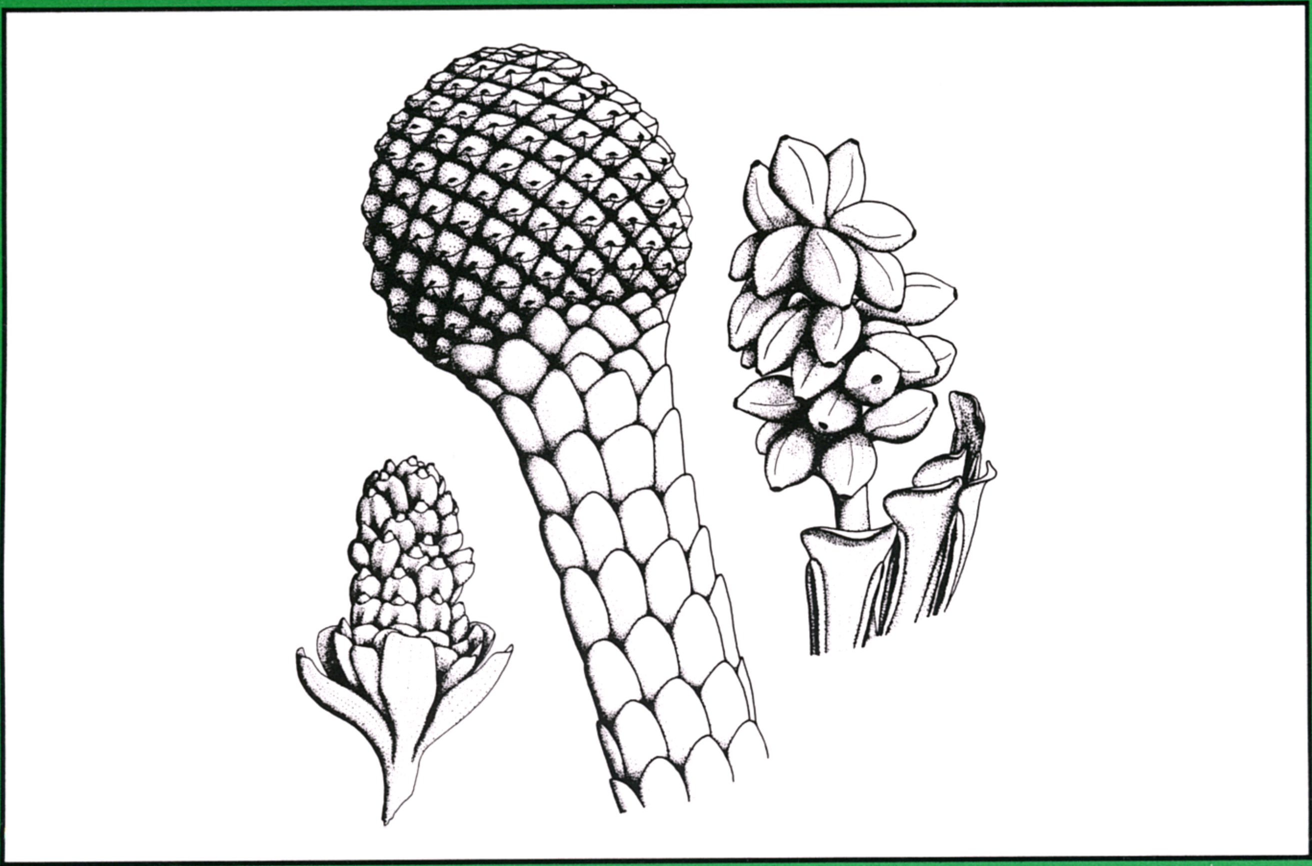
Early to Middle Carnian (Triassic) Flora and Fauna of the Richmond and Taylorsville Basins, Virginia and Maryland, U.S.A.

Bruce Cornet and Paul E. Olsen



Virginia Museum of Natural History

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INTRODUCTION

Early Mesozoic igneous and sedimentary rocks are preserved in rift basins of the eastern North American Atlantic passive margin (Van Houten, 1977; Manspeizer, 1988), which formed during the breakup of the supercontinent of Pangaea (Fig. 1). The initial breakup of Pangaea began in the Late Triassic, with basins and their sediments providing evidence of active rifting well into the Early Jurassic. The formation of these basins signals the development of rifted crust all along the axis of the future North Atlantic Ocean, from Greenland to Mexico.

In eastern North America, nine major rift basins, mostly half-graben, and several minor basins are exposed from Nova Scotia to South Carolina, where their long axes closely follow the trend of the Appalachian orogen (Fig. 1). The sedimentary and igneous rocks that fill these exposed basins are termed the Newark Supergroup (Olsen, 1978; Froelich and Olsen, 1985). Many similar basins lie buried below the coastal plain and continental shelf (Fig. 1). Most of the large basins were filled with thousands of meters of continental sediments and basalt flows that span a period of approximately 45 million years (early Carnian to Pliensbachian). Some of the exposed basins, such as the Richmond and southern Taylorsville basins (Fig. 2), contain some of the oldest fossiliferous Late Triassic sediment of the Newark Supergroup, implying that rifting started in the early Carnian. Other basins, such as the Hartford basin, seem to have formed later. However, deposition in the Richmond and Taylorsville basins apparently ceased prior to the Norian (see below).

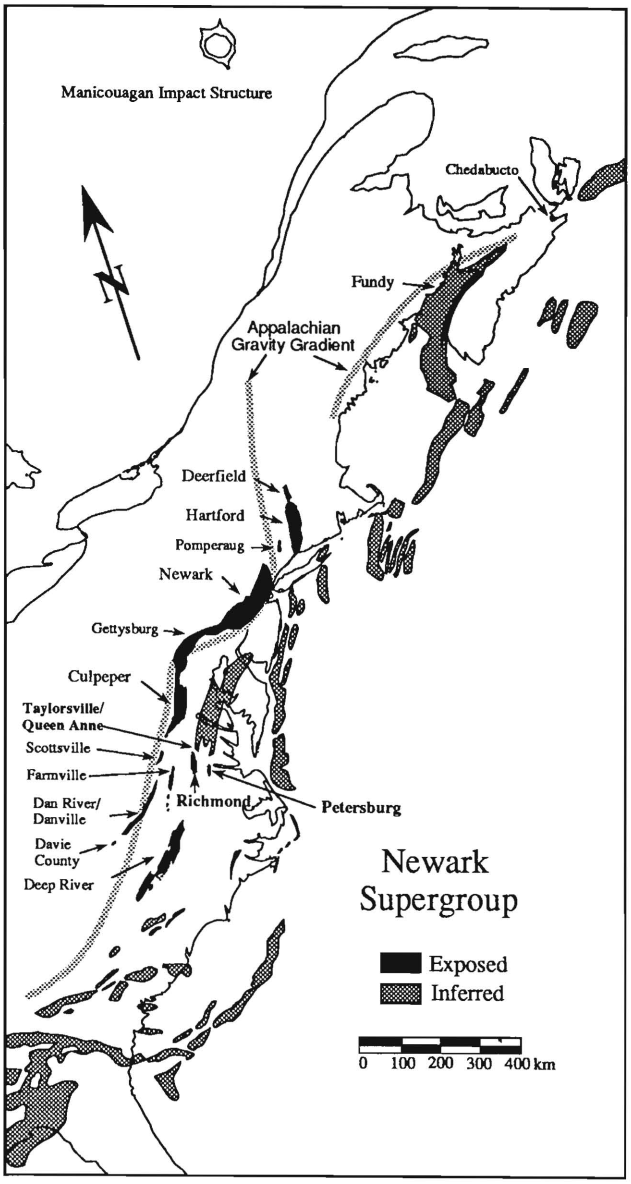

Fig. 1. Newark Supergroup of eastern North America. Modified from Olsen et al., 1989.

The purpose of this field trip and guidebook is to provide a comprehensive overview of the flora and fauna of the Richmond basin and exposed part of the Taylorsville basin, Virginia (Fig. 2). Information on the megaflora of the Deep Run basin, which lies just to the northeast of the Richmond basin (Fig. 3), is also provided. The two primary references for the megaflora are Fontaine (1883) and Bock (1969), with comparative middle to late Carnian data derived from the Pekin Formation (Deep River basin) of North Carolina (e.g., Hope and Patterson, 1969), the Cow Branch Formation (Dan River/Danville basin) of Virginia/North Carolina (e.g., Olsen et al., 1978), the New Oxford Formation (Gettysburg basin) of Pennsylvania (e.g., Wanner and Fontaine, 1900), the Chinle Formation of the southwestern United States (e.g., Ash, 1989), and the Santa Clara Formation of northwestern Mexico (e.g., Garcia and Weber, 1985; Weber, 1985a-c). The fauna of the Richmond and Taylorsville basins is unique for the Newark Supergroup, because it contains elements (such as common, small "mammal-like reptiles") that are more typical of Southern Hemisphere (Gondwanan) faunas than Northern Hemisphere (Laurasian) faunas (Olsen, 1989). Together, the fauna and flora provide a view of equatorial conditions (Witte and Kent, 1989) during the Carnian, a time when floral diversity was the highest for any Newark Supergroup assemblage. It was also a period of rapid floral evolution moderated by low turnover until the late Carnian, when climatic change may have brought about the

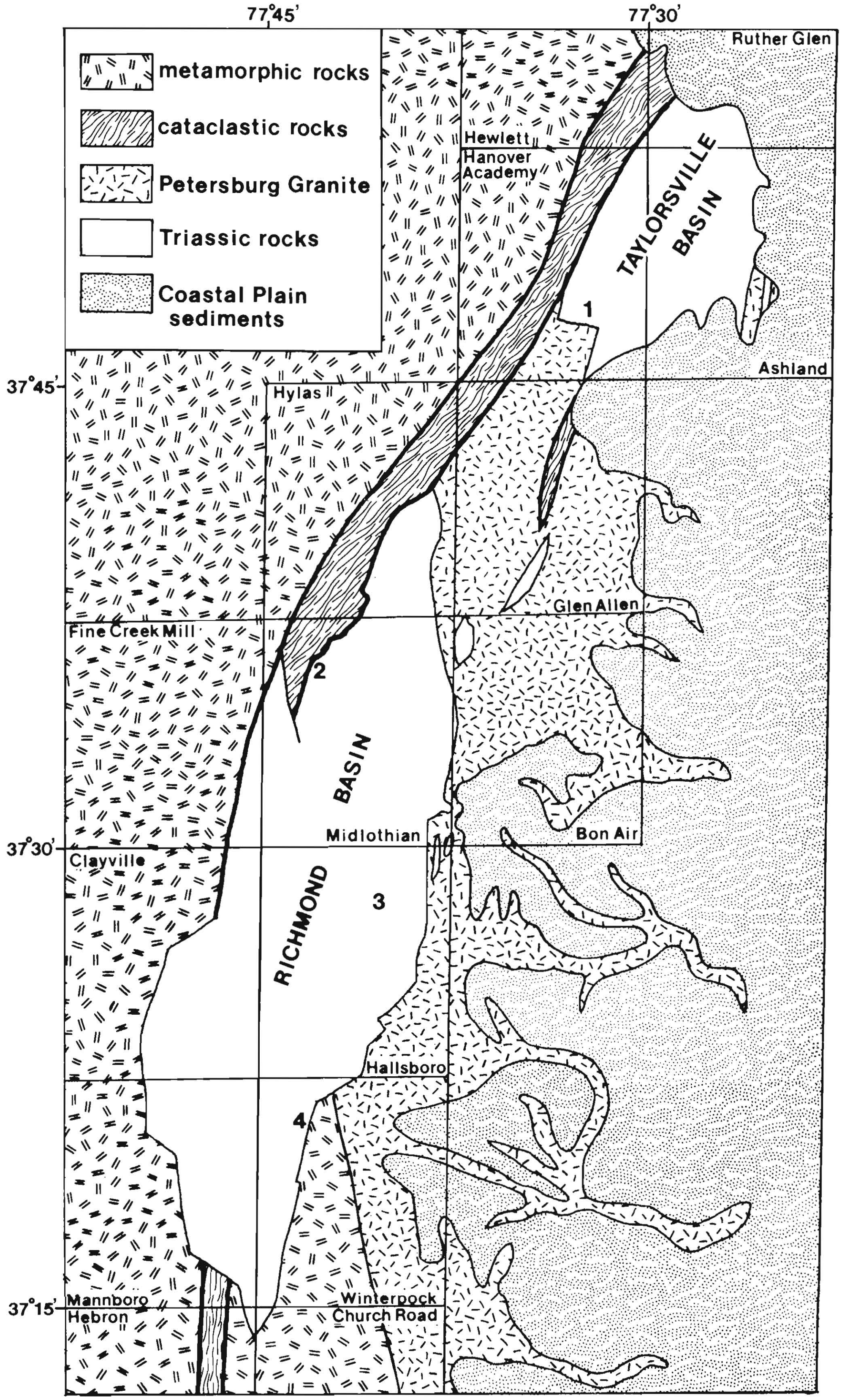

Fig. 2. Richmond and Taylorsville basins, showing generalized geology of surrounding areas and locations of Triassic outlier basins. Names and locations of 7.5 minute quadrangles that include portions of the Triassic basins are given, along with the locations of numbered stops for this field trip. Modified after Goodwin et al. (1985).

end of perennial floodplain wetlands, perhaps with the introduction of a pronounced dry season.

