Palynology and Paleoecology of the Weaverville Formation (Tertiary), Northwestern California

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Abstract

PALYNOLOGY AND PALEOECOLOGY OF THE WEAVERVILLE FORMATION (TERTIARY), NORTHWESTERN CALIFORNIA

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The Weaverville Formation of the Klamath Mountains in northern California consists of non-marine shales, lignites, tuffs, sandstones, and auriferous conglomerates which lie in small, fault-bounded basins. The fine-grained sediments were deposited in lakes and associated streams; whereas, the conglomerates, which generally overlie those sediments, were deposited on a braided alluvial plain. Lithologies of clasts indicate a dominantly local source, and coarsening of conglomerate towards some faults suggests deposition was, at least in part, syntectonic.

The fine-grained sediments in two stratigraphic sections, one at Hayfork and the other at Readings Creek, yielded a diverse and well-preserved pollen and spore flora. A total of 151 types were recognized, and 85 genera or tribes in 51 families were identified. The flora overall consists of 63% angiosperms, 13% ferns, 11% gymnosperms, 11% algae, acritarchs, and dinoflagellates, as well as two bryophytes and a club moss. A total of 27% of the forms recognized are unidentified. Of the total taxa in the pollen and spore flora described here and the leaf flora described by MacGinitie (1937), only 15 (18%) are common to both. Pollen production of the source plants as well as

differential preservation of pollen and leaves may explain these differences in composition.

By comparison with extant vegetation, two major vegetational units are represented: a mixed broad-leaved evergreen and deciduous forest and a mixed coniferous forest. In addition, a *Taxodium-Nyssa* swamp forest grew near the site of deposition, and xeric vegetation, including *Caesalpinia, Bauhinia,* and *Fremontodendron,* inhabited drier areas. The flora is subtropical to warm temperate overall, but is a mixture of tropical-subtropical taxa (Bombacaceae, Sterculiaceae) and temperate to boreal conifers (*Larix, Picea*), if present ecological requirements of taxa were similar in the Tertiary.

The flora contains an interesting array of typically Eocene taxa (*Pistillipollenites,* Bombacaceae, *Triumfetta*) and Oligo-Miocene types (Compositae, Malvaceae, Polygonaceae, Chenopodiaceae, Gramineae). The stratigraphic ranges of the taxa and diversity of herbs suggest that the age is probably late Oligocene or early Miocene. Because the florules at Readings Creek and Hayfork are very similar qualitatively and quantitatively, the Weaverville sediments at these two localities are probably the same age.

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CHAPTER I: INTRODUCTION

The fossil flora of the Weaverville Formation in the Klamath Mountains of northern California is one of several on the West Coast that is associated with Tertiary auriferous gravels such as those of the Sierra Nevada. The finer-grained sediments of the Weaverville Formation have yielded well-preserved fossil leaves that were first reported by Knowlton (in Diller, 1911), and since have been well described by H. D. MacGinitie (1937). Because few other mid-Tertiary floras in this region have been studied, the Weaverville flora is important in elucidating the vegetational and floristic history of the West Coast. In the Klamath Mountains, this history has culminated in a unique and interesting modern flora with a large number of endemic and relict species (Whittaker, 1961). Thus, the Weaverville flora is of specific interest in tracing the development of this modern flora.

Not only does the Weaverville flora occupy an important geographical position, but it occurred during a significant time period as well. In North America, the fossil record of vegetation shows a shift during mid-Tertiary time from tropical and subtropical in the Eocene to dominantly warm temperate in the Miocene (Leopold and MacGinitie, 1972), and the Weaverville flora has been interpreted to exemplify this transition (MacGinitie, 1937). Thus, the present study fills an interesting gap between well-known pollen floras of the Eocene (e.g., Rouse, 1962; Hopkins, 1969; Leopold, 1974; Fisk, 1976) and pollen floras of the Miocene and Pliocene (e.g., Gray, 1958; Wolfe, 1962; Martin and Rouse, 1966; Taggart, 1971).

Unfortunately, a precise age for the Weaverville Formation has not been obtained. Based on the fossil leaf flora, the age has been variously interpreted as early or middle Oligocene (MacGinitie, 1937, 1953) to late Oligocene or early Miocene (Wolfe, 1969; Graham, 1972). Attempts to date the tuffs by radiometric methods have so far proved unsuccessful (Evernden and James, 1964), and no fauna has been discovered in the Weaverville sediments. Because the Weaverville Formation is isolated in relatively small, fault-bounded basins, it is not directly correlative with dated stratigraphic sections.

Objectives

A palynological study complements the known leaf flora in better representing the regional vegetation and in providing a quantitative measure of change in floristic composition. Comparison of microfossil occurrences could determine the temporal relationships between the various basins of Weaverville sediments, and might determine, for instance, whether the auriferous conglomerates are the same age as the underlying tuffs, lignites, and shales. Interpretations of spatial or facies relationships may be enhanced by knowledge of the vegetation near the site of deposition, and quantitative palynology may show changes in vegetation through the sections.

Thus, the purposes of this study are 1) to identify the pollen and spores and to compare the pollen and spore flora with the leaf flora; 2) to interpret the paleoecology of the vegetation and the depositional environments; 3) to determine the age of the Weaverville Formation and age relationships between basins; and 4) to identify floristic or vegetational changes within basins. The approach to accomplishing these objectives was to describe and sample two stratigraphic sections of the Weaverville Formation and to determine relative abundances of palynomorphs through those sections. The study localities are at Hayfork and at Readings Creek, 25 km east of Hayfork, and the stratigraphic sections are the same as those measured by MacGinitie (1937) and include the principal leaf collection sites. The pollen flora was compared with other Tertiary pollen floras to determine the age and with extant taxa represented by the fossil plants to interpret the paleoecology.

Geographical Setting

The Weaverville Formation occurs in central Trinity County in northwestern California, and the areas studied lie just west of Hayfork and at Readings Creek, 14 km south of Weaverville (Figure 1). This region is in the southern Klamath Mountains and is drained by the Trinity River. The weakly consolidated sediments of the Weaverville Formation underlie the flat valleys where the towns of Weaverville, Hayfork, and Hyampom are situated (Plate I). Elevations are 615-775 m in the valleys, surrounding hills rise to 1375-1850 m, and to the north, the Trinity Alps reach 2270 m and support two small glaciers.

The climate at Weaverville is temperate and summer dry, with a

Figure 1. Location of the field areas at Hayfork and Readings Creek.

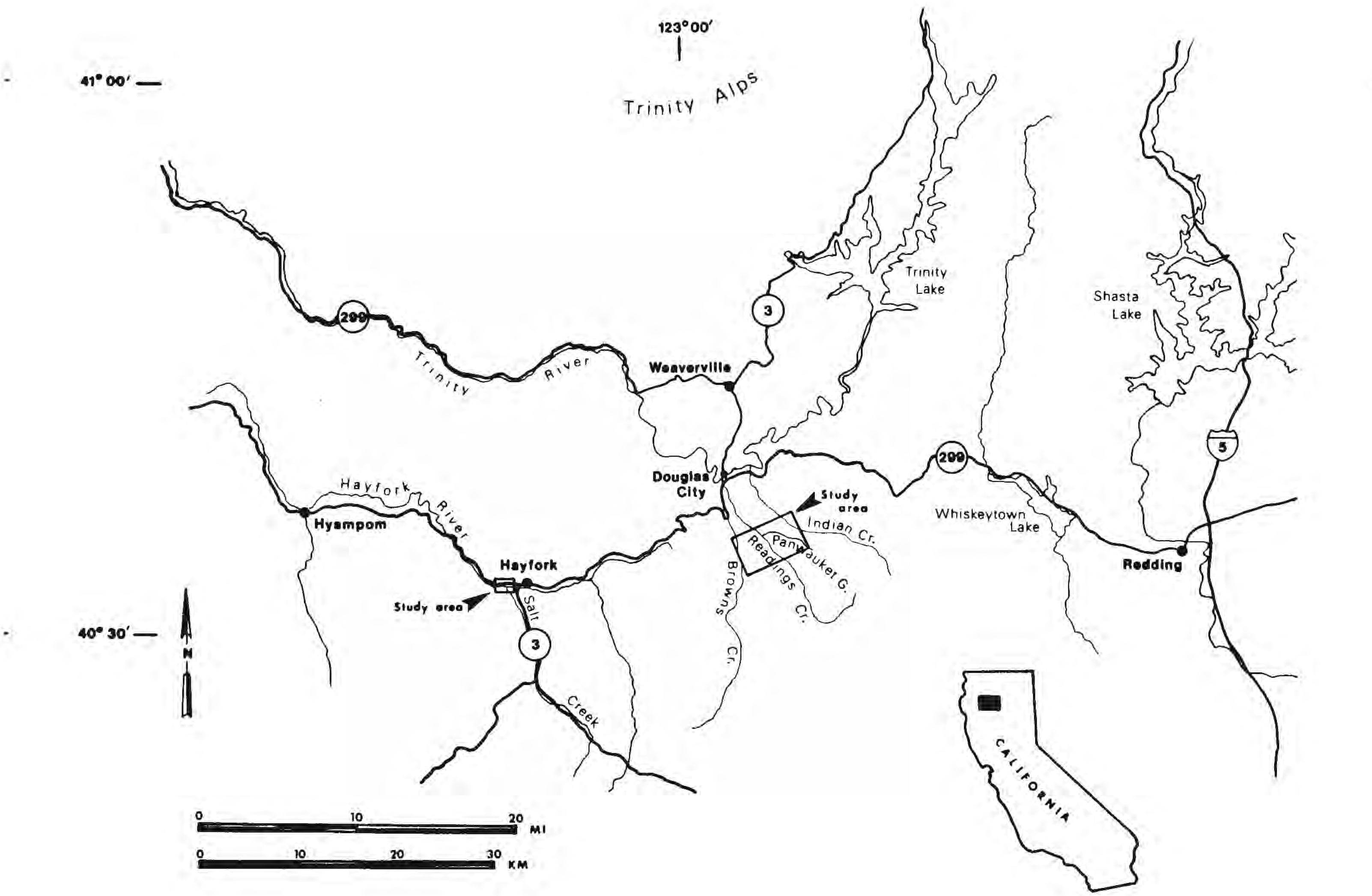

123°00'
41°00'
40°30'
Trinity Alps
Trinity River
Weaverville
Trinity Lake
Shasta Lake
299
3
5
Douglas City
Study area
Indian Cr.
Whiskeytown Lake
Redding
Hayfork River
Hyampom
Hayfork
Study area
Salt Creek
Browns Cr.
Readings Cr.
Paynes Pawaukee G.
N
0 10 20 MI
0 10 20 30 KM
CALIFORNIA

Plate I. Hayfork valley, underlain by the weakly consolidated sediments of the Weaverville Formation.

mean annual temperature of 12°C, average monthly temperatures of 3°C in January, and 22°C in July, and a range of -19°C to 45°C (Weaverville station; O'Brien, 1965). Average annual precipitation is 910 mm at Weaverville, with 760-2030 mm for Trinity County as a whole (O'Brien, 1965).

Modern Vegetation

The vegetation of the Klamath Mountains is characterized by its great diversity, complex geographic patterns, and unique composition that includes many endemic and relict species. The composition is largely a mixed evergreen forest (a two-level canopy of large conifers and small, broad-leaved evergreens or sclerophylls), which represents a transition between the coniferous forests to the north and west and the sclerophyll and oak-pine woodlands to the south and east (Whittaker, 1961; Sawyer and Thornburgh, 1977). Climate, relief, geographical position, and fire are thought to contribute to development and maintenance of this flora (Whittaker, 1961; Sawyer and Thornburgh, 1977). For instance, ultrabasic rocks in some areas host a discontinuous shrub layer and greater diversity of herbs, and species growing on these rocks have wider elevational ranges than where they grow on other rock types (Sawyer and Thornburgh, 1977). Pleistocene glaciation has also affected floristic distribution; for example, Sawyer and Thornburgh (1977) noted that glacial activity reduced regional forests of *Picea engelmanii* to isolated stands. The mixed evergreen forest of the Klamath Mountains is also of interest because it may be the closest modern representation of the late Miocene coniferous forests of the Columbia Plateau-Cascade region (MacGinitie, 1953; Wolfe, 1969).

In the Readings Creek and Hayfork areas, the modern vegetation commonly includes *Pinus ponderosa, Pinus sabiniana, Pseudotsuga menziesii, Arctostaphylus manzanita, Arbutus menziesii, Ceanothus cuneatus, Quercus kelloggii,* and *Quercus garryana* (Plate II). According to local residents, the Readings Creek area has burned several times, and the latest fire was in 1964. Thus, the vegetation there has been fire-maintained in historic time.

Plate II. Mixed evergreen forest of the Readings Creek area.

CHAPTER II: MATERIALS AND METHODS

Sample Collection

Samples were collected from two measured sections, one at Readings Creek, the other along the Hayfork River (Figure 1). The localities of these and other samples are given in Appendix I. These areas were chosen because the sections are relatively long and structurally simple, exposures are acceptable, and the beds contain well-preserved leaf fossils. These sections are the same as those described by MacGinitie (1937). The Readings Creek area and the beds west of Hayfork were mapped on a scale of 1:15,000 to determine structure and extent of the fossiliferous strata. Mapping was based on that done by Irwin (1963, 1974; scale 1:62,500), and base maps were the U.S. Geological Survey advance sheets for the Weaverville SE and Hayfork SE 7½' quadrangles. Detailed stratigraphic sections were measured with tape and compass and conglomerate units were estimated from the map. The leaf horizons and the lignites of the Readings Creek section and the lignites and shales of the Hayfork River section were sampled for pollen and spores. In addition, samples from Reese Coal Mine (between Readings and Browns Creeks), Hyampom, and a shale bed in the underlying Lower Cretaceous rocks were sampled (Appendix I).

Sample Preparation

The maceration procedure followed is standard for most palynological samples and such methods are described by Brown (1960), Gray (1965), Barss and Williams (1973), and Doher (1980). Samples were scrubbed with a stiff-bristle brush to remove surface contamination, dried, and ground to approximately 2 mm size in a Universal No. 2 Food Chopper. A 30 g portion was first treated with 10% hydrochloric acid to dissolve the carbonates and with concentrated hydrofluoric acid to dissolve the silicates. Then, organic matter was oxidized with Schulze solution (a 2:1 mixture of nitric acid and potassium chlorate) followed by 5% potassium hydroxide. Differential flotation in zinc bromide (specific gravity 2.00) separated organic material from mineral debris. Samples then were acetolyzed for 10 minutes, and some samples that contained abundant organic debris were oxidized in sodium hypochlorite ("Clorox"). The residue was stained with 0.1% safranin and stored in hydroxyethylcellulose (HEC). Slides were made from the residue using the cover slip mounting technique described by Schopf (1964), with HEC as the mounting medium and Coverbond mounting medium as the cement.

Palynomorphs were photographed and coordinates recorded for the Zeiss photomicroscope (serial number 61987) in the College of Forest Resources of the University of Washington. The film used was Panatomic X, which was developed in Microdol X (1:3).

Identification was accomplished by comparison with material from the extensive modern reference collection at the University of Washington and by comparison with the literature on modern and fossil pollen

and spores. Palynomorphs were assigned to modern genera, where possible, because such identifications yield the most botanical information. Otherwise, they were designated as form- or organ-genera, or if unidentified, assigned a number such as Trilete-9. A designation such as "*Juniperus*-type" indicates that the type may be one of several genera in a family; the designation "cf. *Vaccinium*" means that the grain superficially resembles a genus, but cannot be identified unequivocally; and "?*Cercis*" indicates general uncertainty in identification.

CHAPTER III: GEOLOGY

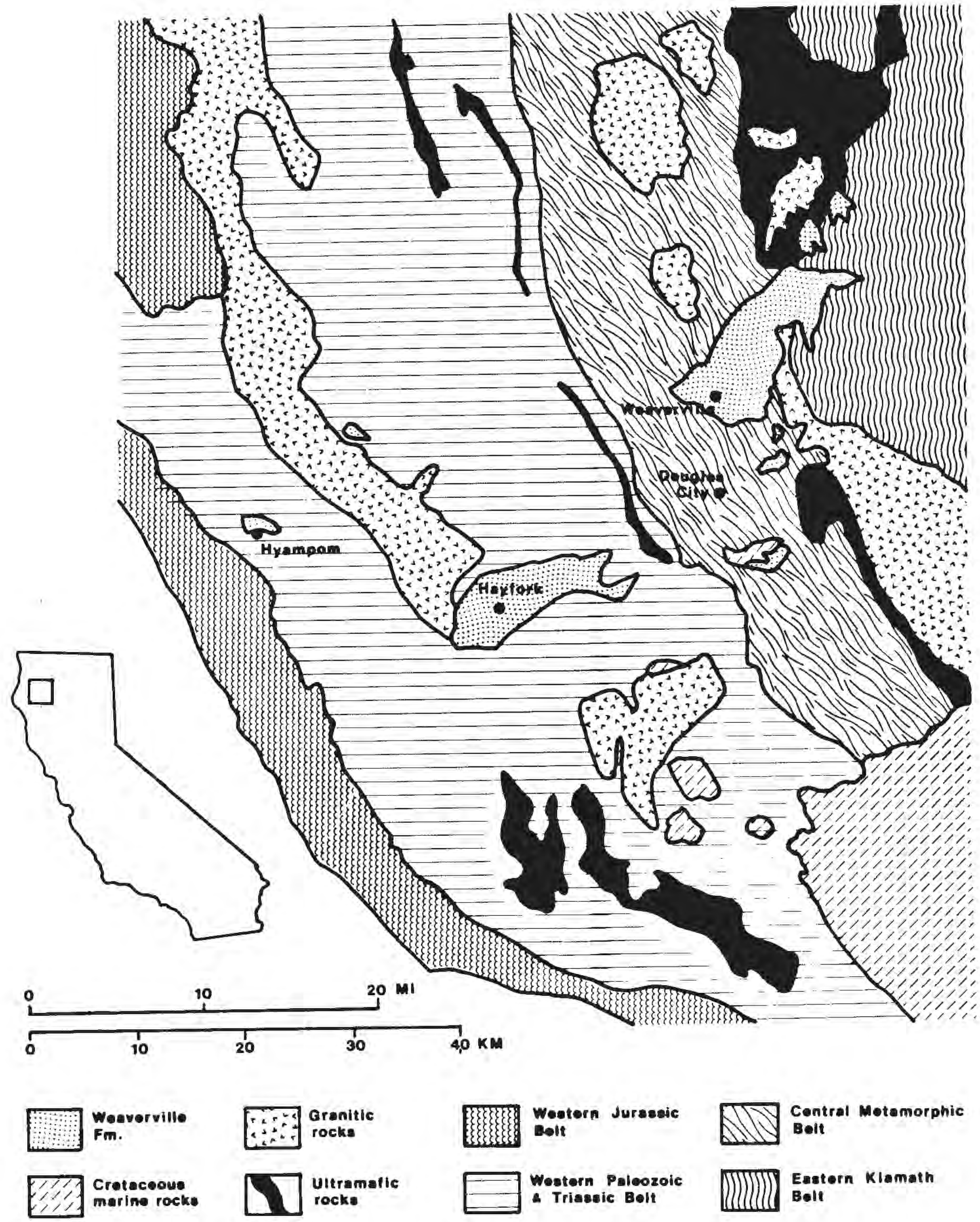
General Geological Setting

The Klamath Mountains geologic province consists of four major concentric, arcuate belts of eugeosynclinal rocks which range in age from Ordovician to Late Jurassic (Irwin, 1966, 1977). Metasedimentary and metavolcanic rocks of different metamorphic grades comprise these belts and were juxtaposed in the Mesozoic by a series of eastward-dipping thrust faults (Irwin, 1966). Linear belts of ultramafic rocks commonly mark these fault zones, and Late Jurassic plutons, primarily of quartz diorite composition, intrude the older rocks (Irwin, 1966).

Nonconformably overlying the basement rocks are fault-bounded Cretaceous and Tertiary sedimentary rocks (Figure 2). In the Readings Creek area occur 338 m of clastic marine rocks that contain abundant ammonites and pelecypods of Early Cretaceous age (Imlay, 1960). These Cretaceous rocks consist of a lower unit of indurated sandstone and conglomerate that is overlain by an upper unit of fossiliferous mudstone (Irwin, 1963). The basal conglomerate contains abundant clasts of mica schist, a rock type exposed nearby, indicating a relatively local sediment source (Irwin, 1966). Irwin (1966) suggested that these sediments are erosional remnants of the northward-thinning edge of the Great Valley Sequence.

The Weaverville Formation disconformably overlies the Cretaceous

Figure 2. Generalized geology of part of the southern Klamath Mountains. Based on maps by Irwin (1963, 1974, 1977), O'Brien (1965), and the Redding Sheet.


