9-1983

Palynostratigraphy of the Eocene Little River Section, Grays Harbor County, Washington

Roy E. Jensen

Abstract

PALYNOSTRATIGRAPHY OF THE EOCENE LITTLE RIVER SECTION
GRAYS HARBOR COUNTY, WASHINGTON

by

Roy E. Jensen

A total of 27 samples from Eocene marine rocks exposed along the Little River, Grays Harbor County, southwestern Washington were analyzed for palynomorphs. Strata studied included the Crescent Formation, "Sedimentary Rocks of Late Eocene Age", and the Lincoln Creek Formation. A total of 77 microfossil types were identified of which 32 were pollen and spores, 24 fungal remains, 18 dinoflagellate cysts, and 3 miscellaneous microfossils.

Based upon the stratigraphic distribution of 21 palynomorphs, three informal palynologic assemblage biozones were recognized. The oldest zone, Zone 1, of late early or early middle Eocene age, contains Platycaryapollenites, Platanoidites, Laevigatosporites type-2, trilete type-2 and D-6 dinoflagellates. Zone 2, of middle Eocene age, is recognized by the presence of Proteacidites, Laevigatosporites type-2, tricolpate reticulate type-1, trilete type-2, and D-14 and D-15 dinoflagellates. Zone 3, of late Eocene age, is recognized by Tsugapollenites, Bombacacidites, Tiliaepollenites, Selaginella, Inaperturopollenites type-2, and D-8 dinoflagellates. None of the palynozones established by previous Pacific Northwest palynologic investigations were recognized in this study.

LOMA LINDA UNIVERSITY

Graduate School

PALYNOSTRATIGRAPHY OF THE EOCENE LITTLE RIVER SECTION, GRAYS HARBOR COUNTY, WASHINGTON

by

Roy E. Jensen

A Thesis in Partial Fulfillment

of the Requirements for the Degree Master of Science

in Geology

September 1983

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

Lanny H. Fisk, Associate Professor of Geology, Chairman

Knut Andersson, Assistant Professor of Geology

H. Paul Buchheim, Assistant Professor of Geology

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INTRODUCTION

Purpose

The objective of this study was to investigate the palynology of Eocene marine rocks exposed along the Little River, Grays Harbor County, southwestern Washington (Figure 1). Data is presented on the sequence of pollen, spores and dinoflagellate cysts from the Little River section for the purpose of establishing palynologic assemblage zones and differentiating lithostratigraphic units based upon their characteristic palynoflora. Additionally, these palynologic assemblage zones are compared with established foraminiferal and palynologic biozones for the purpose of determining age relationships and attempting correlations between marine and nonmarine facies of rocks of similiar ages.

Previous Work

The biostratigraphy of Tertiary rocks in southwestern Washington has been primarily based upon zonations established for marine organisms, such as benthic foraminifera (Rau, 1981), mollusks (Armentrout, 1975; Addicott, 1976), calcareous nannofossils (Armentrout and Worsley, 1980), and diatoms (Barron, 1981) (Figure 2). The foraminiferal zonation developed by Rau and others (see Rau, 1981) is the best known biostratigraphic standard for marine sediments in the Pacific Northwest.

Figure 1. Index map of southwest Washington indicating the location of the study area.

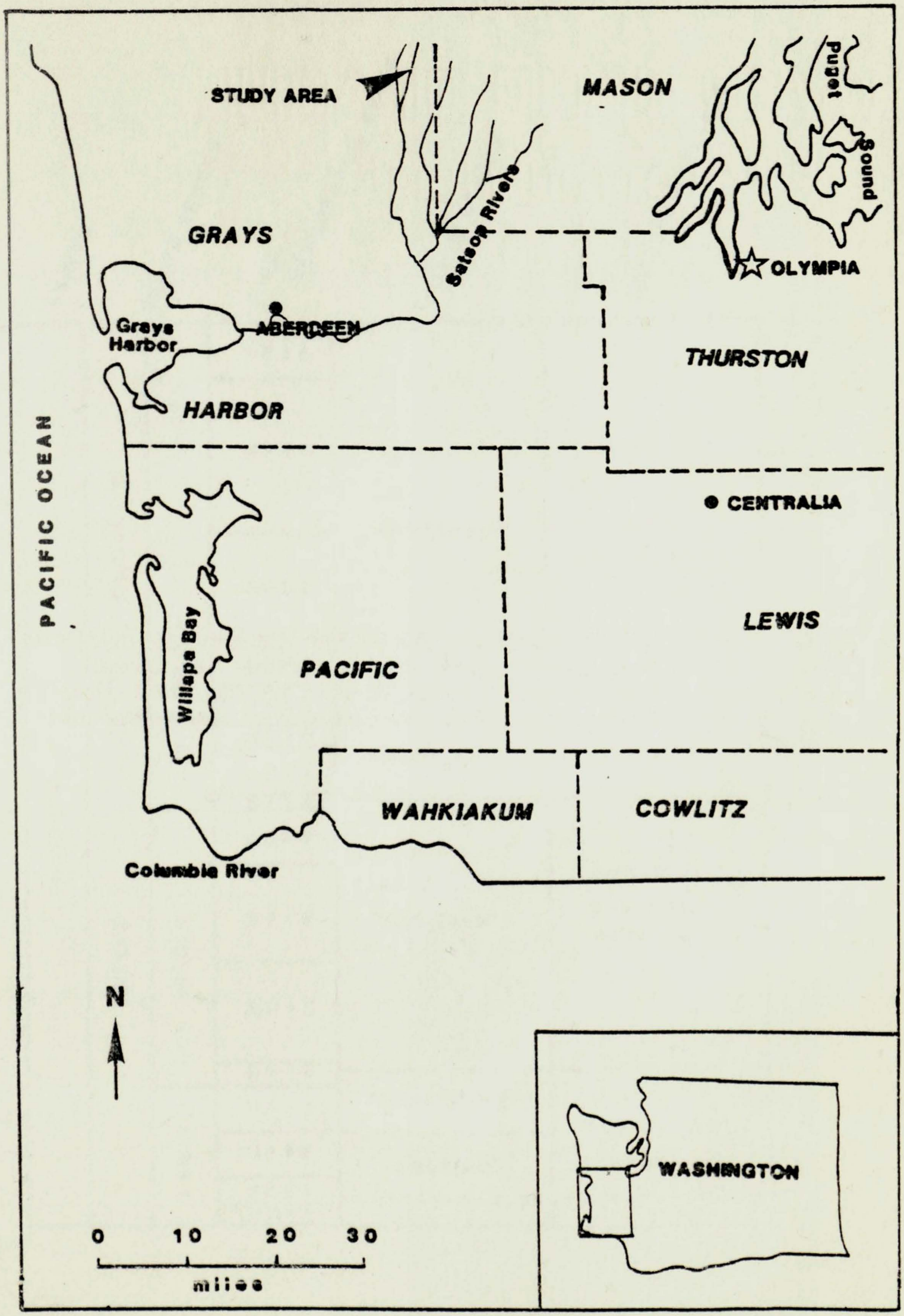
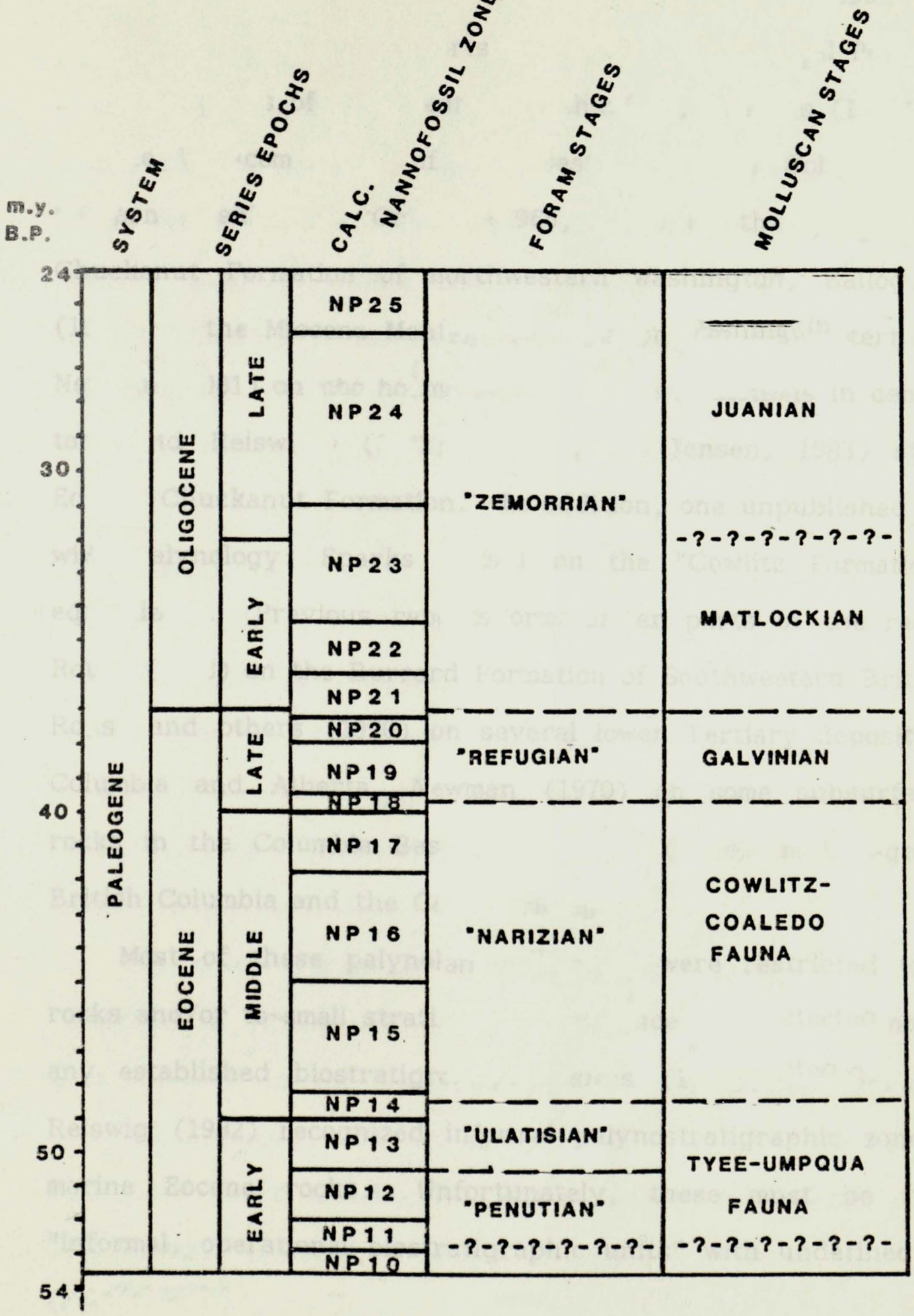

STUDY AREA
MASON
Puget
Sound
GRAYS
Satsop Rivers
OLYMPIA
Grays
Harbor
ABERDEEN
THURSTON
HARBOR
PACIFIC OCEAN
CENTRALIA
Willapa Bay
LEWIS
PACIFIC
WAHKIAKUM
COWLITZ
Columbia River
N
0 10 20 30
miles
WASHINGTON

Figure 2. Correlation of Pacific Northwest Eo-Oligocene foraminiferal and molluscan stages and world wide calcareous nannofossil biostratigraphic units with geologic time scale (modified after Armentrout, 1981; calc. nannofossil zones from Hardenbol and Berggren, 1978).


m.y. B.P.
SYSTEM
SERIES EPOCHS
CALC. NANNOFOSSIL ZONES
FORAM STAGES
MOLLUSCAN STAGES
24
30
40
50
54
PALEOGENE
OLIGOCENE
EOCENE
LATE
EARLY
LATE
MIDDLE
EARLY
NP25
NP24
NP23
NP22
NP21
NP20
NP19
NP18
NP17
NP16
NP15
NP14
NP13
NP12
NP11
NP10
"ZEMORRIAN"
"REFUGIAN"
"NARIZIAN"
"ULATISIAN"
"PENUTIAN"
-?-?-?-?-?-?-
JUANIAN
MATLOCKIAN
GALVINIAN
COWLITZ-
COALEDO
FAUNA
TYEE-UMPQUA
FAUNA
-?-?-?-?-?-?-

In constrast to marine organisms, little work has been published on the palynostratigraphy of Tertiary sediments in western Washington and Oregon. Previous reports include: Crickmay and Pocock (1963) on Paleogene rocks of northwestern Washington, Hopkins (1966, 1968, 1969) on the Whatcom Basin of southwestern British Columbia and northwestern Washington, Griggs (1965, 1970) on the type section of the Chuckanut Formation of northwestern Washington, Ballog and others (1972) on the Miocene Montesano Formation of southwestern Washington, Newman (1981) on the nonmarine Paleogene formations in central Washington, and Reiswig's (1982; Reiswig and Jensen, 1983) study of the Eocene Chuckanut Formation. In addition, one unpublished thesis deals with palynology: Sparks (1970) on the "Cowlitz Formation" and its equivalents. Previous reports from other parts of the region include Rouse (1962) on the Burrard Formation of Southwestern British Columbia, Rouse and others (1970) on several lower Tertiary deposits in British Columbia and Alberta, Newman (1970) on some subsurface Tertiary rocks in the Columbia Basin, and Rouse (1977) on Paleogene rocks in British Columbia and the Canadian Arctic.

Most of these palynological studies were restricted to nonmarine rocks and/or to small stratigraphic sequences which could not be tied to any established biostratigraphy. Rouse (1977), Newman (1981), and Reiswig (1982) recognized informal palynostratigraphic zones for nonmarine Eocene rocks. Unfortunately, these must be regarded as "informal, operational biostratigraphic units" with undefined boundaries (Newman, 1981; Reiswig, personal communication 1983).

GEOLOGY

General Statement

Tertiary rocks in southwestern Washington measure nearly 13,000 feet thick and have been mapped as nine formational units (Figure 3). These rocks crop out in several structural basins separated and underlain by early to middle Eocene volcanics (Figure 4). These strata consist primarily of marine sedimentary and volcanic rocks. Excellent summaries of the Tertiary geologic history of southwestern Washington are found in Snavely and Wagner (1963) and Armentrout (1977).

Stratigraphy

The geology of the Little River area was first studied by Rau (1966) as part of a larger regional study of Tertiary benthic foraminiferal faunas. Rau (1966) assigned rocks in the Little River section to three litho-stratigraphic units: from oldest to youngest, the Crescent Formation, "Sedimentary Rocks of Late Eocene Age", and the Lincoln Creek Formation.

The oldest rocks in the section were assigned to the Crescent Formation of Arnold (1906). The type area for the formation is at Crescent Bay in the northern part of the Olympic Peninsula. The Crescent Formation consists of aphanitic to porphyritic augite-rich basalts with minor interbedded marine sedimentary rocks (Rau, 1966). The volcanic flows show extensive pillow structures, flow breccia and

Figure 3. Stratigraphic column for southwestern Washington (after Armentrout, 1975).