STRUCTURAL SETTING AND BASIN SIZE

The Richmond and Taylorsville basins occupy a broad rift valley complex about 48 kilometers (30 mi.) wide and at least 257 kilometers (160 mi.) long. Four major basins and several small basins occupy this trend. The Richmond, Taylorsville, Deep Run, Tuckahoe (Flat Branch), and Union basins are the only ones exposed at the surface (Goodwin et al., 1985; Goodwin et al., 1986; Wilkes, 1988). Drilling and seismic reflection studies have documented the Queen Anne basin at the northern end of the rift valley in Maryland (Delmarva Peninsula) (Hansen, 1988), the Petersburg basin on the southeastern side of the rift valley in Virginia (Wilkes et al., 1989), and the main body of the Taylorsville basin in the center of the rift valley (Fig. 1). The Taylorsville basin is now known to span at least nine counties and covers an area of about 2,300 square kilometers (1,430 sq. mi.)(Wilkes et al., 1989). The Richmond basin, by comparison, spans four counties and covers an area of only 273 square kilometers (170 sq. mi.) (Goodwin and Farrell, 1979). The following historical scenario is based on the detailed study (by Cornet) of mostly proprietary seismic lines and drill hole data for the Richmond and Taylorsville basins.

The Taylorsville basin comprises several early depocenters similar in size to the Richmond basin. The depositional environments of these early depocenters (including the Richmond depocenter) were characterized by wet floodplains, broad and deep fluvial channels, and/or large deltaic complexes bordering relatively deep lakes (based on core and outcrop study, and electric log correlation between the Richmond and Taylorsville basins). As these areas of initial deposition became filled and as the rift valley (represented by the Queen Anne, Taylorsville, Richmond basins, etc.) continued to subside, sedimentation expanded beyond the early depocenters or valleys to eventually cover the hills and uplands between them on the rift valley "floor." The rift valley "floor," instead of being a peneplain or low-relief surface, was apparently a dissected mountainous terrain with well-defined valley drainage patterns, much like the present-day Ridge and Valley province of western Virginia.

Once the initial depocenters and interconnecting valleys were filled with sediment, the area of deposition progressively expanded. With time, lakes became much shallower, possibly because the amount of water entering the rift valley had to be distributed over a larger and larger area (Schlische and Olsen, 1990). Consequently, fluvial and floodplain deposits became dominant during the later history of basin fill, and interconnected the older areas of deposition with blanket deposits that measure in thousands of square kilometers. The youngest sediments of the rift valley are primarily red floodplain deposits, although wetlands (e.g., gray fossiliferous shales and siltstones) existed locally in areas that had greater rates of subsidence (e.g., adjacent to major active faults).

During and after deposition, localized, periodic uplift and erosion removed the younger blanket deposits between the Richmond and Taylorsville basins (Fig. 2) and gave the area encompassing the northern Richmond and southern Taylorsville basins its unique structural history. In contrast, the northern part of the rift valley (i.e., the central and northern Taylorsville basin and Queen Anne basin) appear relatively undisturbed, with a basal 975 meters (3,200 feet) of section confined to Richmond-size half-graben, and still buried or situated below as much as 1,300 meters (4,200 feet) of younger Carnian deposits. To the north and east of the Richmond basin, Cretaceous and Tertiary sediments increase in thickness, burying Triassic rocks under as much as 670 meters (2,200 ft.) of onlapping Coastal Plain sediments.

RICHMOND AND TAYLORSVILLE BASIN STRATIGRAPHY

Because of extensive drilling and seismic reflection studies done since the early 1980s and the existence of mining records dating from the mid to late nineteenth century, the stratigraphy, structure, chronology, and distribution of formations are more completely known for the Richmond basin than for the Taylorsville basin (Fig. 3; Goodwin, 1970, 1971, 1980a, 1980b, 1981a, 1981b; Goodwin and Johnson, 1967; Goodwin and Farrell, 1979; Goodwin et al., 1985; Goodwin et al., 1986; Cornet and Ziegler, 1985; Robbins et al., 1988; Cornet, 1989a and 1989b). Recent revision of the stratigraphy and nomenclature of the Richmond basin by Ediger et al. (in prep.) is followed here (Figs. 4, 5, and 6). The Richmond basin sequence is divided into three formations, from bottom to top: (1) the Tuckahoe Formation, which represents the sequence restricted to early depocenters of the rift

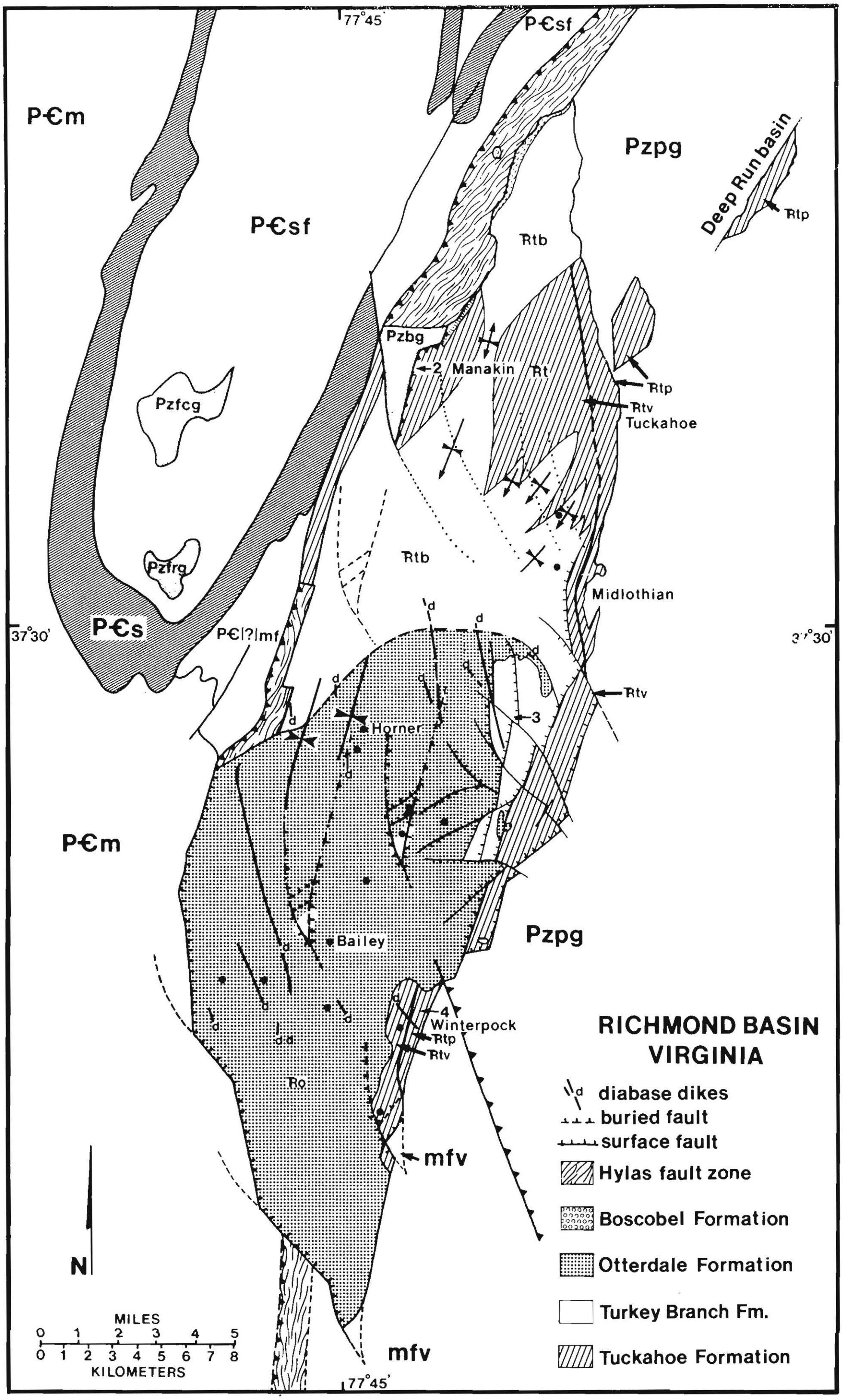

Fig. 3. Geologic map of the Richmond basin, showing probable distribution of Triassic and pre-Triassic formations. Locations of Stops 2-4 shown. Pop-up structures and structural folding in the northern part of the basin are interpreted from seismic data. mfv = metafelsic volcanoclastics (also underlies the southern half of the basin); pE(?)mf = Moseley felsic gneiss; pEm = Maidens Gneiss; pEs = Sabot Amphibolite; pEsf = State Farm Gneiss; Pzbg = Boscobel Granodiorite; Pzfcg = Fine Creek Mills Granite; Pzfrg = Flat Rock Granite; Pzpg = Petersburg Granite (and Pzbg underlie portions of the northern half of the basin).

valley; (2) the Turkey Branch Formation, which either conformably or unconformably overlies the Tuckahoe Formation; and (3) the Otterdale Formation, which is separated from the underlying Turkey Branch Formation by an erosional unconformity or hiatus (Cornet and Ziegler, 1985; Cornet, 1989a and 1989b; Ediger et al., in prep.). The Turkey Branch Formation correlates in part with

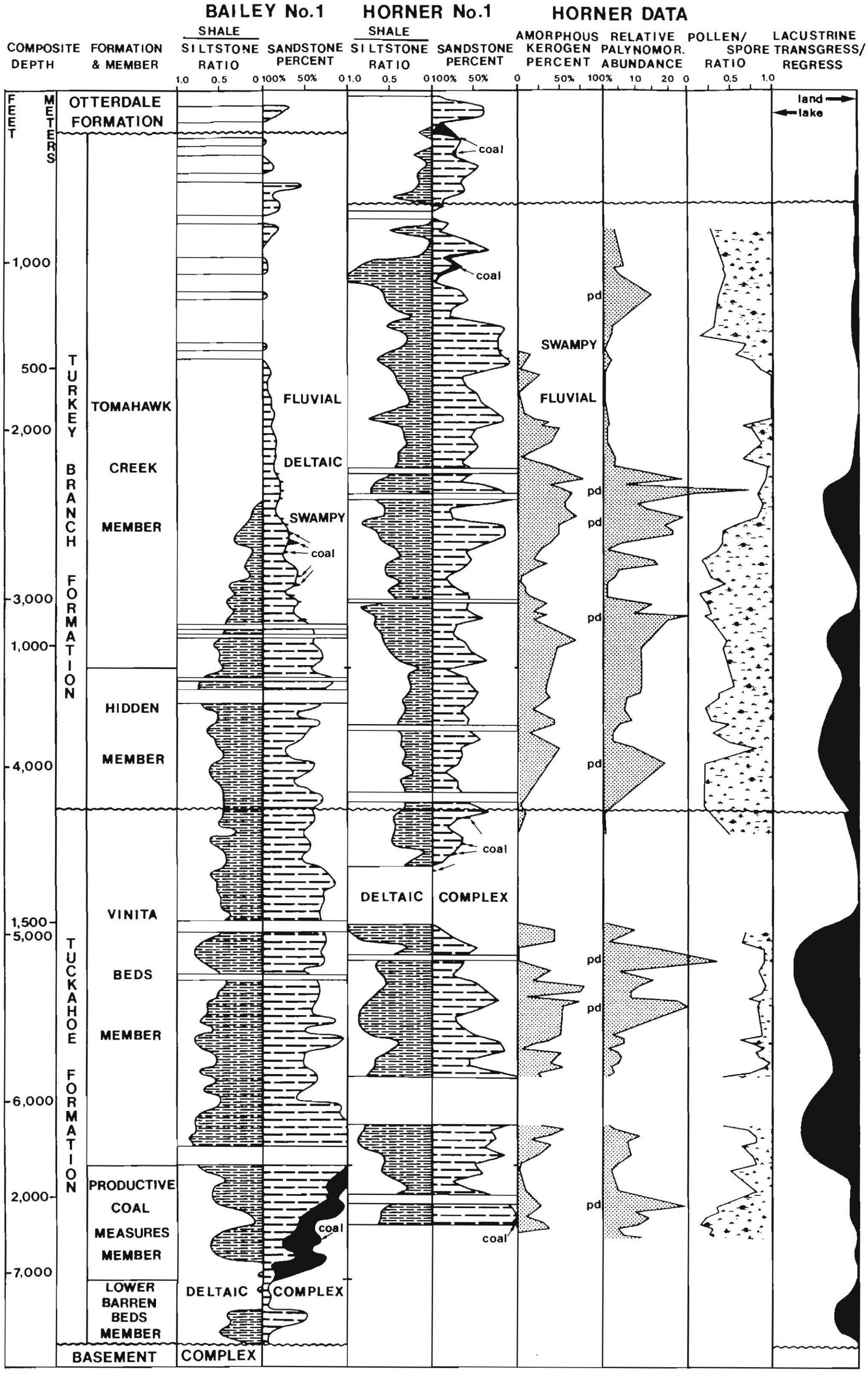

Fig. 4. Richmond basin stratigraphy for the Horner #1 and Bailey #1 wells; kerogen composition, palynomorph abundance, pollen/spore ratios, and paleoenvironmental (water depth) history for the Horner well; lithologic sequences for the Horner and Bailey wells are correlated to show dynamic facies changes in basin over a distance of 9.6 km (six mi.); well lithologies were averaged over 15 m (50 ft.) intervals; lacustrine transgressions and regressions are based on kerogen composition, fluctuations in palynomorph abundances in sediments, and geophysical log interpretations and correlations. Modified from Cornet (1989a).

the Newfound Member of the Doswell Formation in the Taylorsville basin, and both represent sequences that extend across the rift valley and bury paleohills on the rift valley "floor." The Otterdale Formation, which is restricted mainly to the southern two-thirds of the Richmond basin (Fig. 3), has been palynologically dated by Cornet as late Carnian, and may also be present in the exposed part of the Taylorsville basin (Fig. 6).