Hyampom
Hayfork
0
10
20 MI
0
10
20
30
40 KM
Weaverville Fm.
Granitic rocks
Western Jurassic Belt
Central Metamorphic Belt
Cretaceous marine rocks
Ultramafic rocks
Western Paleozoic & Triassic Belt
Eastern Klamath Belt

rocks or nonconformably overlies metamorphic rocks of the Central Metamorphic and Western Triassic and Paleozoic Belts. The sediments are preserved in small, down-dropped basins bounded by high-angle normal faults (Hinds, 1933). Irwin (1963) recognized two units of the Weaverville Formation in some places: a lower unit of fine-grained sediments, including shales, tuffs, and lignites, and an upper unit of ferruginous pebble and cobble conglomerate. The conglomerate represents one of four cycles of gold-bearing gravels: the Lower Cretaceous conglomerates, the Weaverville conglomerates, Pleistocene terraces, and Recent stream gravels (Diller, 1914; Hinds, 1933). The conglomerates and associated sediments of the Weaverville Formation are very similar to the famous auriferous gravels of the Sierra Nevada described by Lindgren (1911), and Diller (1911) suggested that they may be synchronous, though certainly any such correlation must be substantiated by radiometric or other dating methods.

Post-Weaverville deposits include Pleistocene terrace gravels, landslides, and glacial deposits. R. P. Sharp (1960) noted evidence in the Trinity Alps for four glacial episodes, the latter three probably Wisconsinan. Terminal moraines occur as low as about 750 m.

Stratigraphy

Maps 1 and 2 (in pocket) are geologic maps of the Weaverville Formation at Hayfork and Readings Creek, where the sections were measured and sampled. Figures 3, 4, and 5 show the lithologies of the measured sections, and Appendix II presents descriptions of the rock units.

Figure 3. Lithologies of the measured stratigraphic section at Readings Creek. Arrows show locations of samples taken for pollen study, and dots show which samples yielded pollen.

READINGS CREEK

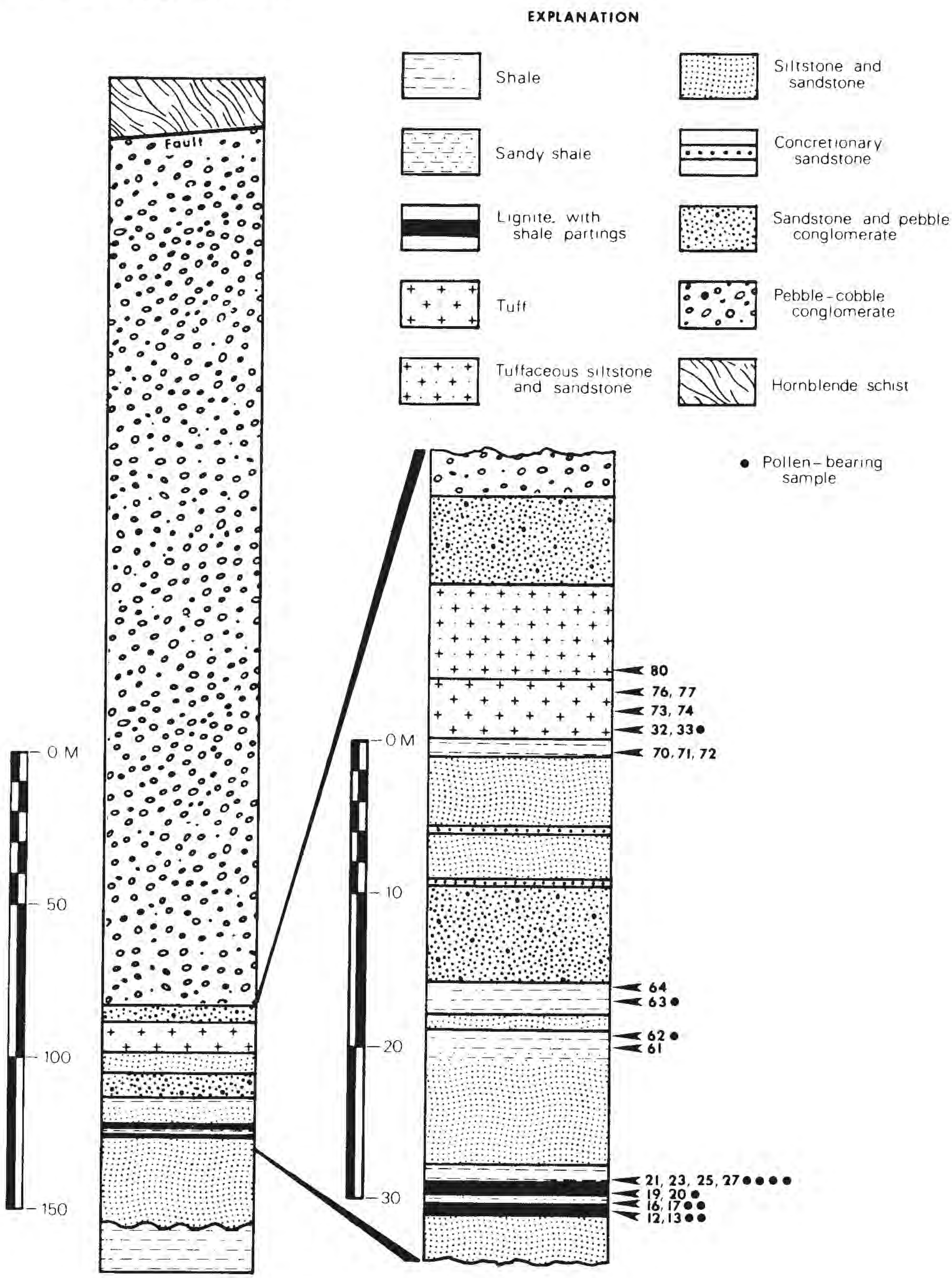


Figure 4. Lithologies of the measured stratigraphic section at Panwauket Gulch. Arrows show locations of samples taken for pollen study, and dots show which samples yielded pollen.

PANWAUKET GULCH

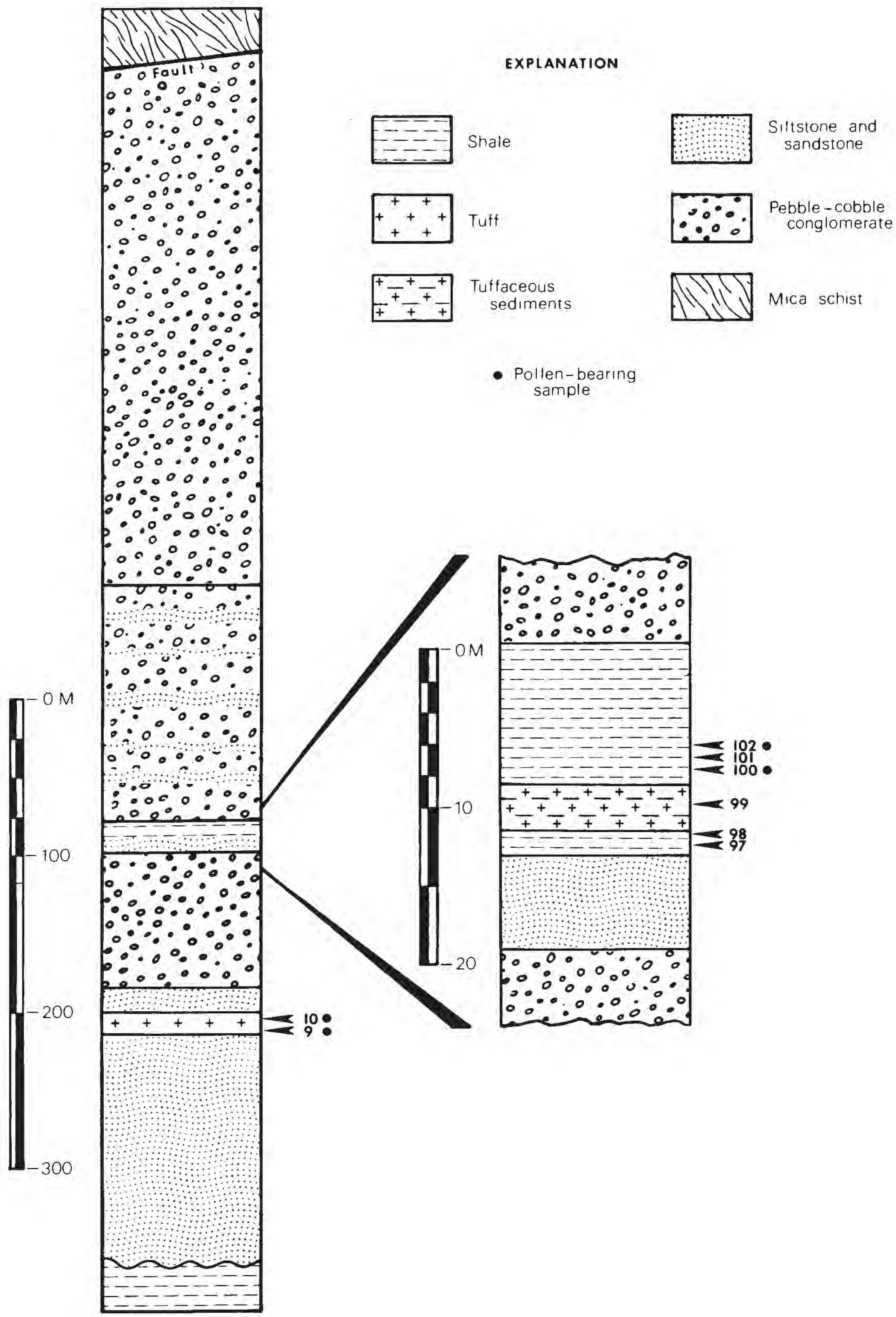
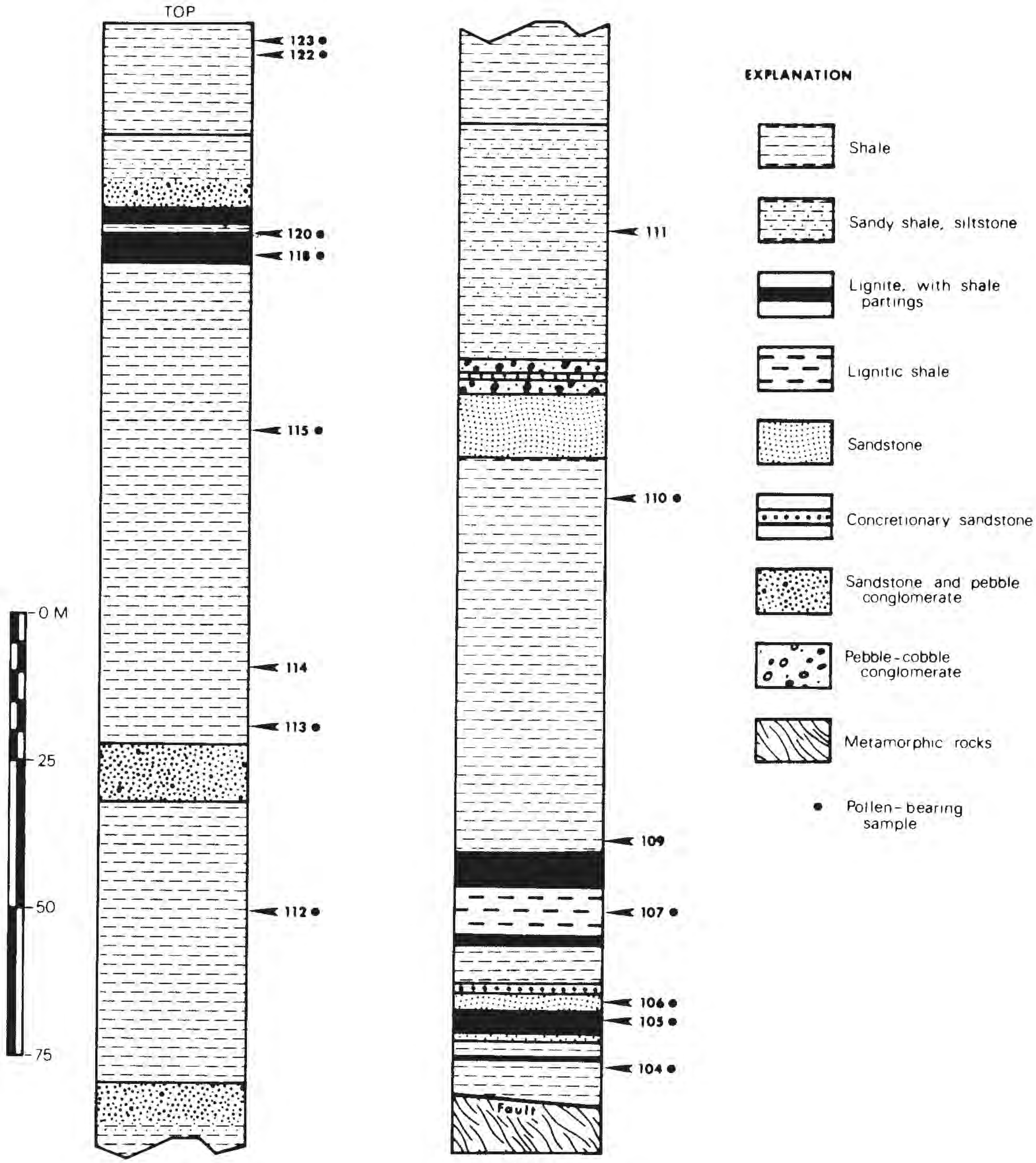


Figure 5. Lithologies of the measured stratigraphic section at Hayfork. Arrows show locations of samples taken for pollen study, and dots show which samples yielded pollen.

HAYFORK RIVER



Readings Creek-Panwauket Gulch. The sections measured at Readings Creek (Figure 3) and Panwauket Gulch (Figure 4) are similar, though the lower unit of the Weaverville Formation is better exposed at Readings Creek and the upper unit better exposed at Panwauket Gulch. At Readings Creek, about 73 m of shale, lignite, siltstone, tuff, sandstone, and minor conglomerate comprise the lower unit, which disconformably overlies the Lower Cretaceous marine rocks. At the base of the section occur about 2 m of lignites and lignitic, tuffaceous shales with leaf impressions and flattened, carbonized logs of *Taxodium* (Plate III; MacGinitie, 1937). These coals and interbedded shales do not crop out at Panwauket Gulch, but thicken to at least 7 m at the Reese Coal Mine (Plate IV). Overlying the lignites are shale, siltstone, and sandstone, with some granular and pebble conglomerate. The sandstone exhibits low-angle, planar cross-stratification and the pebble conglomerate occurs in lenses and cut-and-fill structures. This conglomerate differs from that of the upper unit in being finer and less ferruginous. The sandstone contains predominately lithic clasts, and the conglomerate includes clasts of the underlying tuffaceous shale. Blue shale and sandy shale with plant impressions are interbedded with the coarser sediments.

About 4 m of white, blocky tuff and tuffaceous siltstone and sandstone immediately underlie conglomerates of the upper unit (Plate V). The tuff is massive to finely laminated (Plate VI) and contains thin, organic horizons with abundant leaf impressions. This bed of white tuff is distinctive and crops out in Panwauket Gulch to the east and Browns Creek to the west. The Panwauket Gulch and Readings

Plate III. Flattened, carbonized logs of *Taxodium* in lower unit of the Weaverville Formation, Readings Creek.

Plate IV. Sub-bituminous coal of the lower unit of the Weaverville Formation, Reese Coal Mine.

Plate V. Tuff and tuffaceous sediments of the lower Weaverville Formation, Readings Creek. This bank is one of the leaf-collecting sites of MacGinitie (1937).

Plate VI. Blocky, massive tuff and laminated, tuffaceous sediments, Readings Creek.

Creek sections are correlated by this tuff bed.

The upper, coarse-grained unit of the Weaverville Formation is about 260 m thick at Panwauket Gulch and consists primarily of pebble and cobble conglomerate with some interbedded sandstone and shale (Plate VII). The conglomerate is generally poorly sorted and is mostly clast-supported, but is in part matrix-supported. It is moderately well cemented, but not indurated, and in some places forms resistant embankments. The clasts are generally well-rounded, somewhat flattened to spherical, and the matrix is sand or silt. Clasts consist of a variety of rock types, including meta-andesite, mica schist, sandstone, vein quartz, chert, granular conglomerate, and granitic rocks, as well as tuffaceous shale of the lower Weaverville Formation. Iron oxide commonly coats the clasts and stains the matrix an orange color.

The conglomerate exhibits crude, low-angle stratification and in some places is interbedded with lithic, feldspathic sandstone. In the conglomerate at Panwauket Gulch there is a 19 m-thick unit of blue claystone and sandstone with some pumaceous horizons containing carbonized wood. Near the fault contact with Abrams Mica Schist along Indian Creek, the conglomerate becomes coarser (cobbles and boulders), and the clasts are angular, poorly sorted, and predominantly mica schist (Plate VIII).

Hayfork River. The measured section at Hayfork (Figure 5) totals 368 m and consists primarily of fine-grained sediments. The base lies in apparent fault contact with older metavolcanic and metasedimentary rocks of the Western Triassic and Paleozoic Belt. Nearly 33 m of

Plate VII. Pebble-cobble conglomerate of the upper unit of the Weaverville Formation, Readings Creek.

Plate VIII. Poorly-sorted cobble-boulder conglomerate along Indian Creek near fault with Abrams Mica Schist.

lignite with interbedded shale and micaceous sandstone occur near the base of the section and contain some carbonized logs and leaf impressions. Overlying the lignitic unit are 66 m of blue and brown shale that are rather poorly exposed. Above the shale are 15 m of planar cross-stratified sandstone and poorly sorted pebble and cobble conglomerate followed by a relatively thick sequence of alternating shales, sandy shales and sandstones, with lenses of pebble conglomerate. Overlying these sediments is a second lignitic unit, nearly 9 m thick, which contains a few carbonized logs. Comprising the upper part of the section are dark, organic-rich shales with diatoms, sponge spicules, and horizons of freshwater molluscs (MacGinitie, 1973). The measured section ends at the axis of a syncline.

Structural Geology

The Weaverville Formation is generally bounded by normal faults, and the fault blocks are tilted to the southeast. Folding is mostly gentle except near faults, where it may be steeply-dipping. Major faults such as the unusually well-exposed La Grange fault (Plate IX) trend primarily northeast and minor ones trend northwest. The La Grange fault is marked by a mylonitic surface, dips 35° southeast, and probably has several thousand feet of vertical displacement (Irwin, 1963, 1966). In some places, such as along the Hayfork River, the sediments are buckled into minor folds. Such small-scale folding could account for the apparently greater thickness of lower Weaverville Formation at Panwauket Gulch than in other areas, although structure is difficult to delineate because of limited exposure.

Plate IX. Mylonitic surface of the La Grange fault along Highway 299 just west of Weaverville.

Depositional Environments

The Weaverville Formation is interpreted to represent several depositional environments which include lakes, streams, and alluvial fans. In the Readings Creek area, the blue shales and lignites are probably lacustrine and swamp deposits that were associated with a fluvial system represented by the sandstones, siltstones, and fine conglomerates of the lower Weaverville Formation. The white tuffs consist of glass shards with few minerals and were probably airborne; the presence of laminations, interbedded sandstone, and ripple marks suggests that the ash was locally deposited in a shallow body of water. In the upper unit of the Weaverville Formation, the crude, low-angle stratification, imbrication, and presence of interbedded sandstones indicate deposition on a proximal braided alluvial plain, as described by Rust (1978) and Miall (1978). In some areas, poor sorting, relatively angular clasts, and some matrix-supported conglomerate suggest deposition as distal alluvial fans (Miall, 1978). MacGinitie (1937) noted that imbrication of pebbles in the conglomerate at Readings Creek indicates current direction from the southeast. Near some faults, such as at Indian Creek, clasts in the conglomerates are mostly of local derivation (MacGinitie, 1937; Irwin, 1966) and thus, faulting was probably in part contemporaneous with deposition of some of the Weaverville Formation. Lyndon and Klein (1969) reached a similar conclusion for the Weaverville Formation in the Trinity Lake quadrangle to the north.

The sediments of the Hayfork area are generally finer than those of Readings Creek, although to the east of the main basin, near the old Shock and Montgomery hydraulic mine, there are exposures of conglomerates, lignites, and tuffaceous sediments similar to those of Readings Creek (MacGinitie, 1937). The thick units of shales with some lignitic shales and lignite probably represent a lake of moderate size with associated swamps. The beds of conglomerate and sandstone and associated silty shales indicate a distal braided river system. The Hayfork sediments could be a fluvio-lacustrine facies of the sediments at Readings Creek, but indications of contemporaneous faulting suggest that some of the Weaverville sediments, particularly the conglomerates, may have been deposited in separate basins.

CHAPTER IV: COMPOSITION OF THE FLORA

Results of Sample Preparation

A total of 55 samples from the Weaverville Formation were processed. Of these, 37 contained pollen and spores, and 32 of these 37 yielded enough material to be further analyzed. Most of the producing samples contained abundant and fairly well-preserved pollen and spores. A major problem in processing these samples was their high content of organic debris, and in oxidizing some samples to remove this debris, some of the bisaccate grains were broken.