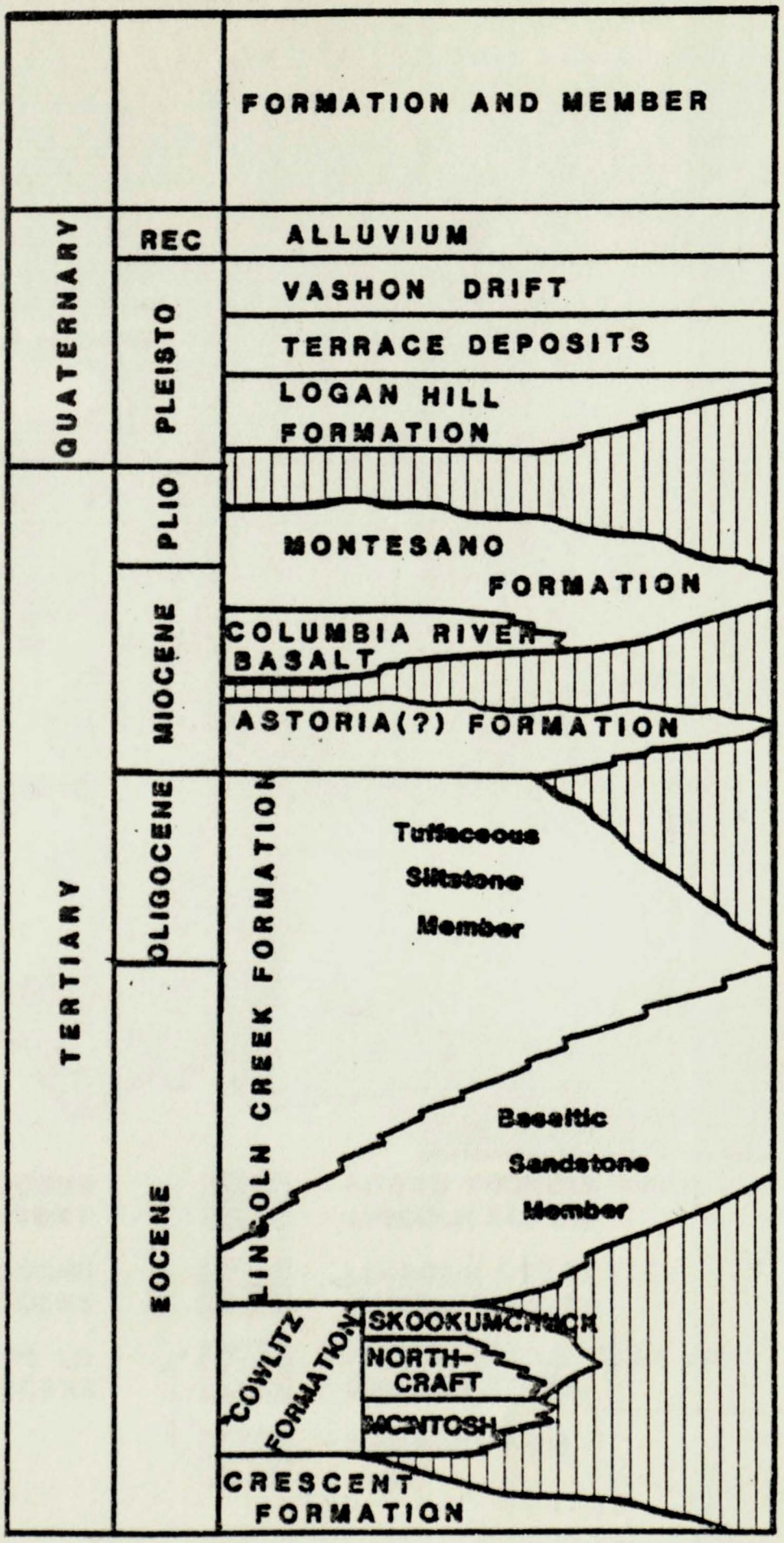
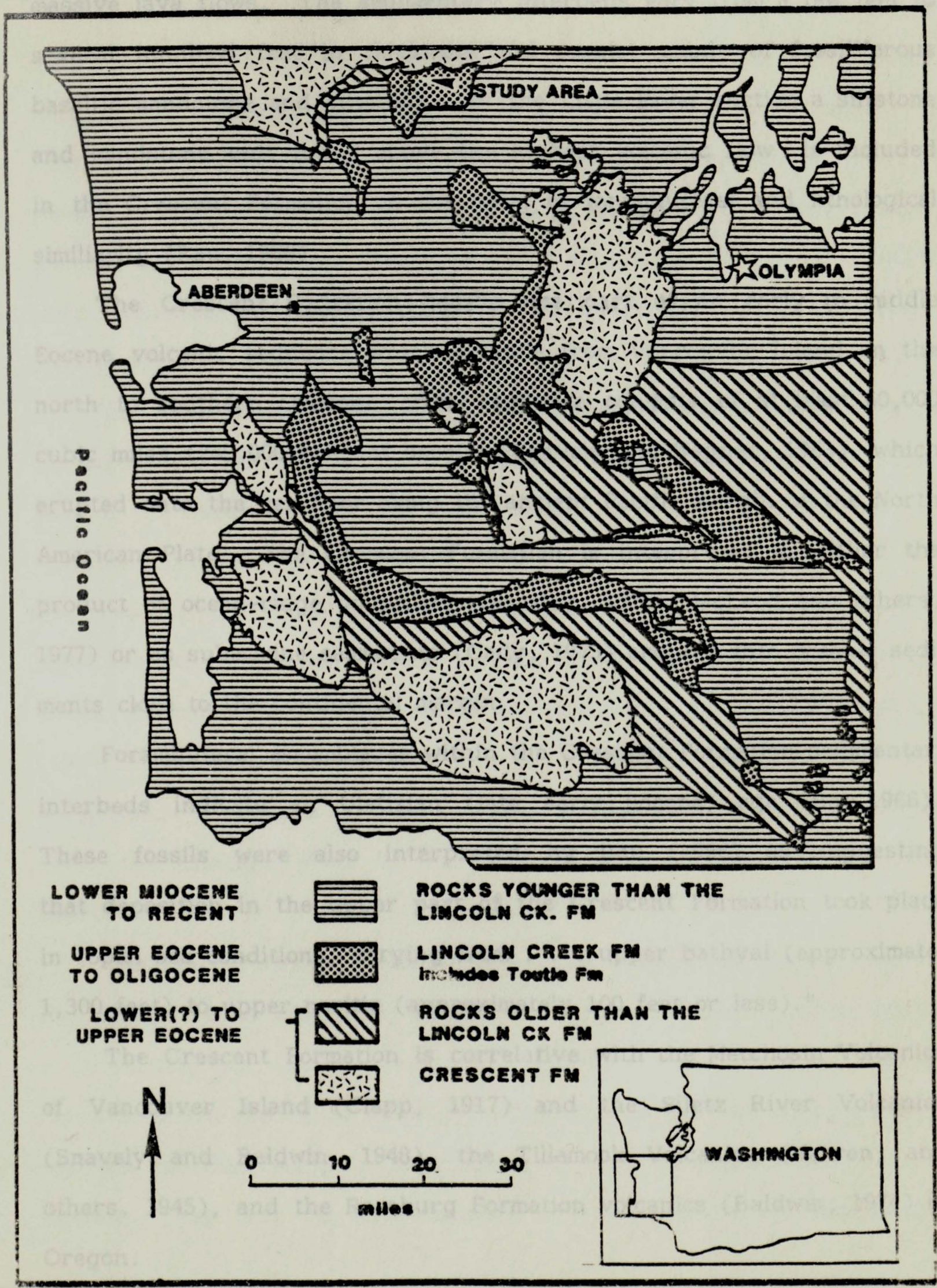

FORMATION AND MEMBER
QUATERNARY
REC
ALLUVIUM
PLEISTO
VASHON DRIFT
TERRACE DEPOSITS
LOGAN HILL FORMATION
PLIO
MONTESANO FORMATION
MIOCENE
COLUMBIA RIVER BASALT
ASTORIA(?) FORMATION
TERTIARY
OLIGOCENE
LINCOLN CREEK FORMATION
Tuffaceous Siltstone Member
Basaltic Sandstone Member
EOCENE
COWLITZ FORMATION
SKOOKUMCHUCK
NORTH-CRAFT
MCINTOSH
CRESCENT FORMATION

Figure 4. Generalized geologic map of southwestern Washington (after Armentrout, 1975).


STUDY AREA
ABERDEEN
OLYMPIA
Pacific Ocean
LOWER MIOCENE TO RECENT
ROCKS YOUNGER THAN THE LINCOLN CK. FM
UPPER EOCENE TO OLIGOCENE
LINCOLN CREEK FM
Includes Toutle Fm
LOWER(?) TO UPPER EOCENE
ROCKS OLDER THAN THE LINCOLN CK FM
CRESCENT FM
N
0 10 20 30
miles
WASHINGTON

massive lava flows. The sedimentary interbeds vary from a few feet to several hundred feet in thickness and consist mainly of fossiliferous basaltic sandstone and siltstone. In the Little River section a siltstone and sandstone unit found above the highest volcanic flow is included in the Crescent Formation on the basis of foraminiferal and lithological similiarity (Rau, 1966).

The Crescent Formation basalts are part of an early to middle Eocene volcanic sequence which extends from Vancouver Island on the north to southern Oregon. This sequence consists of at least 60,000 cubic miles (240,000 km^3) of basalts (Snavely and Wagner, 1963), which erupted onto the sea floor along the ancient Pacific margin of the North American Plate. The Crescent Formation is interpreted as either the product of ocean-ridge volcanism (Glassley, 1975; MacLeod and others, 1977) or as submarine seamounts (Cady, 1975) erupted into oceanic sediments close to the continental margin.

Foraminiferal assemblages within the Crescent Formation sedimentary interbeds indicate an Ulatisian (late early Eocene) age (Rau,1966). These fossils were also interpreted by Rau (1966) as suggesting that deposition in the upper part of the Crescent Formation took place in "open sea conditions, varying from . . . upper bathyal (approximately 1,300 feet) to upper neritic (approximately 100 feet or less)."

The Crescent Formation is correlative with the Metchosin Volcanics of Vancouver Island (Clapp, 1917) and the Siletz River Volcanics (Snavely and Baldwin, 1948), the Tillamook Volcanics (Warren, and others, 1945), and the Roseburg Formation volcanics (Baldwin, 1974) in Oregon.

Unconformably overlying the Crescent Formation are rocks which Rau (1966) called the "Sedimentary Rocks of Late Eocene Age." This unit is approximately 1800 feet thick in the Little River section. It consists of thin-bedded micaceous mudstone, siltstone, and silty sandstone. Foraminiferal faunas of this unit indicate a Narizian (middle Eocene) age according to Rau (1966) who suggested that these sediments were deposited within the upper part of the bathyal depth zone (800-3000 feet).

The "Sedimentary Rocks of Late Eocene Age" are correlated with the upper part of the McIntosh Formation (Snavely and others, 1951), part of the Skookumchuck Formation (Snavely and others, 1958), and the "Cowlitz Formation" (Weaver, 1912, 1937).

Resting conformably on the "Sedimentary Rocks of Late Eocene Age" are strata assigned to the Lincoln Creek Formation. The Lincoln Creek Formation was named and described by Beikman and others (1967) in the Grays Harbor area to replace Weaver's (1912) name Lincoln Formation. The type section includes a composite of many sections along the Chehalis River in the Centralia area (Beikman and others, 1967).

The Lincoln Creek Formation is a thick sequence primarily consisting of tuffaceous mudstone, siltstone, and sandstone. In the Satsop River area, Rau (1966) divided the Lincoln Creek Formation into 10 "local members" based on lithology. Only the bottom four members were sampled in this study. Beginning with the stratigraphically lowest member, they are: a basal member (Tl-1) of massive, fossiliferous

basaltic sandstone; a massive tuffaceous siltstone member (Tl-2) containing concretions; member Tl-3 consisting of interbedded tuffaceous and poorly sorted sandstone; and finally member Tl-4 composed mainly of thickly-bedded, poorly-sorted conglomerate interbedded with massive siltstone.

Fossils from the Lincoln Creek Formation indicate an age ranging from late Eocene to early Oligocene (Armentrout, 1975, 1981). Foraminiferal faunas are assigned to the Refugian and Zemmorian stages (Rau, 1958, 1966). Rau (1966) concluded that the Lincoln Creek Formation was deposited in the upper bathyal depth zone in open-sea conditions.

The Lincoln Creek Formation is correlated with the Blakely Formation (Tegland, 1933; Weaver, 1937; Fulmer, 1975) in the Puget Sound area and part of the Twin River Formation (Brown and Gower, 1958; Rau, 1964) of the northern Olympic Peninsula.

MATERIALS AND METHODS

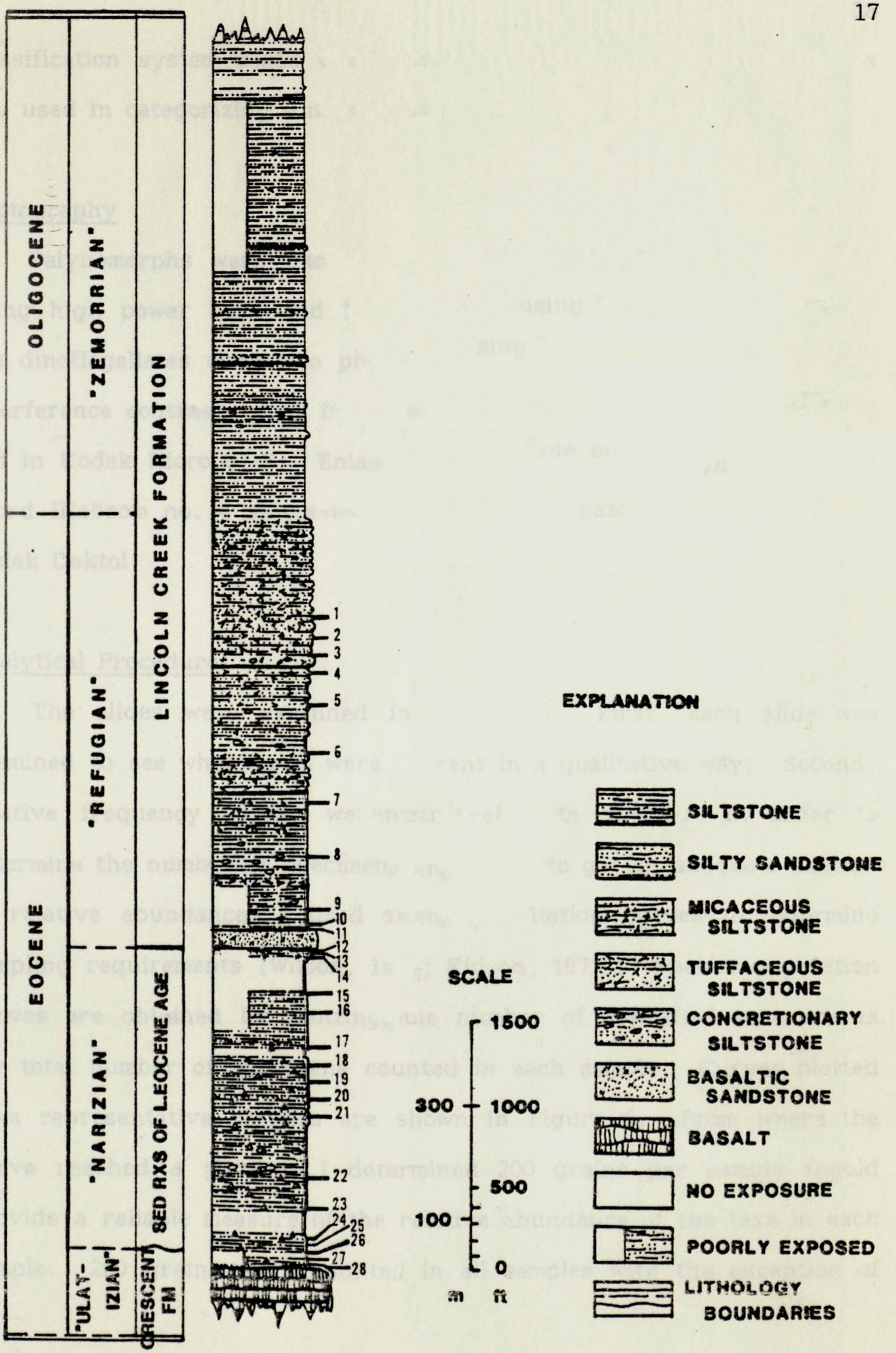
Sampling

The Little River is located in the Satsop River area, Grays Harbor County, southwestern Washington (Figure 1). The bottom of the section begins in NW ¼, NE ¼ Section 14 R7W T22N and extends to NW ¼, SE ¼ Section 27 R7W T2lN. Twenty-eight samples (Figure 5) were collected from the Little River section by John Armentrout in 1972 for Humble Oil and Refining Co., Exploration Division (now known as Exxon Company, U.S.A.). Twenty-seven of the twenty-eight samples were processed at Exxon's palynology lab in Houston using Exxon standard palynological processing techniques. The lowermost sample was not processed, presumably because it was coarse sandstone. Slides and residues of palynological preparations were obtained through the courtesy of Dr. William Elsik and the Exxon Company, U.S.A.

Identification

Palynomorphs discovered on the slides were first photographed and prints of each form were mounted on 5x7" cards. Identifications and taxonomic nomenclature of fossil pollen and spores was based upon the Jansonius and Hill (1976) Genera File of Fossil Spores and Pollen. This reference provides a readily accessible standardized means by which other palynologists can determine what criteria have been used for identifying individual taxa of pollen and spores. Pollen and spores in most cases were identified to form-genera. Elsik (1981) was found to be very useful in the taxonomy of fungal remains. An artificial

Figure 5. Columnar section of rock strata in the Little River section showing location of palynology samples (after Rau, 1966).