Although the lithologic sequences of the Richmond and Taylorsville basins are very similar, stratigraphic treatment differs between the two basins, with formations in the Richmond basin correlating with members of one formation in the Taylorsville basin (Fig. 6). This difference in nomenclature is not as extreme as it appeared when Weems first proposed his nomenclature of the Taylorsville basin in 1980. At that time the Richmond section was divided by Shaler and Woodworth (1899) into two groups with four formations. Recent drilling and seismic reflection studies in the Richmond basin revealed a previously unrecognized sequence of strata (i.e., Turkey Branch Formation). Ediger et al. (in prep.) revised the nomenclature of the Richmond basin (Figs. 3 and 4) to include this new sequence. Palynological correlation between the basins shows that this younger sequence or formation is exposed in the Taylorsville basin (Fig. 7) (Cornet, 1989a).

Without paleontological control, Weems was unable to distinguish this younger sequence from the poorly exposed sandstone sequence underlying the Falling Creek Member of the Doswell Formation. Weems thought that the Stagg Creek Member of the same formation represented the basal sequence in the basin because it onlapped granite basement in exposures along Stagg Creek (Weems, 1980a; Weems, 1981; Goodwin et al., 1985). These exposures of basement are interpreted here as belonging to a rider block that was created when a second border fault formed to the west of the main border fault (Fig. 7). The rider block became a shelf or ledge on the western side of the basin, and was buried by onlapping sediments of Stagg Creek Member age. The older Falling Creek Member of the Doswell Formation, which correlates with the Vinita Beds Member of the Tuckahoe Formation in Richmond basin (Cornet, 1989a), crops out to the east of Stagg Creek, across the main border fault (Fig. 7). The type Stagg Creek Member and the deltaic-lacustrine sequence that overlies it (Figs. 6 and 7) palynologically correlate with the Hidden Member and lower Tomahawk Creek Member of the Turkey Branch Formation in the Richmond basin (Fig. 6; Cornet, 1989a).

The Richmond basin sequence begins with fluvial, overbank, and floodplain-restricted lacustrine environments of the Lower Barren Beds Member of the Tuckahoe Formation. A rapid change to wetland peat-forming environments occurs at the base of the overlying Productive Coal Measures Member (Fig. 4). Only the top of the Lower Barren Beds Member crops out in limited areas beneath the lowermost coal, while exposures of the Productive Coal Measures Member occur mainly along the eastern side of the Richmond basin and in outlier basins (e.g., Deep Run basin) isolated by erosion (Fig. 3). The coal measures do not have a facies equivalent in the Taylorsville basin, whereas the basal fluvial sediments of the Taylorsville basin are similar to the Lower Barren Beds Member of the Richmond basin (Figs. 6 and 7; Weems, 1980a; 1982).

The lower Productive Coal Measures Member is dominated by sandstones alternating with coal beds, but becomes dominated by shales and siltstones towards the top as lacustrine environments expanded at the expense of fluvial environments (Fig. 8). The coal seams, their underclays and roof shales, and interbedded fine sandstone, siltstone, and shale beds all contain common to abundant plant fossils. Our best information about the megafloras of the Richmond and Taylorsville basins comes from this basal part of the section. Stop 4 is the best locality for collecting fossils of the oldest Carnian flora in the Newark Supergroup.

The lower part of the overlying Vinita Beds Member (seen at Stop 2) (Fig. 8) is dominantly lacustrine everywhere, indicating a major increase in water depth. This trend is reversed higher in the Vinita Beds as deltaic-fluvial environments reestablished themselves with a fall in lake level (Fig. 4). At the top of the Vinita Beds Member a syndepositional unconformity developed on the eastern up-dip margins of fault blocks that rotated downward on their western sides due to a rapid increase in tectonic extension and basin subsidence (Fig. 5). Based on lithologic and palynologic correlation of well data and the study of seismic lines in the Richmond basin, sedimentation was temporarily shifted towards the western or down-dropped sides of these fault blocks, creating an onlap unconformity (as seen at Stop 2) and the erosion of sediment from the up-dip areas of each of the rotated fault blocks. Basement rider blocks developed west of the main border fault, and deposition extended onto them as they began to subside (e.g., Fig. 7). The Hidden Member of the Turkey Branch Formation, known only from well cuttings and seismic profiles, was deposited at this time. This member is mainly restricted to areas of greater subsidence, and thins or is absent along the up-dip margins of rotated fault blocks (Fig. 5). Lacustrine conditions predominated in the Richmond basin during Hidden Member time, while fluvial conditions predominated on a basement rider block or shelf along the western margin of the basin and lake.

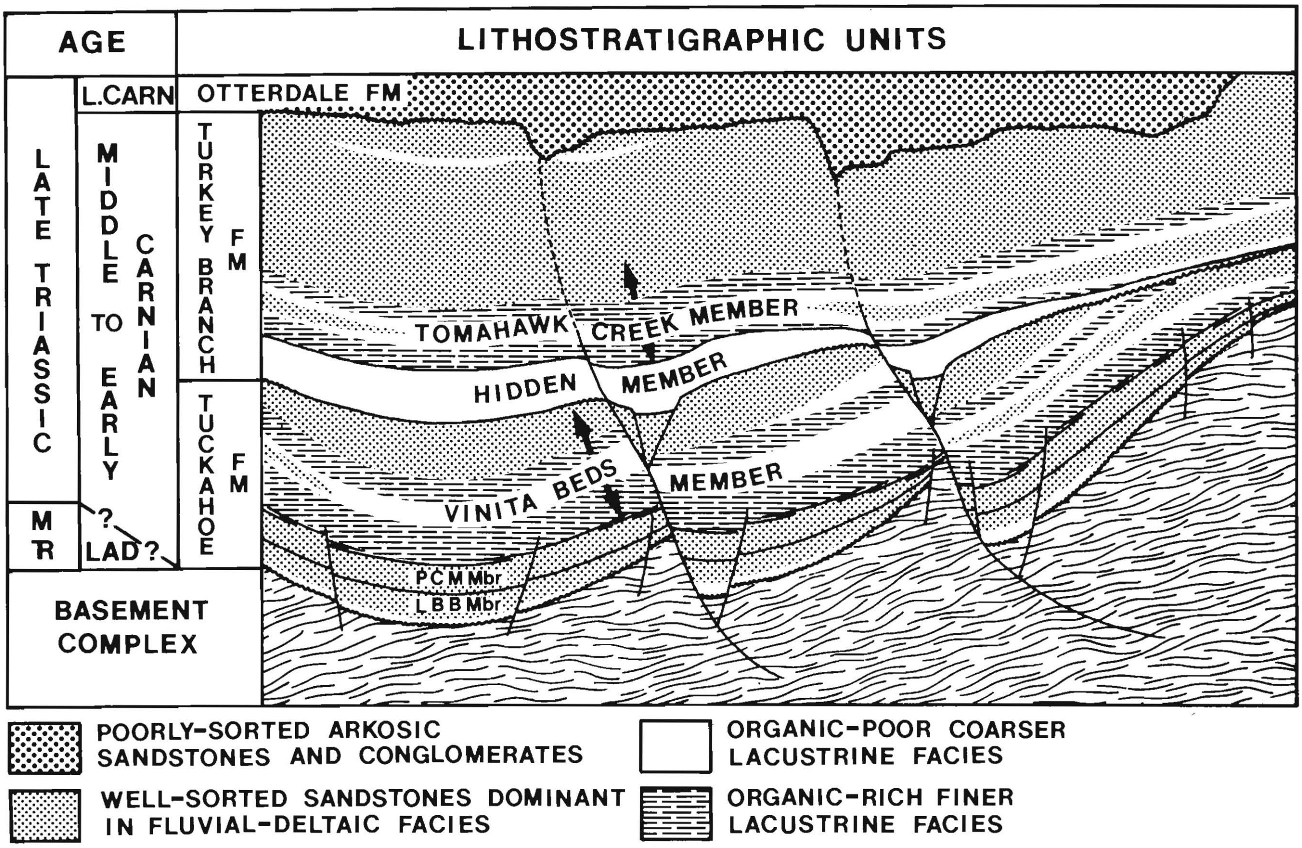

Fig. 5. Idealized east-west cross section in center of the Richmond basin. The similarity in general lithostratigraphy between the Tuckahoe and Turkey Branch formations is thought to be a reflection of long-term climatic cycles, while the up-dip truncation of the Tuckahoe Formation and the wedge shape of the Hidden Member are probably the direct result of tectonism. Basin structure at the eastern and western margins of the half-graben is not shown because seismic lines in the central part of the basin did not cross the basin margins. PCM Mbr. = Productive Coal Measures Member; LBB Mbr. = Lower Barren Beds Member.

The "upper" Stagg Creek Member of the Doswell Formation in Taylorsville basin, seen at Stop 1 along Stagg Creek (Fig. 6), correlates with the Hidden Member of the Turkey Branch Formation in the Richmond basin, and was deposited in a similar structural and depositional setting on a western rider block or basement shelf (Fig. 7). The coarse fluvial arkosic sandstones of the "upper" Stagg Creek Member are replaced by alternating fluvial-deltaic, fluvial overbank, and shallow lacustrine rocks within the "upper" Falling Creek Member of Weems (1980a: Fig. 6). Numerous paleosols with root traces are overlain by shales containing excellently preserved leaves and stems of cycadophytes, articulates, ginkgophytes, occasional ferns, and rare insects. The finer-grained portions of some sandstone units contain common remains of tree ferns (e.g., *Cyathoforma* sp.) and Bennettitales (e.g., *Pterophyllum* sp.).

Above the deltaic-lacustrine facies of the "upper" Falling Creek Member (Taylorsville basin) and correlative lower Tomahawk Creek Member (Richmond basin), fluvial facies predominate as lacustrine interludes become fewer and stratigraphically more widely spaced in outcrop areas on the western side of the Taylorsville basin and on the eastern side of the Richmond basin. The bone locality at Stop 3 in the middle Tomahawk Creek Member of the Turkey Branch Formation occurs within such an alternating fluvial-lacustrine setting. Although the upper Tomahawk Creek Member and Newfound Member (Fig. 6) have produced abundant pollen and spores (Fig. 4), and the palynological history of the upper part of the Richmond-Taylorsville sequence is documented (Cornet, 1989a; Fig. 4), megafossil plant localities are rare and mainly consist of poorly preserved plant fragments and carbonized or silicified wood.

AGE OF THE RICHMOND-TAYLORSVILLE BASIN FLORAS

Fontaine (1883) compared the Richmond and Taylorsville flora to Rhaetian and Jurassic floras

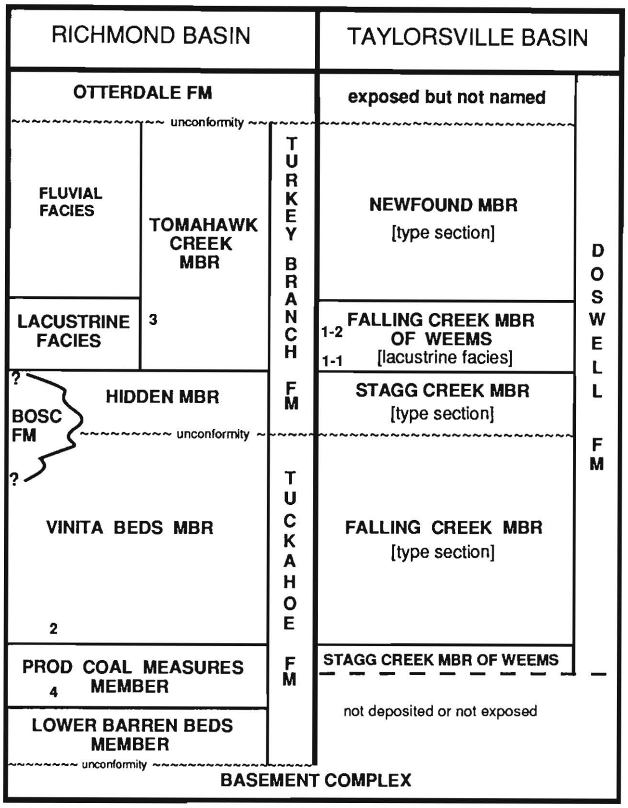

Fig. 6. Stratigraphic correlation between the Richmond basin and the Taylorsville basin, based mainly on palynological correlation. Note that Weems's (1980) members are diachronous and that both the Tuckahoe and Turkey Branch formations are represented by coeval strata in the Taylorsville basin. Relative positions of Stops 1-4 and Substops 1-1 and 1-2 are shown.

known to him at that time. He considered the Rhaetian to claim the largest percentage (28%) of identical and allied species, and stated, "It is clear, then, from these facts that we must consider this flora as not older than Rhaetic. The only question is whether or not its strong Jurassic features ought to cause us to regard it as at least Lower Liassic in age" (Fontaine, 1883: 96). Bock (1969) did not dispute Fontaine's age assignment, even though he had a much more extensive library of information to compare and reference on Late Triassic floras of the world.