The producing samples were evenly distributed between the two areas. The Hayfork area yielded 16, and the Readings Creek area yielded 20 samples, including 2 from the Reese Coal Mine and 4 from Panwauket Gulch. In addition, a sample from Hyampom yielded excellent pollen and spores and a florule similar to those of the described sections, but this florule was not considered in the present study. A sample of the underlying Lower Cretaceous shale also yielded abundant spores, which were used to check for possible reworking.

Pollen and Spore Assemblage

Table 1 is a systematic list of pollen and spores from the Weaverville Formation, and Appendix III presents photomicrographs of these types. Although potentially important, the fungi were not identified in this study. The collective flora (from both Hayfork

Table 1. Systematic list of plant microfossils found in the Weaverville Formation. Classification system is that of Brook (1964).

<u>CHLOROPHYTA</u>
HYDRODICTYACEAE
Pediastrum bifidites Wilson and Hoffmeister
Pediastrum delicatites Wilson and Hoffmeister
Pediastrum kajaites Wilson and Hoffmeister

ZYGNEMATACEAE
Schizosporis parvus Cookson and Dettmann (*Spirogyra*-type)
Tetraporina sp. (*Mougeotia*-type)

INCERTAE SEDIS
Algal cyst-1
Algal cyst-2
Algal cyst-3
Algal cyst-4
Algal cyst-5

<u>PYRROPHYTA</u>
CERATIACEAE
Ceratioid dinoflagellate cyst

CLEISTOSPHAERIDEACEAE
?*Cleistosphaeridium* sp. type 1
?*Cleistosphaeridium* sp. type 2

<u>INCERTAE SEDIS</u>
<u>ACRITARCHA</u>
ACANTHOMORPHITAE
Micrhystridium sp. type 1
Micrhystridium sp. type 2
Micrhystridium sp. type 3

<u>BRYOPHYTA</u>
ANTHOCEROTACEAE
Phaeoceros sp. — Hornwort

INCERTAE SEDIS
Trilete-8

<u>PTERIDOPHYTA</u>
<u>LYCOPSIDA</u>
LYCOPODIACEAE
?*Lycopodium* sp. — Club moss

<u>FILICOPSIDA</u>
?POLYPODIACEAE — Common fern family
Laevigatosporites albertensis Rouse
Laevigatosporites discordatus Thompson and Pflug
Laevigatosporites ovatus Wilson and Webster
Laevigatosporites sp. type 1
Laevigatosporites sp. type 2

Polypodiidites sp. type 1	
Polypodiidites sp. type 2	
Polypodiidites sp. type 3	
Polypodiisporonites sp.	
SCHIZAEACEAE	Climbing fern family
Cicatricosisporites sp.	
Corrugatisporites sp.	
INCERTAE SEDIS	
Deltoidospora sp.	
INCERTAE SEDIS	
Trilete-3	
Trilete-7	
Trilete-9	
Trilete-10	
Trilete-11	
Trilete-12	
Trilete-16	
Trilete-18	
Trilete-19	
SPERMATOPHYTA	
GYMNOSPERMAE	
CUPRESSACEAE	
Juniperus-type	
?*Libocedrus* sp.	
Inaperturate-17	
PINACEAE	
Abies sp.	Fir
Cedrus sp.	Cedar
Larix sp.	Larch
Picea sp. type 1	Spruce
Picea sp. type 2	Spruce
Pinus sp.	Pine
Tsuga cf. *T. canadensis*	Hemlock
Tsuga cf. *T. heterophylla*	Hemlock
PODOCARPACEAE	
Podocarpus sp. type 1	Podocarpus
Podocarpus sp. type 2	Podocarpus
TAXODIACEAE	
?*Cryptomeria* sp.	Japanese cedar
?*Glyptostrobus* sp.	Canton water pine
Taxodium sp.	Swamp-cypress
TAXODIACEAE-CUPRESSACEAE-TAXACEAE, undivided	
ANGIOSPERMAE	
MONOCOTYLEDONAE	

GRAMINEAE	Grass family
Graminidites sp.	
TYPHACEAE or SPARGANIACEAE	
Typha sp. or *Sparganium* sp.	Cat-tail or Burweed
DICOTYLEDONAE	
ACERACEAE	
Acer sp.	Maple, Box elder
AQUIFOLIACEAE	
Ilex sp. type 1	Holly
Ilex sp. type 2	Holly
Ilex sp. type 3	Holly
BETULACEAE	
Alnus sp.	Alder
Betula sp.	Birch
Corylus sp.	Hazel
Ostrya sp. or *Carpinus* sp.	Hop-hornbeam, Ironwood
BOMBACACEAE	
Bombax-type	
BUXACEAE	
Buxus sp.	Boxwood
Pachysandra sp. or *Sarcococca* sp.	Spurge or Sarcococca
?CACTACEAE	Cactus family
cf. *Cereus*	
cf. *Echinocereus*	
CASUARINACEAE	
Casuarina sp.	She-oak
CHENOPODIACEAE	
Sarcobatus sp.	Grease-wood
COMPOSITAE	Sunflower family
Ambrosieae	
Astereae	
Cichorieae	
ERICACEAE	Heath family
cf. *Pieris*	
cf. *Pyrola*	
cf. *Rhododendron*	
cf. *Vaccinium*	
EUPHORBIACEAE	
Croton sp.	Croton
FAGACEAE	
Castanea sp. or *Castanopsis* sp.	Chestnut or Chinquapin
Quercus granopollenites Rouse	Oak
Quercus sp.	Oak

HAMAMELIDACEAE	
Liquidambar sp.	Sweetgum
ILLICIACEAE	
Illicium sp.	Star-anise, Stinkbush
JUGLANDACEAE	
Carya spackmania Traverse	Hickory, Pecan
Carya veripites Wilson and Webster	Hickory, Pecan
Juglans sp.	Walnut, Butternut
Pterocarya sp.	Wingnut
LABIATAE	Mint family
cf. *Salvia*	
LEGUMINOSAE	
Bauhinia cf. *B. congesta*	Orchid tree, Butter-fly tree
Caesalpinia sp.	
?*Cercis* sp.	Redbud
LEITNERIACEAE	
Leitneria sp.	Corkwood
MALVACEAE	Mallow family
cf. *Althaea*	
Sphaeralcea sp.	Globe-mallow
MORACEAE	
Morus sp.	Mulberry
NYSSACEAE	
Nyssa sp.	Sourgum, Tupelo
OLEACEAE	
Fraxinus sp.	Ash
ONAGRACEAE	
Jussiaea sp.	Primrose-willow
Triporate-1	
PLANTAGINACEAE	
Plantago sp.	Plantain
PLATANACEAE	
Platanus sp.	Plane-tree, Sycamore
POLYGONACEAE	
Polygonum cf. *P. coccinium*	Knotweed
RUBIACEAE	Maddar family
SALICACEAE	
Salix apiculata Martin and Rouse	Willow
Salix discoloripites Wodehouse	Willow
STERCULIACEAE	
Fremontodendron sp.	Flannel-bush
Reevesia sp.	

?STYRACACEAE	
?*Styrax* sp.	Spring-orange
SYMPLOCACEAE	
Symplocos sp. type 1	Sweetleaf, Horse-sugar
Symplocos sp. type 2	
?THEACEAE	Tea family
cf. *Franklinia*	
TILIACEAE	
Tilia sp.	Basswood, Linden
Triumfetta sp.	
TRAPACEAE	
Trapa sp.	Water chestnut
ULMACEAE	
Celtis sp.	Hackberry
Ulmus sp. or *Zelkova* sp.	Elm
INCERTAE SEDIS	
Diporate-1	
Pistillipollenites sp.	
Stephanocolpate-7	
Stephanocolporate-1	
Stephanocolporate-2	
Tricolpate-1	
Tricolpate-7	
Tricolpate-9	
Tricolpate-10	
Tricolpate-11	
Tricolpate-12	
Tricolpate-14	
Tricolpate-15	
Tricolpate-18	
Tricolpate-20	
Tricolpate-28	
Tricolporate-4	
Tricolporate-9	
Tricolporate-13	
Tricolporate-16	
Tricolporate-17	
Tricolporate-19	
Tricolporate-23	
Tricolporate-27	
Tricolporate-28	
Tricolporate-29	
Tricolporate-30	
Tricolporate-42	
Tricolporate-44	
Triporate-10	
Triporate-12	

and Readings Creek) is very diverse, with a total of 151 types assigned to 85 genera or tribes in 51 families. For the total pollen flora, the distribution in the major groups is 63% angiosperms, 13% ferns, 11% gymnosperms, and 11% algae, acritarchs, and dinoflagellates, as well as two bryophytes, and a club moss. A total of 27% of the forms recognized remain unidentified.

Appendix IV shows that the Hayfork and Readings Creek areas each yielded a diverse assemblage, with 125 from Hayfork and 106 from Readings Creek, and a total of 100 of 151 types (66%) common to both areas. Of the 26 taxa found only at Hayfork and 25 only at Readings Creek, most are represented by only one or two grains. Hence, their absence in either section may be due to scarcity in the record rather than absence from the regional flora. Thus, the two florules are quite similar in composition.

Comparison of Leaf and Pollen Floras

Table 2 shows the distribution of taxa in the microfossil and megafossil records. The composite list totals 84 taxa referable to modern genera and families. Of these taxa, 52 types are found only as microfossils and 17 types only as megafossils, with only 15 (18%) occurring as both micro- and megafossils. Even at the family level, the differences are striking. Of a total of 57 families, 33 are represented only by microfossils and 10 only by megafossils, with only 14 (25%) common to both leaf and pollen floras. The most notable additions to the flora are the gymnosperms, which are well-represented by pollen of Pinaceae, Cupressaceae, Taxodiaceae, and Podocarpaceae, but except

Table 2. Comparison of microfossil and megafossil occurrences of taxa referable to modern genera and families. List of megafossils by MacGinitie (1937 and personal communication, 1982).

	Taxon	Microfossils	Megafossils
Bryophyta			
Anthocerotaceae	*Phaeoceros* sp.	x	
Stictaceae	*Lobaria*		x
Pteridophyta			
Lycopodiaceae	?*Lycopodium* sp.	x	
Polypodiaceae		x	x
Schizaeaceae		x	
Spermatophyta			
Gymnospermae			
Cupressaceae	*Juniperus*-type	x	
	?*Libocedrus* sp.	x	
Pinaceae	*Abies* sp.	x	
	Cedrus sp.	x	
	Larix sp.	x	
	Picea sp.	x	
	Pinus sp.	x	
	Tsuga sp.	x	
Podocarpaceae	*Podocarpus* sp.	x	
Taxodiaceae	?*Cryptomeria* sp.	x	
	?*Glyptostrobus* sp.	x	
	Taxodium sp.	x	x
Taxodiaceae-Cupressaceae-Taxaceae		x	
Angiospermae			
Gramineae		x	x
Typhaceae	*Typha* sp.		x
Typhaceae or Sparganiaceae	*Typha* sp. or *Sparganium* sp.	x	
Liliaceae	*Smilax* sp.		x
Aceraceae	*Acer* sp.	x	
Anacardiaceae	*Rhus* sp.		x
Aquifoliaceae	*Ilex* sp.	x	x
Aristolochiaceae	*Aristolochia* sp.		x
Betulaceae	*Alnus* sp.	x	
	Betula sp.	x	
	Corylus sp.	x	
	Ostrya sp. or *Carpinus* sp.	x	
Bombacaceae	*Bombax*-type	x	
Buxaceae	*Buxus* sp.	x	
	Pachysandra or *Sarcococca* sp.	x	
?Cactaceae		x	
Caprifoliaceae	*Viburnum* sp.		x
Casuarinaceae	*Casuarina* sp.	x	
Chenopodiaceae	*Sarcobatus* sp.	x	
Compositae		x	

	Taxon	Micro-fossils	Mega-fossils
Dilleniaceae	*Actinidia* sp.		x
Ericaceae		x	
Euphorbiaceae	*Croton* sp.	x	
Fagaceae	*Castanea* sp. or *Castanopsis* sp.	x	x?
	Quercus sp.	x	x
Hamamelidaceae	*Liquidambar* sp.	x	
Illiciaceae	*Illicium* sp.	x	
Juglandaceae	*Carya* sp.	x	
	Juglans sp.	x	x
	Pterocarya sp.	x	
Labiatae	cf. *Salvia*	x	
Lauraceae	*Lindera* sp.		x
	Ocotea sp.		x
	Persea sp.		x
Leguminosae	*Bauhinia* sp.	x	
	Caesalpinia sp.	x	
	Cassia sp.		x
	?*Cercis* sp.	x	
	Dalbergia sp.		x
	Inga sp.		x
Leitneriaceae	*Leitneria* sp.	x	
Malvaceae	cf. *Althaea*	x	
	Sphaeralcea sp.	x	
Myrtaceae	*Calyptranthes* sp.		x
Moraceae	*Morus* sp.	x	
Nyssaceae	*Nyssa* sp.	x	x
Oleaceae	*Fraxinus* sp.	x	
Onagraceae	*Jussiaea* sp.	x	
Plantaginaceae	*Plantago* sp.	x	
Platanaceae	*Platanus* sp.	x	x
Polygonaceae	*Polygonum* sp.	x	
Rhamnaceae	*Berchemia* sp.		x
	Rhamnus sp.		x
Rubiaceae		x	
Salicaceae	*Salix* sp.	x	x
	?*Populus* sp.		x
Saxifragaceae	*Hydrangea* sp.		x
Sterculiaceae	*Fremontodendron* sp.	x	
	Reevesia sp.	x	
Styracaceae	*Styrax* sp.	x?	x
Symplocaceae	*Symplocos* sp.	x	
?Theaceae	cf. *Franklinia*	x	
Tiliaceae	*Tilia* sp.	x	x
	Triumfetta sp.	x	
Trapaceae	*Trapa* sp.	x	x
Ulmaceae	*Celtis* sp.	x	
	Ulmus sp. or *Zelkova* sp.	x	x?

for *Taxodium*, are lacking in the leaf record. Similarly, Betulaceae, Onagraceae, Ericaceae, and Sterculiaceae each contain two or more genera represented only by pollen. On the other hand, the families Rhamnaceae, Myrtaceae, and Dilleniaceae, as well as three genera in Lauraceae are found only as leaves. Although both leaves (MacGinitie, 1937) and pollen of some genera such as *Taxodium, Nyssa,* and *Salix* are abundant, leaves of *Rhus, Calyptranthes, Inga,* and *Ocotea* are common, but pollen is absent. On the other hand, pollen of *Picea, Pinus, Pterocarya* and *Carya* is abundant in some samples, yet leaves of these genera were not found.

Differential pollen production, transport, or differential preservation of pollen and leaves probably account for these occurrences. For instance, leaves of laurel are thick and leathery and commonly well preserved; whereas, the pollen is rather fragile and may be poorly preserved or destroyed by maceration. Also, the genera occurring only as microfossils are largely wind-pollinated and produce abundant pollen; whereas, the plants occurring only as megafossils are mostly insect-pollinated and produce little pollen. Thus, the micro- and megafossils corroborate each other to some extent, and certainly well complement one another. For a most complete description of a fossil flora, both records should be considered, if possible.

CHAPTER V: VEGETATION AND PALEOECOLOGY

Comparison with Modern Vegetation

The ecological requirements and geographical distributions of extant taxa represented in the Weaverville pollen flora are given in Table 3. In overall composition, the Weaverville flora, like other North American mid-Tertiary floras, is most similar to the modern vegetation of the southeastern United States, southeastern Mexico, and eastern Asia. These regions are noted for their floritic similarities (A. J. Sharp, 1966; Graham, 1972). The Weaverville pollen and leaf flora contains taxa now distributed among several major vegetational units in these regions, and there is no direct modern analog for the Weaverville assemblage.

Eastern Asia. A large number of taxa in the Weaverville fossil flora now occur in China in the Evergreen Broad-Leaved Forest or in the Mixed Mesophytic Forest (Wang, 1961), and many of these taxa grow in both forests, though in varying proportions. The Notophyllous Broad-Leaved Evergreen Forest (Wolfe, 1979), or "oak-laurel" forest occupies lowland areas of central and southern China. It is highly diverse, but is dominated by several genera of Fagaceae and Lauraceae, along with Theaceae and Magnoliaceae (Wang, 1961; Wolfe, 1979), and these families are all represented or probably represented in the Weaverville flora. (*Illicium* is placed in Magnoliaceae by some workers.) The broad-leaved

Table 3. Ecological requirements and geographical ranges of extant taxa represented by microfossils of the Weaverville Formation. Modified from Pierce (1961), Rouse (1962), Smiley (1966), Hopkins (1969), Fisk (1976), Barnett and Fisk (1980), with additions from Lawrence (1951), Benson (1957), Gray (1958), and Willis (1973). A number of regional floras and surveys were also used: Anderson (1959), Wang (1961), Gleason and Cronquist (1963), Polunin (1969), Tralau (1969, 1974, 1981), Britton and Brown (1970), Francis (1970), Hitchcock and Cronquist (1973), Numata (1974), Martin and Hutchins (1980), Wiggins (1980), and Godfrey and Wooten (1981).

Taxon	Habitat	Climate	Geographic Range
CHLOROPHYTA			
Pediastrum	freshwater lakes, ponds, and slow-moving streams	tropical to boreal	cosmopolitan
Zygnemataceae	shallow, stagnant, mesotrophic fresh-water	(tropical, subtropical?) temperate to boreal	Northern Hemisphere; Kerguelen Islands
BRYOPHYTA			
Phaeoceros	moist, shady areas	tropical to cool temperate	nearly cosmopolitan
PTERIDOPHYTA			
Ferns			
Lycopodium	moist areas, sometimes epiphytic	tropical to boreal	cosmopolitan
Polypodiaceae	rain forests to deserts	tropical to boreal	cosmopolitan
Schizaeaceae	moist forests	tropical to warm temperate	Primarily Southern Hemisphere; eastern North America

Taxon	Habitat	Climate	Geographic Range
Gymnosperms			
Abies	highlands and mountainous regions	warm temperate to boreal	Northern Hemisphere, south to Guatamala and northern Africa
Cedrus	dense mesic to dry forests	subtropical to cool temperate	Mediterranean region, northern Africa, western Himalayas
Cupressaceae	variable	tropical to boreal	cosmopolitan
Cryptomeria	dry montane slopes	warm to cool temperate	Japan and China
Glyptostrobus	moist areas, river banks, swamps	tropical to warm temperate	southeastern China
Larix	marshes and wet woodlands	cool temperate to boreal	Northern Hemisphere
Libocedrus	moist lowland to subalpine forests	(tropical?) subtropical to cool temperate	West Coast of North and South America, New Zealand, East Indies, China
Picea	swamps to well-drained uplands	warm temperate to boreal	Northern Hemisphere
Pinus	swamps to dry, rocky highlands	subtropical to boreal	Northern Hemisphere
Podocarpus	moist woodlands	subtropical to warm temperate	Southern Hemisphere, north to Mexico, southern Japan, and central China
Taxodium	swamps, streambanks, and floodplains	subtropical to warm temperate	southeastern U.S. and Mexico

Taxon	Habitat	Climate	Geographic Range
Tsuga	moist woodlands	warm to cool temperate	North America, Himalayas to Japan
ANGIOSPERMS MONOCOTYLEDONS			
Gramineae	variable	tropical to boreal	cosmopolitan
Sparganium	aquatic in ponds and lakes; marshes	subtropical to boreal	cosmopolitan
Typha	marshes; shallow water of ponds and lakes	tropical to boreal	cosmopolitan
DICOTYLEDONS			
Acer	variable, but often moist uplands and mountainous regions	subtropical to cool temperate	Northern Hemisphere
Alnus	swamps, streambanks, wet slopes	warm temperate to boreal	Northern Hemisphere, south to Central America and Andes Mts.
Bauhinia	commonly dry hills, savannas	tropical to warm temperate	southern U.S. to South America; Asia, Africa, Australia
Betula	bogs and swamps to moist uplands	subtropical to boreal	Northern Hemisphere
Bombax	moist, humid lowlands	tropical to subtropi-cal	Africa, Asia, Mexico to South America

Taxon	Habitat	Climate	Geographic Range
Buxus	dry hills	tropical to cool temperate	Northern Hemisphere, South Africa, Asia
Cactaceae	dry rocky or sandy areas and epiphytic in rain forests	tropical to cool temperate	North and South America
Caesalpinia	dry hillsides	tropical to subtropical	southwestern North America to South America; eastern Asia, eastern Africa
Carpinus	coastal swamps to moist uplands	subtropical to cool temperate	Northern Hemisphere
Carya	variable; commonly moist woodlands and streambanks	subtropical to cool temperate	eastern North America, China, southeast Asia
Castanea	thickets and dry woods	warm to cool temperate	Northern Hemisphere
Castanopsis	dry canyons to moist woodlands	subtropical to warm temperate	West Coast of U.S.; Southeast Asia
Casuarina	swampy ground to poor sandy soils	tropical to subtropical (warm temperate?)	Eurasia and northern Africa, Australia, South Pacific, South America
Celtis	wet lowlands to rocky hills and barrens	tropical to cool temperate	cosmopolitan
Cercis	streambanks, open woods to rocky hills	warm to cool temperate	Northern Hemisphere