OLIGOCENE
"ZEMORRIAN"
"REFUGIAN"
LINCOLN CREEK FORMATION
EOCENE
"NARIZIAN"
SED RXS OF LEOCENE AGE
"ULAT-IZIAN"
CRESCENT FM
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
EXPLANATION
SCALE
1500
300
1000
500
100
0
m
ft
SILTSTONE
SILTY SANDSTONE
MICACEOUS SILTSTONE
TUFFACEOUS SILTSTONE
CONCRETIONARY SILTSTONE
BASALTIC SANDSTONE
BASALT
NO EXPOSURE
POORLY EXPOSED
LITHOLOGY BOUNDARIES

classification system based upon broadly defined morphological features was used in categorizing dinoflagellate cysts.

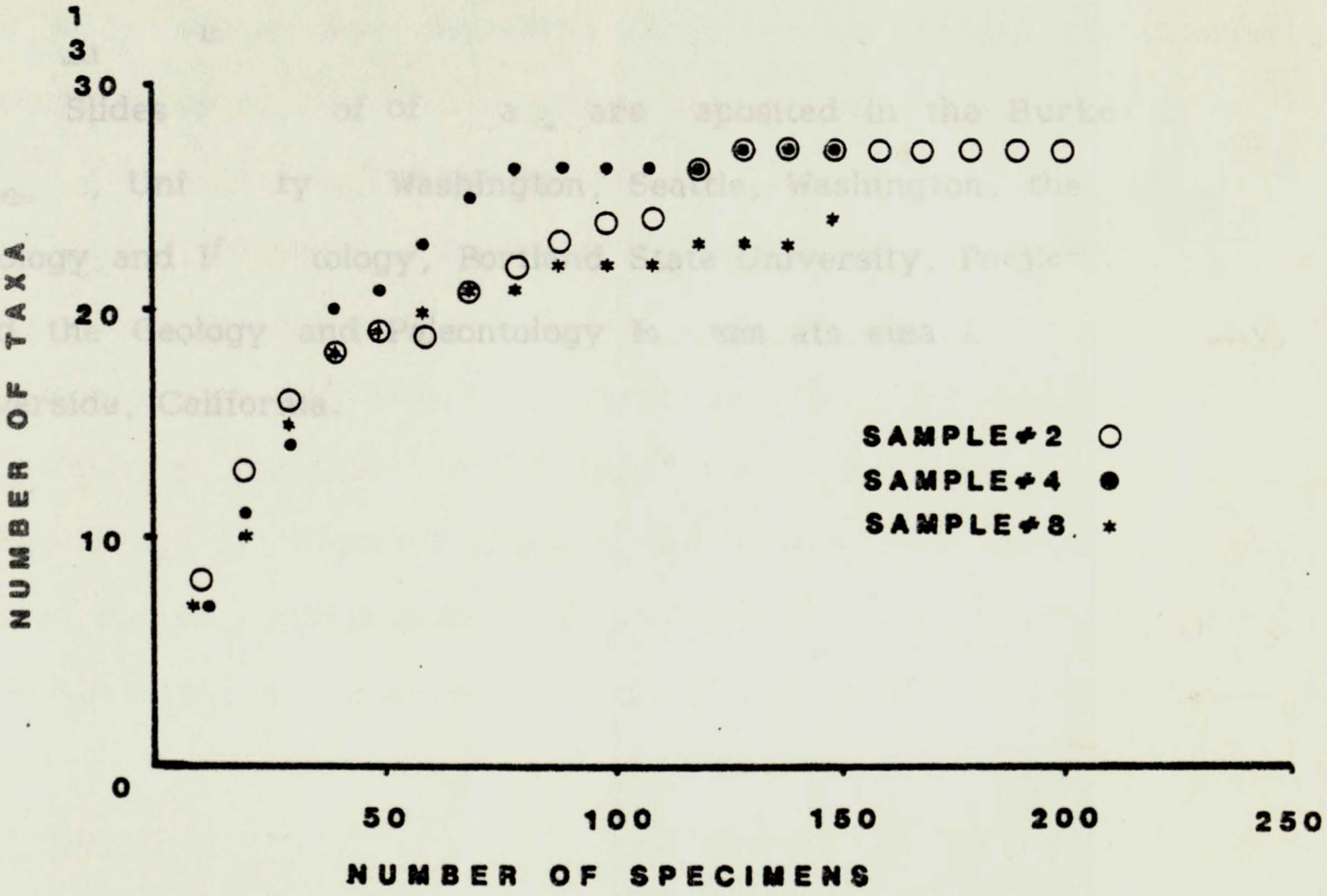
Photography

Palynomorphs were photographed with a Zeiss Photomicroscope III using high power (40X and 100X) planachromatic objectives. Most of the dinoflagellates were also photographed using differential (Nomarski) interference contrast. The film Kodak Panatomic X was used and processed in Kodak Microdol-X. Enlargements were made on black and white Ilford Ilfobrom no. 4 single-weight photographic paper developed using Kodak Dektol.

Analytical Procedure

The slides were examined in two ways: First, each slide was examined to see what forms were present in a qualitative way. Second, relative frequency counts were made of each sample. In order to determine the number of specimens necessary to get an adequate measure of relative abundance, I used species-population curves to determine sampling requirements (Wilson, 1959; Kidson, 1971). Species-population curves are obtained by plotting the number of identified taxa versus the total number of specimens counted in each sample. Curves plotted from representative samples are shown in Figure 6. From where the curve reached a plateau, I determined 200 grains per sample should provide a reliable measure of the relative abundance of the taxa in each sample. 200 grains were counted in all samples with the exception of

Figure 6. Species-population curves for three samples used to determine sampling requirement for pollen counts.


NUMBER OF TAXA
1
3
30
20
10
0
50
100
150
200
250
NUMBER OF SPECIMENS
SAMPLE #2
SAMPLE #4
SAMPLE #8

sample #25 which contained insufficient grains on the slides provided by Exxon. These data were used to plot a relative frequency diagram for the section.

Slide Repository

Slides used in this study are deposited in the Burke Memorial Museum, University of Washington, Seattle, Washington, the Museum of Geology and Paleontology, Portland State University, Portland, Oregon, and the Geology and Paleontology Museum at Loma Linda University, Riverside, California.

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RESULTS

General Statement

The samples from the Little River section yielded an abundant assemblage of pollen, spores, fungal remains, and dinoflagellate cysts. Lists of identified palynomorphs from the Little River section are shown on Tables 1, 2, and 3. A total of 77 types were identified of which 32 were pollen and spores, 24 fungal remains, 18 dinoflagellate cysts, and 3 miscellaneous microfossils. The stratigraphic distribution of the palynomorphs identified within the Little River section is shown in Plates 1 and 2. Figure 7 presents the relative percentage of pteridophyte spores, gymnosperm and angiosperm pollen, fungal remains, dinoflagellates, and miscellaneous microfossils present in each sample.

Palynozonation

Three zones based on plant microfossils have been established for the Little River section. The zonation is based on the stratigraphic ranges of 21 selected palynomorphs. The stratigraphic distribution of these diagnostic palynomorphs is summarized in Figure 8. Stratigraphic ranges of dinoflagellates are shown in Figure 9.

The stratigraphically lowest zone is characterized by the presence of Platycaryapollenites, Platanoidites, and the dinoflagellates D-6 and D-3. Absent from Zone 1 are Trilites solidus, tricolpate reticulate type-1, and D-14 and D-15 dinoflagellates. Zone 1 is represented by

TABLE I

List of pollen and spores identified from the Little River section

GYMNOSPERMS

Inaperturopollenites type-1
Inaperturopollenites type-2
Pityosporites sp.
Podocarpidites sp.
Tsugapollenites sp.

PTERIDOPHYTES

Cicatricosisporites sp.
Deltoidospora sp.
Laevigatosporites type-1
Laevigatosporites type-2
Lycopodium sp..
Osmundacidites sp.
Polypodiidites sp.
Polypodiisporonites sp.
Selaginella sp.
Trilites solidus (Potonie) Krutzsh
Trilete type-1
Trilete type-2
Trilete type-3

ANGIOSPERMS

Bombacacidites sp.
Caryapollenites sp.
Ilexpollenites sp.
Ludwigia sp.
Momipites sp.
Monocolpopollenites sp.
Pistillipollenites mcgregorii Rouse
Platycaryapollenites sp.
Platanoidites sp.
Polyvestibulopollenites sp.
Proteacidites sp.
Pterocaryapollenites sp.
Tiliaepollenites sp
Tricolpate reticulate type-1

TOTAL 32 types

TABLE 2

List of fungal remains identified from the Little River section

Brachysporisporites sp.
Dicellaesporites type-1
Dicellaesporites type-2
Didymoporisporonites sp.
Dyadosporites sp.
Inapertisporites type-1
Inapertisporites type-2
Inapertisporites type-3
Monoporisporites sp.
Multicellaesporites sp.
Reduviasporonites sp.
Pesavis sp.
Polyadosporites type-1
Polyadosporites type-2
Polyporisporites sp.
Pluricellaesporites sp.
Striadiporites type-1
Striadiporites type-2
Dicell type-3
hyphae type-1
hyphae type-2
hyphae type-3
hyphae type-4
Microthriaceae

TOTAL 24 types

TABLE 3

List of dinoflagellate and miscellaneous microfossils identified from the Little River section

DINOFLAGELLATE CYSTS

Deflandrea sp.
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10
D-11
D-12
D-13
D-14
D-15
D-16
D-17

TOTAL 18 types

MISCELLANEOUS TYPES

Thyttadiscus sp.
scolecodonts
microforams

TOTAL 3 types

Figure 7. Relative abundance of the palynomorph types from the Little River section.

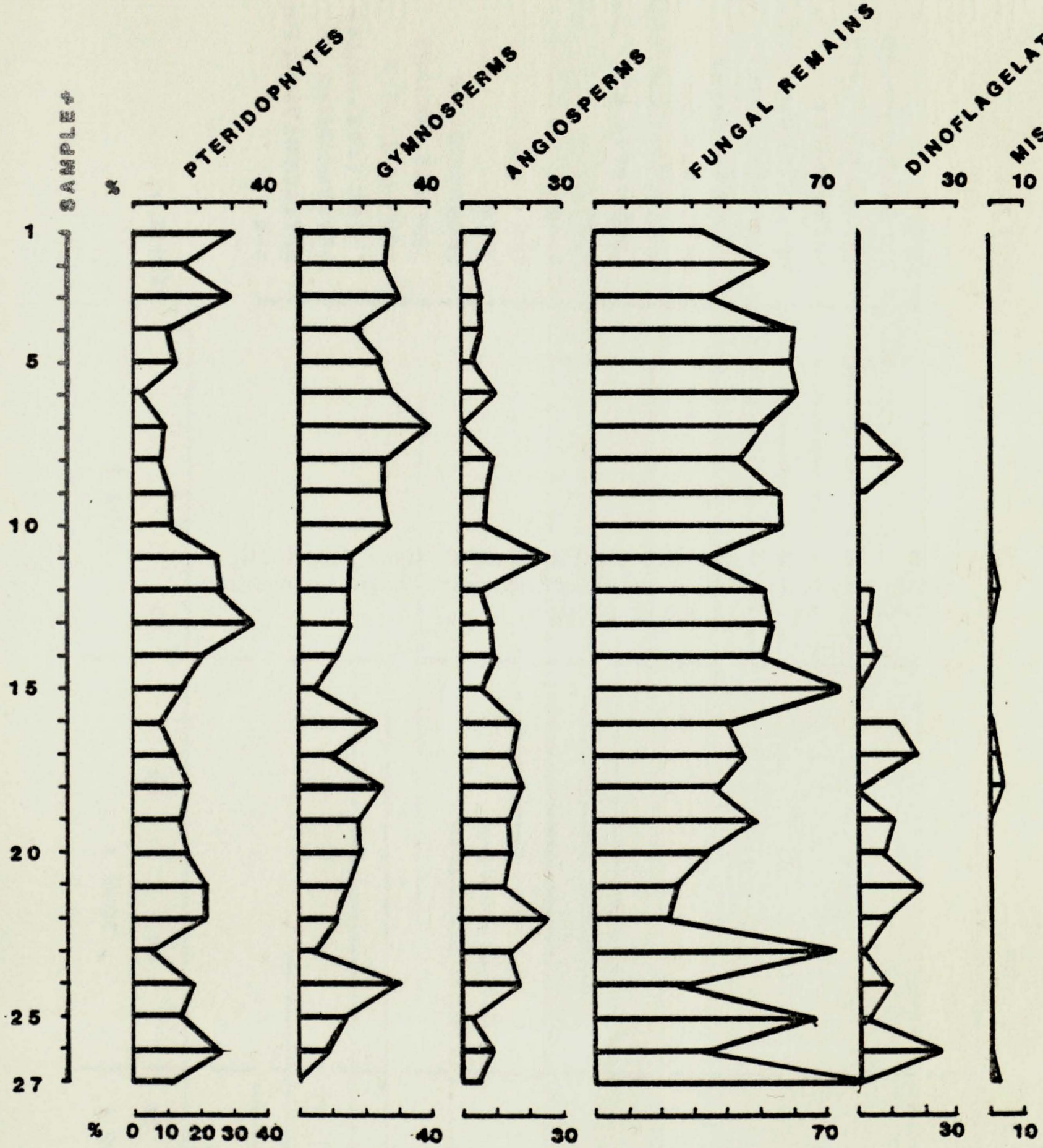

SAMPLE #
%
PTERIDOPHYTES
GYMNOSPERMS
ANGIOSPERMS
FUNGAL REMAINS
DINOFLAGELATES
MISC
40
40
30
70
30
10
1
5
10
15
20
25
27
% 0 10 20 30 40
40
30
70
30
10

Figure 8. The stratigraphic distribution of some diagnostic palynomorphs used in establishing palynologic assemblage zones in the Little River section.