It was not until Dunay and Fisher (1974) and Cornet (1977a) studied and compared the palynofloras of the Richmond and Taylorsville basins to European palynochronology that a significantly older age for these deposits and their floras was indicated (Robbins et al., 1989). Ash (1980, 1987) recognized four major floral subdivisions of the North American Late Triassic (and Early Jurassic): (1) Zone of *Eoginkgoites* (middle Carnian), (2) Zone of *Dinophyton* (late Carnian), (3) Zone of *Sanmiguelia* (Norian-Rhaetian), and (4) an upper (unnamed) zone (Rhaeto-Liassic). All four zones were recognized in the Newark Supergroup (Ash, 1980; Cornet and Olsen, 1985; Axsmith and Kroehler, 1989).

The Richmond Winterpock flora (Stop 4), *sensu stricto*, is older than Ash's zone of *Eoginkgoites*, because the type taxon of this zone first occurs in the middle Carnian, middle Pekin Formation of the Deep River basin (Fig. 1) in North Carolina (R. C. Hope, pers. comm., 1989). *Eoginkgoites* has not yet been found in younger strata of the Richmond or Taylorsville basins. The middle Pekin and stratigraphically overlying Cumnock formations produce palynoflorules that are similar to those of the Turkey Branch Formation, but uniform differences in composition reduce confidence in correlation (e.g., Schultz and Hope, 1973; Cornet, 1977a; Cornet and Olsen, 1985). If the Pekin and Cumnock formations are approximate time equivalents of the Turkey Branch Formation, local floras must have been significantly different. Evidence in support of environmental and floral diversity is given below under megafossil and palynofloral change in the Carnian. Alternatively, palynofloral differences could imply that the Pekin and Cumnock formations are slightly younger than the Turkey Branch Formation. The middle Pekin Formation megaflora and palynoflora (Hope and Patterson, 1969, 1970; Delevoryas and Hope, 1973, 1975, 1976, 1978, 1981, 1987; Schultz and Hope, 1973; Taylor, Delevoryas, and Hope, 1987) may correlate with the spore-dominated shallow lacustrine interval between 800 meters and 1,000 meters depth in Fig. 4, while the basal Cumnock Formation, coal measures flora and palynoflora (Emmons, 1856 and 1857; Fontaine, 1883; Cornet, 1977a) may correlate with the spore-dominated swampy interval above 500 meters depth in Fig. 4. If the middle Pekin Formation does correlate with the lower Tomahawk Creek Member, its flora would be approximately contemporaneous with the Stagg Creek flora of the Taylorsville basin (Stop 1), rather than younger.

Ash's zones of *Eoginkgoites* and *Dinophyton* may not be distinguishable in the Newark Supergroup, because these taxa (Ash, 1970, 1977) have been found in the same formation in the Newark basin. Bock (1969) documented *Eoginkgoites*, and Axsmith and Kroehler (1989) illustrated *Dinophyton* in the late Carnian, upper Stockton Formation flora from the southern Newark basin, Pennsylvania. Both taxa may also be present in the middle Carnian, middle Pekin Formation flora of the Deep River basin (Gensel, 1986; R. C. Hope, pers. comm., 1989).

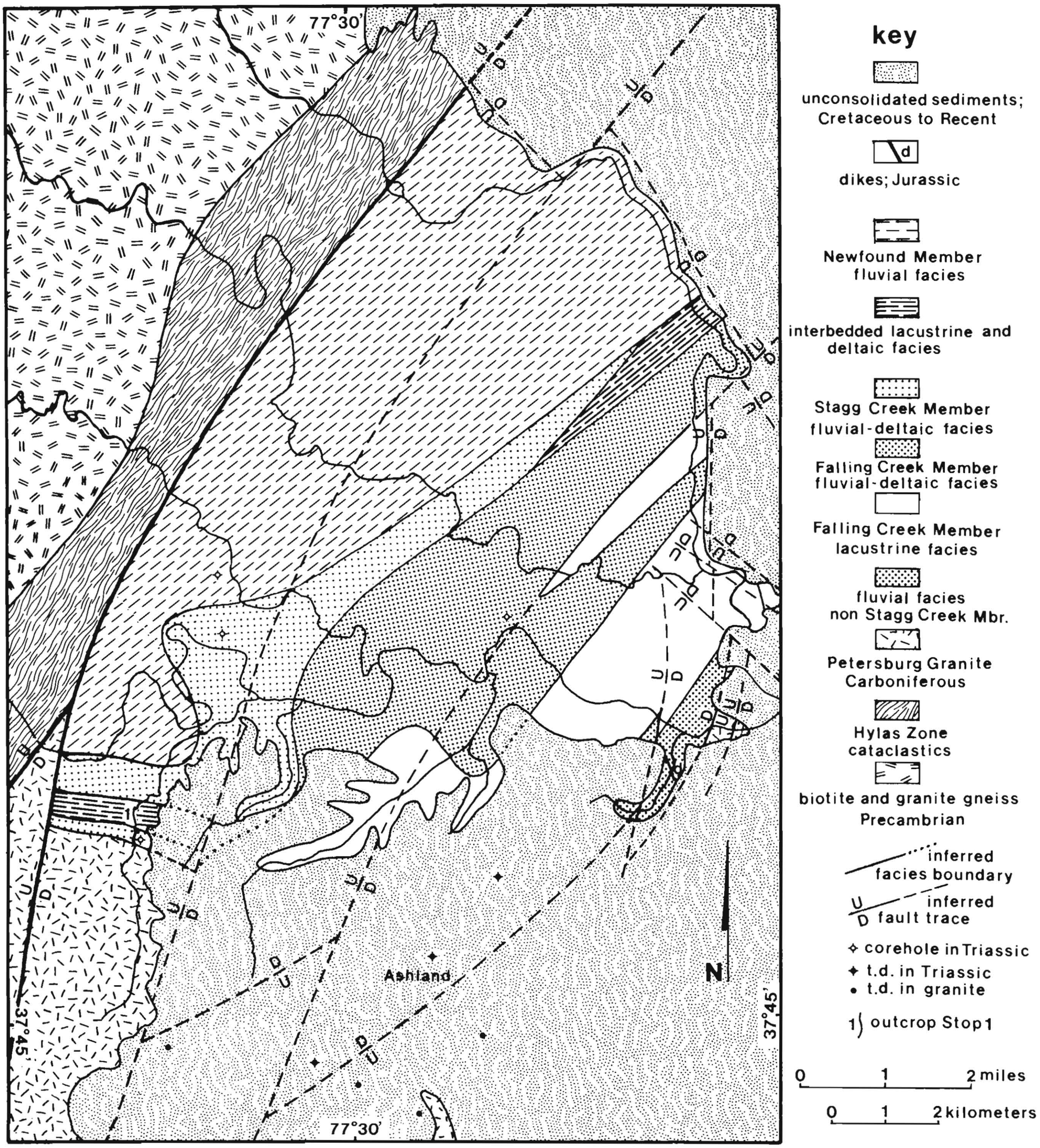

Fig. 7. Geologic map of the southern exposed part of the Taylorsville basin, showing probable distribution of Triassic and pre-Triassic formations. Location of Stop 1 shown. Revised after Weems (1980).

This blurring of zonal distinction does not detract, however, from the utility of Ash's zones in providing a basic framework for the chronostratigraphic separation of isolated floras—a problem that reached major proportion during the late nineteenth century and early twentieth century when all Newark floras were considered approximately coeval in age. It does, however, indicate that Ash's zones of *Eoginkgoites* and *Dinophyton* are at least partly contemporaneous, at least in the Newark Supergroup if not in the Chinle Formation of the southwestern United States, with either taxon defining a single zone of middle to late Carnian age.

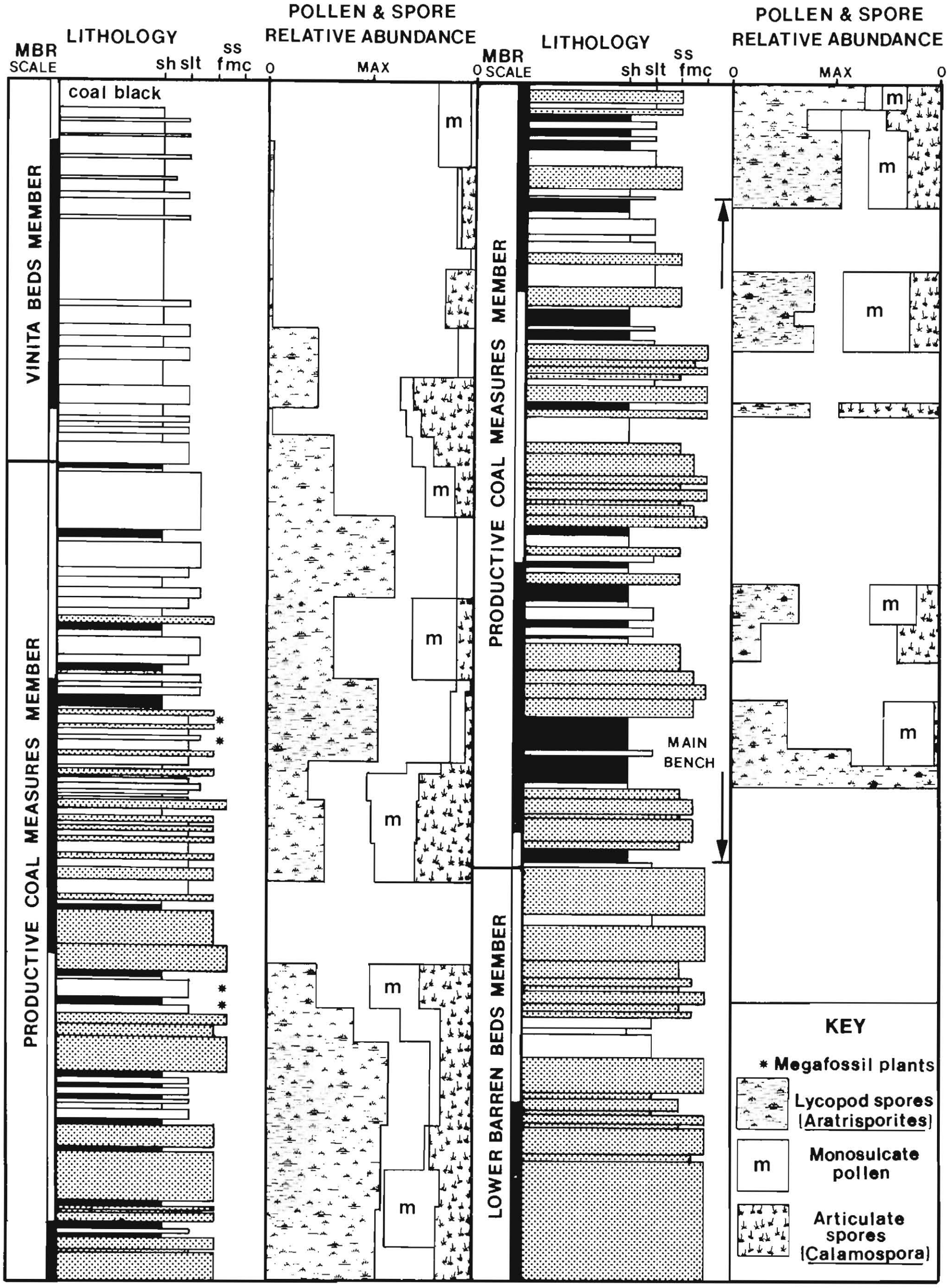

Fig. 8. Lithostratigraphy of the Productive Coal Measures Member, upper Lower Barren Beds Member, and the lower Vinita Beds Member, based on interpretations by Cornet of geophysical logs and cuttings from the Bailey #1 well. Scales bar in 100-foot intervals. Also shown are relative palynomorph abundances of *Aratrisporites, Calamospora*, and psilate monosulcate pollen through the Productive Coal Measures and basal Vinita Beds members (compiled from outcrop and subsurface data), locations of megafossil plants identified in cuttings, and that portion of the Productive Coal Measures Member (arrows) described by Fontaine (1883: p. 9) at Winterpock, VA (Stop 4).

Palynology has provided a more detailed chronostratigraphy for Newark rocks than megafossil plants or vertebrates, in part because megafossil localities are few and scattered, while palyniferous strata are common to abundant (e.g., Cornet et al., 1973; Cornet and Traverse, 1975). Cornet (1977a) considered all the rocks of the Richmond basin to belong to the late middle Carnian. Cornet and Olsen (1985) stressed the possibility that the Richmond basin section may be as old as Middle Triassic. Ediger (1986) correlated the fossil spore (in particular *Aratrisporites* abundance) and pollen assemblages of the Productive Coal Measures with those of the Lettenkohle deposits of the continental Germanic facies of Europe, and assigned a Middle Triassic (late Ladinian) age to the Productive Coal Measures and Lower Barren Beds members of the Tuckahoe Formation, and a Late Triassic (early Carnian) age to the Vinita Beds Member of the Tuckahoe Formation (Fig. 5). Ediger (1986) interpreted the lower Vinita Beds Member palynoflora as transitional between typical Ladinian and Carnian palynofloras, implying that lithofacies and palynofacies changes across the Vinita Beds–

Productive Coal Measures boundary (Fig. 8) may be close to the Middle-Late Triassic boundary.

Because of stratigraphic problems in the Cordevolian Substage (Krystyn, 1978; Lieberman, 1980; Van Der Eem, 1982), however, the position of the Ladinian-Carnian boundary cannot be established with certainty (Ediger et al., in prep.). Correlation of continental "Germanic" and marine "Alpine" facies with Newark deposits is complicated by local palynofacies. In addition, many Middle Triassic taxa range up into the Carnian or are endemic to a particular basin (Brugman, 1983). Veevers (1989) correlates the initiation of Newark rifting with other worldwide tectonic events and concludes that the incipient dispersal of Pangaea began at about the Middle/Late Triassic boundary (230 ±5 Ma) during an epoch of radical crustal change. Consequently, the presence of Ladinian age strata in the Richmond basin is problematic at this time.