Taxon	Habitat	Climate	Geographic Range
Chenopodiaceae	variable; often dry and alkaline soil	tropical to boreal	cosmopolitan
Compositae	variable	tropical to boreal	cosmopolitan
Corylus	moist thickets and woodlands	warm to cool temperate	Northern Hemisphere
Croton	variable	tropical to cool temperate	North and South America, Africa, eastern Asia
Ericaceae	variable	subtropical to boreal	Northern Hemisphere, tropical mountains
Fraxinus	damp woods, swamps	tropical to cool temperate	Northern Hemisphere, Cuba, and Java
Fremontodendron	dry slopes	warm temperate	California, Arizona, and New Mexico
Ilex	bogs, low moist areas	tropical to cool temperate	cosmopolitan
Illicium	woodlands, commonly swampy areas and near streams	(tropical?) subtropical to warm temperate	Southeast Asia, southeastern U.S., Mexico
Juglans	moist woods, river terraces	subtropical to warm temperate	southeastern U.S., southeastern Europe to eastern Asia; Central America to Andes Mts.
Jussiaea	wet soil; aquatic in shallow water	tropical to warm temperate	southern U.S. south to Argentina

Taxon	Habitat	Climate	Geographic Range
Labiatae	variable; marshes to deserts	tropical to boreal	cosmopolitan
Leitneria	swamps	(subtropical?) warm temperate	southeastern U.S.
Liquidambar	moist or wet woods to dry hillsides	subtropical to warm temperate	Northern Hemisphere
Malvaceae	variable	tropical to cool temperate	cosmopolitan
Morus	moist woods	tropical to warm temperate	nearly cosmopolitan
Nyssa	swamps and lakeshores to moist lowlands	tropical to cool temperate	eastern U.S. and Asia
Pachysandra	moist woods	subtropical to cool temperate	eastern Asia, eastern U.S.
Plantago	variable	tropical to boreal	cosmopolitan
Platanus	lowlands, streambanks, and lake shores	subtropical to cool temperate	Northern Hemisphere
Polygonum	variable; aquatic to xerophytic	tropical to boreal	cosmopolitan
Pterocarya	swamps and moist slopes	warm temperate	Caucasus Mts. to China and Japan
Quercus	variable; mesic to dry forests	subtropical to cool temperate	Northern Hemisphere; mountains of the tropics

Taxon	Habitat	Climate	Geographic Range
Reevesia	moist mountain forests	tropical to subtropical	Southeast Asia, Java
Rubiaceae	variable	tropical to boreal	cosmopolitan
Salix	moist thickets, swamps, streambanks	tropical to boreal	cosmopolitan
Sarcococca	open woods, moist forests	tropical to cool temperate	China and Indo-Malaya, southern Mexico and Central America
Styrax	moist thickets, streambanks, swamps	tropical to cool temperate	Eurasia, Malaysia, North and South America
Symplocos	swamps, bottomlands, and moist woods	tropical to warm temperate	Asia, South America to Mexico and southern U.S.
Theaceae	variable	tropical to warm temperate	North and South America, East Asia, Indo-Malaya, and Africa
Tilia	moist slopes, streambanks, floodplains	subtropical to cool temperate	Northern Hemisphere
Trapa	floating in ponds, lakes, and streams	tropical to cool temperate	Europe, Africa, Asia, eastern U.S.
Triumfetta	hillsides and along streams	tropical to subtropical	Central and South America, Africa
Ulmus	river valleys, moist woodlands to dry uplands	subtropical to cool temperate	Northern Hemisphere

Taxon	Habitat	Climate	Geographic Range
Zelkova	moist woodlands	subtropical to warm temperate	eastern Mediterranean, Caucasus Mts. east to central China and Japan

evergreen forest contains some deciduous plants such as *Liquidambar, Alnus, Celtis, Styrax, Acer, Carpinus, Betula, Salix, Tilia,* and *Carya,* which are common in the Weaverville flora, as well as some conifers, including *Tsuga, Podocarpus, Libocedrus,* and *Cryptomeria.* The genus *Reevesia* is typical of evergreen rain forest, but is also found in the evergreen oak forest of Fukien (southeast China; Wang, 1961). Xerophytic plants, such as *Pieris* and *Bauhinia* occur in understories of open stands and in pine-oak forests (Wang, 1961).

In terms of Weaverville taxa, the Notophyllous Broad-Leaved Evergreen Forest and the Mixed Mesophytic Forest are floristically similar, but differ in relative dominance of plants in the forest. The Mixed Mesophytic Forest in southern China is generally found north of the Evergreen Broad-Leaved Forest or at higher elevations (Wang, 1961). A diverse assemblage of deciduous trees comprises the bulk of the forest, and no single species is dominant (Wang, 1961). Weaverville taxa common in this forest are *Acer, Alnus, Betula, Ostrya* or *Carpinus, Liquidambar, Celtis, Salix, Carya, Quercus, Fraxinus, Juglans, Morus, Pterocarya, Tilia,* and *Ulmus* or *Zelkova.* Some broad-leaved evergreens in the families Fagaceae, Lauraceae, and Ericaceae, as well as a number of conifers, also grow in the Mixed Mesophytic Forest (Wang, 1961).

The Weaverville pollen flora includes a diverse coniferous element, and some of these taxa occur today in the Mixed Coniferous Forest (Wolfe, 1979) of southwest China and the Himalayas. The montane coniferous forest grows above the Mixed Mesophytic and Evergreen Broad-Leaved Forests, e.g., at 2400-3000 m in eastern Szechuan (southwest China; Wang, 1961). In the tropical mountains of Taiwan, conifers and deciduous trees grow at 1800-2250 m, above the broad-leaved evergreen and deciduous forests, and spruce-fir forests grow above 2250 m (Li, 1963). Plants in the associated understory include *Rhododendron, Ilex, Symplocos,* and *Viburnum,* with *Salix* and *Betula* along streams (Wang, 1961).

Mexico. The pine-oak-*Liquidambar* and montane rain forests of the mountains of eastern and southern Mexico contain a mixture of deciduous and evergreen plants which is particularly similar to the Weaverville fossil flora. The pine-oak-*Liquidambar* forests of the Central and Northern Highlands of Chiapas and the mountains of Veracruz contain a diverse assemblage of plants, including *Fraxinus, Ostrya, Styrax, Juglans, Persea, Salvia, Ilex, Viburnum, Triumfetta, Inga,* and *Cassia* (Breedlove, 1973; Gomez-Pompa, 1973; Zuill and Lathrop, 1975). These forests are of interest because northern, temperate taxa such as *Alnus, Nyssa, Platanus,* and *Ulmus* grow along with southern, tropical taxa such as *Ocotea, Podocarpus,* and *Symplocos* (Miranda and Sharp, 1950; Hernandez X., 1951). The montane rain forest commonly grows adjacent to the pine-oak-*Liquidambar* forest, but on the wetter, more humid, windward sides of mountains (Zuill and Lathrop, 1975). Though containing a large number of genera not found in the Weaverville flora, the montane rain forest does include *Podocarpus,* some oaks, and several laurels, including *Persea* (Zuill and Lathrop, 1975). Thus, the Weaverville flora is most similar to the pine-oak-*Liquidambar* forests, but also has some affinities with the montane rain forest.

Southeastern United States. The Weaverville pollen flora contains a number of taxa found today in the Mixed Mesophytic Forest and the

Southeastern Evergreen Forest of the southeastern United States. For instance, *Quercus, Acer, Liquidambar, Tilia, Juglans, Illicium, Ulmus, Platanus, Carya, Fraxinus, Ostrya* or *Carpinus, Morus,* and *Ilex* are trees or shrubs of the Mixed Mesophytic Forest of the southern Appalachian Mountains (Braun, 1964). Wolfe (1979) noted that this forest is not the exact climatic or physiognomic equivalent of the Mixed Mesophytic Forest of eastern Asia and differs in its paucity of evergreens and cooler climate. In the southeastern Evergreen Forest of the Atlantic Coastal Plain, the above taxa comprise the mesic bottomland forests, and *Taxodium* and *Nyssa* with associated *Acer, Pinus, Fraxinus, Carya, Polypodium,* and *Leitneria* dominate the swamp vegetation (Braun, 1964; Godfrey and Wooten, 1981). At high elevations (above about 1250 m) in the Great Smoky Mountains grow *Picea, Larix,* and *Abies,* along with *Betula, Rhododendron,* and *Vaccinium*. Thus, in comparison to vegetation of the southeastern United States, the Weaverville pollen flora is most similar to the mixture of evergreens and deciduous plants of the Atlantic Coastal Plain, but also contains genera of Pinaceae found in montane coniferous forests.

Vegetation and Habitats

The Weaverville fossil flora is interpreted to represent two major vegetational units: a mixed broad-leaved evergreen and deciduous forest and a mixed coniferous forest. Additional local communities were a *Taxodium-Nyssa* swamp forest near the basin of deposition and a scrub or woodland in more xeric areas. A rich representation of both broad-leaved evergreens and deciduous trees is present in the Weaverville pollen and leaf floras, and from floristics alone it is difficult to determine whether the vegetation was dominantly evergreen or deciduous. Several interpretations of this mixture are possible. The forest in the nearby region may have had a mixed canopy of evergreen and deciduous trees, perhaps as an ecotone between major vegetational units. Another possibility is that pollen from different vegetational units was deposited in the sediments. On the other hand, most of the deciduous plants represented in the Weaverville flora today inhabit swamps, shores, or wet bottomlands and were probably growing near the site of deposition. Hence, fossil leaves and pollen may "over-represent" the importance of those plants in vegetation that is otherwise evergreen (Wolfe, 1979). The occurrence of evergreen oak and several lauraceous genera in the leaf flora, as well as genera such as *Reevesia, Liquidambar,* and *Podocarpus* in the pollen flora, suggest closest affinities to the pine-oak-*Liquidambar* forests of Mexico near the transition to montane rain forest (Breedlove, 1973), or the Notophyllous Broad-Leaved Evergreen Forest of southeastern Asia (Wolfe, 1979). For comparison, the Weaverville pollen flora is similar to that of the Oligocene Brandon lignite of Vermont (Traverse, 1955), and Wolfe (1979) suggested that the Brandon flora may represent a broad-leaved evergreen forest with a lesser deciduous element.

Another approach to interpreting vegetation (and climate) is based on physiognomic leaf characteristics, and a commonly used general rule is that the percentage of entire-margined leaves increases with mean annual temperature (Wolfe, 1979). MacGinitie (1937) indicates a value of 47% entire-margined leaves in the Weaverville leaf flora, and this value falls within the range of 40-60% given by Wolfe (1979) for the Notophyllous Broad-Leaved Evergreen Forest, and in the range of 40-55% for the sclerophyllous oak forest of southern Mexico (Wolfe, 1979). If, however, the numerous deciduous genera of the pollen record were also considered, this percentage would undoubtedly be lower and could possibly approach the upper range of 20-38% (Wolfe, 1979) for the Mixed Mesophytic Forest. Thus, the Weaverville flora may be somewhat "transitional" between these two forest types, but probably more closely resembles the Broad-Leaved Evergreen Forest.

An assemblage not seen in the leaf flora is a diverse group of conifers, and some genera are indicative of a montane coniferous forest. Although members of Taxodiaceae are typical of broad-leaved forests, and Cupressaceae is found in both broad-leaved and coniferous forests, certain genera of Pinaceae--*Abies, Picea,* and *Larix*--are almost exclusive to the Mixed Coniferous Forest of southeastern Asia, for instance, (Wang, 1961) or the spruce forest at high elevations in the Great Smoky Mountains. The occurrence of mixed coniferous forest along with broad-leaved evergreen and deciduous forest suggests that the southern Klamath region had moderate topographic relief in the Tertiary. Even though bisaccate grains of conifers are known to travel long distances, the great abundance (to greater than 50%) of *Picea* in some samples suggests proximity of source plants to basin of deposition, rather than transport from a distant upland.

Abundant in the Weaverville sediments are pollen and leaves of *Taxodium* and *Nyssa*, as well as carbonized logs of *Taxodium* (MacGinitie, 1937), suggesting the presence of a swamp forest near the basin of deposition. The freshwater alga *Pediastrum* is abundant in some samples, and the form-genus *Tetraporina* probably represents zygospores of the green alga *Mougeotia* (van Geel, 1976). Additional algal types include *Schizosporis* and a number of thin-walled, inaperturate forms identified as algal cysts. The presence of several types of plankton in the Weaverville samples indicates that deposition took place in freshwater lakes and ponds or slow-moving streams. The acritarch *Micrhystridium* is also aquatic, although its exact ecological requirements are unknown. Of interest is the occurrence of types tentatively identified as the dinoflagellate *Cleistosphaeridium*. These dinoflagellates are typical of marine or brackish water, and the abundance of a single type suggests the presence of a restricted, brackish environment (W. S. Drugg, personal communication, 1982). The only truly aquatic macrophyte is *Trapa*, a floating pondweed, which is represented both by pollen and by seeds in the shales at Hayfork.

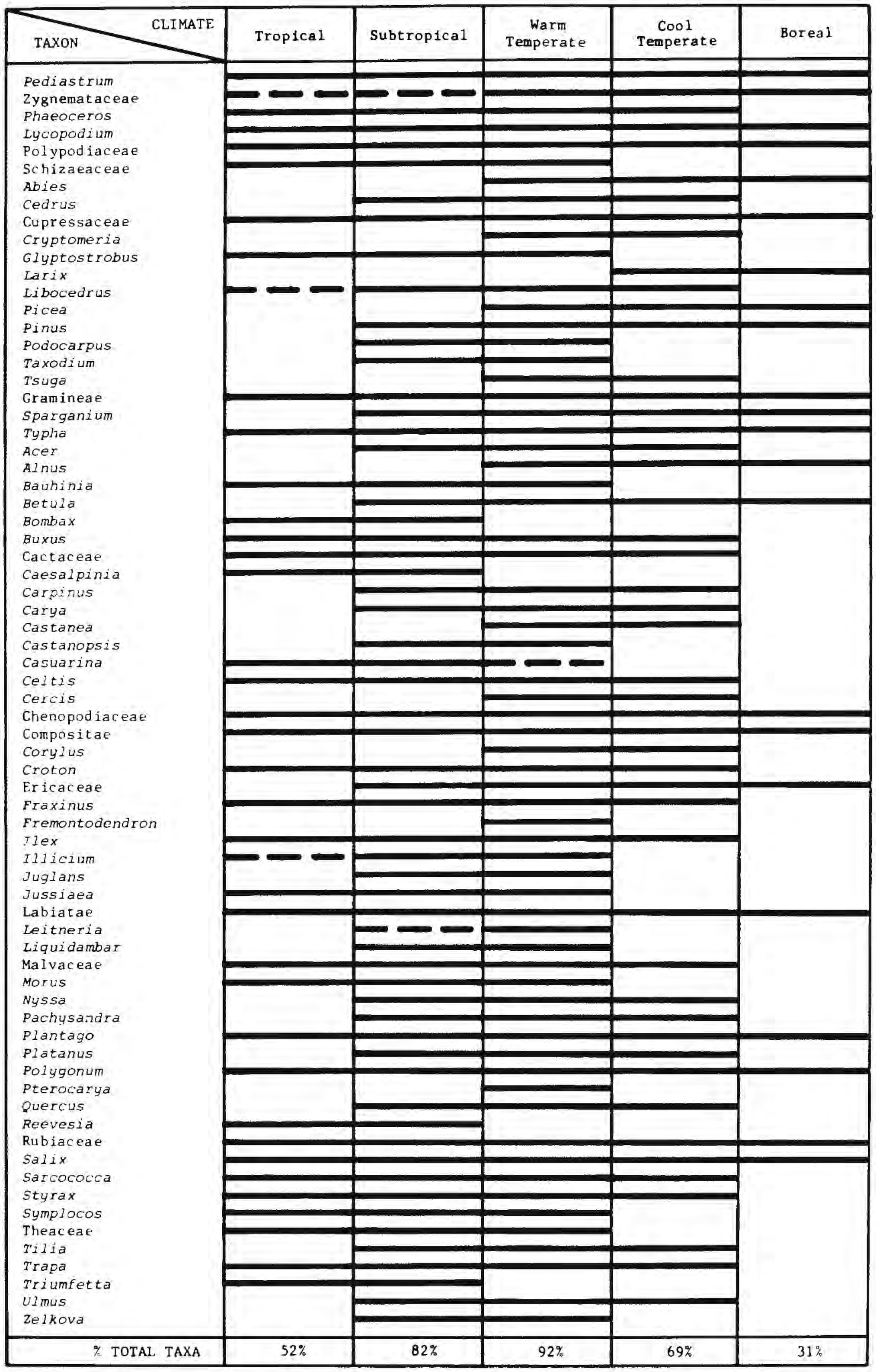
In contrast to the swamp vegetation, *Bauhinia, Caesalpinia,* ?Cactaceae, *Sarcobatus, Fremontodendron,* cf. *Salvia,* and *Croton* represent a xeric assemblage, though species of some of these taxa are not strictly xeric. *Bauhinia, Caesalpinia,* and *Cereus* grow today in the Arid Tropical Scrub of southwestern Mexico (A. S. Leopold, 1950), and *Bauhinia* and *Croton* occur in the Thorn Woodland of Chiapas (Breedlove, 1973). The evergreen *Fremontodendron* occurs in arid habitats of the American Southwest and northern Mexico. This xeric Weaverville assemblage may have inhabited drier areas in the region generally occupied by broad-leaved evergreen and deciduous forest.

Climate

Figure 6 is a summary of the climatic ranges of extant taxa represented in the Weaverville pollen flora. The purpose of this chart is to show general climatic conditions, and not to define strict temperature parameters. Nearly all taxa are subtropical to warm temperate, although a number also range into other climatic zones as well. The percentages of taxa in each climatic zone change hardly at all when taxa from either Hayfork or Readings Creek alone are considered. Thus, the two florules have identical climatic requirements. No taxa are restricted to tropical environments, although Bombacaceae, *Caesalpinia, Bauhinia, Casuarina, Reevesia,* and *Triumfetta* are chiefly tropical to subtropical, and these constitute 6% of the total vascular flora. On the other hand, *Larix* and *Picea* are more typically cool temperate or boreal. Assuming that climatic requirements have not changed appreciably through time, the fossil flora is a mixture of tropical-subtropical and warm to cool temperate types, reflecting the inferred lowland evergreen and deciduous and upland coniferous vegetation. An alternative interpretation is that ecological requirements of certain taxa were different in the Tertiary and that vegetational zonation in the region was not very pronounced.

An approach to determining more specific climatic parameters is to consider the present climatic requirements of the vegetation inferred from the Weaverville fossil flora. This method is based on a correct interpretation of the vegetation, as well as on the assumption that present climatic requirements were similar in the Tertiary. Although

Figure 6. General climatic ranges of extant taxa represented in the Weaverville pollen and spore flora.


CLIMATE
TAXON
Tropical
Subtropical
Warm Temperate
Cool Temperate
Boreal
Pediastrum
Zygnemataceae
Phaeoceros
Lycopodium
Polypodiaceae
Schizaeaceae
Abies
Cedrus
Cupressaceae
Cryptomeria
Glyptostrobus
Larix
Libocedrus
Picea
Pinus
Podocarpus
Taxodium
Tsuga
Gramineae
Sparganium
Typha
Acer
Alnus
Bauhinia
Betula
Bombax
Buxus
Cactaceae
Caesalpinia
Carpinus
Carya
Castanea
Castanopsis
Casuarina
Celtis
Cercis
Chenopodiaceae
Compositae
Corylus
Croton
Ericaceae
Fraxinus
Fremontodendron
Ilex
Illicium
Juglans
Jussiaea
Labiatae
Leitneria
Liquidambar
Malvaceae
Morus
Nyssa
Pachysandra
Plantago
Platanus
Polygonum
Pterocarya
Quercus
Reevesia
Rubiaceae
Salix
Sarcococca
Styrax
Symplocos
Theaceae
Tilia
Trapa
Triumfetta
Ulmus
Zelkova
% TOTAL TAXA
52%
82%
92%
69%
31%

the Weaverville flora is not exactly equivalent to any modern vegetation, it most closely resembles the Evergreen Broad-Leaved Forest of southeastern Asia (Wang, 1961; Wolfe, 1979), and the pine-oak-*Liquidambar* forests of southern Mexico (Breedlove, 1973). The climate of both regions is summer wet, with about 1500-1700 mm total annual precipitation (Miranda and Sharp, 1950; Wang, 1961; Gomez-Pompa, 1973). The Notophyllous Broad-Leaved Evergreen Forest occupies regions with mean annual temperatures of 13-20°C, mean annual ranges of 5-25°C and the mean of the coldest month greater than 1°C. For the pine-oak-*Liquidambar* forests of Mexico, Miranda and Sharp (1950) and Gomez-Pompa (1973) give climatic data that indicate a mean annual temperature of 16-17°C and a mean annual range of about 7-8°C. These conditions fall within the range of the Notophyllous Broad-Leaved Evergreen Forest of Asia, but the climate in southern Mexico is generally more equable than that of Asia, probably due to its more southerly latitude.