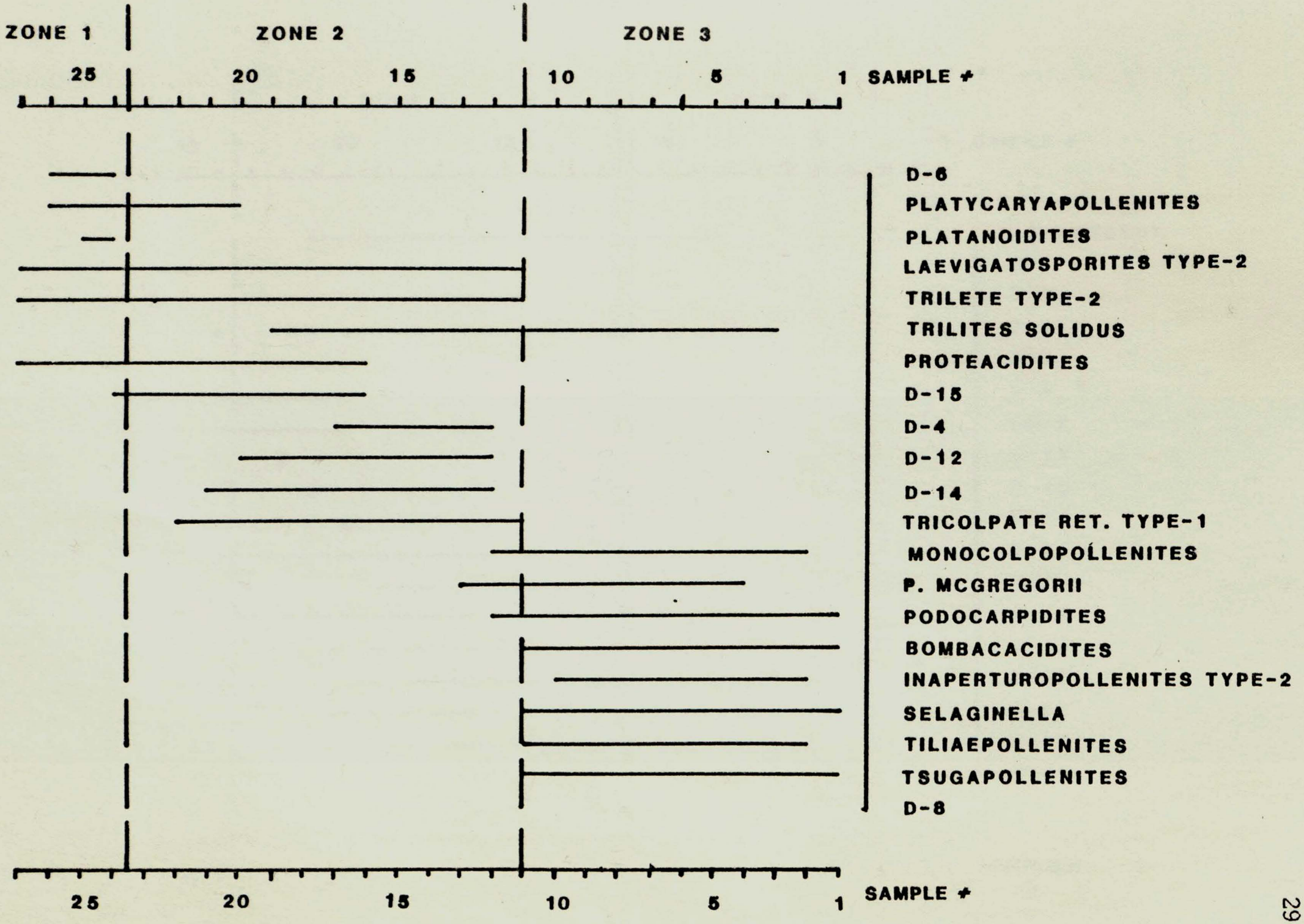
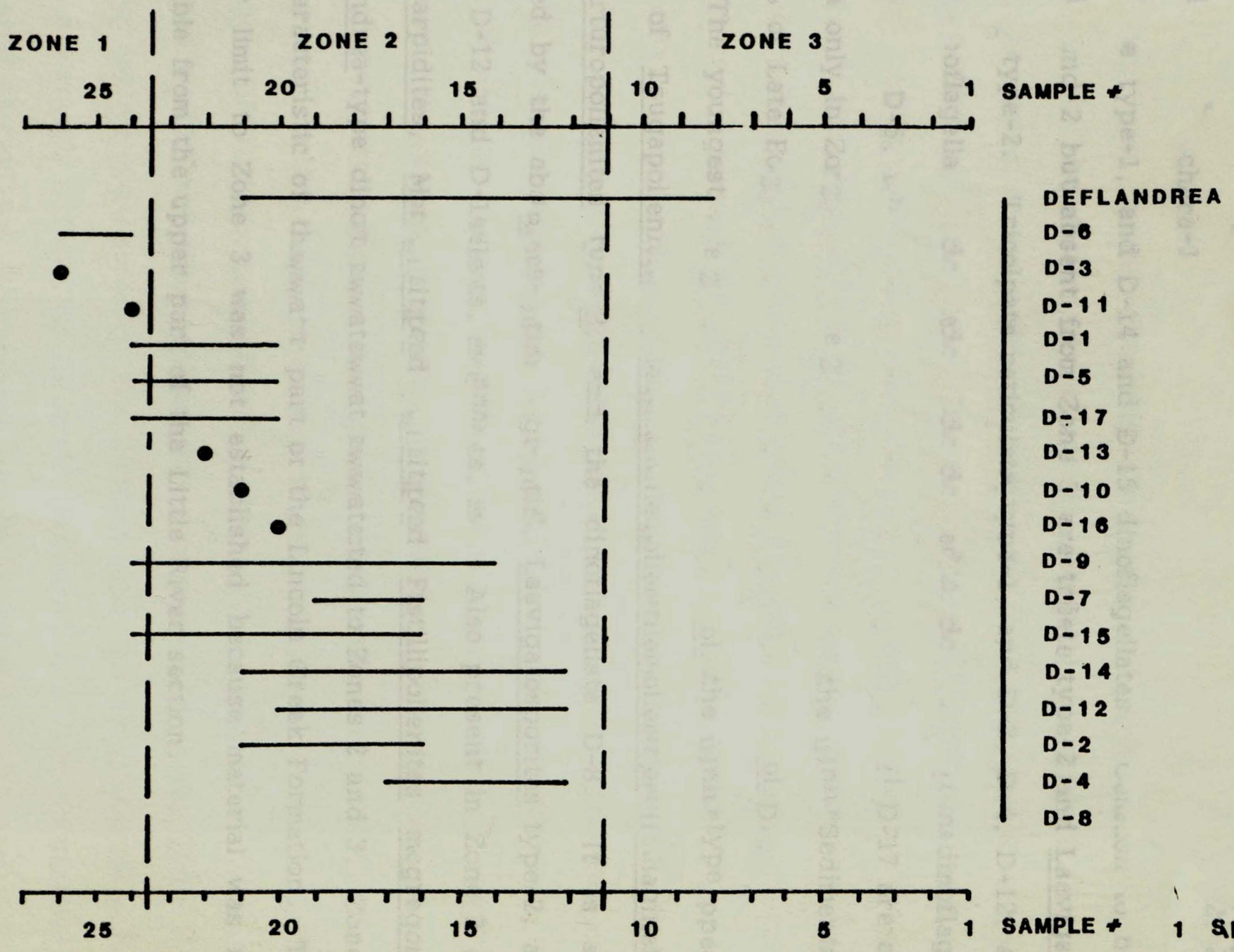

ZONE 1
ZONE 2
ZONE 3
25
20
15
10
5
1
SAMPLE #
D-6
PLATYCARYAPOLLENITES
PLATANOIDITES
LAEVIGATOSPORITES TYPE-2
TRILETE TYPE-2
TRILITES SOLIDUS
PROTEACIDITES
D-15
D-4
D-12
D-14
TRICOLPATE RET. TYPE-1
MONOCOLPOPOLLENITES
P. MCGREGORII
PODOCARPIDITES
BOMBACACIDITES
INAPERTUROPOLLENITES TYPE-2
SELAGINELLA
TILIAEPOLLENITES
TSUGAPOLLENITES
D-8
25
20
15
10
5
1
SAMPLE #

Figure 9. The stratigraphic ranges of the dinoflagellate groups within the Little River section.


ZONE 1
ZONE 2
ZONE 3
25
20
15
10
5
1
SAMPLE #
DEFLANDREA
D-6
D-3
D-11
D-1
D-5
D-17
D-13
D-10
D-16
D-9
D-7
D-15
D-14
D-12
D-2
D-4
D-8
25
20
15
10
5
1
SAMPLE #
1
SAMPLE #

the sedimentary rocks in the upper part of the Crescent Formation and the lowest sample from the unit "Sedimentary Rocks of Late Eocene Age."

Zone 2 is characterized by the presence of Proteacidites, tricolpate reticulate type-1, and D-14 and D-15 dinoflagellates. Common to both Zone 1 and 2 but absent from Zone 3 are trilete type-2 and Laevigatosporites type-2. Tricolpate reticulate type-1, and D-2, D-4, D-12, and D-14 dinoflagellates are restricted to Zone 2. Additionally, dinoflagellates D-1, D-5, D-7, D-9, D-10, D-11, D-13, D-16, and D-17 are also found only in Zone 2. Zone 2 is characteristic of the unit "Sedimentary Rocks of Late Eocene Age."

The youngest zone (Zone 3) is distinguished by the first appearance of Tsugapollenites, Bombacacidites, Tiliaepollenites, Selaginella, Inaperturopollenites type-2, and the dinoflagellate D-8. It is also marked by the absence of trilete type-2, Laevigatosporites type-2, and D-4, D-12 and D-14 dinoflagellate cysts. Also present in Zone 3 are Podocarpidites, Monocolpopollenites, and Pistillipollenites mcgregorii. Deflandrea-type dinoflagellates are restricted to Zones 2 and 3. Zone 3 is characteristic of the lower part of the Lincoln Creek Formation. The upper limit to Zone 3 was not established because material was not available from the upper part of the Little River section.

DISCUSSION

Palynostratigraphy

Pollen and spores generally enter the sedimentary environment from the air, but water transport is generally considered the most important factor in controlling the subsequent sedimentary distribution of palynomorphs (Muller, 1959; Cross and others, 1966). Because of their small size palynomorphs tend to sort as fine silt particles (Muller, 1959) and are abundant in fine-grained rocks. The resistance of the exine in palynomorphs to most geological processes (except metamorphism and strong oxidation) ensures their preservation in various types of sediments.

The resistence to degradation and transportability of palynomorphs introduces a number of problems to their use in biostratigraphy. The first problem is that of differential degradation. Some palynomorphs are more susceptible to corrosion, oxidation, abrasion and damage during transport than others. As a general rule fungal remains, fern spores and conifer pollen are more resistant to these types of damage (Havinga, 1964; Sangster and Dale, 1964). The presence of pitted and corroded conifer and other pollen grains in samples from the Little River section implies that some of the delicate and fragile grains may have been destroyed. Thus, if differential degradation has occurred, the recovered palynofloral assemblages may be incomplete.

Reworked or recycled grains is another problem. Palynomorphs may be reworked from older strata and redeposited with younger sediments.

Stanley (1966) (19e di differential absorption of Safanin-O stain as a criteria for distiner dolng the presence of older "reworked" grains. Because none of the prrehologic preparations in this study were stained, neither this nor any other criteria were found practical in detecting the presence of recycled palynomorphs.

The purpose of palynostratigraphy is to define or characterize and divide strata based upon their contained palynoflora, independent of lithostratigraphic and chronostratigraphic units. Formal palynostratigraphic units are of three kinds: interval, assemblage, and abundance biozones (International Subcommission on Stratigraphic Classification (ISSC), 1976; North American Commission on Stratigraphic Classification (NACSC), 1983). Because of the preliminary nature of this study, I chose to divide the Little River section into informal assemblage zones using criteria similar to those used for establishment of formal assemblage zones or cenozones (ISSC, 1976; NACSC, 1983).

Of the various palynomorph groups used in this study, I found spores, pollen and particularly dinoflagellate cysts to be the most useful for zonation. Figure 9 summarizes the stratigraphic distribution of the various dinoflagellate groups. Each of the zones established in this study could be characterized by a unique type of dinoflagellate. With detailed taxonomic study of these dinoflagellates, I believe it will be possible to further subdivide the Little River section and establish interval biozones based solely upon dinoflagellate cysts.

For the most part, coniferous pollen were poorly preserved and were not used in zonation. Generally, it has been found that these types of pollen are not useful in palynozonation; however, in this study

Podocarpidites and Inaperturopollenites type-2 proved useful in characterizing Zone 3. I lumped most of the bisaccate grains into the genus Pityosporites. Future studies may find it practical to further subdivide this group.

Most fungal remains were not found to be useful in palynozonation, although a number of types such as the di- and multicellular fungal remains appear to have restricted stratigraphic ranges. It is interesting to note that the fungal taxon Ctenosporites wolfei, so common in the coeval Chuckanut Formation (Reiswig, 1982) and Skookumchuck Formation (personal observation, 1983), was not present in the samples I studied from the Little River section.

Age and Correlation

Benthic foraminiferal assemblages from the Little River section have been assigned to the "Ulatisian", "Narizian", and "Refugian" stages by Rau (1966) (Figure 5). These provincial foraminiferal stages have been correlated to the Cenozoic worldwide geologic time scale by Armentrout (1981) (Figure 2). Using these data, rocks studied in the Little River section range in age from late early Eocene or early middle Eocene to late Eocene.

The palynologic data in this study supports the Eocene age for these strata. No palynomorphs diagnostic of strata older or younger than Eocene were found in the recovered palynologic assemblages. Based upon correlation with Rau's foraminiferal stages, Zone 1 is approximately equivalent to late early or early middle Eocene, Zone 2

approximately equivalent to middle Eocene, and Zone 3 roughly equal to late Eocene.

Only broad correlations are possible between the palynozonation recognized in this study and previous palynozones established for Paleogene strata elsewhere in the Pacific Northwest by Rouse (1977), Newman (1981), and Reiswig (1982). These palynologic studies were conducted on nonmarine rocks and direct correlation between marine and nonmarine strata may not be possible. Theoretically, the transportability of palynomorphs might permit direct correlation of nonmarine and marine sediments; however, this is often rendered difficult by the fact that many continental facies (e.g. coal) are dominated by a palynoflora of lowland swamp plants, whereas marine strata are dominated by a mixture of upland pollen and marine plankton (Stanley, 1969). The selective nature of transport to and within the marine environment is indicated by the decreased diversity of marine pollen assemblages when compared to continental pollen assemblages (Heusser and Florer, 1973; Davis and Webb, 1975; Heusser and Balsam, 1977). For example, pine pollen grains make up 90% of the pollen found in core tops from the continental margin of eastern North America, whereas on the adjacent coast pine pollen ranges from 30% to 75% of the total (Davis and Webb, 1975).

Rouse (1977) used two palynozones to divide Eocene rocks in south-central British Columbia. Zone E-1 of early to middle Eocene age was recognized by the presence of the pollen grains Pistillipollenites mcgregorii, Tilia, and the fungal remains Diporisporites A and Ctenosporites wolfei. Gothanipollis A, Fagus, Quercus, and Juglans

were some of the main diagnostic types in the late Eocene Zone E-2. Multicellaesporites spp., Punctodiporites A, and Carya were common to both zones.

Newman (1981) used two concurrent palynozones to subdivide Eocene rocks cropping out in central Washington. The oldest palynozone of probable early to middle Eocene was based upon the overlapping range zone of Pistillipollenites and Platycarya. The youngest palynomorph biozone, middle and/or late Eocene, was recognized by the overlapping ranges of Platycarya and Bursera.

Two Eocene palynozones were identified by Reiswig (1982) in the Chuckanut Formation. Zone E-1 of early to middle Eocene age was recognized by the presence of Pistillipollenites mcgregorii, Platycarya spp., Holkopollenites A, and Rhoiipites latus. The second zone (E-2) was characterized by the presence of Quercus, Fagus, Gothanipollis A and probably is late middle to late late Eocene in age. Multicellaesporites A, Ctenosporites wolfei, Tilia sp., and Carya were common to both palynozones.

I was unable to recognize any of the previously established palynozones by Rouse (1977), Newman (1981) and Reiswig (1982) in the palynological assemblages in the Little River section. In my study, Platycarya was not found associated with either Pistillipollenites or Tilia-type pollen. Also, I did not recognize any form assignable to Bursera. Ecological and/or environmental differences in the source area of palynomorphs may account for the differences between the nonmarine and marine palynofloras. These apparent differences highlight the difficulty of making

regional correlations between coeval marine and nonmarine rocks particulary in a preliminary study of this nature. One advantage of this study is that samples were collected from stratigraphically controlled strata whereas both Newman (1981) and Reiswig (1982) used random "grab" samples collected in poorly exposed and structurally complex strata. Further palynologic work is needed on both marine and nonmarine palynofloras particularly on stratigraphically continuous sequences to verify the zonation established in this and other regional studies.

CONCLUSIONS

This palynological study of the Little River section revealed the following:

1) Eocene marine strata of the Little River section contains an abundant palynoflora. Of the 77 identified types: 32 were pollen and spores, 24 were fungal remains, 18 were dinoflagellates, and 3 were miscellaneous microfossils.

2) The stratigraphic range of 21 palynomorphs can be used to divide the Little River section into three informal palynomorph assemblage zones. Based on correlations with foraminiferal stages, Zone 1 is of late early or early middle Eocene age, Zone 2 is middle Eocene in age, and Zone 3 is of late Eocene age.

3) Previous Pacific Northwest palynomorph biozones established for time-equivalent strata by Rouse (1977), Newman (1981), and Reiswig (1982) were not identified in the sequence of palynomorphs from the Little River section.

4) Further palynological investigation is necessary to clarify the stratigraphic relationship between coeval marine and nonmarine palynofloras in the Pacific Northwest.