Aratrisporites is a sculptured, perinate monolete sporomorph recovered from several different types of lycopod cones in Australia and western Europe (Grauvogel-Stamm and Duringer, 1983). The acme zone for *Aratrisporites* spp. in the Richmond basin occurs in the Productive Coal Measures Member (Fig. 8), but this genus is also common in the underlying Lower Barren Beds Member. *Aratrisporites* spp. become an insignificant palynofloral component above the Productive Coal Measures Member (cf. Stop 2; Table 9; Fig. 8). This genus survived the Triassic (Pedersen and Lund, 1980; Brugman, 1983), persists to the Recent, and is produced by the extant lycopod, *Isoetes* (Scagel et al., 1967). Because *Aratrisporites* dominance is more typical of the Middle Triassic (Ediger, 1986: 318 and references therein), Ediger placed age significance on the relative abundance of this lycopod spore type in the Productive Coal Measures Member. The combined occurrence of the palynomorphs *Patinasporites densus*, *Vallasporites ignacii*, *Lagenella martinii*, and *Camerozonosporites rudis* in the oldest strata of the Richmond basin (these taxa range throughout the Richmond basin sequence) at present favors an age no older than early Carnian for these basal strata (Cornet, 1989a), because the oldest occurrences of these four palynomorph taxa palynologically define the base of the Carnian Stage in the "Alpine facies" (Brugman, 1983).

The high abundance of *Aratrisporites* in the Productive Coal Measures Member is interpreted as an example of a relic lycopod-dominated community that survived from the Ladinian, and an indication of an early Carnian age for the two oldest members in the basin (Figs. 4 and 5). There are no definitive examples of arborescent lycopods (e.g., *Pleuromeia*, *Pleuromeiopsis*, or *Isoetodendron*) known from strata younger than the Productive Coal Measures flora (Boureau, 1967; Bock, 1969); however, *Aratrisporites* is sporadically abundant in the younger Turkey Branch and Pekin formations, and *Leptocyclotes* is known from the Deep River basin of North Carolina (Emmons, 1856, 1857; Fontaine, 1883). Therefore, instead of marking a worldwide datum or event, the extinction of these lycopods appears to have been gradual, with declining populations and frequency of occurrence in their usual habitats.

A palynofloral break occurs at the top of the Vinita Beds Member of the Tuckahoe Formation (at the middle unconformity: Fig. 4; Cornet and Olsen, 1985; Cornet, 1989a: 42). This break may represent the transition from early to middle Carnian. It represents a change in relative abundance of preexisting taxa rather than a period of significant taxonomic turnover (i.e., extinction and origination) between the early and middle Carnian. This break correlates with a change in sedimentary facies (Fig. 4), implying a change in climate. The magnitude of this change (or lack thereof) is reflected in the quantitative and qualitative changes in megafloral and palynofloral assemblages between Stop 4 (early Carnian) and Stop 1 (middle Carnian).

The youngest strata in the Richmond and Taylorsville basins are represented by the Otterdale Formation in the Richmond basin and an unnamed correlative formation in the Taylorsville basin (Fig. 6). The age of the Otterdale Formation is important in determining the youngest possible age for the Richmond-Taylorsville rift basin flora. Because sandstones and conglomerates dominate its lithology, the Otterdale is mostly barren of macrofossils, except for locally abundant silicified and carbonized wood. The Otterdale has been given age estimates ranging from Carnian (Cornet, 1977a; Cornet and Olsen, 1985; Ediger, 1986) to Early Jurassic (Cornet and Ziegler, 1985). Two pycnoxylic wood taxa, *Araucarioxylon virginianum* and *A. woodworthii*, were described by Knowlton (in Shaler and Woodworth, 1899) from the Richmond basin and possible Otterdale equivalent in the Taylorsville basin (cf. Goodwin et al., 1985). These taxa differ mainly in the height of their uniseriate rays and in the density of radial pitting. They are not age-diagnostic, because similar types of wood have

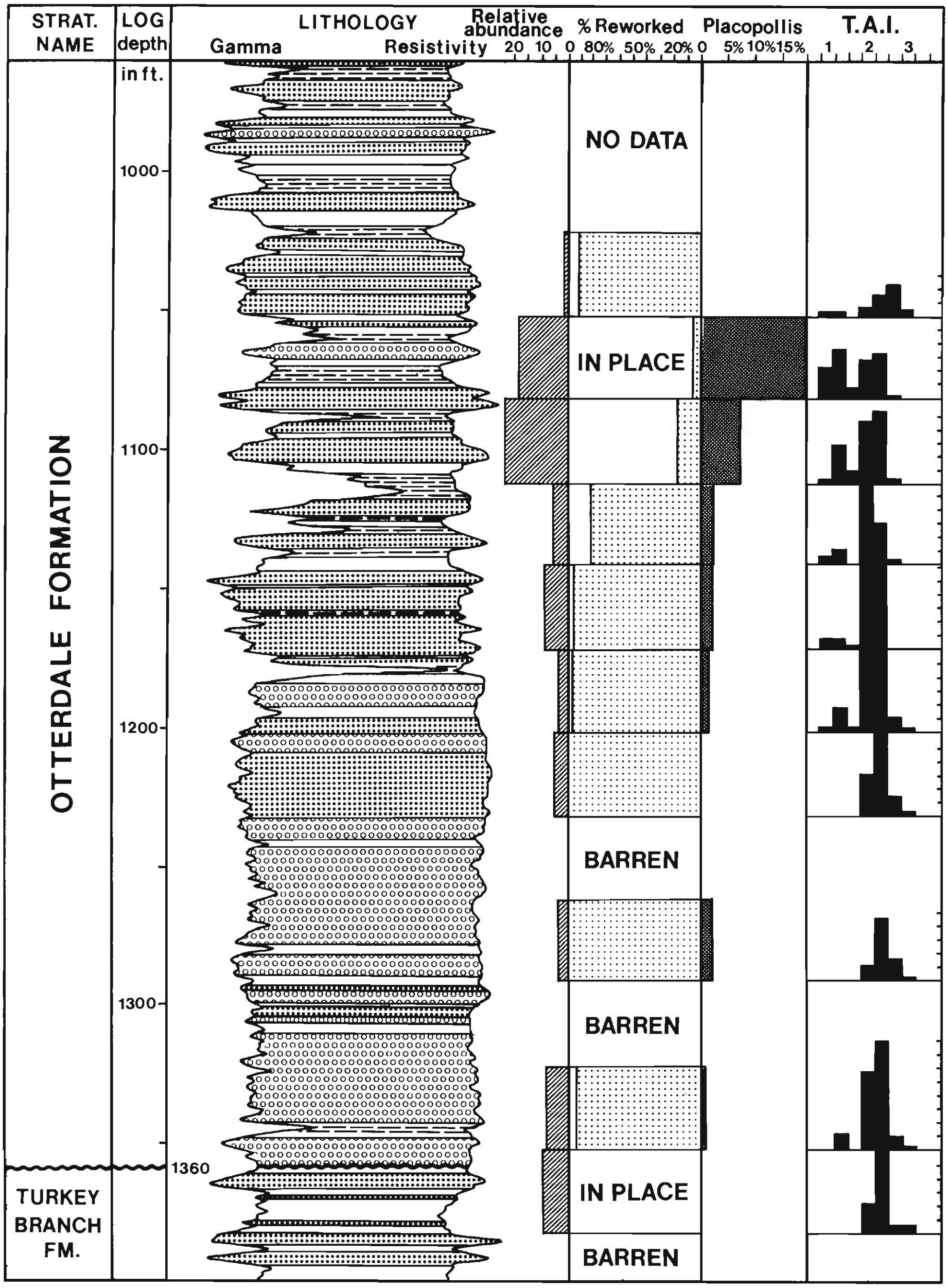

Fig. 9. The Otterdale Formation–Turkey Branch Formation tansition (unconformity) in the Hicks #1 well (Richmond basin), and thermal maturation (T.A.I.) evidence for *in situ* and reworked palynoflorules. Relative palynomorph abundance is the count (per traverse of microscope slides) in kerogen residues processed for palynology. All *Placopollis* pollen is reworked (T.A.I. = 2− to 2+).

been found at other Late Triassic to Early Jurassic localities (e.g, *A. arizonicum* from the middle-late Carnian, Petrified Forest Member of the Chinle Formation, Arizona: Daugherty, 1941; Ash, 1989). The presence of Jurassic dikes that pass through both the Triassic and Otterdale sections indicates a minimum Early Jurassic age for the Otterdale Formation (Sutter and Smith, 1979).

Recently, *in situ* and reworked palynoflorules were recovered from the lower part of this formation in the Hicks #1 well (cf. Cornet, 1989a: Text-Fig. 1). The *in situ* assemblage was recovered from black shales deposited above a conglomerate sequence at the bottom of a canyon fill (Fig. 9), the base of which marks the erosional unconformity near the top of the Richmond basin section (Figs. 4 and 5). Reworked palynomorphs can be easily distinguished from *in situ* ones by their higher level of thermal maturity or color (Figs. 9 and 10). The reworked assemblages from within and above the conglomerate sequence have a relatively uniform TAI (Thermal Alteration Index) of 2 to 2+ (Rϕ% equivalent: 0.4 to 0.6), with minor percentages of 2− and 3− values (Phillips, 1984 pollen/

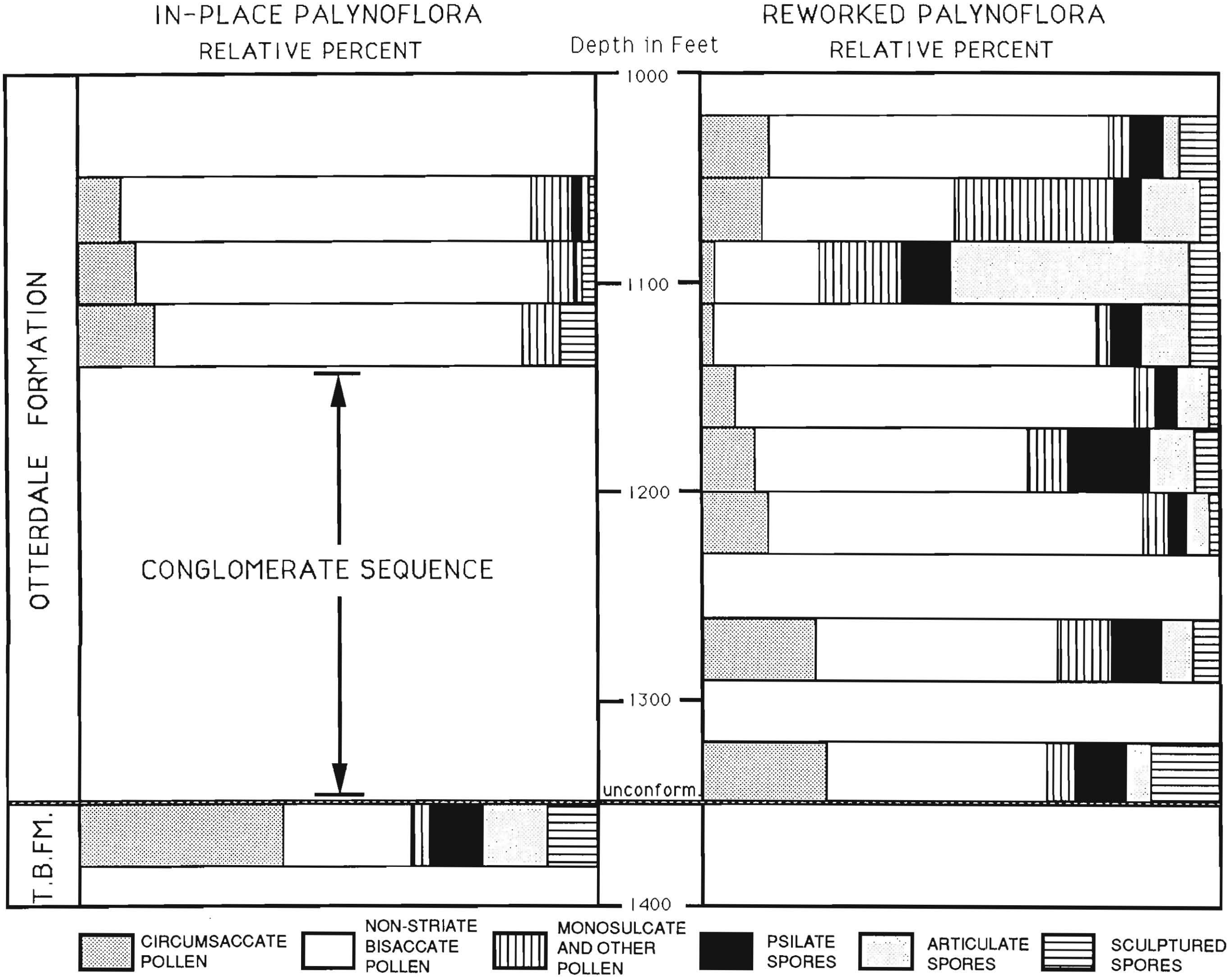

Fig. 10. Comparison of the composition of *in situ* versus reworked palynofloral assemblages from the basal Otterdale Formation and underlying Turkey Branch Formation in the Hicks #1 well (Richmond basin). Both sides of the graph represent the same stratigraphic interval. Reworked and *in situ* components of palynoflorules containing both were distinguished from one another by color maturity (TAI) and are positioned opposite one another in the graph. Reworked assemblages from conglomerate sequence come from shale clasts, while reworked grains above conglomerate were possibly deposited as individual grains (e.g., increase in *Placopollis* concentrations in Fig. 9). Note similarity of reworked assemblage just above unconformity to *in situ* assemblage below it, implying local contribution.

spore color "standard"). This maturity is identical to that of palynoflorules from the upper Tomahawk Creek Member. The *in situ* palynoflorules have a uniform TAI of 1 to 1+ (Rϕ% equivalent: 0.1 to 0.2) and are clear to pale yellow, with a minor percentage of canary yellow grains, which is in marked contrast to the light brown and golden brown colors of the reworked fossils. The reworked assemblage from just above the conglomerate sequence contains a high percentage of spores dominated by *Pilasporites* spp. and *Laricoidites* spp. (representing the spores of articulates; Fig. 10) and is similar to the youngest palynoflora of the upper Tomahawk Creek Member (Fig. 4; Cornet and Olsen, 1985; Cornet, 1989a).