In contrast, the Mixed Coniferous Forest of eastern Asia and the spruce and northern hardwood forests of eastern North America grow in a climate with mean annual temperatures of about 4-11°C and mean annual ranges of about 9-30°C (Wolfe, 1979). Assuming similar equability with increasing altitude (see Wolfe, 1979, p. 14), the presence of cool temperate coniferous taxa in the Weaverville flora suggests a climate with a mean annual range of about 15°C. Thus, the climate interpreted for the Weaverville flora was summer wet, fairly equable, with about 1500-1700 mm precipitation, a mean annual temperature of about 16°C (to about 9°C at higher elevations), and no or infrequent frost in the lowlands. By comparison, the climate of Weaverville today is summer dry, with a mean annual temperature of 12°C and a mean annual range of 20°C (Weaverville station; O'Brien, 1965; Wolfe, 1979). Hence, climate in the mid-Tertiary was somewhat warmer and more equable, as well as being summer wet, rather than summer dry.

Quantitative Palynology

Quantitative palynological methods measure relative changes in taxa which may be interpreted to represent changing climatic or local environmental conditions. Of a total of 20 samples counted, 10 were from the measured section at Readings Creek-Panwauket Gulch, 8 were from the section at Hayfork, and 2 were from the Reese Coal Mine. Appendix V is a table of these results. Figures 7 and 8 are pollen diagrams of the most important taxa (those comprising over 3% in any one sample). These counts show that although the overall flora is very diverse, only about 18 families or genera have moderately abundant pollen and spores. Although a number of taxa such as *Bombax*-type, *Reevesia, Bauhinia,* and *Pistillipollenites* are relatively rare, their presence in the flora is important for climatic or stratigraphic interpretations. Because no attempt was made to determine absolute abundances, these diagrams show only relative changes through the sections. There is not necessarily a correspondence between pollen percentages and abundance of plants in the vegetation. Differential pollen production and preservation, as well as transportation and sorting, may affect the pollen percentages of a given sample (Gray, 1958; Tauber, 1965).

Although the producing samples are distributed throughout each

Figure 7. Pollen diagram for the Readings Creek-Panwauket Gulch section. Taxa shown are those that comprise 3% or more in any one sample. Percentages for pollen and spores are based on tallies of about 500 grains. Percentages for algae and acritarchs (including ?*Cleistosphaeridium*) are based on sum of total palynomorphs (pollen and spores + plankton). The category "Tricolpates and Tricolporates" includes all undetermined tricolpate and tricolporate grains.

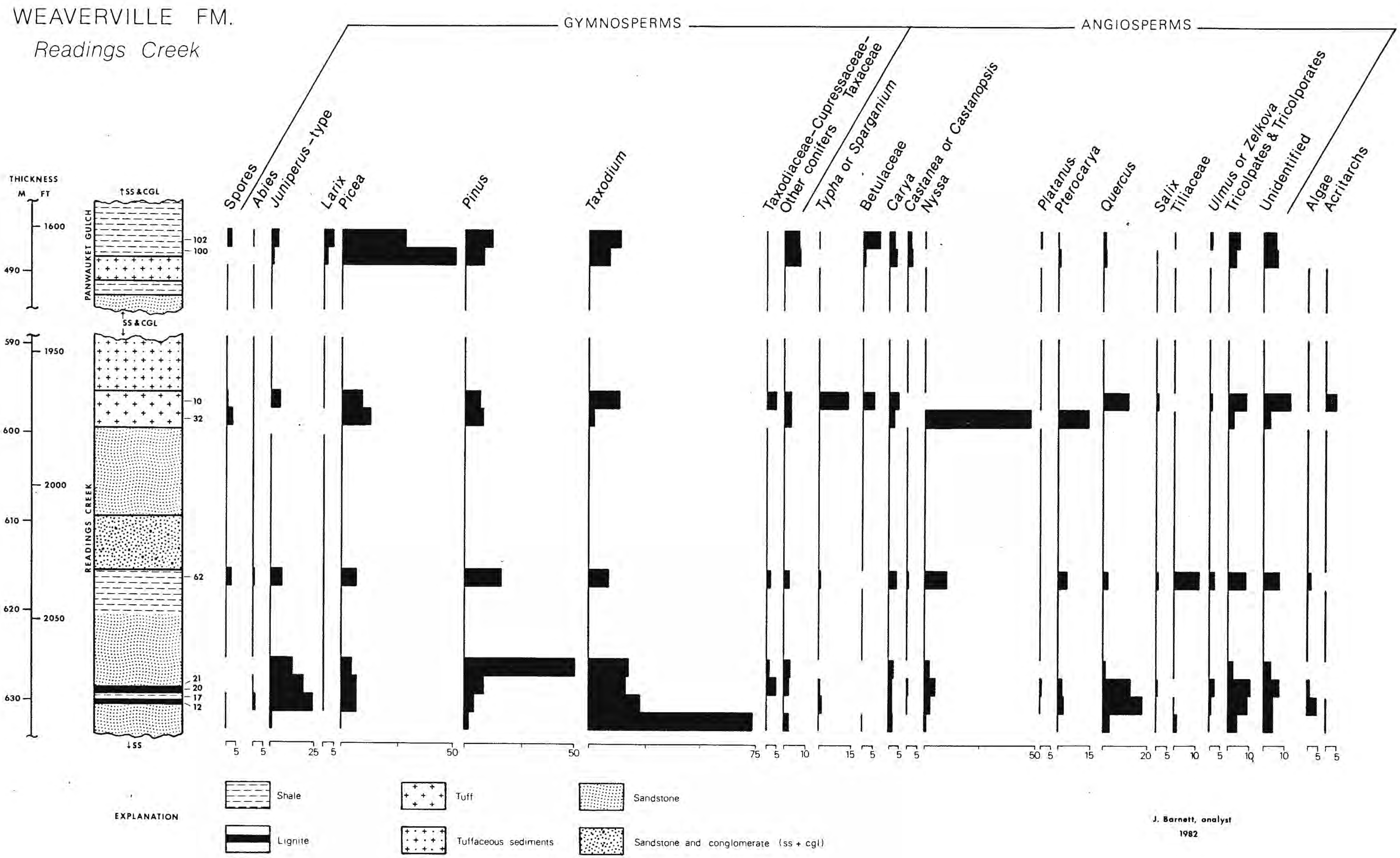
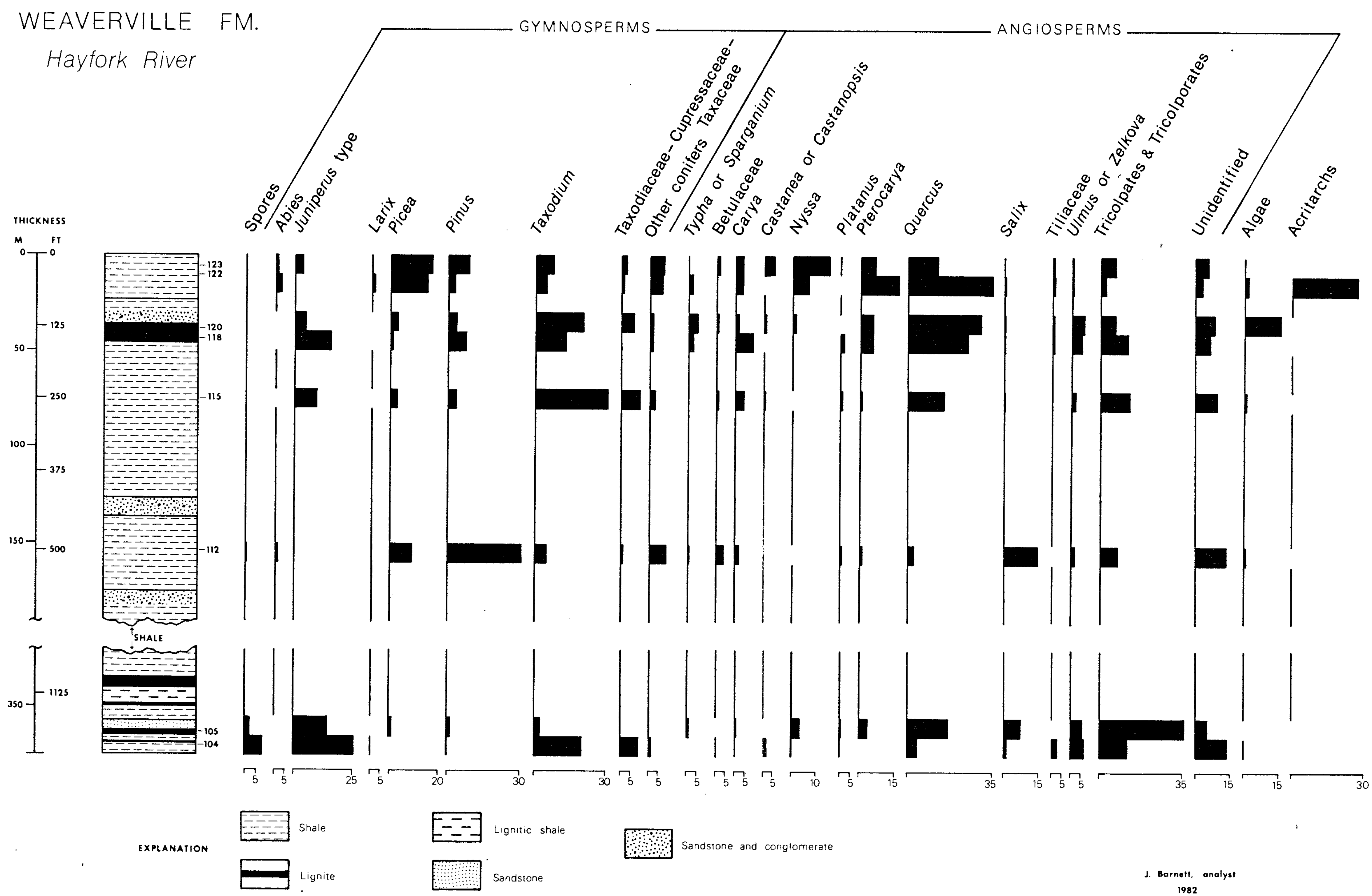

WEAVERVILLE FM.
Readings Creek
GYMNOSPERMS
ANGIOSPERMS
THICKNESS
M FT
PANWAUKET GULCH
READINGS CREEK
SS & CGL
SS
Spores
Abies
Juniperus-type
Larix
Picea
Pinus
Taxodium
Taxodiaceae-Cupressaceae-Taxaceae
Other conifers
Typha or Sparganium
Betulaceae
Carya
Castanea or Castanopsis
Nyssa
Platanus
Pterocarya
Quercus
Salix
Tiliaceae
Ulmus or Zelkova
Tricolpates & Tricolporates
Unidentified
Algae
Acritarchs
EXPLANATION
Shale
Lignite
Tuff
Tuffaceous sediments
Sandstone
Sandstone and conglomerate (ss + cgl)
J. Barnett, analyst
1982

Figure 8. Pollen diagram for the Hayfork River section. Taxa shown are those that comprise 3% or more in any one sample. Percentages for pollen and spores are based on tallies of about 500 grains. Percentages for algae and acritarchs (including ?*Cleistosphaeridium*) are based on sum of total palynomorphs (pollen and spores + plankton). The category "Tricolpates and Tricolporates" includes all undetermined tricolpate and tricolporate grains.



WEAVERVILLE FM.
Hayfork River
GYMNOSPERMS
ANGIOSPERMS
THICKNESS
M FT
Spores
Abies
Juniperus type
Larix
Picea
Pinus
Taxodium
Taxodiaceae-Cupressaceae-Taxaceae
Other conifers
Typha or Sparganium
Betulaceae
Carya
Castanea or Castanopsis
Nyssa
Platanus
Pterocarya
Quercus
Salix
Tiliaceae
Ulmus or Zelkova
Tricolpates & Tricolporates
Unidentified
Algae
Acritarchs
SHALE
EXPLANATION
Shale
Lignitic shale
Sandstone and conglomerate
Lignite
Sandstone
J. Barnett, analyst
1982

section, they are mostly limited to four or five plant-bearing horizons associated with lignites or organic-rich shales. Furthermore, samples within meters of each other (e.g., 17, 20, 21, 22 of Readings Creek) may have vastly different pollen counts for a given taxon. Certain genera such as *Taxodium, Nyssa, Pterocarya,* and *Salix* have some high peaks which may be due to abundance of those plants near the site of deposition. Indeed, clusters of grains or even whole anthers of these genera (Plate XXVII-10) are common in some samples, and thus, these local taxa are "over-represented" in the sample. (A cluster of grains was counted as a single grain, but undoubtedly grains from these clusters were contributing to the abundance of certain taxa in the samples.) For a general measure of variability in a particular horizon along strike, two samples from Reese Coal Mine were counted (Appendix V). The lignites at Reese Coal Mine correlate with those near the base of the section at Readings Creek, 2 km to the east. These results show that abundances of *Pinus, Picea, Taxodium,* and *Quercus* are fairly variable for this stratigraphic horizon. Thus, the diagrams may show some general trends, though perhaps such trends are somewhat tenuous with this degree of variability and with so few samples analyzed in a given section.

All the moderately abundant taxa shown on the diagrams are present in both sections indicating, as did the qualitative data, that compositions of the florules in these areas were very similar. Furthermore, no taxa are restricted entirely to any part of either section, although some changes in relative abundance are evident. In the Hayfork River section, the monolete and trilete spores, undetermined tricolpate and tricolporate grains, *Salix,* and *Juniperus*-type tend to decrease up-section; whereas, *Picea* and a number of dicotyledonous trees--*Carya, Castanea* or *Castanopsis, Nyssa, Pterocarya,* and *Quercus*--generally increase upwards. *Taxodium,* on the other hand, is most abundant in the lignitic horizons, and plankton are most numerous in shales with shell horizons, which probably represent a freshwater lake. Thus, some of these shifts apparently reflect changes in local habitats or depositional environments.

At Readings Creek *Picea,* along with *Larix* amd Betulaceae, again increases up-section. *Taxodium* is again most abundant in the lignitic horizon, and plankton and *Typha* or *Sparganium* peak in the tuffaceous horizon and are notably absent in the uppermost shale bed at Panwauket Gulch. Likewise, *Nyssa, Pterocarya, Quercus, Salix,* Tiliaceae, and *Ulmus* or *Zelkova* have little or no representation in this upper shale bed.

If these trends are real, the relative increase upwards of *Picea* and *Larix* in both sections may represent a climatic cooling trend. Another possible explanation is that cool temperate taxa were more prominant in the vegetation during uplift in the region and development of the alluvial plain represented by the conglomerates of Readings Creek. However, the variability of aquatic vegetation and conifers within a single stratigraphic horizon suggests that these interpretations are somewhat speculative.

CHAPTER VI: COMPARISON AND AGE

Comparison with Other Pollen Floras

The Weaverville pollen flora has a rather anomalous composition in comparison with other Tertiary pollen floras in western North America (Figure 9). In addition to a large number of long-ranging taxa such as *Alnus, Betula, Carya, Juglans, Nyssa,* and *Taxodium,* the flora contains tropical-subtropical families characteristic of the Eocene (e.g., Bombacaceae, Sterculiaceae, Leguminosae), as well as several types typical of the Miocene (e.g., Compositae). [Until the debate on the proposed recalibration (Armentrout, 1981) of the Eocene-Oligocene boundary to 32 m.y. is settled, I choose to use the time scale of Hardenbol and Berggren (1978), which places the Eocene-Oligocene boundary at 37 m.y. and the Oligocene-Miocene boundary at 24 m.y.]

Eocene. The auriferous gravels of the Ione Formation in the Sierra Nevada contain the well-known Chalk Bluffs flora, which is early Eocene in age (MacGinitie, 1941; Bateman and Wahrhaftig, 1966; MacGinitie, personal communication, 1982). The leaf flora is distinctly different from that of the Weaverville in containing a number of Eocene types such as *Sabalites, Magnolia, Cinnamomum, Neolitsea,* and *Alangium* (MacGinitie, 1941). Comparison of pollen taxa, however, shows some similarities. A list of Chalk Bluffs pollen and spores by Leopold (in Penny, 1969) includes a number of types also found in the

Figure 9. Locations of some Tertiary floras of western North America.

125°
120°
115°
110°
105°
50°
45°
40°
35°
Fraser River
BRITISH
COLUMBIA
WASHINGTON
Skookumchuck
McIntosh
Wenatchee
Swauk
Willamette
Goshen
Comstock
Clarno
Bridge Creek
Rujada
OREGON
Amethyst Mt.
Kisinger Lakes
WYOMING
Weaverville
La Porte
Chalk Bluffs
CALI-
FORNIA
Florissant
COLORADO
0 100 200 300 400 500 MI
0 200 400 600 800 KM

Weaverville pollen flora, although several of these are common taxa such as *Picea, Pinus, Carya, Betula,* and *Alnus.* Of interest are the occurrences of *Croton,* Bombacaceae, *Cicatricosisporites,* and *Fremontodendron* in both floras, though the Weaverville pollen flora lacks *Ephedra, Platycarya, Proteacidites,* and *Phytocrene,* which are common in the Eocene. The tropical-subtropical taxa of the Weaverville pollen flora also occur in the Eocene pollen floras of the Rocky Mountains. For instance, *Bauhinia, Triumfetta,* Bombacaceae, and Sterculiaceae are reported from the Kisinger Lakes pollen flora (Leopold, 1974), and *Reevesia,* Bombacaceae, and *Triumfetta* occur in the Yellowstone pollen flora at Amethyst Mountain (Fisk, 1976). *Triumfetta* (as *Rhoiipites latus*) is also characteristic of the Eocene in south-central British Columbia (Rouse, 1977).

Of particular significance in the Weaverville pollen flora is a single, well-preserved grain of *Pistillipollenites* sp., an organ-genus which resembles the extant taxa *Tournefortia* (Boraginaceae; Rouse, 1977), *Herpyza* (Leguminosae; Kavanagh and Ferguson, 1981; V. D. Wiggins, personal communication, 1982), and the family Gentianaceae (Rouse, 1962; Crepet and Daghlian, 1981). *Pistillipollenites* is a well-known stratigraphic marker for the Paleocene and lower-middle Eocene of British Columbia (Rouse, 1977; Rouse and Srivastava, 1970), and has been reported for the middle to upper Eocene of southwestern Washington (Sparks, 1967). However, V. D. Wiggins (personal communication, 1982) reports a non-porate form from the Oligocene of Alaska. In a palynological zonation study of central Washington, Newman (1981) noted that the lower Eocene Swauk Formation (Gresens and others, 1981) is characterized by a *Pistillipollenites-Platycarya* biozone, which also contains *Proteacidites, Caryapollenites, Alnus, Bombacacidites, Cicatricosisporites, Polypodiidites,* and *Triletes solidus,* and several of these genera are found in the Weaverville formation.

Oligocene. In contrast to published Eocene pollen floras, few Oligocene pollen floras have been described from western North America and few stratigraphic markers of regional extent are known. The lower Oligocene pollen flora of the Fraser River Formation in central British Columbia occurs in fluvio-lacustrine sediments associated with auriferous gravels (Piel, 1971), a depositional environment much like that of the Weaverville Formation. Overall, this flora is dominated by pollen of angiosperms such as *Alnus, Quercus,* and *Ulmus* or *Zelkova,* the conifers *Taxodium, Glyptostrobus,* and *Metasequoia,* as well as ferns, and has been interpreted as subtropical to warm temperate (Piel, 1971). About one half of the taxa are also found in the Weaverville pollen flora, and although Bombacaceae, Sterculiaceae, and *Triumfetta* are not present in the Fraser River sediments, other tropical-subtropical genera such as *Engelhardtia, ?Dorstenia,* and *?Psilotum* are present (Piel, 1971). Thus, the Fraser River and Weaverville pollen floras are rather similar in overall composition and ecological requirements.

In Washington, the lower Oligocene (34 m.y.) Wenatchee Formation (Gresens and others, 1981) is characterized by a *Gothanipollis-Elaeagnus* concurrent-range zone, along with cf. Acanthaceae, *Symplocoipollenites, Nyssa,* cf. *Engelhardtia,* and *Selaginella* cf. *sinuites* (Newman, 1981). Of these characteristic genera, only *Nyssa* and *Symplocoipollenites* (*Symplocos*) occur in the Weaverville Formation; *Gothanipollis* and

Elaeagnus were not seen. Also in the Wenatchee Formation are a number of common types such as *Alnus*, *Carya*, *Quercus*, *Liquidambar*, *Tilia*, *Ulmus*, *Pterocarya*, *Taxodium*, and bisaccate pollen, which are also found in the Weaverville Formation.