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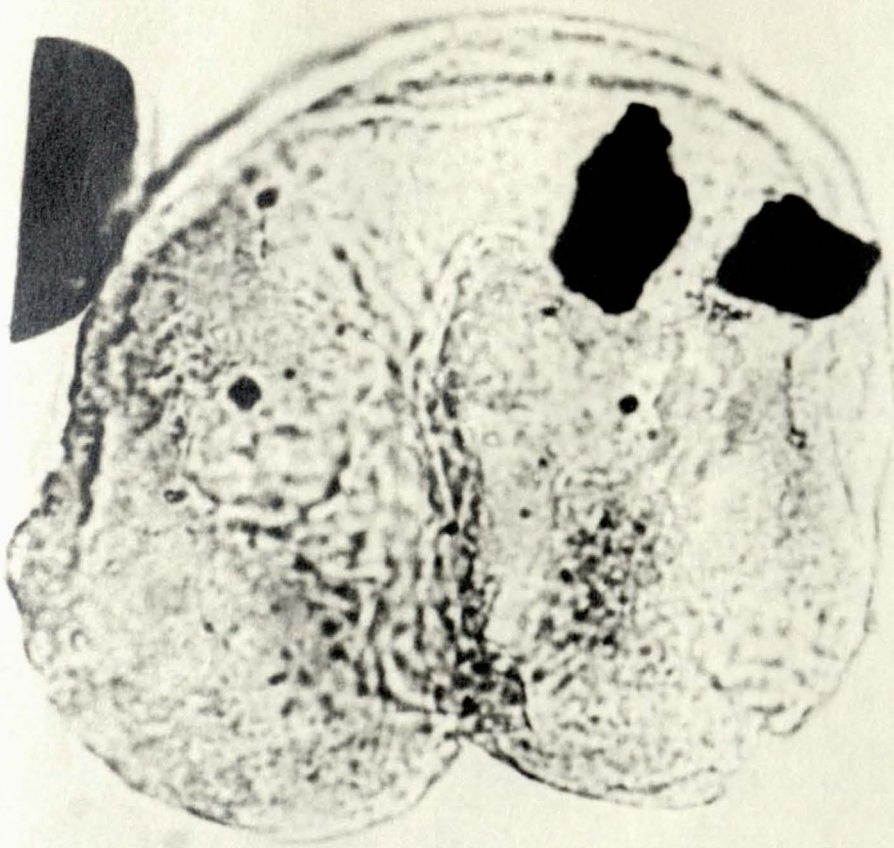
PLATE 3

GYMNOSPERM POLLEN

All figures 1000X

Figure

1. Pityosporites sp.
2. Tsugapollenites sp.
3. Pityosporites sp.
4. Pityosporites sp.



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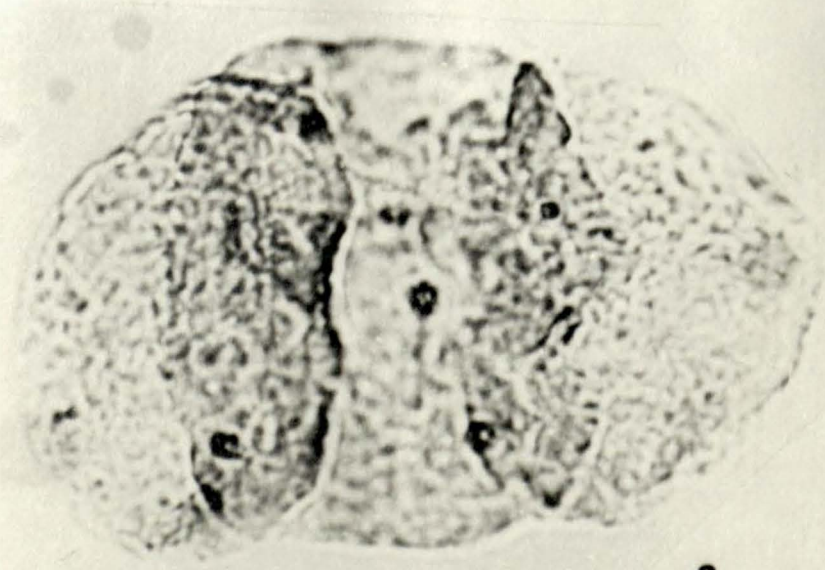

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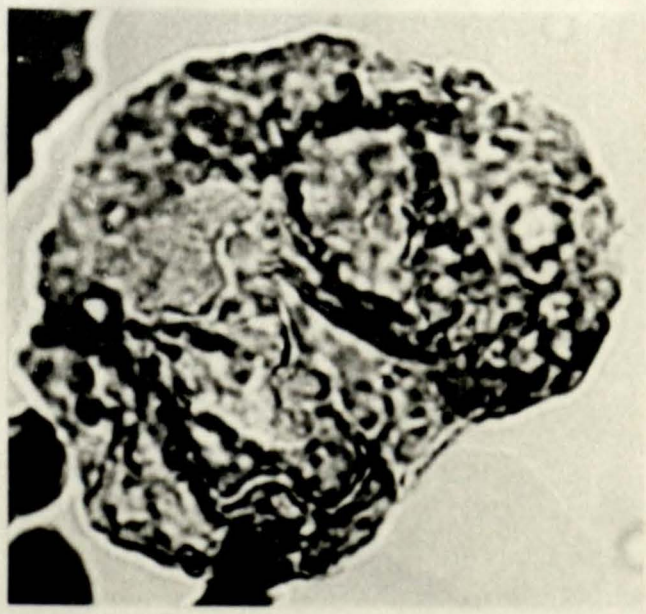

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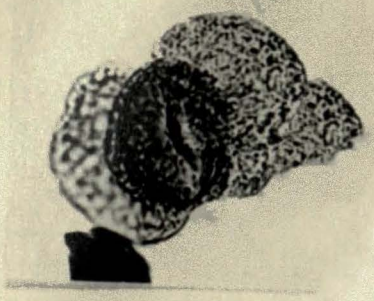
PLATE 4

GYMNOSPERM POLLEN

All figures 1000X

Figure

1. Podocarpidites sp.
2. Inaperturopollenites type-2
3. Inaperturopollenites type-2
4. Inaperturopollenites type-2
5. Inaperturopollenites type-1
6. Inaperturopollenites type-1



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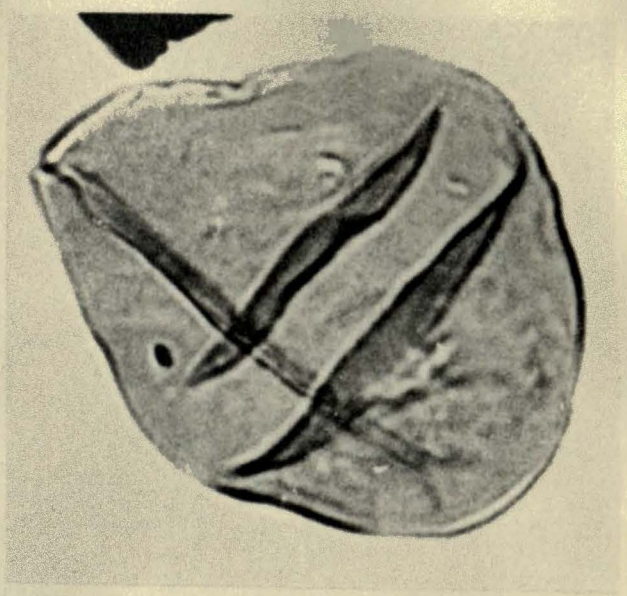

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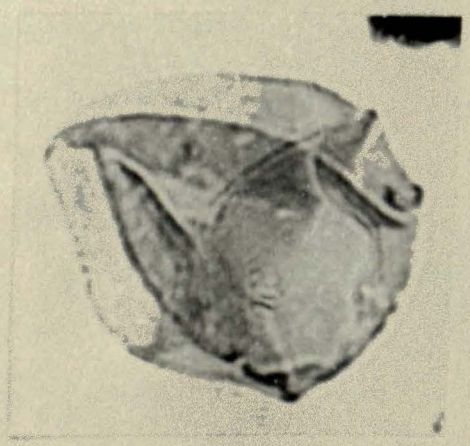

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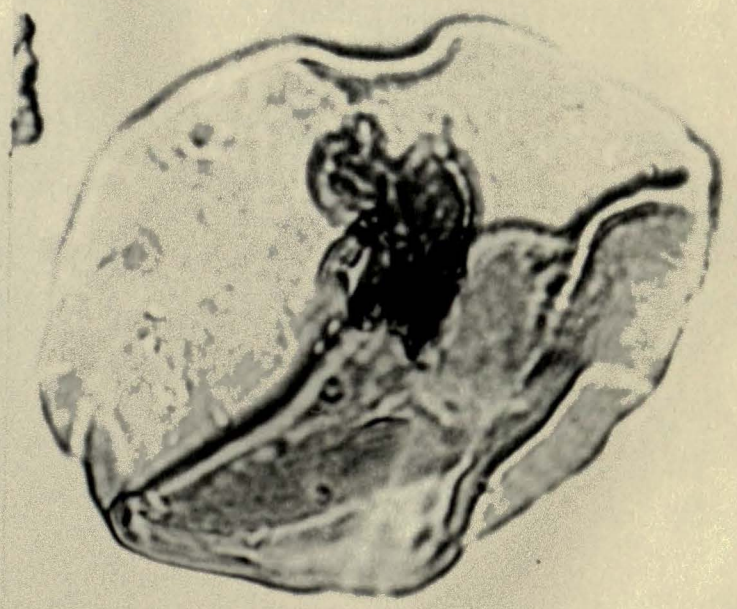

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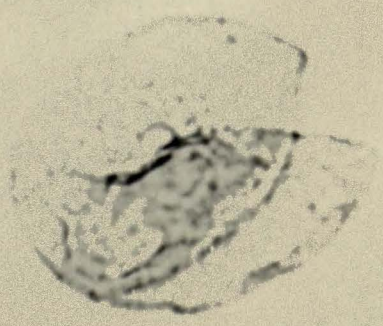

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PLATE 5

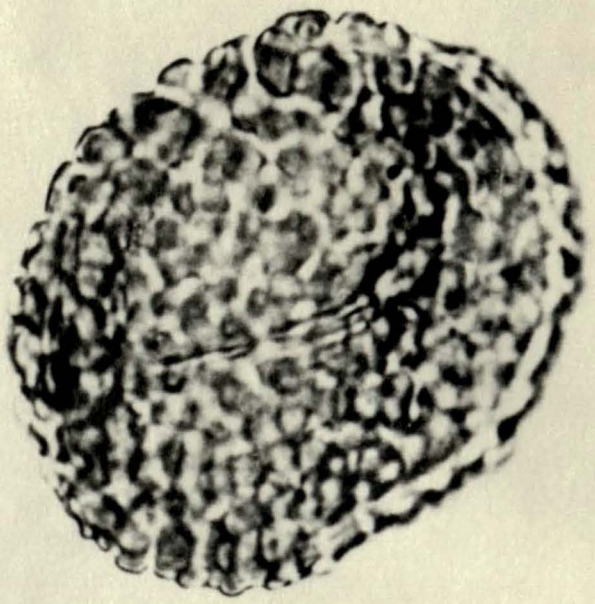
PTERIDOPHYTE SPORES

All figures 1000X

Figure

1. Polypodiisporonites sp.
2. Polypodiisporonites sp.
3. Polypodiidites sp.
4. Laevigatosporites type-2
5. Laevigatosporites type-1
6. Laevigatosporites type-2

1



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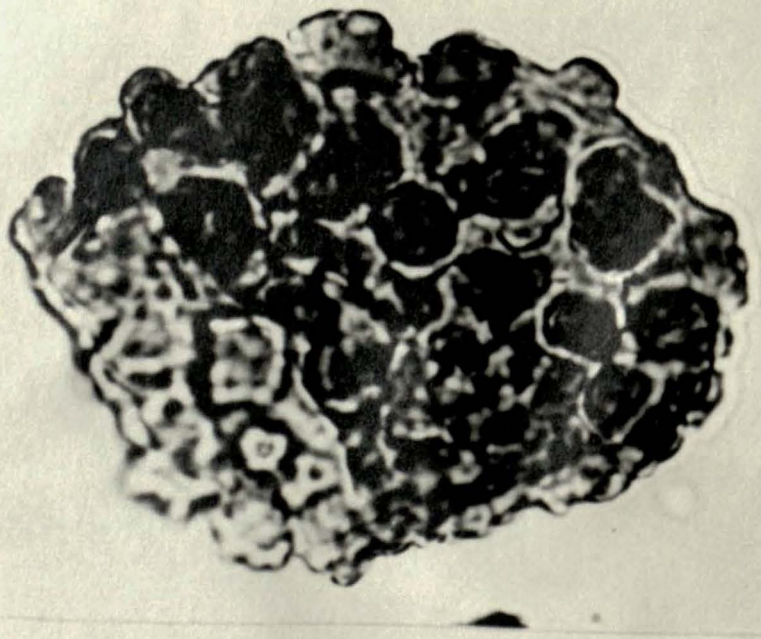

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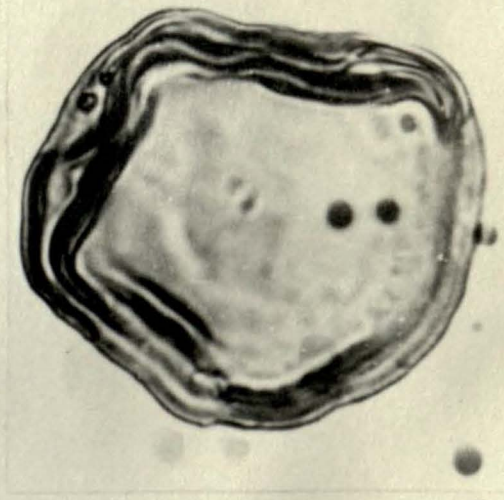

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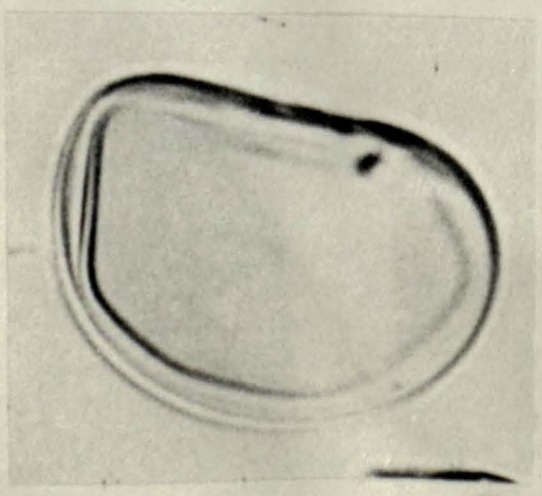

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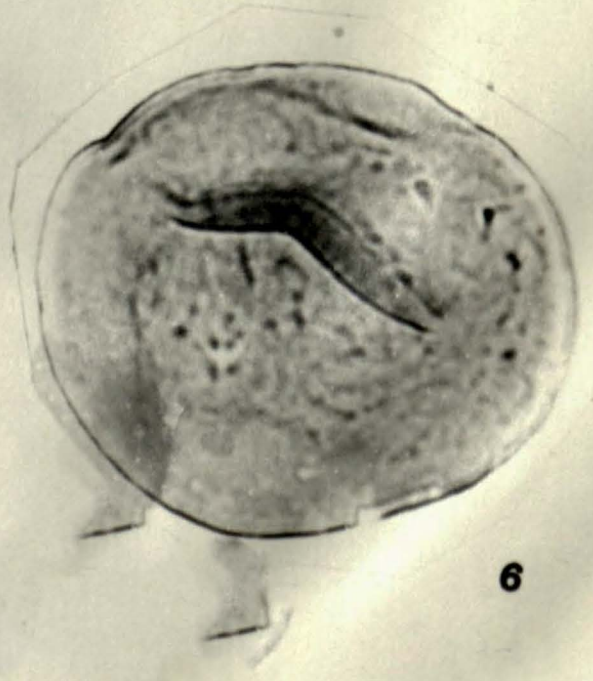


6

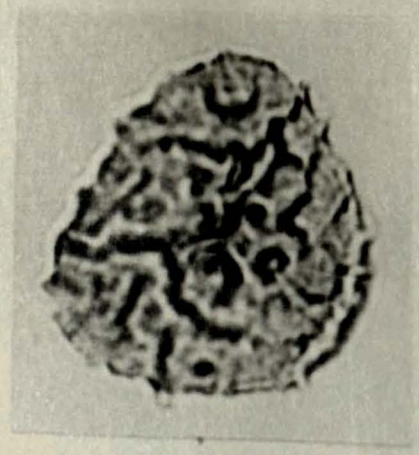
PLATE 6

PTERIDOPHYTE SPORES

All figures 1000X

Figure

1. Lycopodium sp.
2. Cicatricosisporites sp.
3. Trilete type-1
4. Trilete type-2
5. Trilites solidus (Potonie) Krutzsh
6. Deltoidospora sp.