A late Carnian age for the Otterdale Formation is based on a dominance of the *in situ* palynoflora by non-striate bisaccate and circumsaccate pollen, including such genera as *Alisporites, Brachisaccus, Colpectopollis, Klausipollenites, Lorisporites, Patinasporites, Pityosporites, Platysaccus, Protodiploxypinus, Sulcatisporites, Vallasporites*, and *Vitreisporites*. The presence of *Camerosporites pseudoverrucatus, Cyclotriletes oligogranifer, Ovalipollis ovalis, Praecirculina granifer*, and *Pseudoenzonalasporites summus*, and the absence of *Pyramidosporites traversei* and *Camerosporites verrucosus*, indicate a pre-Norian age (cf. Litwin and Skog, in press). The absence of light-colored (unreworked) *Placopollis koobii*, which is age diagnostic for early and middle Carnian strata of

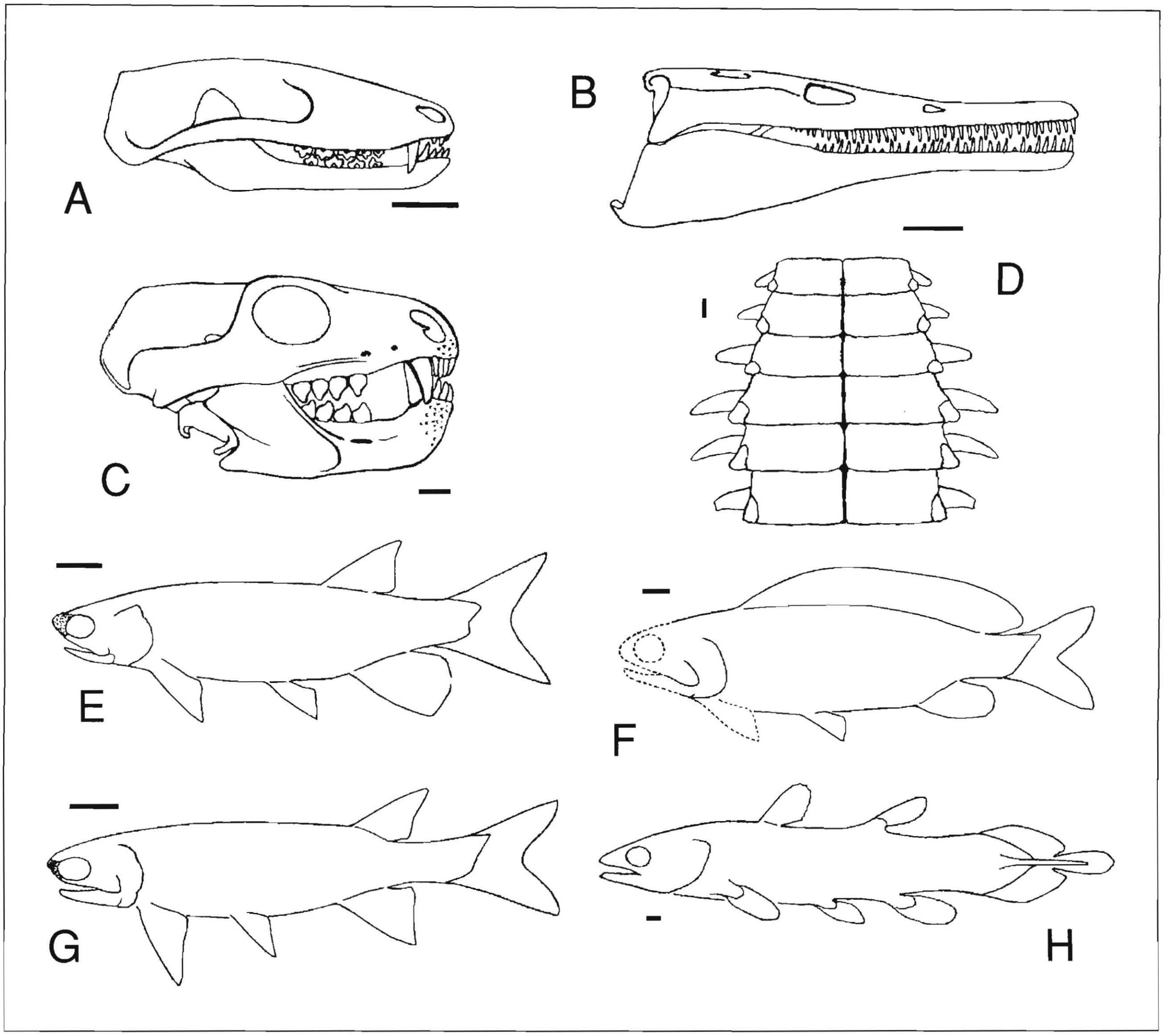

Fig. 11. Reconstruction of representative vertebrates from the Richmond and Taylorsville basins: A, skull of advanced probable Chiniquodontid synapsid resembling *Microcondon* (cranium hypothetical, although represented in unprepared material); B, skull of *Doswellia kaltenbachi* (adapted from Weems, 1980b); C, new genus of traversodont synapsid similar to *Luwanga* (posterior part of cranium hypothetical, although represented in unprepared material); D, partial dorsal armor of new possible crocodilomorph; E, *Dictyopyge macurus* (adapted from Olsen et al., 1982); F, *Tanocrossus* sp. (adapted from Olsen et al., 1982); G, *Cionichthys (Dictyopyge) meekeri* nov. comb. (based on *Cionichthys* cf. *greeni* in Olsen et al., 1982); H, undetermined coelacanth, reconstruction based on *Diplurus longicaudatus* (adapted from Olsen et al., 1982). Scale bars represent 1 cm.

the Newark Supergroup (Cornet, 1989a), indicates a post-middle Carnian age. Together these data imply an age equivalent to the late Carnian upper Stockton and Lockatong formations of the Newark basin (Fig. 1) of Pennsylvania and New Jersey (cf. Cornet, 1977a; Cornet and Olsen, 1985). The Otterdale palynoflora also indicates an age younger than the Cumnock Formation of the Deep River basin (Fig. 1) of North Carolina, which contains *Placopollis koobii* (Cornet, 1989a).

VERTEBRATE ASSEMBLAGES

The Richmond and Taylorsville basins (along with the Farmville and associated basins: Fig. 1) stand out as unique among Newark Supergroup basins because their lacustrine deposits are very strongly dominated by the apparently endemic redfieldiid palaeonisciform fish *Dictyopyge macrurus*(Fig. 11). This very distinctive and abundant redfieldiid is present in every fish-producing unit in these basins, regardless of stratigraphic position. Its omnipresence, along with the palynostratigraphically based age assessment (Cornet, 1977a; Cornet and Olsen, 1985) indicating an older age than all other Newark basin fish-bearing strata, implies that *Dictyopyge* might be useful as a guide fossil for a formal zone: the *Dictyopyge* zone (Olsen et al., 1982). The other fish found within the *Dictyopyge* zone are the redfieldiid *Cyonichthys meekeri* (Schaeffer and McDonald) nov. comb., the paleonisciform *Tanaocrossus* sp., and possibly a coelacanth (Table 1).

As might be expected from the peculiar fish assemblage, the associated tetrapod assemblages have proved equally unusual. Until recently, there were only the most sketchy of reports of tetrapod remains from the Richmond and Taylorsville basins (e.g., Shaler and Woodworth, 1899; Bock, 1969). However, Weems (1980b) described an excellently preserved skull and skeleton of *Doswellia kaltenbachi* from temporary exposures of the upper Falling Creek Member of the Taylorsville basin at Doswell, Virginia. He also described associated teeth from the same locality, as well as several bones from a locality 5.5 km to the southwest. In addition to *Doswellia*, Weems suggested that a phytosaur (based on isolated teeth) and possibly a rauisuchid "pseudosuchian" reptile (based on a vertebra) were represented. These discoveries implied that the Richmond-Taylorsville sequences might be richer than previously thought. A new tetrapod assemblage from the lower Turkey Branch Formation of the Richmond basin (the Tomahawk locality of Stop 3) shows that indeed this is the case, and now the assemblage is recognized as the richest in the Newark Supergroup (Olsen et al., 1989). This new assemblage is dominated by non-mammalian synapsids (so called "mammal-like reptiles") and is unique in the Northern Hemisphere (Table 1; Fig. 11; see also Fig. 21).

The Tomahawk assemblage sheds light on a striking and long-standing paleobiological conundrum revolving around the apparent presence of strong faunal and floral provinciality during the Late Triassic—a time when continental unity would imply that cosmopolitan assemblages should be the rule. Two basic faunal provinces have long been recognized: a Laurasian assemblage, dominated by phytosaurs and metoposaur amphibians, and a Gondwanan assemblage, dominated by non-mammalian synapsids (for a review, see Olsen and Sues, 1986). The Tomahawk assemblage is much more similar to the Gondwanan assemblages than it is to those of the rest of Laurasia. This implies at least that this faunal provinciality might be more a function of time than of geography; it may also be an artifact caused by poor stratigraphic sampling of the Middle Triassic–Late Triassic transition in Laurasia. However, floral provinciality in the early part of the Late Triassic is apparently present, with a *Dicroidium*-dominated megaflora and Ipswich-Onslow-type palynoflora in Gondwanaland, and a cycadophyte/conifer-dominated flora in Laurasia (Cornet and Olsen, 1985). This floral provinciality does not correspond geographically or temporally in a simple way with the faunas. The best examples of provinciality include Indian occurrences of typical Laurasian-type assemblages having abundant phytosaurs and metoposaurs associated with *Dicroidium*-dominated megafossil florules and Ipswich-Onslow-type palynoflorules (Kumaran and Maheswari, 1980; Cornet and Olsen, 1985), and of course the Richmond-Taylorsville vertebrate assemblage associated with Laurasian florules.

CARNIAN MEGAFLORAS OF THE NEWARK SUPERGROUP: PREVIOUS SYSTEMATIC TREATMENTS

Most of our knowledge about Carnian megafloras of the Newark Supergroup comes from Bunbury (1847), Emmons (1856, 1857), Fontaine (1883), Wanner and Fontaine (1900), Wherry (1916), and Bock (1954, 1969), with more recent additions by Delevoryas (1970, 1982), Delevoryas and Hope (1973, 1975, 1976, 1978, 1981, 1987), Hope and Patterson (1969, 1970), Cornet (1977b; 1986), Olsen et al. (1978), Gensel (1986), Taylor, Delevoryas, and Hope (1987), and Axsmith and Kroehler (1989). With the exception of Bock (1969), no systematic revision of Newark megafloras has been undertaken; and with the exception of works by Delevoryas, Hope, and Taylor (referenced above) and Cornet (1977b; 1986), few researchers have exploited known fossil localities for new evidence of gymnospermous reproductive organs or the growth habits of complete plants. There are two major problems connected with taxonomic studies carried out by early investigators. First, very poor locality information was given by the early collectors, and some locality reports are clearly inaccurate. A prime example of the latter comprises *Walchia variabilis*, which was described as having come from Upper Triassic strata of North Carolina when in fact it came from Lower Jurassic strata at Turner's Falls in Massachusetts (Fontaine, 1883: 108).

Second, problems exist with respect to nomenclature and generic assignments. For example, Fontaine (1883) created new names for taxa validly described and named by Emmons (1856; 1857). Bock (1969) attempted to combine and reduce the number of redundant taxonomic names, using Emmons's specific epithets when they had priority. However, Bock also substituted his own generic names (e.g., *Glandulozamites* for *Sphenozamites*, and *Macropterygium* for *Ctenophyllum* and *Pterophyllum*) without giving adequate justification, and he may have overcombined taxa with similar European taxa (e.g., *Macropterygium angustum* for *Filicites vittarioides* 1828, *Pterozamites angustus* 1843, *Pterophyllum braunianum* 1844, etc.) without considering effective publication of the oldest names. This procedure resulted in questionable new combinations. No actual comparison of type or paratype specimens was conducted by Bock, because many of the original specimens of Emmons and Fontaine are lost or no longer exist.

TAXONOMIC TREATMENT IN THIS FIELD GUIDE

This field guide book will attempt to provide a comprehensive picture of the known flora of eastern North America during the Carnian without a detailed systematic treatment. Taxonomic treatment is limited to the selection of binomial combinations that are most likely (but not necessarily) correct and to new combinations where certain generic names (e.g., *Pterophyllum* instead of *Ctenophyllum*) have been placed in synonymy by others. In some cases, the use of another name would require additional new combinations (e.g., *Asterotheca* versus *Cyathoforma*), or there was uncertainty over the correct generic name; in those cases, the name used was selected from either Fontaine (1883) or Bock (1969) solely for the purpose of reducing confusion.