An interesting upper Oligocene pollen flora of the Rocky Mountains is that of the Florissant Formation (Leopold in Penny, 1969). The Florissant flora has been interpreted to represent chaparral in an intermontane basin of moderate relief (MacGinitie, 1953; personal communication, 1982). The pollen flora has a number of taxa in common with the Weaverville pollen flora such as *Taxodium*, *Pinus*, *Picea*, *Abies*, *Sarcobatus*, *Fremontia* *(Fremontodendron)*, Ericales, Onagraceae, and Gramineae, though the Weaverville lacks *Ephedra*, *Eucommia*, *Cardiospermum*, *Normapollis*-group and *Eleagnus*. In the Florissant pollen flora *Fremontodendron*, *Sarcobatus*, and *Ephedra* represent xeric conditions, and a similar xeric element is present in the Weaverville pollen flora.

A number of upper Eocene and Oligocene floras occur in western and central Oregon and northwestern California, but these can be compared with the Weaverville flora only in general characteristics because only one palynology study has been published. A pollen flora from three formations in the Coos Bay area spans the upper Eocene to middle Oligocene and has been interpreted as subtropical to warm temperate (Hopkins, 1967). The Rujada leaf flora is interpreted as upper Oligocene (Lakhanpal, 1958) and is similar to the Weaverville flora in containing a mixture of deciduous plants and broad-leaved evergreens, but differs in the lack of a swamp cypress component. The a variety of warm temperate deciduous trees, along with conifers such as *Pinus, Picea,* and *Tsuga*. Wolfe (1962) briefly described a pollen sequence from northern Oregon spanning lower to upper Miocene and noted that subtropical-warm temperate types such as *Caesalpinia* and *Lagerstroemia*-type are restricted to the lower three or four zones (Latah equivalent or older, according to Wolfe). Gray (1964) noted that an expansion of herbs such as Gramineae, Cyperaceae, Compositae, Malvaceae, Onagraceae, Polemoniaceae, Umbelliferae, and *Plantago* marks the Miocene. Leopold (1969) noted that Gramineae, Onagraceae, and Cyperaceae, though known from the Eocene, first appear consistantly in the Neogene. Similarly, Labiatae occurs in Oligocene and younger sediments, and *Trapa* is first found in the Miocene on the West Coast (Wolfe, in Leopold, 1969). The family Compositae is generally taken as a world-wide marker for the Upper Oligocene and Miocene (Gray, 1964; Leopold, 1969).

Of these typical Miocene taxa, the Weaverville flora has several: Compositae, Malvaceae, Onagraceae, *Plantago,* and *Sarcobatus*. In addition, both leaves and pollen of Gramineae and seeds and pollen of *Trapa* are found in the Weaverville sediments. A taxon identified as *Polygonum* cf. *coccinium* in the Weaverville is also known as *Rugaepollis kachemakensis,* and in Alaska occurs in middle Miocene and younger sediments (Engelhardt, 1966; V. D. Wiggins, personal communication, 1982).

Age of the Weaverville Formation

An attempt by myself and Professor Joseph Vance to date the tuffs of the lower unit of the Weaverville Formation by fission track methods was not successful. A sample from Readings Creek yielded very few heavy minerals and no zircons suitable for fission-track dating.

The use of fossil floras for age determinations in the Tertiary depends not so much on evolutionary development of plants as on distributional response to changing climatic conditions (Wolfe, 1969). Some specific index fossils such as Compositae (Neogene) and *Pistillipollenites* (Paleogene) are also useful, although such indicators of regional extent are not abundant for the mid-Tertiary. Because climatic trends vary from one area to another, the local responses of vegetation may also vary, and age determinations based on inferred climate or climatic trends are perhaps tenuous. Thus, pollen floras are most useful for correlating rock units once a well-dated palynostratigraphy is established for a given area. Because no such zonation has been established for northern California-southern Oregon, interpreting the age of the Weaverville Formation assumes that stratigraphic ranges of certain key taxa hold for this area. An additional problem is that there are almost no well-described and independently dated floras of late Oligocene-early Miocene age on the West Coast, and this interval is of particular interest for the Weaverville flora.

Overall, the Weaverville contains an interesting assortment of typically Eocene and Oligo-Miocene types, and these categories are found both at Hayfork and Readings Creek and throughout the stratigraphic columns. The occurrence of Compositae in any sediments supposedly older than Miocene is generally viewed with deep suspicion (if not superstition) and so several samples of the Weaverville shales were

3. The climatic ranges of extant taxa represented in the Weaverville pollen flora indicate that overall the flora was subtropical to warm temperate. If present climatic requirements were similar in the Tertiary, comparison with extant forests of eastern Mexico and southeastern Asia indicates a summer wet climate, with a mean annual temperature of about 16°C, little or no frost, and about 1500-1700 mm total annual precipitation.

4. The depositional environment for the shales at Hayfork is interpreted as a freshwater lake with associated swamps. The lower unit of the Weaverville Formation at Readings Creek records a similar swamp environment; however, the conglomerates probably represent a braided alluvial plain which may have developed with uplift in the region. No major changes in vegetation are seen between, or within basins, although a slight increase upwards in montane conifers may be coincident with a change in depositional environment or climate. Thus, the two florules of the Weaverville sediments are interpreted to represent similar vegetation and the two basins are interpreted to be about the same age.

5. The age of the Weaverville Formation is difficult to interpret based on the flora because pollen of typically Paleogene types (e.g., *Pistillipollenites* and *Triumfetta*) is found together with that of typically Neogene types (e.g., Compositae and *Polygonum*). No changes through the sections or differences between basins can account for this mixture, and reworking or modern contamination are unlikely. An Oligocene age is most compatible with the total known stratigraphic ranges of the taxa, and a diversity of herbaceous types suggests a late

Oligocene or early Miocene age for the Weaverville Formation.

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APPENDIX I. Locations of measured stratigraphic sections and other sample localities.

Readings Creek NW1/4 S. 33, T. 32N, R. 9W The section was measured along southwest bank of Readings Creek, starting 1.6 km south of Clements Ranch and continuing southeast to contact with metamorphic rocks.

A sample of Lower Cretaceous sediment was collected from north bank of Readings Creek about 50 m southeast of bridge over Readings Creek, just south of Clements Ranch (SE1/4 S. 29, T. 32N, R. 9W).

Panwauket Gulch NE1/4 S. 28, SW1/4 S. 27, T. 32N, R. 9W The shale bed in the conglomerate unit is located approximately 1 km east of road.

Reese Coal Mine NW1/4 S. 32, T. 32N, R. 9W The coal mine can be reached by turnoff from Browns Creek road (with permission of local residents), or by poorly marked trail from Coal Mine Road.

Hayfork River NE1/4 S. 9, W1/2 S. 10, T. 31N, R. 12W The measured section started about 300 m east of small bridge over Hayfork River, 2.9 km west of the intersection of Hwy. 3 and Salt Creek road. Continued east about 1 km to about 850 m west of the bridge over Salt Creek.

Hyampom SE1/4 S. 23, T. 3N, R. 6E A sample was collected from exposures on northeast bank of South Fork of Trinity River, about 0.5 km east of Hyampom near location of former bridge across the river.

APPENDIX II. Descriptions of rock units in the measured sections of the Weaverville Formation. Top of table is base of section.

READINGS CREEK

Rock Unit	Thickness
Weaverville Formation, lower unit	
Sandstone and siltstone. The base of the Weaverville Formation disconformably overlies Lower Cretaceous marine shales. This unit is weakly consolidated and poorly exposed.	26.4 m
Lignite. Two 1 m-thick beds of lignite with shale partings are separated by 0.5 m of carbonaceous, tuffaceous shale. The lower lignite is fissile; whereas, the upper lignite contains flattened, carbonized logs of *Taxodium*.	2.0
Shale and siltstone. The lignite is overlain by poorly exposed, tuffaceous shale and siltstone with little organic matter. At least the upper 4 m are blue shale and siltstone with lenses of thin (3-6 cm) layers of tuffaceous sandstone. The fine-grained sediments here contain lignitic stringers and leaf impressions.	13.4
Sandstone and pebble conglomerate. The contact with the underlying unit is sharp and marked by iron oxide. The lower 2 m is granular-pebble conglomerate and sandstone which exhibits planar cross-stratification and some cut-and-fill structures. Overlying it are 4 m of pebble conglomerate with well-rounded, flattened to spherical clasts in a sandy matrix. The conglomerate	8.8

Rock Unit	Thickness
includes some clasts of soft, tuffaceous shale. Overlying the conglomerate is the following sequence: 10 cm of blue shale; then concretionary (calcite-cemented), lithic sandstone forming a resistant layer (50 cm); fine, tuffaceous sandstone (2 m); followed by a second concretionary sandstone (30 cm).	
Tuffaceous sediments. Overlying the coarse sediments are tuffaceous shale, siltstone, and sandstone which are weakly consolidated.	7.0
Tuff and tuffaceous sediments. In sharp contact with the underlying shale is massive, white tuff 20-40 cm thick which alternates with finely laminated tuffaceous siltstone with organic horizons containing leaf impressions. Ripple marks occur on some bedding planes. The upper 6 m of exposure are tuffaceous, finely laminated siltstone and sandstone. The unit forms a resistant outcrop and is well exposed on both sides of Readings Creek.	9.9
Weaverville Formation, upper unit	
Sandstone and conglomerate. Overlying the tuffaceous sediments are poorly exposed sandstone and pebble conglomerate.	5.8
Conglomerate. This thick unit of pebble-cobble conglomerate is well exposed in the lower part, but poorly exposed for most of the upper part of the	282.0

Rock Unit	Thickness
section. Clasts are well rounded and consist of chert, pebble conglomerate, white tuff, sandstone, vein quartz, and granitic rocks, which are set in a sandy and silty matrix and coated with iron oxide. Foliation of sheared metamorphic rocks near the contact suggests that the contact is a high-angle fault with Salmon Hornblende Schist.	
TOTAL	355.3 m

PANWAUKET GULCH

Rock Unit	Thickness
Weaverville Formation, lower unit	
Siltstone and sandstone. The Weaverville Formation apparently lies disconformably over Lower Cretaceous marine shales. The sediments are weakly consolidated, micaceous siltstone and sandstone and are poorly exposed. About 3 m of white tuff are exposed near the center of the unit. This tuff is very similar to the following unit and is perhaps exposed here due to folding or faulting.	?168 m
Tuff. White, blocky tuff and tuffaceous siltstone with thin grayish horizons containing impressions of broadleafs and *Taxodium*.	10
Conglomerate. Moderately well-consolidated pebble and cobble conglomerate, with clasts of a variety of rock types set in a sandy matrix. The clasts and matrix are commonly stained with iron oxide.	85
Tuffaceous sediments. Interbedded with conglomerate is a unit of tuffaceous, fine-grained sediments. Weakly stratified tuffaceous sandstone (6 m) is overlain by tuffaceous siltstone and sandstone. The latter contains pumice to about 2 cm across and small pieces of carbonized wood. Above this is blue claystone (9 m), a massive concretionary sandstone (1 m), and a thin layer of blue clay.	20

Rock Unit	Thickness
Weaverville Formation, upper unit	
Conglomerate and sandstone. Pebble and cobble conglomerate is interbedded with micaceous sandstone 1-2 m thick.	145
Conglomerate. Pebble and cobble conglomerate is stained with iron oxide and is moderately well consolidated. Upper contact is not well exposed, but is apparently a fault contact with Abrams Mica Schist.	334
TOTAL	762 m

HAYFORK

Rock Unit	Thickness
Blue shale. This basal unit is in fault contact with metasedimentary rocks.	7.2 m
Lignite. Two lignite beds (0.3 and 3.3 m thick) are separated by carbonaceous shale and sandstone. The upper lignite contains leaf impressions and carbonized logs and stumps. Sandstone and siltstone 3 m thick overlie the lignite.	9.6
Sandstone. Concretionary, lithic sandstone forms a distinctive, resistant bed.	1.4
Blue shale. Some siltstone and micaceous sandstone occurs with the blue shale.	6.8
Lignite. Lignite (2-6 m) is overlain by lignitic shale (7.2 m), which is overlain by a second lignite bed (6.2 m) with partings of tuffaceous shale and micaceous, sandy siltstone. The lignites contain carbonized logs and the partings have leaf impressions.	16.2
Blue shale. Some sandy shale, sandstone, and minor conglomerate lenses are interbedded with blue shale. Poorly exposed.	66.4
Conglomerate. Well-cemented pebble and cobble conglomerate is interbedded with sandstone several meters thick. The clasts are rounded, but irregularly shaped and set in a sandy matrix. The sandstone exhibits crude planar cross-stratification.	15.5

Rock Unit	Thickness
Blue shale, etc. This unit includes blue shale, sandy, shale, siltstone, and sandstone, with some small lenses of pebble conglomerate.	67.8
Shale. The shale is mostly bluish, with some sandy beds, although about 10 m of brown-and-white, fissile shale with organic material also occur.	46.9
Sandstone. Buff-colored sandstone which contains some lenses of pebble conglomerate.	10.0
Shale. Primarily blue shale, which has some horizons of brown concretions.	71.1
Lignite and shale. The lower 10 m is tan, organic-rich shale with leaf impressions and some sponge spicules. It is overlain by about 9 m of lignite with shale partings which contain some flattened pieces of carbonized wood.	19.2
Sandstone and conglomerate. Overlying the lignites is shale which grades upwards to sandstone and some fine conglomerate beds and lenses.	13.6
Shale. The shale is brown, organic-rich, and contains thin layers of broken shells. It is also somewhat diatomaceous and contains sponge spicules. This unit is exposed along the axis of a syncline which marks the end of the measured section.	16.5
TOTAL	368.2 m

APPENDIX III. Photomicrographs of palynomorphs occurring in the Weaverville Formation.

Plate X. Algae.

Magnifications as noted.

1. *Tetraporina* sp. 1000x
2. *Pediastrum kajaites* Wilson and Hoffmeister 500x
3. *Pediastrum bifidites* Wilson and Hoffmeister 500x
4. *Pediastrum delicatites* Wilson and Hoffmeister 500x
5. Ceratioid dinoflagellate cyst 500x
6. *Schizosporis parvus* Cookson and Dettmann 1000x
7. Algal cyst-1 500x
8. Algal cyst-2 1000x


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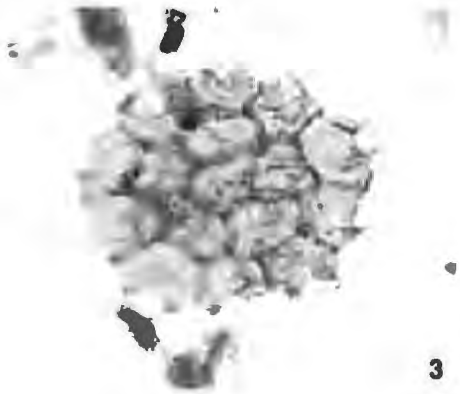
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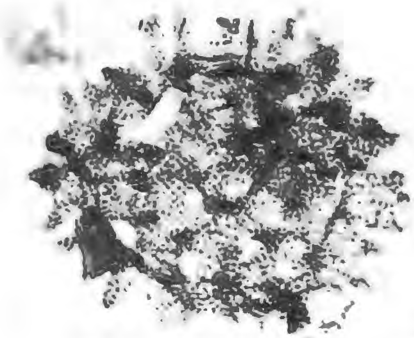
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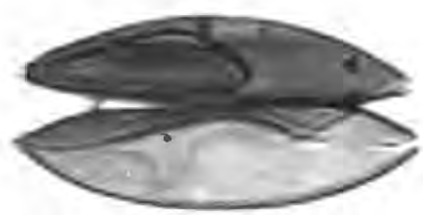
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Plate XI. Acritarchs, dinoflagellates, and algae.
All magnifications 1000x, except as noted.

1. *Micrhystridium* sp. type 1
2. *Micrhystridium* sp. type 2
3. *Micrhystridium* sp. type 3
4. ?*Cleistosphaeridium* sp. type 1
5. ?*Cleistosphaeridium* sp. type 2
6. ?*Cleistosphaeridium* sp. type 1
7. Algal cyst-5 500x

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Plate XII. Monolete spores.
All magnifications 1000x.

1. *Laevigatosporites albertensis* Rouse
2. *Laevigatosporites ovatus* Wilson and Webster
3. *Laevigatosporites* sp. type 2
4. *Polypodiisporonites* sp.
5. *Laevigatosporites discordatus* Thompson and Pflug
6. *Polypodiidites* sp. type 1
7. *Polypodiidites* sp. type 2
8. *Polypodiidites* sp. type 3

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Plate XIII. Monolete and trilete spores.
All magnifications 1000x.

1. *Laevigatosporites* sp. type 1
2. Trilete-12
3. Trilete-16
4. Trilete-11
5. Trilete-7 (low focus)
6. Trilete-7 (high focus)
7. *Deltoidospora* sp.
8. *Phaeoceros* sp.
9. Trilete-8 (Bryophyta)
10. ?*Lycopodium* sp.

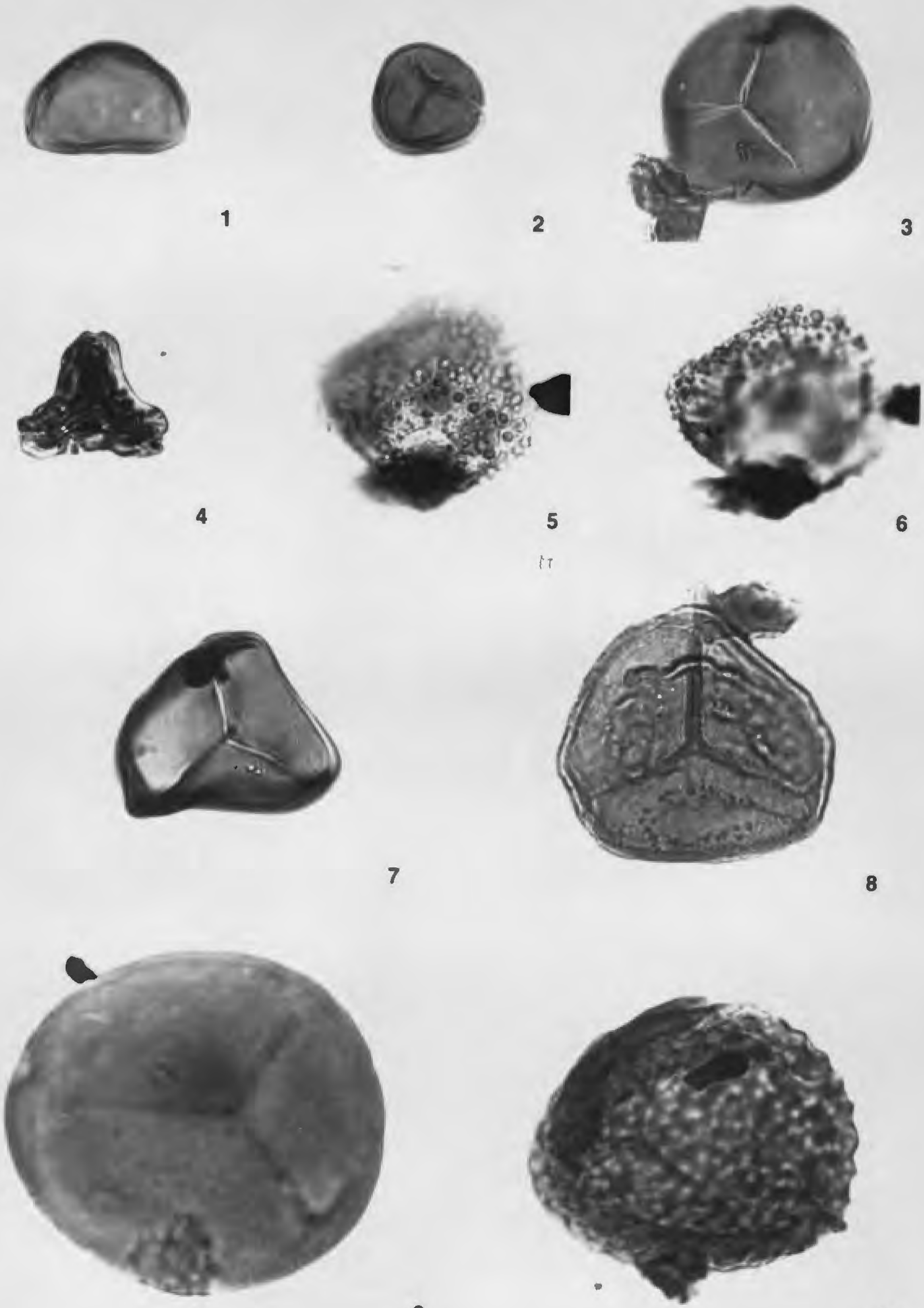
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Plate XIV. Trilete spores.
All magnifications 1000x.

1. Trilete-10 (low focus)
2. Trilete-10 (high focus)
3. Trilete-3
4. Trilete-18
5. *Corrugatisporites* sp.
6. Trilete-19 (high focus)
7. Trilete-19 (low focus)
8. Trilete-9
9. *Cicatricosisporites* sp.