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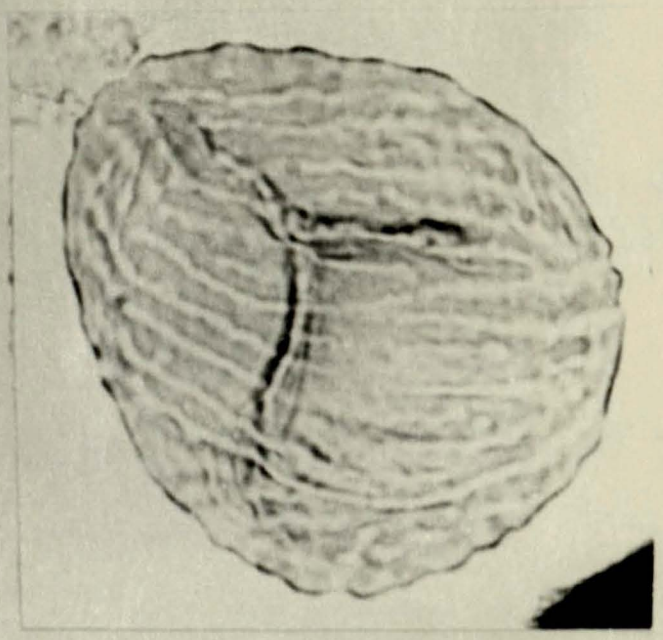

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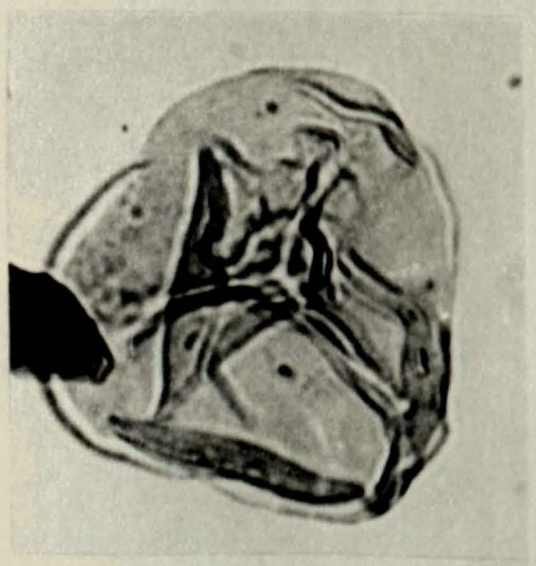

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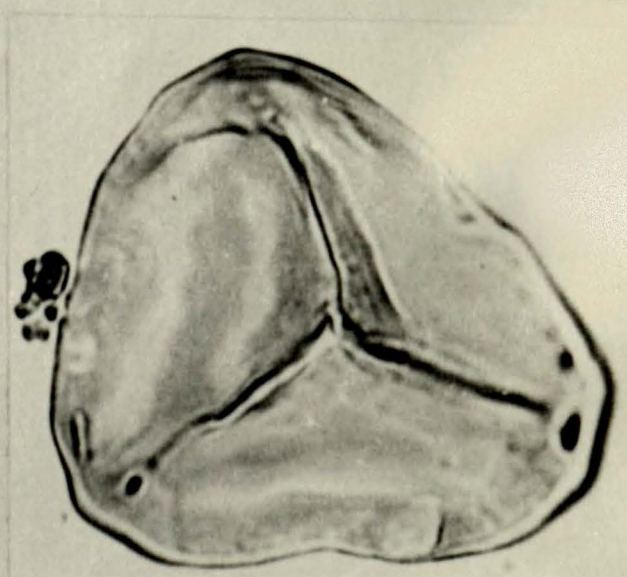

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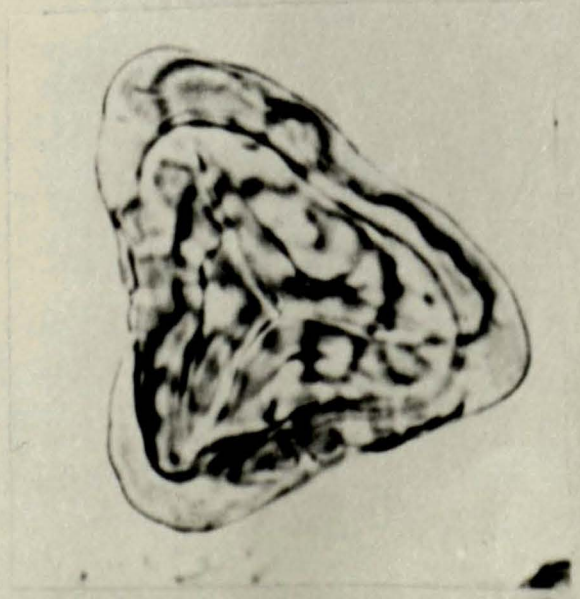

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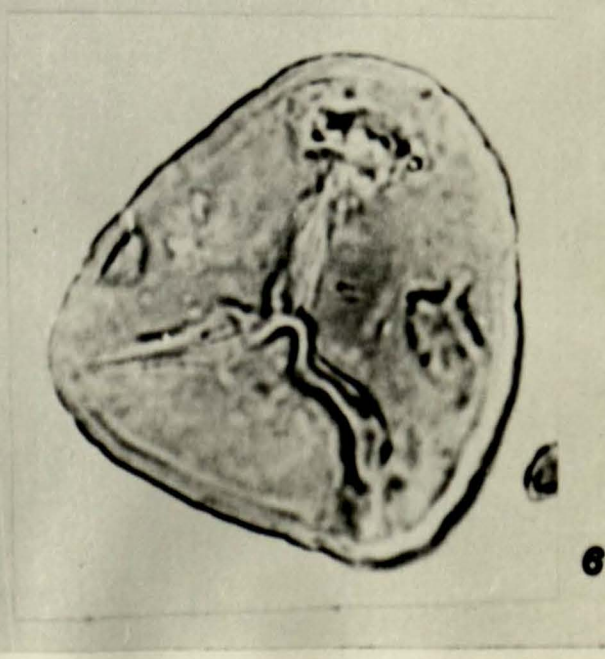

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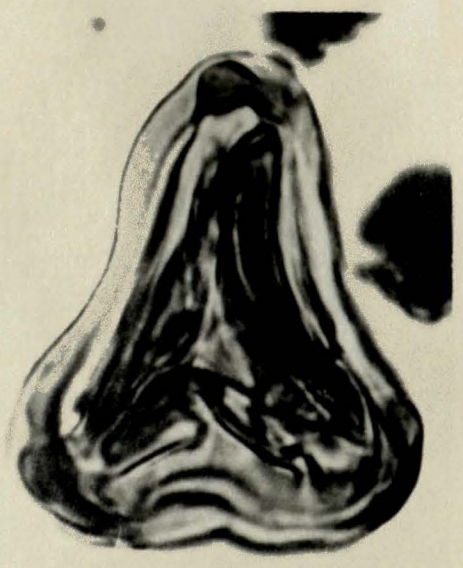
PLATE 7

PTERIDOPHYTE SPORES

All figures 1000X

Figure

1. Trilete type-3
2. Trilete type-3
3. Unidentified trilete spore
4. Unidentified trilete spore
5. Selaginella sp.
6. Unidentified trilete spore



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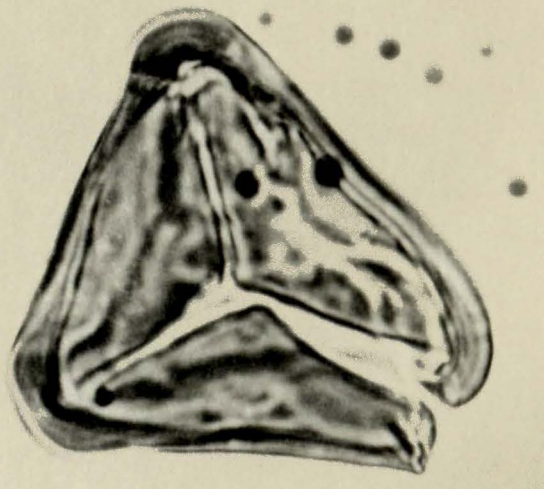

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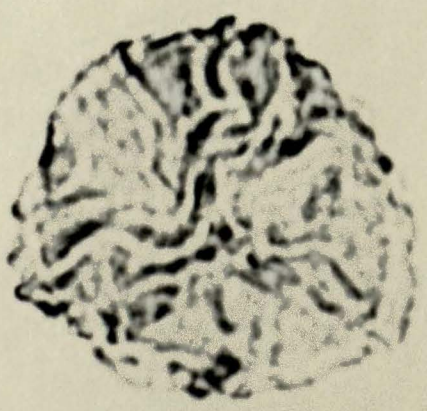

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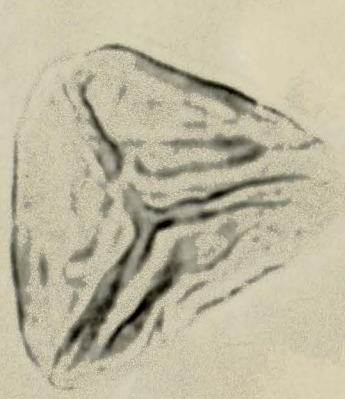

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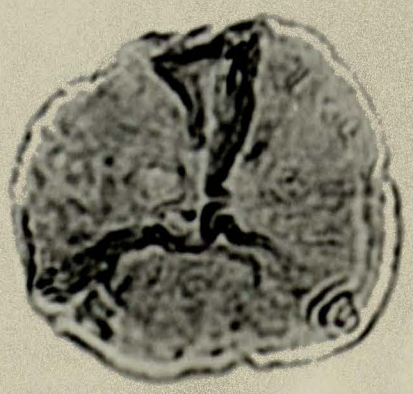

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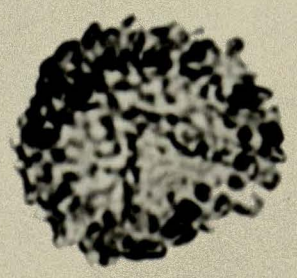


6

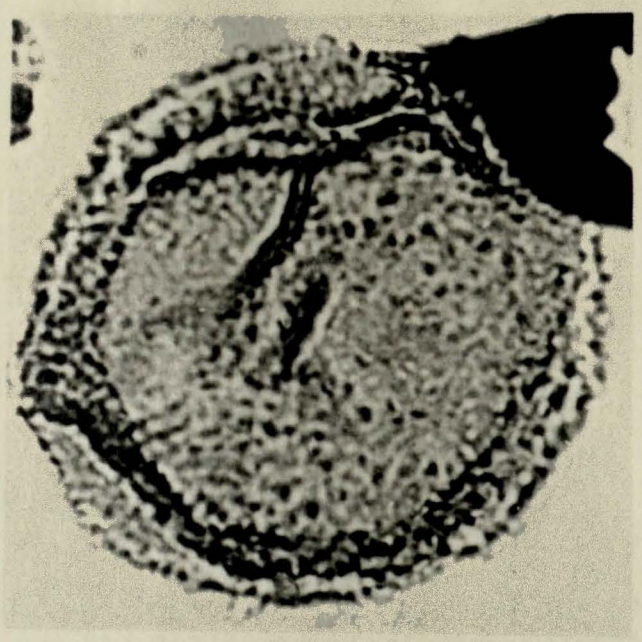
PLATE 8

PTERIDOPHYTE SPORES AND ANGIOSPERM POLLEN

All figures 1000X

Figure

1. Osmundacidites sp.
2. Osmundacidites sp.
3. Momipites sp.
4. Polyvestibulopollenites sp.
5. Unidentified triporate
6. Polyvestibulopollenites sp.
7. Pterocaryapollenites sp.
8. Platycaryapollenites sp.
9. Monocolpopollenites sp.
10. Unidentified triporate
11. Proteacidites sp.



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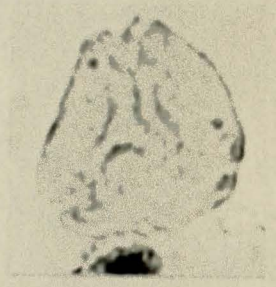

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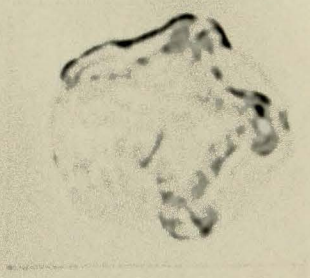

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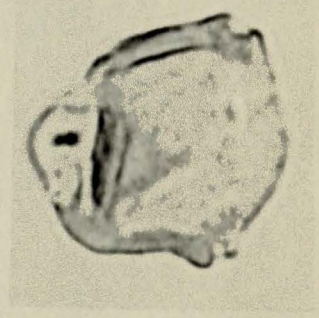

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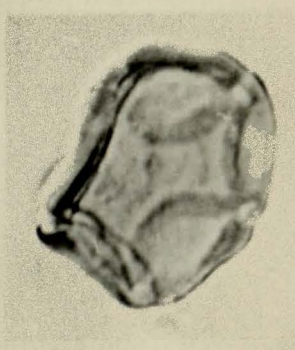

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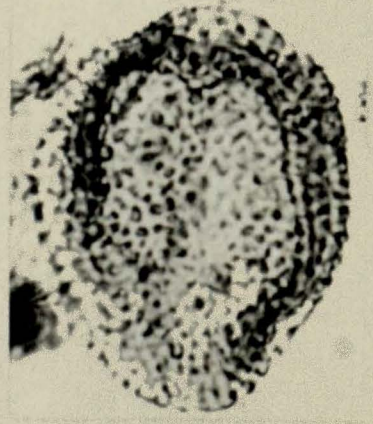

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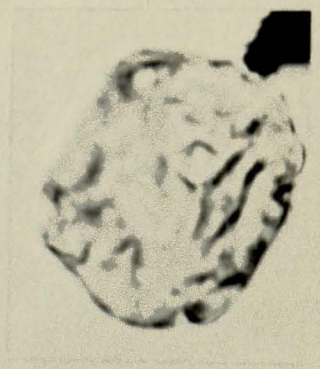

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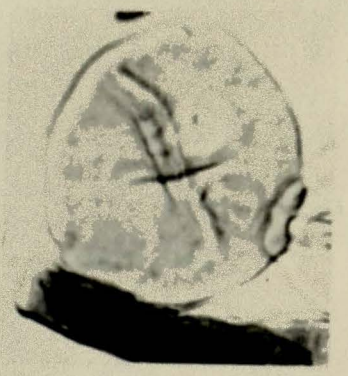

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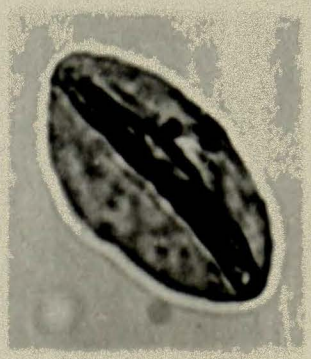

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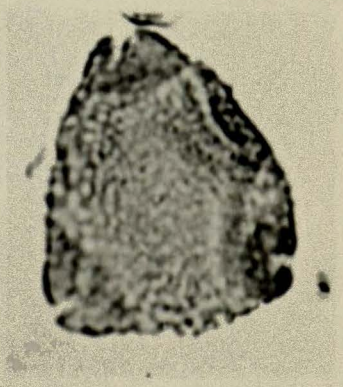


11

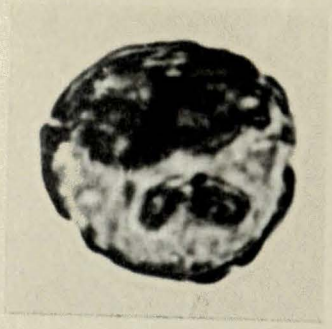
PLATE 9

ANGIOSPERM POLLEN

All figures 1000X

Figure

1. Pterocaryapollenites sp.
2. Caryapollenites sp.
3. Unidentified triporate
4. Bombacacidites sp.
5. Tiliaepollenites sp.
6. Tiliaepollenites sp.
7. Ludwigia sp.
8. Pistillipollenites mcgregorii Rouse
9. Unidentified tricolpate
10. Undentified tricolpate
11. Undentified tricolpate
12. Undentified tricolpate



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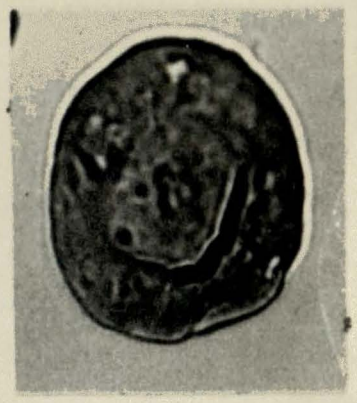

