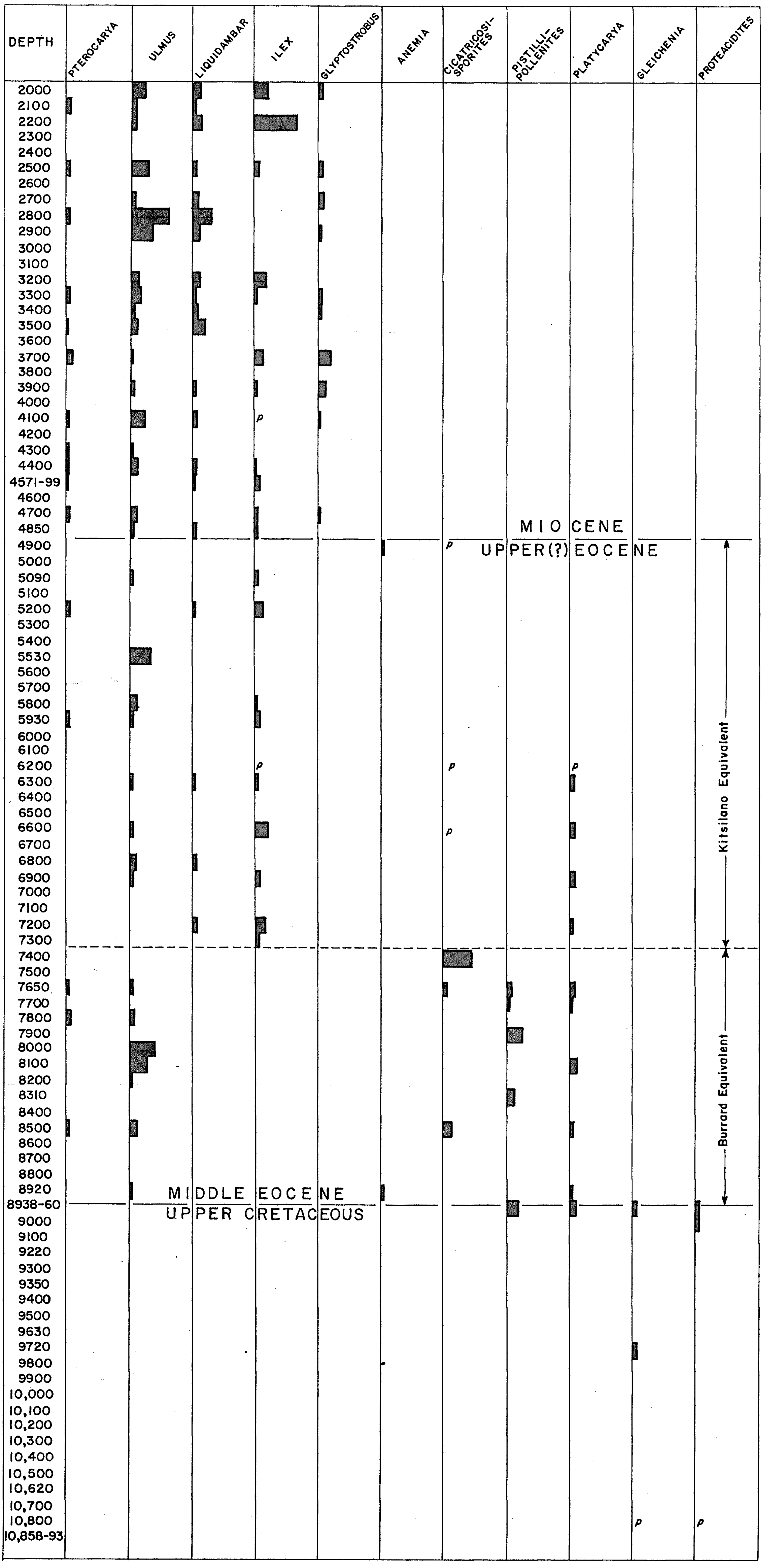
MICROFOSSIL FREQUENCY

POINT ROBERTS WELL

0 20

Percent of Total Fossil Count

TABLE B



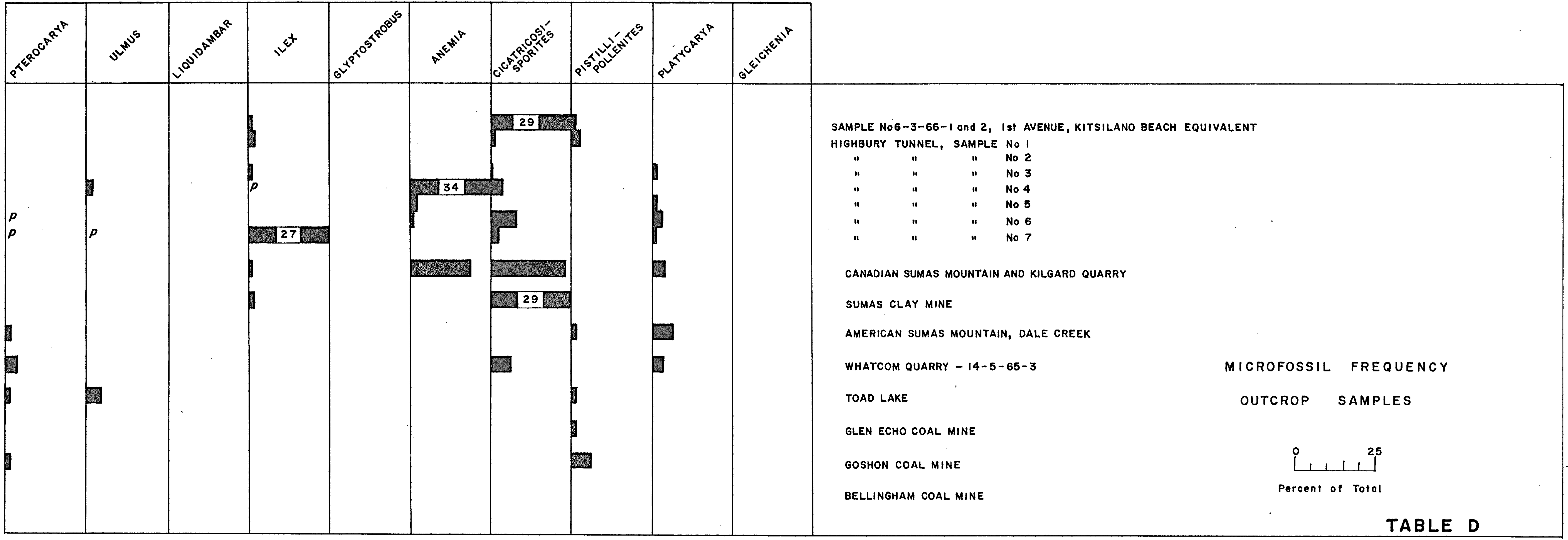
MICROFOSSIL FREQUENCY

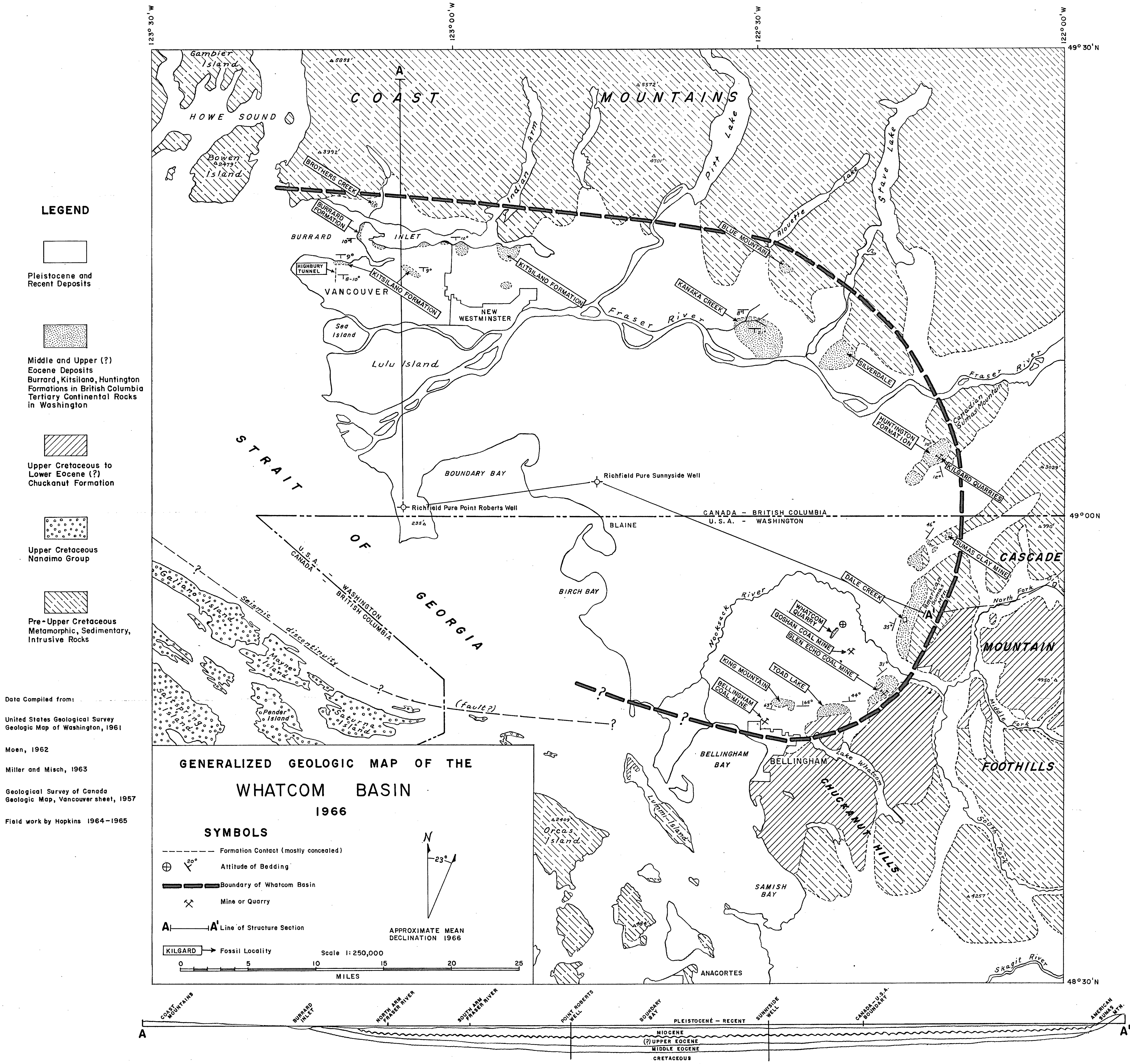
SUNNYSIDE WELL

0 20

Percent of Total Fossil Count

TABLE C


PTEROCARYA
ULMUS
LIQUIDAMBAR
ILEX
GLYPTOSTROBUS
ANEMIA
CICATRICOSI-SPORITES
PISTILLI-POLLENITES
PLATYCARYA
GLEICHENIA
29
34
27
29
p
p
p
p
SAMPLE No6-3-66-1 and 2, 1st AVENUE, KITSILANO BEACH EQUIVALENT
HIGHBURY TUNNEL, SAMPLE No 1
" " " No 2
" " " No 3
" " " No 4
" " " No 5
" " " No 6
" " " No 7
CANADIAN SUMAS MOUNTAIN AND KILGARD QUARRY
SUMAS CLAY MINE
AMERICAN SUMAS MOUNTAIN, DALE CREEK
WHATCOM QUARRY - 14-5-65-3
TOAD LAKE
GLEN ECHO COAL MINE
GOSHON COAL MINE
BELLINGHAM COAL MINE
MICROFOSSIL FREQUENCY
OUTCROP SAMPLES
0
25
Percent of Total
TABLE D



HYPOTHETICAL CROSS SECTION OF THE WHATCOM BASIN

Horizontal and Vertical Scale the Same

FIGURE D