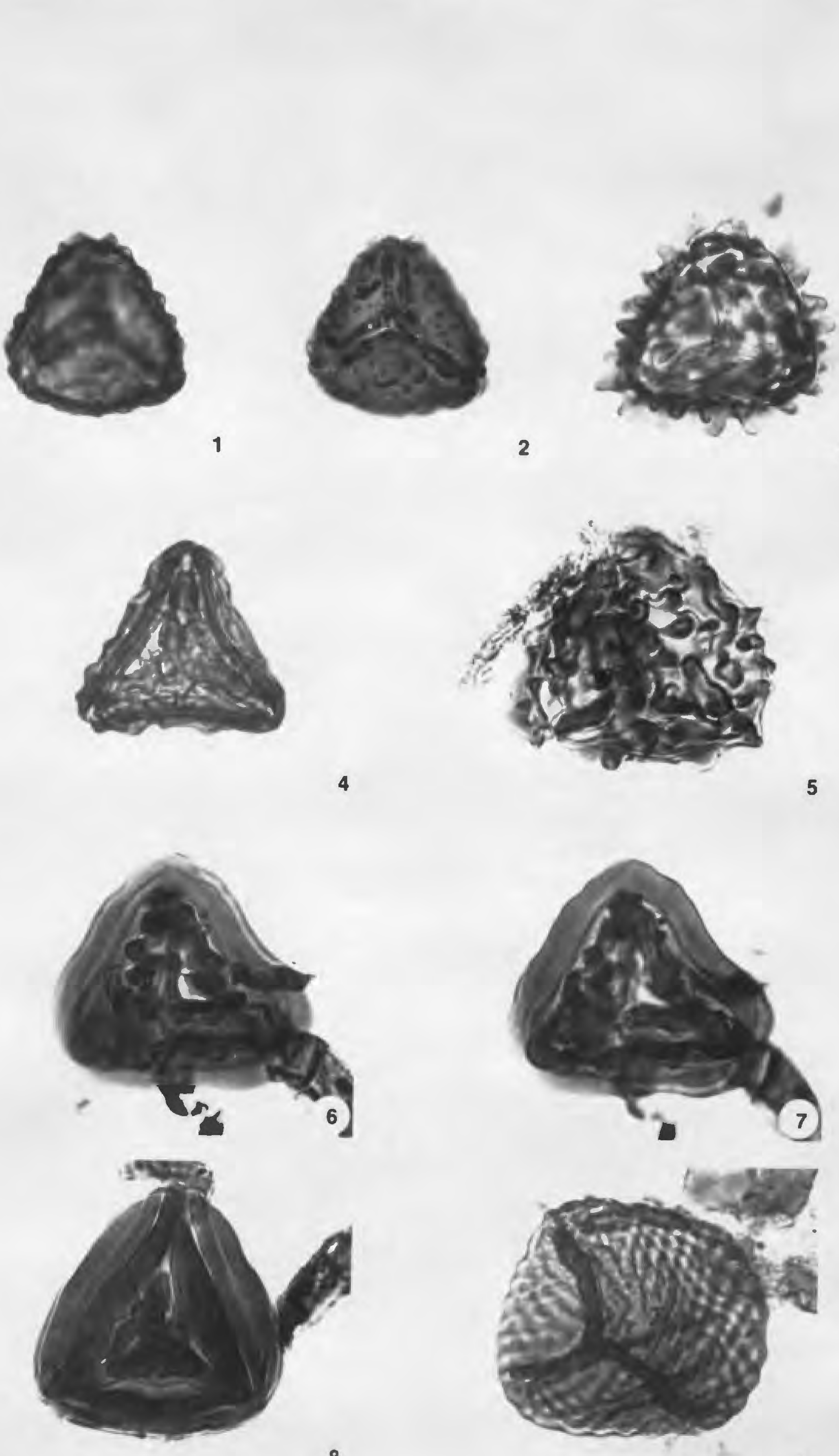
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Plate XV. Inaperturate and vesiculate pollen.
All magnifications 1000x, except as noted.

1. *Juniperus*-type
2. Inaperturate-17 (Cupressaceae)
3. ?*Libocedrus* sp.
4. ?*Cryptomeria* sp.
5. ?*Glyptostrobus* sp.
6. Taxodiaceae-Cupressaceae-Taxaceae, undivided
7. *Taxodium* sp.
8. *Taxodium* sp.
9. *Taxodium* sp.
10. *Tsuga* cf. *T. heterophylla*
11. *Tsuga* cf. *T. canadensis* 500x

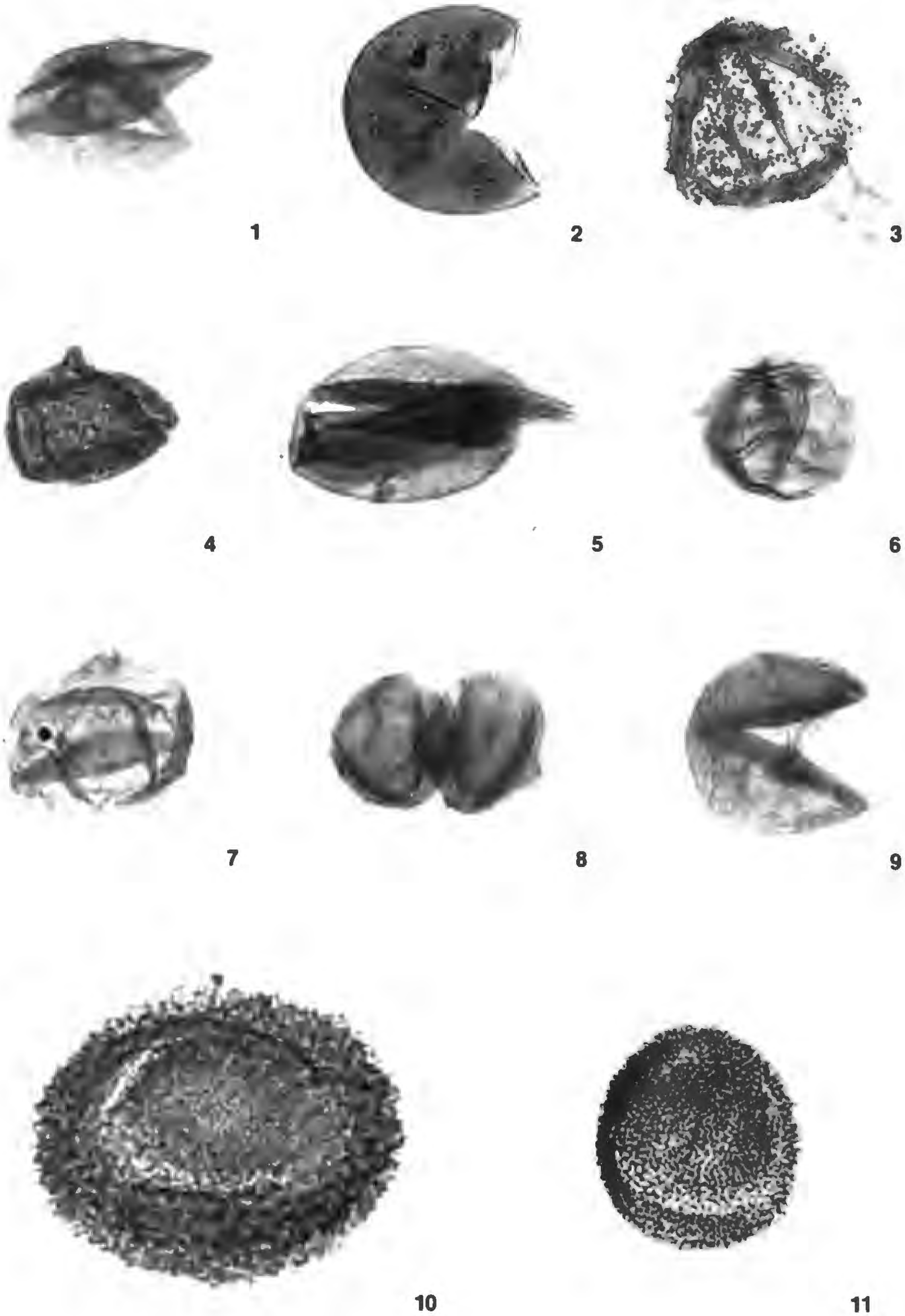
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Plate XVI. Vesiculate and inaperturate pollen.
All magnifications 500x.

1. *Cedrus* sp.
2. *Pinus* sp.
3. *Picea* sp. type 1
4. *Picea* sp. type 2
5. *Podocarpus* sp. type 1
6. *Podocarpus* sp. type 2
7. *Abies* sp.
8. *Larix* sp.

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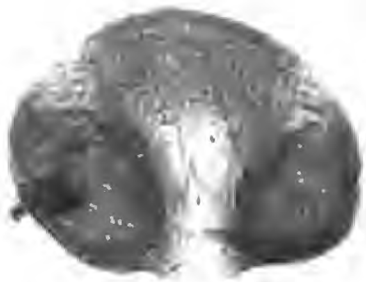

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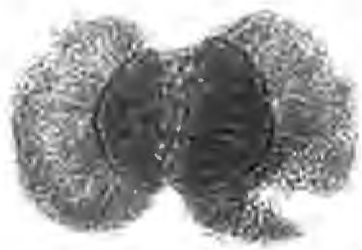

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Plate XVII. Porate pollen.
All magnifications 1000x.

1. Gramineae
2. *Typha* sp. or *Sparganium* sp.
3. *Morus* sp.
4. Diporate-1
5. *Betula* sp.
6. *Corylus* sp.
7. *Ostrya* sp. or *Carpinus* sp.
8. *Ostrya* sp. or *Carpinus* sp.
9. Triporate-12
10. *Alnus* sp.
11. *Alnus* sp.
12. Triporate-10

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Plate XVIII. Triporate, polyporate, and ?inaperturate pollen. All magnifications 1000x.

1. *Celtis* sp.
2. *Ulmus* sp.
3. *Ulmus* sp.
4. *Casuarina* sp.
5. *Pterocarya* sp.
6. *Juglans* sp.
7. *Carya veripites* Wilson and Webster
8. *Carya spackmania* Traverse
9. *Carya* sp.
10. *Croton* sp.

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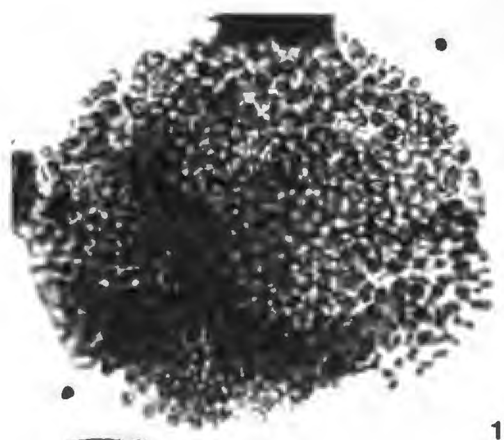

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Plate XIX. Polyporate and ?triporate pollen.
All magnifications 1000x.

1. *Pistillipollenites* sp.
2. *Liquidambar* sp.
3. *Sarcobatus* sp.
4. *Plantago* sp.
5. *Pachysandra* sp. or *Sarcococca* sp.
6. *Buxus* sp.
7. *Sphaeralcea* sp.
8. cf. *Althaea*
9. *Polygonum* cf. *P. coccinium*
10. *Polygonum* cf. *P. coccinium*

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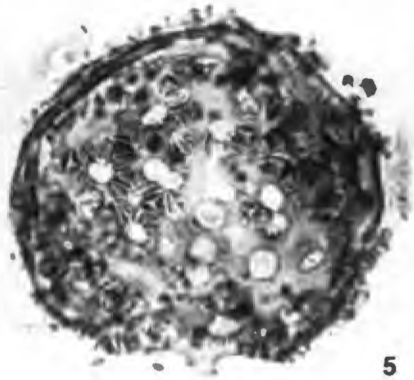

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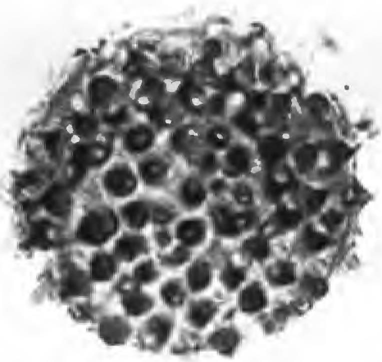

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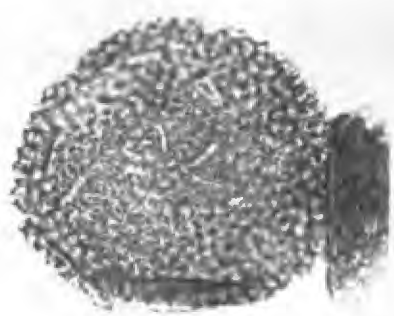

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Plate XX. Triporate and tricolpate pollen.
All magnifications 1000x.

1. *Jussiaea* sp.
2. *Jussiaea* sp.
3. Triporate-1 (Onagraceae)
4. cf. *Franklinia*
5. cf. *Echinocereus*
6. cf. *Cereus*

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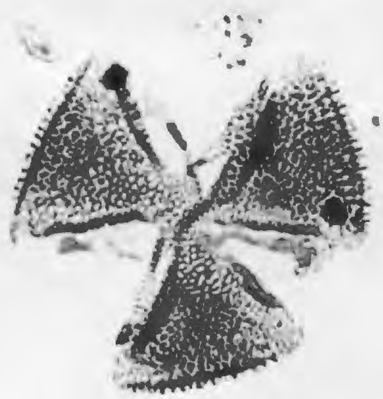

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Plate XXI. Tricolpate pollen.
All magnifications 1000x.

1. *Acer* sp.
2. *Illicium* sp. (low focus)
3. *Illicium* sp. (high focus)
4. *Quercus granopollenites* Rouse (polar view)
5. *Quercus granopollenites* Rouse (equatorial view)
6. *Quercus* sp. (polar view)
7. *Quercus* sp. (polar view)
8. *Quercus* sp. (equatorial view)
9. *Platanus* sp.
10. *Salix discoloripites* Wodehouse (polar view)
11. *Salix discoloripites* Wodehouse (equatorial view)
12. *Salix apiculata* Martin and Rouse

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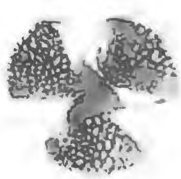

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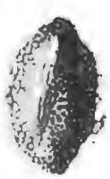

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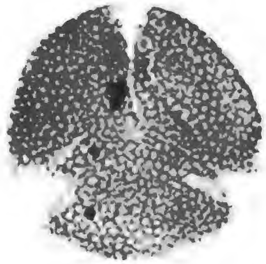
Plate XXII. Unidentified tricolpate pollen.
All magnifications 1000x.

1. Tricolpate-7
2. Tricolpate-9
3. Tricolpate-10
4. Tricolpate-11
5. Tricolpate-14 (low focus)
6. Tricolpate-14 (high focus)
7. Tricolpate-15
8. Tricolpate-18
9. Tricolpate-28
10. Tricolpate-12
11. ?*Styrax* sp.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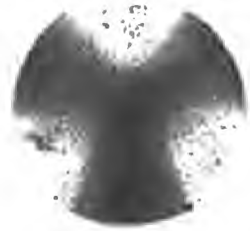
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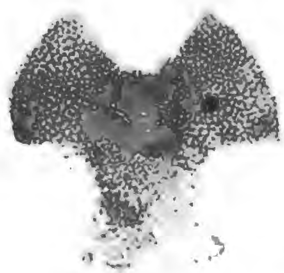
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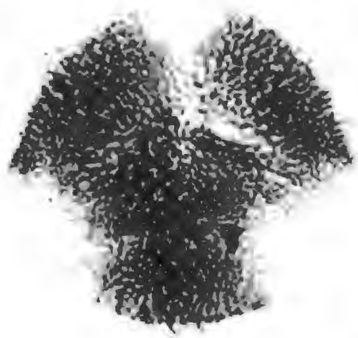
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Plate XXIII. Tricolporate pollen.
All magnifications 1000x.

1. *Ilex* sp. type 1
2. *Ilex* sp. type 2
3. *Ilex* sp. type 3 (polar view)
4. *Ilex* sp. type 3 (equatorial view)
5. *Castanea* sp. or *Castanopsis* sp.
6. *Leitneria* sp.
7. Cichorieae (Compositae)
8. Ambrosieae (Compositae)
9. Astereae (Compositae)
10. *Nyssa* sp. (polar view)
11. *Nyssa* sp. (equatorial view)

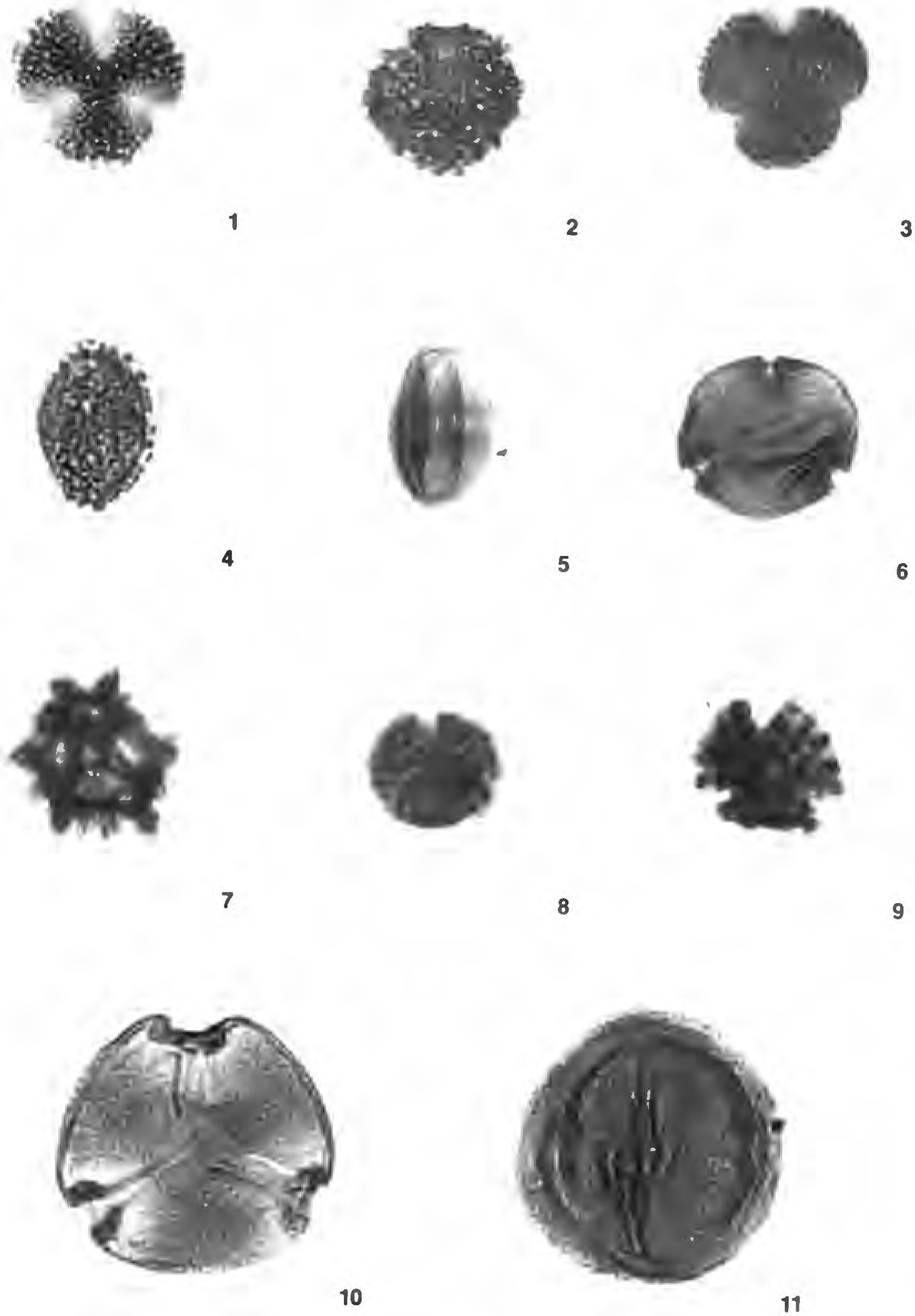
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Plate XXIV. Tricolporate, quadracolporate, and stephanocolporate pollen.

All magnifications 1000x.

1. *Bombax*-type
2. *Fremontodendron* sp. (polar view)
3. *Fremontodendron* sp. (equatorial view)
4. *Tilia* sp.
5. *Triumfetta* sp.
6. Tricolporate-16
7. *Reevesia* sp. (low focus)
8. *Reevesia* sp. (high focus)
9. *Reevesia* sp.
10. *Trapa* sp.
11. *Trapa* sp.


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Plate XXV. Tricolporate and stephanocolporate pollen. All magnifications 1000x.