THE RICHMOND AND TAYLORSVILLE MEGAFLORAS

The Richmond basin Productive Coal Measures and Vinita Beds members (Fig. 8) have produced the bulk of the early Carnian megaflora of eastern North America (Table 2; Plates 1-22). The Taylorsville basin has very poor exposure of coeval strata, and has not produced a megaflora of similar age. Instead, the megaflora of the Taylorsville basin primarily comes from outcrops along Stagg Creek (Stop 1), which correlate with the lower Tomahawk Creek member of the Turkey Branch Formation in the Richmond basin (cited above). This younger flora is middle Carnian in age. Based on palynological correlation, it appears to be older in age than floras of the Deep River basin described by Hope and Patterson (1969) and Emmons (1857) from the middle Pekin Formation and lower Cumnock coal measures near Gulf, North Carolina (Cornet and Olsen, 1985; Cornet, 1989a); but how much older is not known.

With the exception of silicified and carbonized wood from the Otterdale Formation, no leaf floras of late Carnian age are known from the Richmond and Taylorsville basins. Late Carnian megafloras have been documented, however, from the northern Gettysburg basin and southern Newark basin of Pennsylvania (Wanner and Fontaine, 1900; Cornet 1977a; Axsmith and Kroehler, 1989) and from the Dan River/Danville basin of North Carolina/Virginia (Olsen et al., 1978; Robbins and Traverse, 1980).

THE EARLY CARNIAN MEGAFLORA

Our knowledge of early Carnian megafloras of the Newark Supergroup comes primarily from the work of Fontaine (1883), who paid miners a small bonus to collect good specimens from the then-active coal mines at Winterpock, Virginia (Stop 4). Some of Fontaine's specimens are so large and complete that only the miners could have collected them. Subsequently, Bock (1969: 265, 309) collected plant fossils from the refuse mounds of shale, siltstone, sandstone, and shaley or boney coal from the mines and their access shafts. Over a period of about twenty years, Bock added 14 of the 40 known taxa, which represents a 54% increase (Table 2). The Winterpock flora comes from numerous fossiliferous zones through the mined section of the coal measures (Fontaine, 1883). More detailed information on the distribution of taxa through the lower coal measures is given under the section for Stop 4.

Additional taxa were described by Fontaine (1883) from the Midlothian and Manakin coal-mining districts (Table 3; Fig. 3). Wilkes (1988) provided an updated compilation of coal-mining areas in the Richmond basin. Bunbury (1847) described a contemporaneous flora from the coal measures of the Deep Run outlier basin on the northeastern side of the Richmond basin (Fig. 3), which is updated in Table 4.

The Winterpock area has produced about 21 cryptogam or pteridophyte species (Table 2), including osmundaceous, dipteridaceous, and gleicheniaceous ferns, marattiaceous or cyathiaceous tree ferns, calamitaceous and equisetaceous articulates, and isoetalean lycopods. This area has also produced about 19 gymnosperm species (Table 2), including common cycadophytes (e.g., *Macrotaeniopteris, Taeniopteris, Pterophyllum,* and *Sphenozamites*), rare conifers (e.g., *Podozamites lanceolatus* and *P. tenuistriatus*), a common ginkgophyte (e.g., *Sphenobaiera*), possible pteridosperms (e.g., *Stangerites* spp. and *Sphenopteris sitholeyi*), and other rare gymnosperms, including several enigmatic plants that may belong to the anthophytes (i.e., *Primaraucaria wielandii*: Cornet, 1986).

Reproductive remains of gymnosperms and possible anthophytes are rare. Fontaine (1883) recognized *Zamiostrobus virginiensis* from the Midlothian coal-mining area (Table 3), additional specimens of which were apparently collected by Bock from Winterpock and named *Primaraucaria wielandii* (Plate 13; Bock, 1954, 1969). Cornet (1986) studied specimens of *P. wielandii* collected by Bock from Winterpock, recognizing at least three different types of strobili that Bock thought were female, male, and immature forms of the same species. *P. wielandii* comprises strobili terminating long leafy axes, which are typically 2-3 cm wide, bearing spirally arranged bract-shaped leaves with paracyclocytic and anomocytic stomata. Cornet reinterpreted them as possible anthophyte inflorescences based on well-preserved compressions that resembled carpels with enclosed seeds subtended by latrorse laminar stamens. He also noted a strong similarity between some strobili and the fruits and flowers of *Magnolia*. This taxon is apparently fairly common at Winterpock (Bock collected over 200 specimens), and additional material may help resolve the reproductive structure, habit, and affinity of this unusual plant.

Fontaine also discovered another gymnospermous reproductive structure, which he called an unidentified cone of a conifer, and other specimens of apparently the same taxon were collected by Bock and named *Triassiflorites grandiflora* (Plate 13; Bock, 1969). *Triassiflorites* is a strobilus of moderate size that may belong to *Macrotaeniopteris magnifolia*, with which it is intimately associated (Bock, 1969). Bock regarded this reproductive structure as "a primitive cycadophytian transition type toward the Bennittitales" (Bock, 1969: 274). Its superficial resemblance to *Westersheimia pramelreuthensis* from the Upper Triassic (Carnian) of Lunz, Austria (Kräusel, 1948; Crane, 1988) should be noted.

Bock also discovered and named *Zamiostrobus lissocardius* and *Z. triassicus* from the Winterpock area. *Z. lissocardius* comes from the Productive Coal Measures Member and may represent the first credible cycad cone of the Winterpock flora. *Z. triassicus*, however, comes from a roadside outcrop somewhere near but not at Winterpock and is associated with numerous possible phytosaurian teeth (Bock, 1969: 216). The only roadside outcrops in the vicinity of Winterpock encircle the coal-mining area to the north, south, and west (Fig. 3) and expose the Otterdale Formation of late Carnian age. *Z. triassicus* probably came from these strata, rather than from older Winterpock strata, because Bock also discovered *Z. triassicus* in the Newark basin at Miller's Quarry, near Doylestown, Pennsylvania. Miller's Quarry exposes the Lockatong Formation of late Carnian age.

The supposed conifer cone, *Araucarites carolinensis* of Fontaine (1883: Pl. XLIV, Fig. 8) from North Carolina, was originally described by Emmons (1857) as *Leptocyclotes circularis* (= *L. ellipticus*: Bock 1969). Bock (1969) discovered a new *Leptocyclotes* species at Winterpock (i.e., *L. americana*). *Leptocyclotes* is probably, instead, a fragment of a large isoetalean lycopod cone. No araucarian pollen has been identified yet in the Richmond basin, but it does occur in Jurassic strata of the Newark Supergroup (Cornet, 1977a; Cornet and Olsen, 1985; Cornet, 1989c). Because these megafossil species all closely resemble one another, they are illustrated together in Plate 2 and here classified as *L. americana*. The individual cone scales also resemble, but differ slightly in shape from, those of *Annalepis zeilleri* Fliche, which Grauvogel-Stamm and Duringer (1983) showed was one of the plants that produced *Aratrisporites* spores around the margins of the Tethys Sea.

Aratrisporites spp. is the dominant spore type throughout much of the Productive Coal Measures Member (Fig. 8; Cornet and Olsen, 1985; Ediger, 1986; Robbins et al., 1988). Interestingly, the abundance of *Aratrisporites* spores in the coal measures contrasts with the absence of recognizable lycopod leaf remains. The common presence of large coaly stems of *Isoetodendron striata* (6 cm to over 19 cm wide), which occasionally show surface impressions of longitudinal ribbing that may represent traces of old leaf scars, implies that these lycopods may have been large and tree-like, similar in habit to *Pleuromeia*, but even larger (see Bock, 1969: 51

for more details). Some of the coals dominated by *Aratrisporites* seem to lack layers of cuticle, implying that they may represent accumulations of wood from nearly pure stands of these giant lycopods. The absence of recognizable leaves could be due to one or both of the following reasons: (1) leaves were long, wide, and fleshy, and easily mistaken for smooth *Neocalamites* stem impressions; and (2) the peat swamp was domed. Domed peat swamps occur when rainfall is plentiful year-round (G. R. Upchurch, Jr., pers. comm., 1990), as it apparently was during Productive Coal Measures Member times, and they poorly preserve aerial plant parts.

Pteridophytes make up a substantial component of the Winterpock flora (Fontaine, 1883; Bock, 1969). Perhaps the most elegant pteridophytes, *Cyathoforma* spp., are remarkable for the large size of their fronds (Plates 4 and 5) and their association with stem impressions possessing large leaf scars (Plate 6), which imply that they were tree ferns. *Cyathoforma carolinensis* and *C. penticarpa* (Plate 5) were originally described by Fontaine under the generic name *Asterocarpus*. Stur (1885) replaced *Asterocarpus* with *Asterotheca* without giving adequate justification (see Bock, 1969: 127 for further discussion of this taxonomic problem). Bock rejected both *Asterocarpus* Goeppert and *Asterotheca* Brongniart as the generic names for the American species, citing perceived differences in sporangial arrangement and distribution for *Asterotheca*, but only stating that Brongniart's genus was different and too broadly defined. Bock established a new generic name, *Cyathoforma*, for the Winterpock species, creating a name that implies botanical affinity.

Bock (1969) considered *Cyathoforma carolinensis* (Emmons 1856) Bock to be conspecific with *Asterotheca meriani* (Brongn.) Stur from Carnian strata at Lunz, Austria. Bharadwaj and Singh (1956) studied the synangia and spores of *A. meriani* from the Lunzer Schichten, discovering possibly eusporangiate synangia and *in situ* spores that are moderately large (av. 42 um) and monolete, having a regular granulate sculpture. Bharadwaj and Singh compared the spores to *Latosporites*. These characters (monolete; granulate sculpture) instead imply a marattiaceous affinity for *A. meriani* (Andrews, 1961: 102). An upright, unbranched tuberous stem or short trunk to which large, pinnately compound leaves and thick, fleshy roots are attached typifies extant tropical members of this ancient family, while Carboniferous members (e.g., *Psaronius*) are known to have had much taller (6-7 meter) upright stems (Foster and Gifford, 1974).

Similar monolete spores, but smaller (av. 30 um) than those of *A. meriani*, are quite common in some horizons of the Productive Coal Measures Member, and fall under the name *Leschikisporis aduncus* (Cornet, 1977a; Cornet and Olsen, 1985). *L. aduncus* is a common to abundant component of the deltaic Lunzer Sandstein and is restricted to the early and middle Carnian, Lunzer Schichten of Austria (Bharadwaj and Singh, 1963; Brugman, 1983). To complicate matters, spores similar in size and sculpture to the spores of *A. meriani* have been found in the Richmond and Taylorsville basins, but they are rare. If Bock is correct in comparing *C. carolinensis* and *A. meriani*, and *Leschikisporis* belongs to *Cyathoforma*, then the dominant tree ferns in the Richmond and Taylorsville floras may have been marattiaceous rather than cyatheaceous. Consequently, the name *Asterocarpus* or *Asterotheca* is preferred (cf. Weber, 1985b).

DEEP RUN FLORA

The early Carnian Deep Run basin flora (Table 4) is less diverse (15 taxa) than the Winterpock flora, perhaps because only one fossiliferous zone is known beneath the main coal. Knowledge of this plant locality and the updating of its flora were possible due to field work and mapping by R. E. Weems and E. I. Robbins (Robbins and Weems, 1988; Goodwin and Johnson, 1967; Goodwin, 1981a; B. Goodwin, unpublished data). The Deep Run stratigraphic sequence is a basement onlap facies, like that at Winterpock, and can therefore be correlated only broadly with the Winterpock section. The Deep Run section is thermally very mature (range of mean Rϕ% = 1.49–1.69: Cornet, unpublished data; TAI 4– to 4: Robbins and Weems, 1988), due to a much greater depth of burial and/or a thermal event not recorded by organic matter in the other basins nearby (Robbins and Weems, 1988). Because of high maturity and surface weathering (i.e., oxidation), palynomorphs could not be concentrated for study from woody kerogen residues. Therefore, the main coal bed exposed along Deep Run cannot be correlated with certainty with any of the coal beds mined at Winterpock (Fig. 8; see Stop 4).

Fossil plants at Deep Run mostly come from an interbedded siltstone and shale sequence directly beneath the main coal. This sequence reveals a floral succession from river levee to floodplain swamp. For example, well-preserved *Clathropteris meniscoides* fronds and a small *Equisetites* sp. (coll. by R. E. Weems and E. I. Robbins) were found preserved together in a claystone interbed possibly deposited as a clay drape on a river point bar or levee (Plate 21, no. 3). Because this locality will not be visited during the field trip, the section is described in Table 5.