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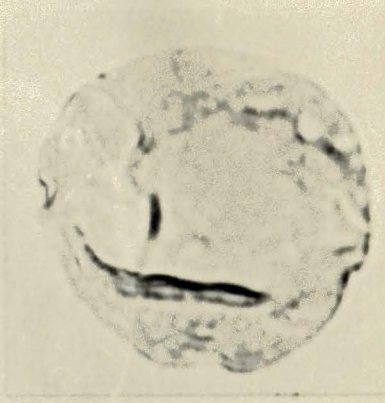

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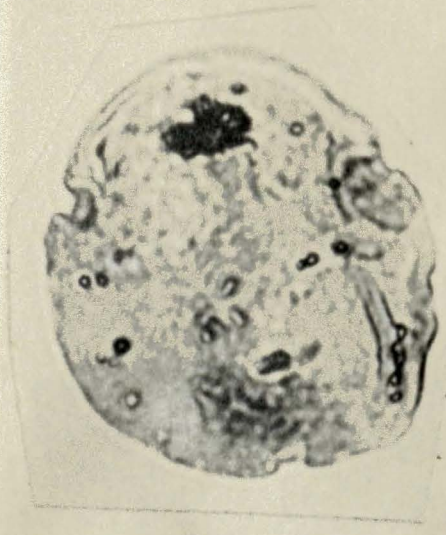

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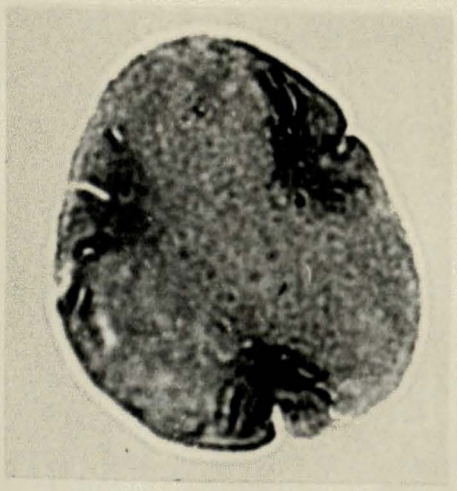

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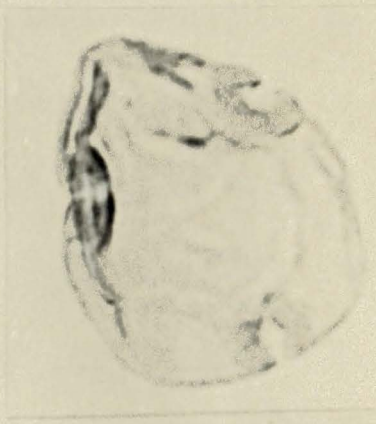

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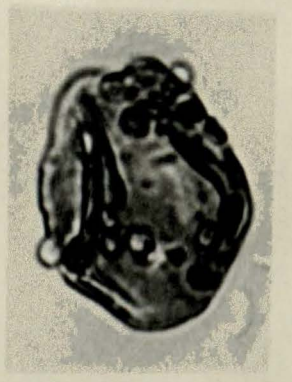

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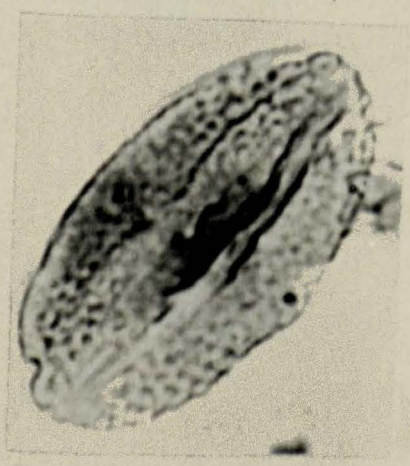

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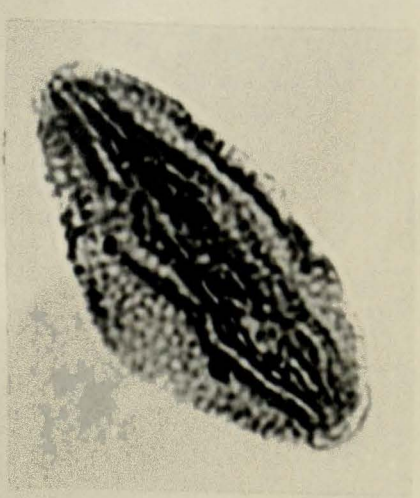


12

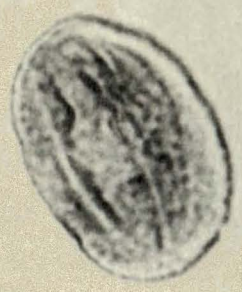
PLATE 10

ANGIOSPERM POLLEN AND FUNGAL REMAINS

All figures 1000X

Figure

1. Unidentified tricolporate
2. Unidentified tricolporate
3. Unidentified tricolporate
4. Unidentified tetracolporate (?)
5. Tricolpate reticulate type-1
6. Unidentified tricolpate
7. Inapertisporites type-1
8. Polyporisporites sp.
9. Inapertisporites type-3
10. Inapertisporites type-2
11. Unidentified monocell fungal spore
12. Polyporisporites sp.



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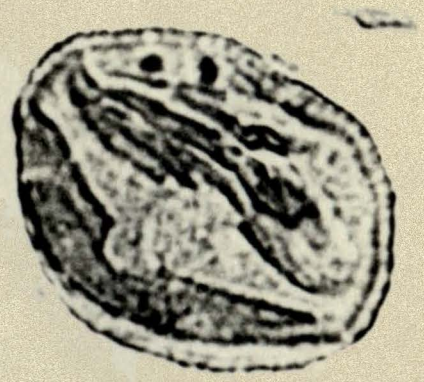

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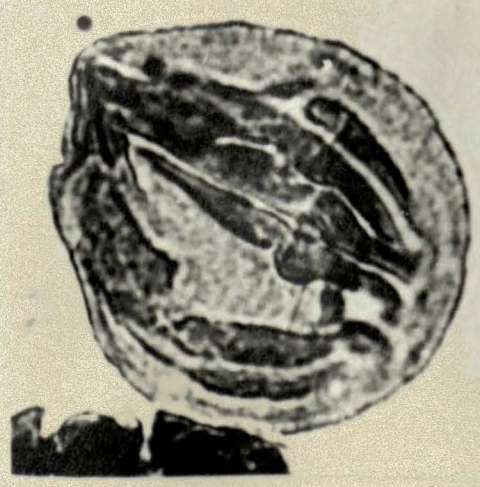

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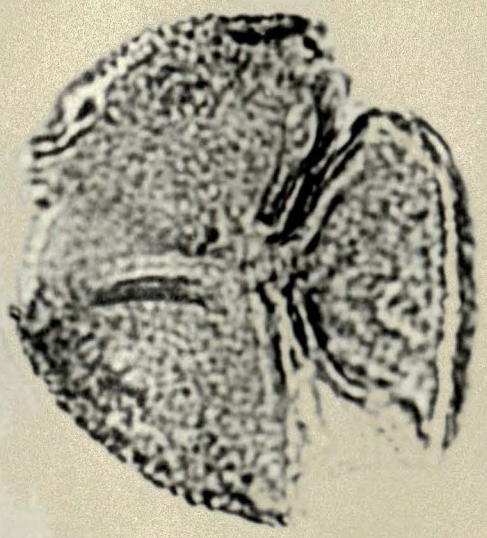

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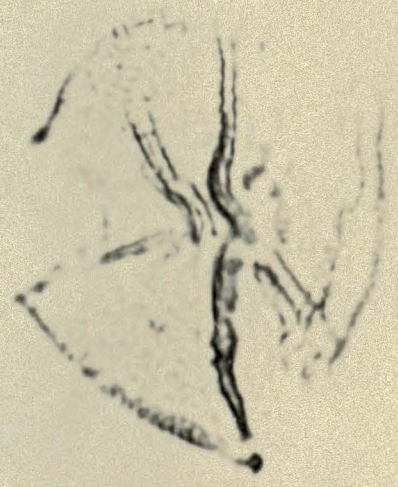

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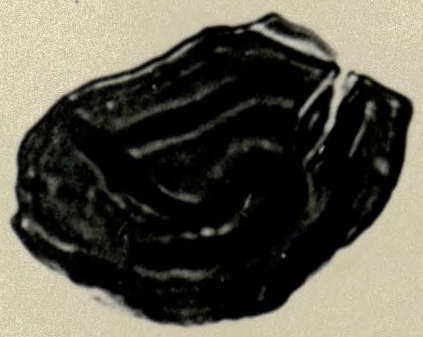

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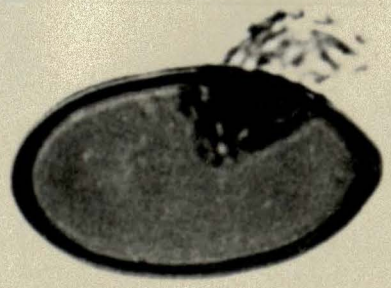

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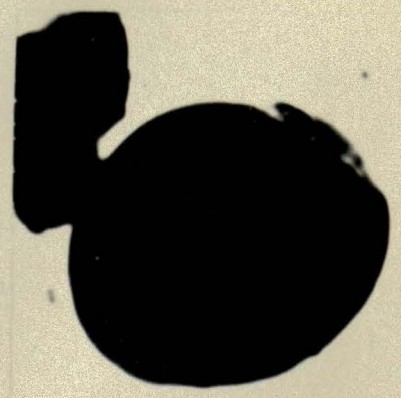

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12

PLATE 11

FUNGAL REMAINS

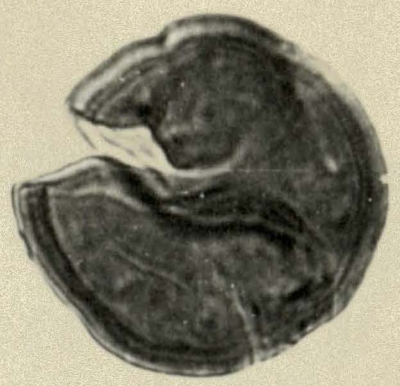
All figures 1000X

Figure

1. Monoporisporites sp.
2. Monoporisporites sp.
3. Inapertisporites type-3
4. Striadiporites type-2
5. Striadiporites type-1
6. Dicellaesporites type-2
7. Dicellaesporites type-1
8. Dyadosporites sp.
9. Didymoporisporonites sp.
10. Pluricellaesporites sp.

1

2



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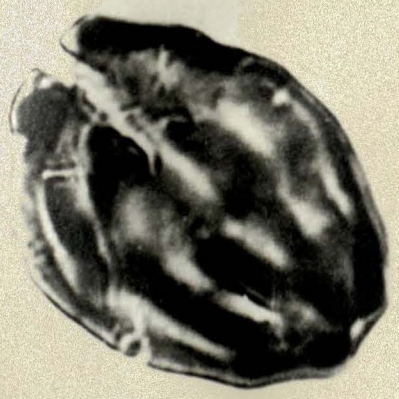

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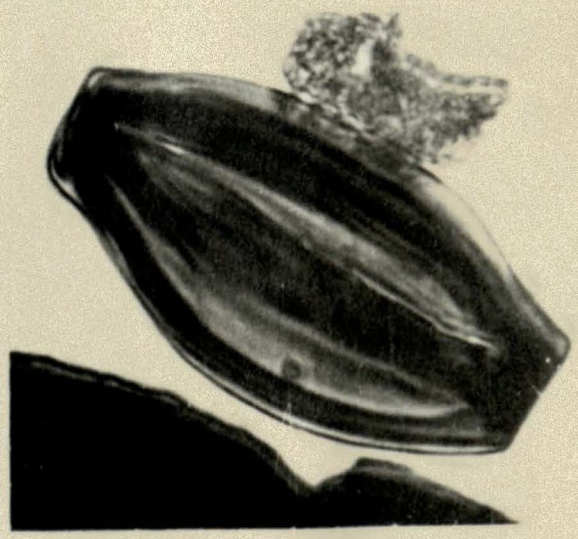

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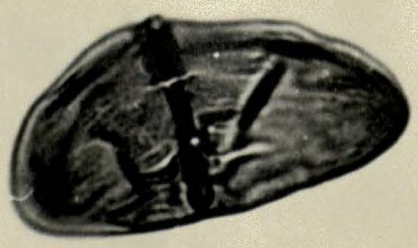

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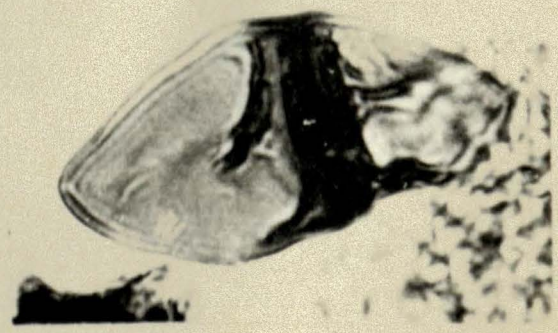

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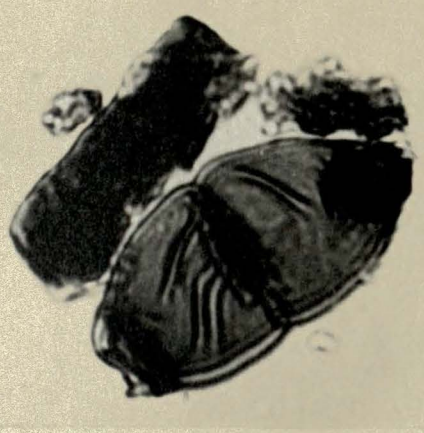
PLATE 12

FUNGAL REMAINS

All figures 1000X

Figure

1. Dicell type-3
2. Pluricellaesporites sp.
3. Brachysporisporites sp.
4. Multicellaesporites sp.
5. Brachysporisporites sp.
6. Pluricellaesporites sp.
7. Unidentified dicell fungal spore



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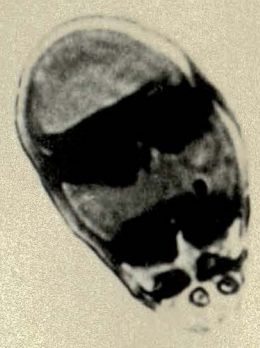

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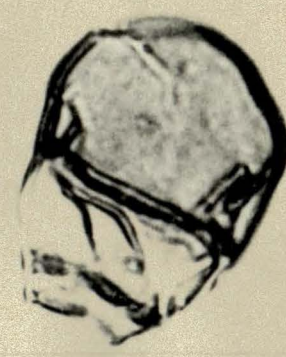

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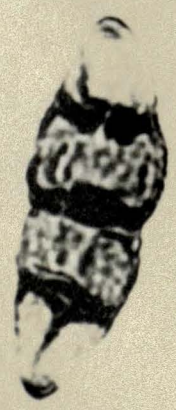

4

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7

PLATE 13

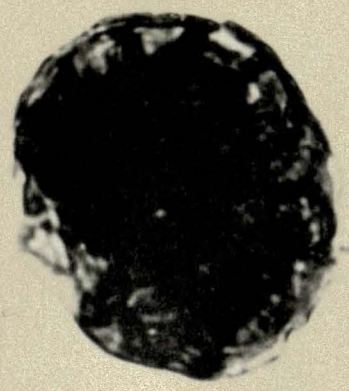
FUNGAL REMAINS

All figures 1000X

Figure

1. Pesavis sp.
2. Polyadosporites type-2
3. Polyadosporites type-1
4. Pesavis sp.
5. Unidentified multicell fungal spore
6. Microthriaceae
7. hyphae type-2
8. hyphae type-1

1



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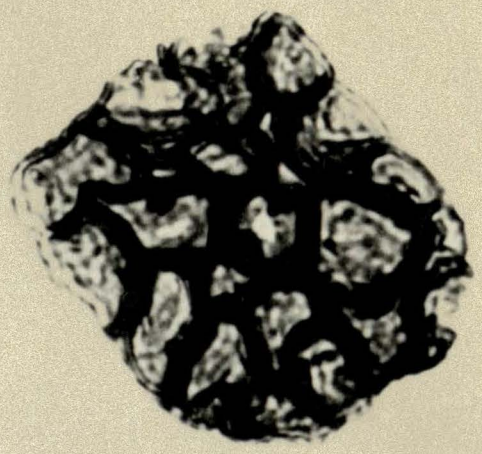
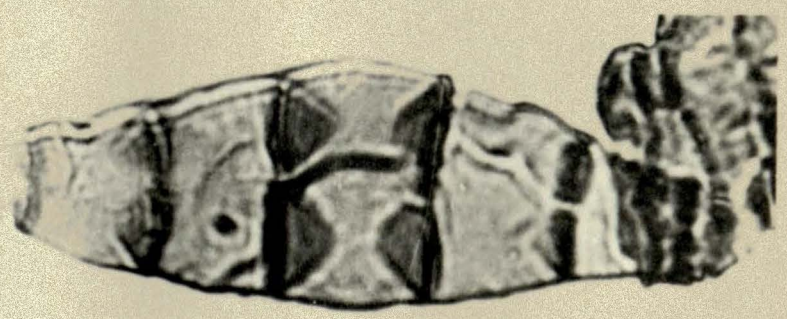