1. cf. *Pieris*
2. cf. *Vaccinium*
3. Stephanocolporate-2
4. cf. *Rhododendron*
5. cf. *Pyrola*
6. ?*Cercis* sp.
7. *Bauhinia* cf. *B. congesta*
8. *Caesalpinia* sp.

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Plate XXVI. Tricolpate, stephanocolpate, and tricolporate pollen.

All magnifications 1000x.

1. Tricolpate-20
2. *Fraxinus* sp.
3. Stephanocolpate-7
4. Rubiaceae
5. cf. *Salvia*
6. Tricolporate-23
7. Tricolporate-27
8. *Symplocos* sp. type 1
9. *Symplocos* sp. type 2
10. Tricolporate-28
11. Tricolporate-30
12. Tricolporate-29

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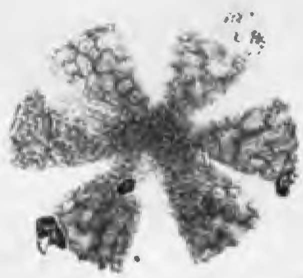

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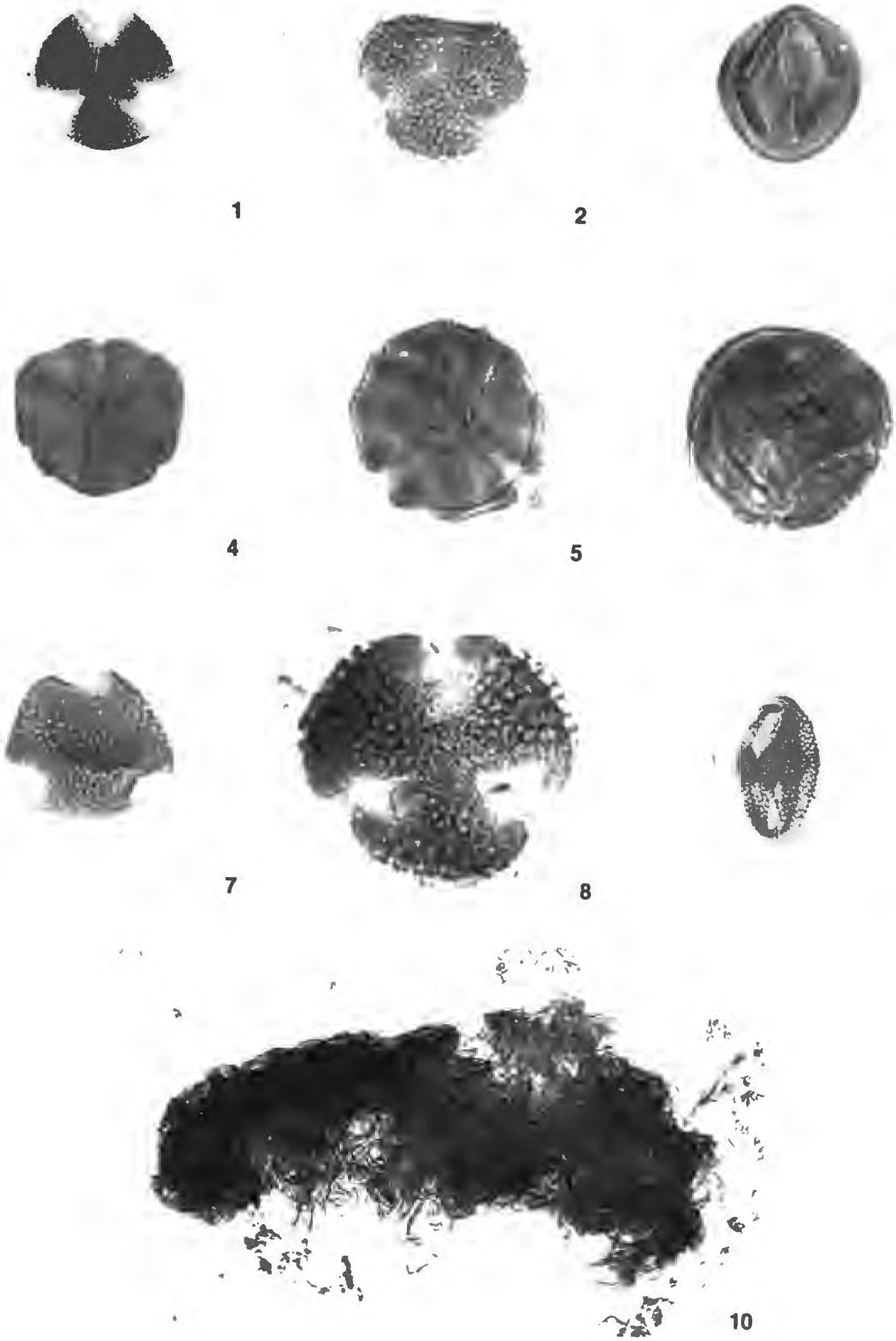
Pláte XXVII. Tricolporate, stephanocolporate pollen, and anther.

All magnifications 1000x, except as noted.

1. Tricolporate-44
2. Tricolporate-19
3. Tricolporate-9
4. Tricolporate-4
5. Stephanocolporate-1
6. Stephanocolporate-1
7. Tricolporate-13
8. Tricolporate-17
9. Tricolporate-42
10. *Nyssa* (anther) 200x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APPENDIX IV. Occurrences of microfossils at the collection localities.

Taxon	Hayfork	Readings Creek	Reese Mine	Panwauket Gulch
Pediastrum bifidites	x	x		
Pediastrum delicatites	x	x		
Pediastrum kajaites	x	x		
Schizosporis parvis	x			
Tetraporina	x	x		
Algal cyst-1	x	x		
Algal cyst-2	x	x		
Algal cyst-3	x	x		
Algal cyst-4	x	x	x	x
Algal cyst-5	x	x		
Ceratioid dinoflagellate cyst	x			
?*Cleistosphaeridium* type 1	x	x		
?*Cleistosphaeridium* type 2	x			
Micrhystridium type 1			x	x
Micrhystridium type 2	x	x	x	x
Micrhystridium type 3	x			
Phaeoceros	x			
Trilete-8	x	x		x
?*Lycopodium*				x
Laevigatosporites albertensis				x
Laevigatosporites discordatus	x	x	x	x
Laevigatosporites ovatus	x	x	x	x
Laevigatosporites type 1	x	x	x	
Laevigatosporites type 2				x
Polypodiidites type 1	x	x	x	x
Polypodiidites type 2	x	x	x	x
Polypodiidites type 3	x	x	x	x
Polypodiisporonites	x	x		x
Cicatricosisporites	x			x
Corrugatisporites	x	x	x	
Deltoidospora	x	x	x	
Trilete-3		x	x	
Trilete-7				x
Trilete-9	x	x		
Trilete-10	x			
Trilete-11	x			
Trilete-12		x		
Trilete-16	x			
Trilete-18	x			
Trilete-19	x	x		
Juniperus-type	x	x	x	x
?*Libocedrus*	x	x		
Inaperturate-17	x			
Abies	x	x	x	x
Cedrus	x	x	x	x
Larix	x	x	x	x

Taxon	Hayfork	Readings Creek	Reese Mine	Panwauket Gulch
Picea type 1	x			
Picea type 2	x	x	x	x
Pinus	x	x	x	x
Tsuga cf. *canadensis*	x	x	x	x
Tsuga cf. *heterophylla*	x			
Podocarpus type 1		x		x
Podocarpus type 2	x	x	x	x
?*Cryptomeria*		x		
?*Glyptostrobus*		x		
Taxodium	x	x	x	x
Taxodiaceae-Cupressaceae-Taxaceae	x	x	x	x
Graminidites	x	x		x
Typha or *Sparganium*	x	x	x	x
Acer	x	x		
Ilex type 1	x			
Ilex type 2		x		
Ilex type 3	x	x	x	x
Alnus	x	x	x	x
Betula	x	x	x	x
Corylus	x	x		x
Ostrya or *Carpinus*	x		x	x
Bombax-type	x	x		x
Buxus	x			
Pachysandra or *Sarcococca*		x		
cf. *Cereus*		x		
cf. *Echinocereus*		x		
Casuarina	x	x	x	
Sarcobatus	x	x		
Ambrosieae	x			x
Astereae	x			x
Cichorieae	x			x
cf. *Pieris*	x			
cf. *Pyrola*		x		
cf. *Rhododendron*	x	x	x	
cf. *Vaccinium*		x		
Croton	x	x	x	
Castanea or *Castanopsis*	x	x	x	x
Quercus granopollenites	x	x	x	x
Quercus	x	x	x	x
Liquidambar	x	x	x	x
Illicium		x		
Carya spackmania	x	x	x	x
Carya veripites	x			
Juglans	x	x	x	x
Pterocarya	x	x	x	x
cf. *Salvia*	x			
Bauhinia cf. *congesta*			x	

Taxon	Hayfork	Readings Creek	Reese Mine	Panwauket Gulch
Caesalpinia	x		x	x
?Cercis	x	x		
Leitneria	x			
cf. *Althea*	x			
Sphaeralcea	x	x		
Morus	x	x	x	x
Nyssa	x	x	x	x
Fraxinus	x	x	x	x
Jussiaea	x	x	x	
Triporate-1	x		x	x
Plantago		x		
Platanus	x	x	x	x
Polygonum cf. *coccinium*	x	x		x
Rubiaceae	x			
Salix apiculata	x	x	x	
Salix discoloripites	x	x	x	x
Fremontodendron	x	x		x
Reevesia	x	x	x	x
?Styrax	x	x		
Symplocos type 1	x			
Symplocos type 2	x			
cf. *Franklinia*	x	x		
Tilia				
Triumfetta	x	x	x	x
Trapa	x	x	x	x
Celtis	x	x	x	x
Ulmus or *Zelkova*		x		
Diporate-1	x			
Pistillipollenites	x			
Stephanocolpate-7		x		
Stephanocolporate-1		x		
Stephanocolporate-2				x
Tricolpate-1	x			
Tricolpate-7	x	x	x	
Tricolpate-9	x	x	x	
Tricolpate-10		x		
Tricolpate-11	x	x		
Tricolpate-12	x	x		
Tricolpate-14	x	x	x	x
Tricolpate-15	x	x		x
Tricolpate-18	x	x	x	x
Tricolpate-20	x	x	x	
Tricolpate-28	x	x	x	x
Tricolporate-4	x	x	x	
Tricolporate-9	x	x		
Tricolporate-13		x	x	
Tricolporate-16	x	x		x
Tricolporate-17		x	x	x

Taxon	Hayfork	Readings Creek	Reese Mine	Panwauket Gulch
Tricolporate-19	x		x	
Tricolporate-23	x	x		
Tricolporate-27	x		x	
Tricolporate-28	x	x		
Tricolporate-29	x	x	x	x
Tricolporate-30	x			x
Tricolporate-42	x	x	x	
Tricolporate-44	x	x		
Triporate-10	x	x		
Triporate-12	x			
TOTAL	125	106	64	67

APPENDIX V. Quantitative data for samples from the Hayfork and Readings Creek sections. A "p" indicates type present, but not encountered in counting. Taxa not shown occurred in samples not counted. Samples from Reese Coal Mine are from lignites correlative with base of Readings Creek section.

SAMPLE / TAXON	Readings Creek							Pan G.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Pediastrum bifidites			9										1	1	1	85	p	1			98
Pediastrum delicatites			p																		0
Pediastrum kajaites			p																		0
Schizosporis parvus											p										0
Tetraporina	p		p	p										p			p				0
Algal cyst-1		3	p	7		1		p		p	p				1		1		1		14
Algal cyst-2											1										1
Algal cyst-3		52	9	1				3						3		2	9				79
Algal cyst-4		2															p				2
Algal cyst-5		p						p									1	p		p	1
Ceratioid dinoflagellate cyst																	1				1
?*Cleistosphaeridium* type 1		20	1					1									188				210
?*Cleistosphaeridium* type 2																	p				0
Micrhystridium type 1								p											p		0
Micrhystridium type 2	2	10					p	26									p		8		46
Micrhystridium type 3											p										0
Phaeoceros										p	p										0
Trilete-8					p					p				p	1			1			2
?*Lycopodium*										p											0
Laevigatosporites albertensis											p										0
Laevigatosporites discordatus										2						1					3
Laevigatosporites ovatus		1	p	p	p		4	1	p	10	24	8	2	p	p		p			32	82

TAXON / SAMPLE	Readings Creek							Pan. G.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Laevigatosporites type 1		p			p	p					p									p	0
Laevigatosporites type 2									p												0
Polypodiidites type 1	p	p	p		p	2	p	p		1	p	p		p		1		p	p	p	4
Polypodiidites type 2	1	p	2	p	p	4	2		p			1		1	1	1		p		1	14
Polypodiidites type 3						p		9			4	p									13
Polypodiisporonites								1			1										2
Cicatricosisporites									p	p			p								0
Corrugatisporites						p														p	0
Deltoidospora											4		p				p			2	6
Trilete-3																				2	2
Trilete-7										p											0
Trilete-9						p															0
Trilete-12						p															0
Trilete-16											p										0
Trilete-18											p										0
Trilete-19						p					p										0
Juniperus-type	6	45	97	78	49	28		23	7	14	128	72	3	44	74	23		15	50	5	761
?*Libocedrus*				2								p									2
Inaperturate-17											p										0
Abies		2	7	1		3	1	3		2	p	p	6	p			12	4		2	43
Cedrus	1	p				p	4	p										1	1		7
Larix		2	2	1	2	1		3	9	22	1		3				7	3	1	1	58
Picea type 1														p							0
Picea type 2	1	20	34	34	23	36	67	44	261	146		6	44	12	5	13	76	87	5	130	1044
Pinus	11	91	23	46	251	87	44	37	46	66	4	8	151	17	36	16	13	41	16	96	1100

TAXON \ SAMPLE	Readings Creek							Pan. G.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Tsuga cf. *canadensis*	p	p	1		1	p			3	3	3	p		2	1	p	1	5	p	1	21
Tsuga cf. *heterophylla*														p							0
Podocarpus type 1										p											0
Podocarpus type 2		3	p	2	2		p	p	1	2			1		p	1	2	3		1	18
?*Glyptostrobus*				18																	18
Taxodium	373	27	116	86	91	48	9	68	48	70	99	10	22	151	62	99	21	35	46	10	1491
broken conifer grains	11	1	3	11	12	13	14	17	30	28	2	1	37	8	7	7	20	20	6	15	263
Taxodiaceae-Cupressaceae-Taxaceae	1		3	2	7	8		11	2	2	39	2	3	40	1	28	7	12	7	5	180
Graminidites	p		p			1		p					1		p	1	1	p			4
Typha or *Sparganium*	1	5	8	5	p	4	1	67		1		8	4	1	10	21	7	3	11	1	158
Acer			p															p			0
Ilex type 1															p						0
Ilex type 3	2	3	1	4	3	2	3	p	p	1		1		p	1	1		2	p	17	41
Alnus	1	3	1	1	p		1	26	5	39	p		17	4	p	3	3	5	p	2	111
Betula			p	p	p		p	p			1	p		1			p	1	p	p	3
Corylus			p			p		1						p		p	p	p			1
Ostrya or *Carpinus*									p			p			1			1	1		3
Bombax-type						2				p							1				3
Pachysandra or *Sarcococca*					p																0
cf. *Cereus*			p																		0
cf. *Echinocereus*			p																		0
Casuarina	p	p												p		p			p		0
Sarcobatus	p	1	p											p							1
Ambrosieae										p								p			0

TAXON \ SAMPLE	Readings Creek							Pan. G.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Astereae										p			5	p			p	1			6
Cichorieae									1	p								p			1
Ericaceae		p	p		p														p	p	0
Croton			p																	1	1
Castanea or *Castanopsis*			3	5			7		9	8	4		2	3		2		20		1	64
Quercus	16	112	90	61	6	12	3	56	8	7	22	87	10	74	124	152	174	62	176	4	1256
Liquidambar		1	p	2	p	p		1			1	1		p	6	p	p	1	1		14
Illicium	1			p																	1
Carya spackmania	9	14	8	8	10	18	9	20	15	12	1	5	7	17	37	7	15	14	11	10	247
Carya veripites											p										0
Juglans	p	p	p	p	p	p		p						p	p	p		p	p	p	0
Pterocarya	1	13	11	9	3	20	69	3	7	1		14	5	5	25	23	79	31	7	23	349
Bauhinia cf. *congesta*																				p	0
cf. *Salvia*											p										0
Caesalpinia									1											p	1
?*Cercis*						3					1	1	1				2	4			12
Leitneria		p												p				p			0
cf. *Althaea*																		p			0
Sphaeralcea																		p			0
Morus		p	p	p											1						1
Nyssa	6	19	13	27	13	52	237			2	2	14		p	1	6	32	75	52	83	634
Fraxinus			1	p		1		p		p		1		11				p	2		16
Jussiaea				p	p	1								p			1		p	1	3
Triporate-1										p										p	0
Plantago					p																0

TAXON \ SAMPLE	Readings Creek							Pan C.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Platanus		36	2	4		1		6	p	6	1	3	3	2	8	1		1	3	1	78
Polygonum cf. *coccinium*			p							p											0
Salix apiculata				3		2					1	34		4			p		11		55
Salix discoloripites	1	1	2	2		6	1	6	2	p	5	1	69	p	1	1	2	1	3	3	107
Fremontodendron		p	p			1				p					p			p			1
Reevesia	p	p		p	p	p			p					p	p			p	p		0
?*Styrax*		1		p								p									1
Symplocos type 1														p							0
Symplocos type 2															p						0
cf. *Franklinia*			p												p	p					0
Tiliaceae (mostly *Triumfetta*)	7	7	1		1	57	1			2	9			1	2	2	4	2	4	2	102
Trapa																		1			1
Celtis		3	1	5		1		2				3		1		1	2	p	3		22
Ulmus or *Zelkova*	2	7	3	10	1	9	1	6	p	6	25	23	8	8	20	24	5	4	1	1	164
Diporate-1			p	p		p															0
Stephanocolpate-7		p		p																	0
Stephanocolporate-1			p																		0
Stephanocolporate-2									p												0
Tricolpate-7	p	8	p		p									5	p				p		13
Tricolpate-9				p	p							73							p		73
Tricolpate-10				p																	0
Tricolpate-11		p									p		1		1						2
Tricolpate-12	p	p		p	p											p					0
Tricolpate-14		8	1		p			1	1	4				4		p		p		17	36
Tricolpate-15		p						p			p			p			3	p			3
Tricolpate-18		p	4	11		p	p	4			p	p	p	p	p	4		3	4	5	35

TAXON \ SAMPLE	Readings Creek							Pan G.			Hayfork								Reese		TOTAL
	12	16	17	20	21	62	32	10	100	102	104	105	112	115	118	120	122	123	39	42	
Tricolpate-20			p	2															3		5
Tricolpate-28																		p			0
Tricolporate-4			1	p															13		14
Tricolporate-9				1	p													p			1
Tricolporate-13				1															p		1
Tricolporate-16			2	2		5				7								1			17
Tricolporate-17			p	2				p												p	2
Tricolporate-23			p												p						0
Tricolporate-27															p				p		0
Tricolporate-28					p									p		1					1
Tricolporate-29					p		3													p	3
Tricolporate-30									p					p							0
Tricolporate-42					7							p								1	8
Tricolporate-44			3	1								19				1					24
Triporate-10		p	p		p	p					1	p	5	1	p	p					7
Triporate-12															p	2					2
Tricolpates, unidentified	23	34	32	20	1	21	7	33	15	13	48	76	31	40	45	20	1	18	27	7	514
Tricolporates, unidentified	1										5		1								7
Unidentified	24	32	27	36	18	45	16	63	31	29	65	27	58	43	29	38	14	25	35	17	672
TOTAL POLLEN + SPORES	500	500	503	503	501	500	500	502	502	506	501	499	500	500	500	500	506	503	500	500	10026
TOTAL PALYNOMORPHS	502	585	524	511	501	509	500	532	502	506	502	499	501	504	502	588	707	504	509	500	10488

Chevron Oil Field Research Co.
P.O. Box 446
La Habra, CA 90631
20 Dec 1982

Weaverville Library
Weaverville, CA 96093

Dear Librarians:

I've just recently completed a Masters thesis at the University of Washington and thought that a copy might be of interest to the library or museum at Weaverville. This is a study of fossil pollen associated with the fossil leaves found in the area such as at Blanchard Flat. Dr. Harry D. MacGinitie studied the leaves in some detail (Carnegie Institute of Washington Publication 465, 1937), and the pollen study was meant to complement his excellent work. The interpretations present an interesting picture of the vegetation and climate in Tertiary time, when a large lake covered the present site of Weaverville.

From '80 to '82 I made several short trips to Trinity County collecting samples and mapping some of the rock formations. I much appreciate the help I recieved from various people in the area, especially with regards to leaf-collecting localities and access to land. If you have any questions feel free to contact me: (213) 694-9194 (8am-4pm).

Sincerely,

Jeanie Barnett

Jeanie Barnett