3

4



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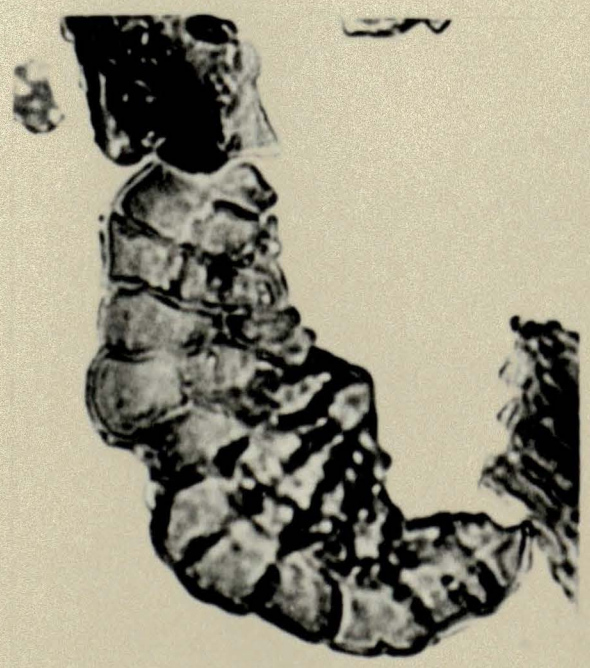

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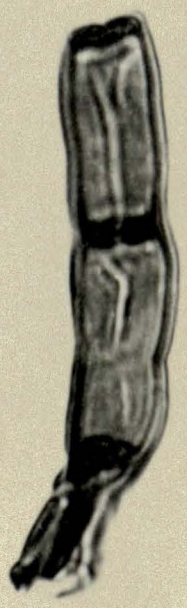

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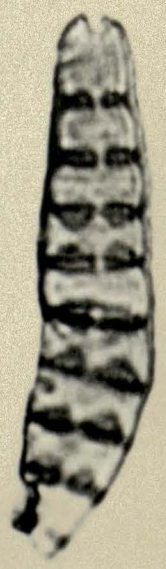


8

PLATE 14

FUNGAL REMAINS AND MISCELLANEOUS MICROFOSSILS

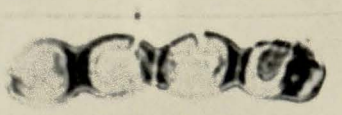
All figures 1000X

Figure

1. hyphae type-3
2. hyphae type-4
3. Reduviasporonites sp.
4. scolecodont
5. microforam
6. Thyttadiscus sp.

1

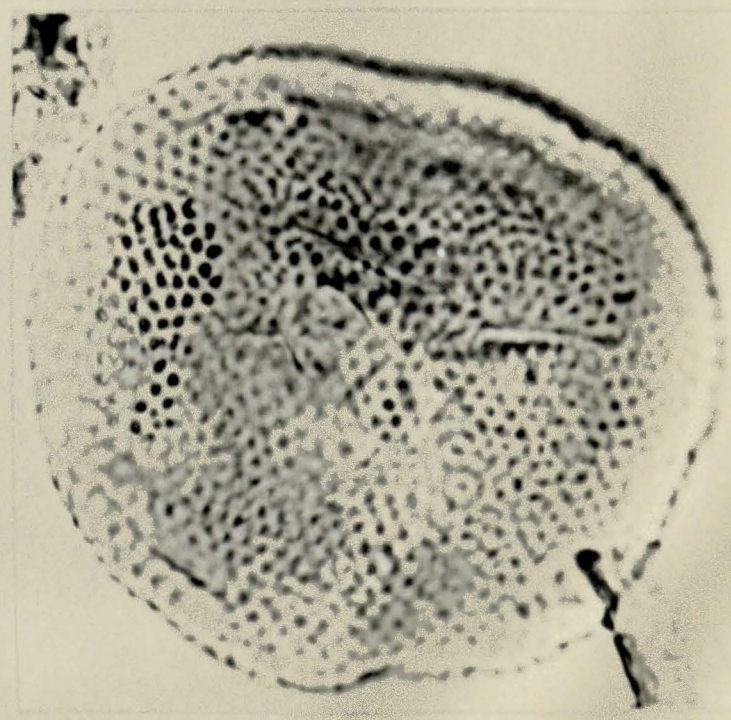
2



3

4

5



6

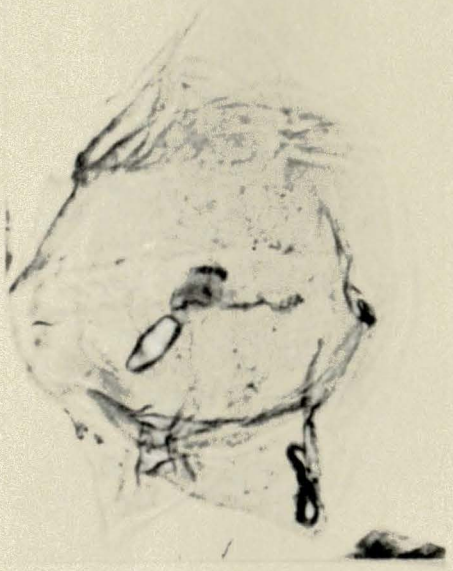
PLATE 15

DINOFLAGELLATES

All figures 500X

Figure

1. Deflandrea sp.
2. Deflandrea sp.
3. Deflandrea sp.
4. ? Deflandrea
5. D-1
6. D-2
7. D-3
8. D-4
9. D-4



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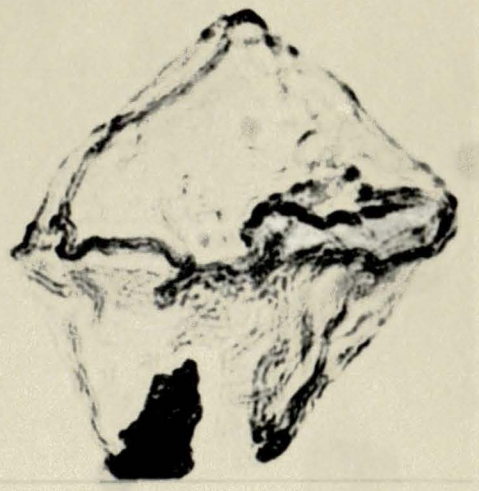
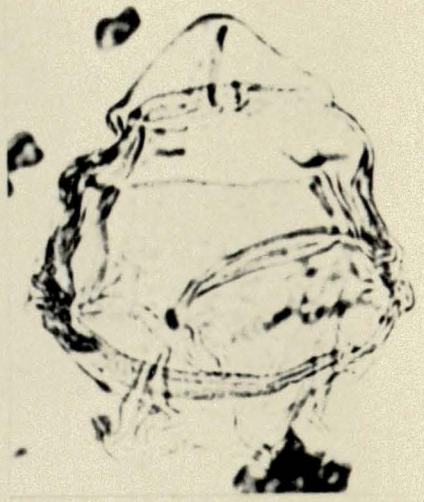


2



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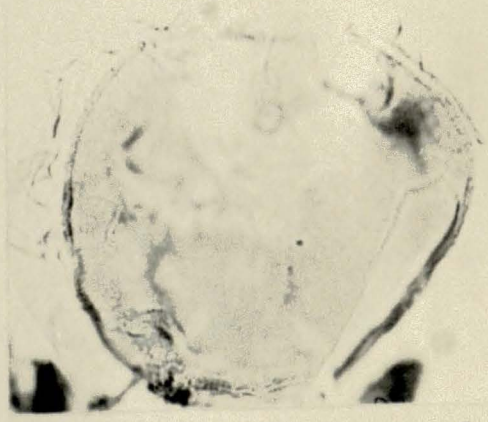
4

5



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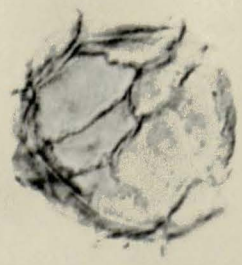

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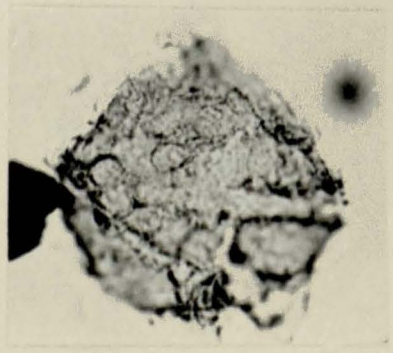

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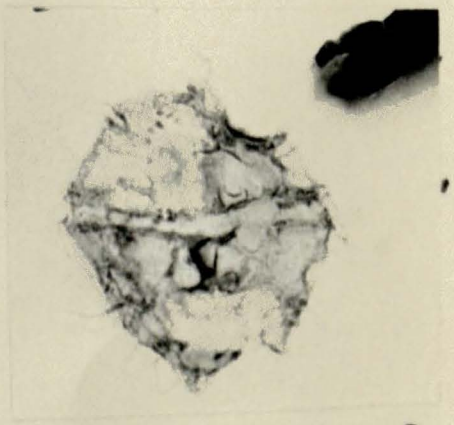


9

PLATE 16

DINOFLAGELLATES

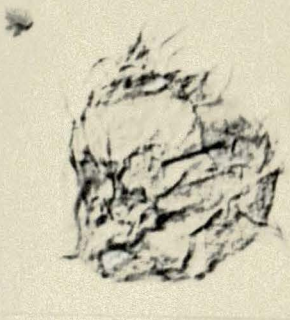
All figures 500X

Figure

1. D-4
2. D-4
3. D-5
4. D-6
5. D-6
6. D-6
7. D-8
8. D-8
9. D-9

Figures 1, 2, and 7 are interference contrast

1



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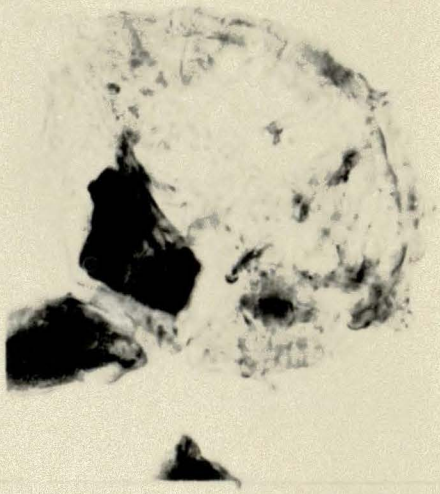

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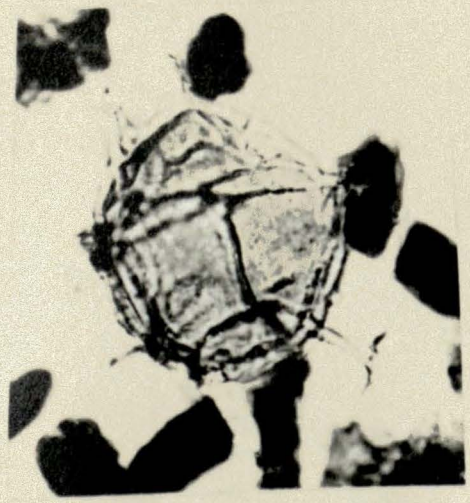

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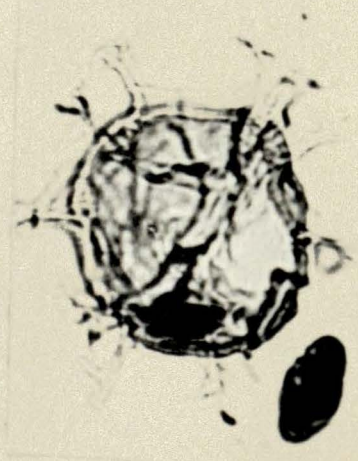

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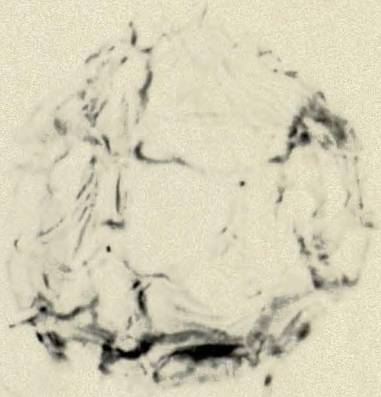

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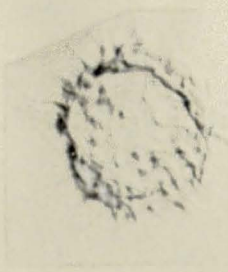

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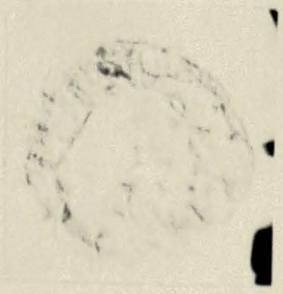

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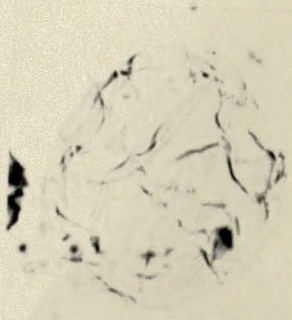


9

PLATE 17

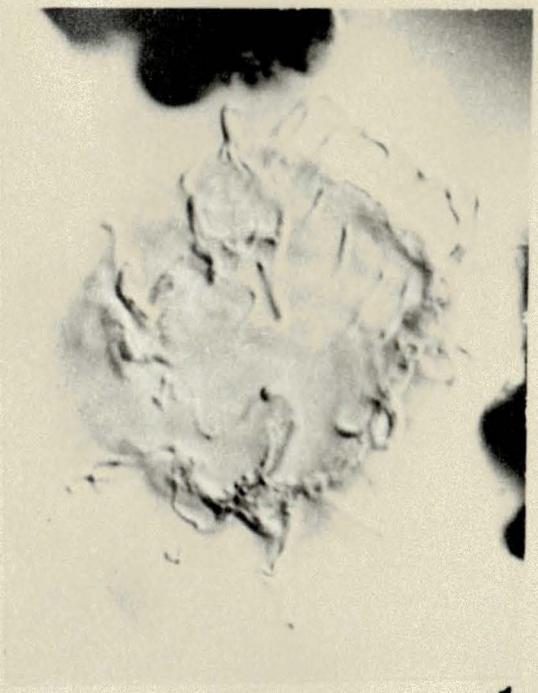
DINOFLAGELLATES

All figures 500X

Figure

1. D-10
2. D-11
3. D-12
4. D-13
5. D-14
6. D-14

Figures 1,4, and 5 are interference contrast

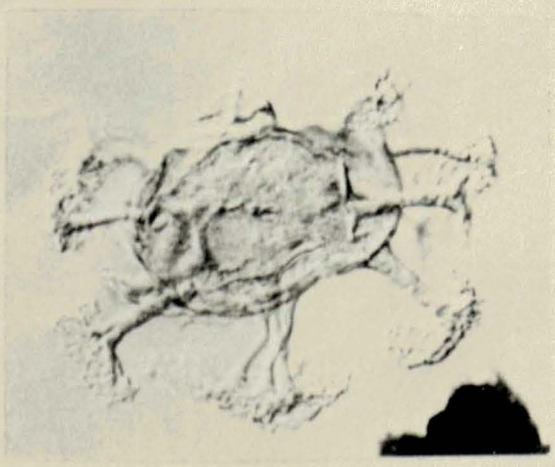


1

2

4

3



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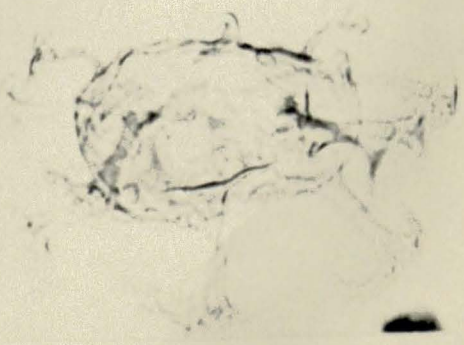

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