The Deep Run flora is strongly dominated by cryptogams and pteridophytes and contains five ferns, five calamitaceous and equisetaceous sphenophytes, four gymnosperms, and one possible anthophyte of uncertain affinity. Cycadophytes are represented by the cosmopolitan *Macrotaeniopteris*, which forms layers of overlapping leaves and coal at the top of the plant-bearing sequence. *Podozamites tenuistriatus* (Plate 21, no. 4), a conifer, is associated with small male cones, each borne singly at the end of a narrow elongate axis or pedicel (Plates 20; 22, no. 5). Small fronds of *Pterophyllum braunianum* (Plate 17) were found associated with *Macrotaeniopteris* and *Neocolamites.*

The possible anthophyte is represented by leaves that closely resemble those of *Sanmiguelia* (Cornet, 1986, 1989d). They range in size from small (7+ cm long by 3.5 cm wide), entire ovate leaves with weak plications to very large, incomplete leaves with strong plications and several sizes of parallel venation. The largest leaf found is 23+ cm long with a folded width of 6 cm, is gently curved abaxially, and narrows apically (Plate 21, no. 1). The thick leaf compression and size of the leaf imply a large or robust plant (i.e., comparison to the associated articulates), similar in habit to *Veratrum viride* (extant Melanthaceae, formerly Liliaceae: Dahlgren et al., 1985) and *Sanmiguelia* (Cornet, 1986; Tidwell et al., 1977). A semiaquatic plant (i.e., growing close to water and sometimes growing in shallow water, similar to *Veratrum* and *Sanmiguelia*) is implied because the leaves are associated with articulates in a peat-forming wetland habitat. Fragments of large leaves sometimes resemble the associated stem compressions of *Neocalamites* (Plate 21, no. 2), from which they differ in having more numerous wide and narrow, irregularly parallel veins between centimeter-wide plications and no evidence of articulate leaf nodes. The leaf of *Sanmiguelia* has also been compared to a large leaf of the articulate *Schizoneura* by Takhtajan (1969). The resemblance to the ridge pattern of wide *Neocalamites* stems might help explain why this leaf type has not been recognized previously in such deposits.

Cornet (1989a) reported a high diversity (six genera) of angiosperm-like pollen from the Richmond and Taylorsville basins. He placed most of them in the Crinopolles Group because of their overlapping suite of morphological characters. Most of the 11 species have a reticulate-columellate exine structure typical of angiosperm pollen, and the endexinal laminations typical of gymnosperm pollen have not been observed. The similarity of many of these taxa to monocot pollen was noted, particularly the prevalence of a dimorphic exine sculpture. However, the absence of a distal footlayer and the presence of an endexine prevented Cornet from classifying these taxa as monocot pollen. *Monocrinopollis doylei* and *Tricrinopollis olsenii* were described from the lower Productive Coal Measures Member (see also Ediger, 1986: 338) and came from the interbedded siltstones and roof shales of the main coal seam. Although they were very rare (less that 0.1%), the occurrence of monocot-like pollen and leaves in similar and perhaps coeval wetland environments is an important clue in the search for the earliest angiosperms and their ancestors.

THE MIDDLE CARNIAN MEGAFLORA

Our knowledge of the middle Carnian megafloras of the Newark Supergroup comes in part from the Taylorsville basin. Fontaine (1883) described *Pterophyllum tenuinervis* from Hanover County, which is identical to the dominant *Pterophyllum* species at Stratigraphic Section 2 along Stagg Creek (see Stop 1) in Hanover County. Cornet has recovered 16 megafossil taxa from eight intervals along Stagg Creek (Table 6), all but four of which occur in the early Carnian flora from the Richmond basin. This flora occurs both as *in situ* plants entombed in mudstones and siltstones on top of paleosols containing root traces and as transported plants in lacustrine silty claystones and shales. The fossiliferous sequence belongs to Weems's (1980a) "upper" Falling Creek Member, which correlates with the lower Tomahawk Creek Member of the Richmond basin (Fig. 6).

The Stagg Creek flora is dominated by gymnosperms, both in numbers of specimens and in diversity of species. *Pterophyllum* spp. occur within thinly bedded, sandy siltstone beds (levee or point bar facies) of a river channel sequence, and within a silty claystone lacustrine bed overlying a paleosol. Rotted fragments of *Sphenobaiera striata*, a large ginkgophyte leaf, occur within the layers of that paleosol, and *Macrotaeniopteris* spp. occur below and above a small delta lobe on top of the lacustrine bed. Fern remains are dominantly fragments and occur in similar facies as the *Pterophyllum* species. Articulates occur exclusively in lacustrine shales and mudstones and form a thin coal in the upper part of a shallowing-upwards lacustrine sequence. A more detailed description of this locality is given under the section for Stop 1. These facies provide well-exposed examples of diverse paleoenvironments and give paleobotanists an opportunity to understand floral communities of the Late Triassic.

The presence of *Zamites powellii* is significant. This taxon is one of the most conspicuous members of the middle Carnian, middle Pekin Formation flora in North Carolina (Hope and Patterson, 1969), the middle-late Carnian–upper Stockton and Lockatong formations in Pennsylvania (Bock, 1969; Axsmith and Kroehler, 1989), the middle-late Carnian Chinle Formation of the southwestern United States (Ash, 1975), and the middle-late Carnian Dockum Group of Texas (Ash, 1975; Cornet, 1989d). The presence of rare fragments of this cycadophyte at Stagg Creek may represent the oldest known occurrence of this taxon in eastern North America, and it helps to distinguish the Stagg Creek flora from the older Winterpock flora of the Richmond basin.

MEGAFOSSIL AND PALYNOFLORAL CHANGE IN THE CARNIAN

Interpretation of floral change through the Carnian is dependent on accurate age determination. There is a close correspondence between Newark and European palynostratigraphy. There are 36 palynomorph species in the Newark Supergroup that have last occurrences in the Carnian of western Europe (incl. the Alpine Triassic). Of these, 27, or 75%, have their last occurrences that correspond with those for the middle and late Carnian of the Newark Supergroup (e.g., *Camerosporites secatus, Cyclotriletes oligogranifer, Convolutispora affluens, Cyclogranisporites oppressus, Paracirculina scurrilis, Pityosporites devolvens, Striatoabieites aytugii*, and *Zebrasporites corneolus*). A smaller number of palynomorphs taxa (about nine species, or 25%) have last occurrences in the early or middle Carnian of Europe, but range into the Norian and/or late Carnian in the Newark Supergroup (e.g., *Adivisisporites dispertatus, Plicatisaccus badius, Triadispora modesta, T. stabilis, Trilites klausii, Tuberculatisporites hebes*, and *Pseudoenzonalasporites summus*). Adjusting Newark ages to restrict these species to the middle Carnian would eliminate late Carnian and Norian age sediments and move species restricted to the Norian in Europe (e.g., *Camerosporites verrucosus*) down into the Carnian.

Early, middle, and late Carnian megafloras have a similar number of total taxa (compare Tables 7 and 8) but show an increase in the relative percentage of gymnosperm taxa through the Carnian. In contrast, palynofloras give a picture of strong gymnosperm dominance throughout the Carnian, with the greatest total number of species occurring in the middle Carnian (Table 8). For example, the early Carnian, Productive Coal Measures flora of the Richmond and Deep Run basins (E.C. in Table 7) comprises about 49 taxa, of which 24 (49%) are pteridophytes and their allies (i.e., cryptogams: Table 8). The middle Carnian Taylorsville basin and Deep River basin floras combined (M.C. in Table 8) contain 42 taxa, of which 13 (31%) are cryptogams. The late Carnian Gettysburg, Newark, and Dan River/Danville basin floras (Bock, 1969; Wanner and Fontaine, 1900; Olsen et al., 1978) combined (L.C. in Table 8) contain 46 taxa, of which only 10 (21.7%) are cryptogams.

There is a slight decline in the total number of leaf taxa (34) in the middle Carnian (Table 8) compared to 45 in the early Carnian and 38 in the late Carnian. The middle Carnian floras of the Deep River and Taylorsville basins have only 10 of their combined 42 species in common (23.8%), which is due in part to the lower number of taxa identified in the Taylorsville basin flora, and in part to the higher number of reproductive taxa (8) recorded in the Deep River basin flora. Excluding the reproductive taxa, the similarity increases only slightly to 29.4%.

The decline in megafloral diversity (from 45 to 38 leaf species) through the Carnian contrasts with an increase in palynomorph diversity from 77 taxa in the early Carnian to 99 taxa in the middle Carnian, followed by a significant drop to 47 taxa in late Carnian (Table 8). The apparent increase in floral diversity in the middle Carnian is not evident from the study of individual palynoflorules. Similarly, the number of megafossil taxa from the combined Deep River and Taylorsville floras is much higher than at any one locality. This difference between local and regional floral composition may reflect a higher niche (i.e., facies) diversity during the middle Carnian than is apparent from the study of early and late Carnian floras of the Newark Supergroup.

The Winterpock coal measures flora, which contains 40 species (Table 2), is the product of intensive collecting by at least two paleobotanists over many years, and certainly reflects what was commonly preserved in the wetlands and coal swamps at that time. The Deep Run basin flora of the same age, by comparison, has produced 15 species (Table 4), only one of which has not yet been found at Winterpock. The middle Pekin Formation flora (at Gulf, North Carolina: Gore, 1989), which contains about 22 species, is also the product of intensive collecting by several paleobotanists over many years. The basal Cumnock Formation coal measures flora (Emmons, 1856, 1857) of slightly younger age (Reinemund, 1955) has produced about 14 species during the active coal-mining period, but only one taxon is shared between the Pekin and Cumnock floras, possibly indicating significant facies or environmental control. Palynoflorules from the same plant beds also show significant differences in taxonomic composition.

The unusually high palynofloral diversity for the middle Carnian (99 taxa: Table 8) can be explained by an increase in drier floodplain habitats within the rift valleys during that period. Active rift basins during the early Carnian were commonly filled with large lakes and deltas during high water stages, or very wet floodplains during low water stages, as evidenced by the high organic content of their gray to black shales and siltstones and the relative frequency of coals. The occurrence of fewer dark-gray and black shale beds and an increase in frequency of tan, brown, and reddish brown to red strata through the Turkey Branch Formation (Figure 4) indicate that lakes became shallower and floodplains became, on average, drier during the middle Carnian. In addition, organic content decreased in all but the wettest of environments. The Pekin Formation is also predominantly brown and red (Reinemund, 1955; Gore, 1989). The Cumnock Formation of the Deep River basin, with its basal coal seams and black shales, reversed that trend for a short period of time. Instead of wet habitats dominating the ecology of the basins, floodplain habitats may have become more diverse as edaphic changes caused in part by local variations in water-table levels created new ecological niches (cf. Gore et al., 1989). As a consequence of decreased annual water supply, which probably became more seasonal in distribution, upland floral communities expanded their ranges into the basins as drier habitats appeared there, while wetland communities became restricted to the margins of rivers and lakes. An intermediate ecological zone between perennial wetlands and seasonally dry floodplains may have expanded, creating the opportunity for new taxa to evolve or appear that could tolerate moderate fluctuations in soil moisture and water-table levels. The result would be an increase in floral diversity, largely through expanded "edge" or transitional communities.

The numbers of gymnosperm leaf taxa and pollen taxa are more similar between the early and middle Carnian than they are between the middle and late Carnian (Table 8). The higher number of pollen taxa (52-58 compared to 38) during the early and middle Carnian reflects more equitable climatic conditions than during the late Carnian, when the relative percentage of gymnosperm taxa increased to its highest level (76.3%) for the Newark Carnian (Table 8). A 31.8% increase in gymnosperm leaf taxa for the late Carnian, coupled with a closer correspondence between numbers of megafloral and palynofloral species, implies that floral environments within the rift basins became on average less diverse toward the end of the Carnian.

Late Carnian sediments appear to have been strongly influenced by a ~20,000 year precession of the equinoxes, which had a profound influence on depositional environments within active Newark basins (Olsen, 1986). Only during the wettest phases of the precession cycles did the late Carnian megaflora approach the diversity of the early and middle Carnian. The late Carnian megaflora differed from that of the early and middle Carnian by the presence of both megaphyllous and microphyllous leaf types (Olsen et al., 1978). For short periods of time, large lakes developed within the active basins (e.g., Dan River/Danville, northern Gettysburg, and Newark basins), only to shrink into playa lakes and eventually disappear as the climate became more arid every ~20,000 years (Olsen, 1986). Microphyllous conifer leaves of the *Brachyphyllum* and *Pagiophyllum* type dominate megafloras where plants are preserved in the more arid (commonly red) portions of these cycles (Olsen et al., 1978). Similarly, *Pagiophyllum* spp. are conspicuous elements of the middle to late Carnian Chinle Formation of Arizona and New Mexico (Ash, 1972, 1978), which is also dominantly red.

Floral data imply that environmental diversity at any one time during the late Carnian was low because of climatically mediated change. Those taxa that could expand their ranges rapidly from refugia or survive periods of climatic adversity undoubtedly had a significant advantage during the late Carnian. For example, one group of conifers, the Cheirolepidiaceae, successfully expanded its range and survived periods of adversity during the Late Triassic. The Cheirolepidiaceae (e.g., *Hirmeriella*, *Tomaxella*, *Frenelopsis*, and *Pseudofrenelopsis*: Stewart, 1983; Watson, 1988) dominated lower-latitude floras of the world during the Jurassic but were gradually replaced (displaced?) by angiosperms in the Early Cretaceous (Watson, 1988). Similarly, the Cheirolepidiaceae, along with subordinate Araucariaceae and ancestral Pinaceae (based on pollen and ovuliferous scales: Cornet, 1977a; Cornet and Olsen, 1985), dominated Early Jurassic floras of the Newark Supergroup (Cornet, 1989c). The ancestors of the Cheirolepidiaceae make their presence known in late Carnian leaf floras of the Newark (mainly as vegetative shoots of *Brachyphyllum* and *Pagiophyllum*), even though their pollen (e.g., *Praecirculina* and *Paracirculina*: Traverse, 1988) is a persistent palynofloral component throughout the Newark Carnian (Cornet, 1977a; Cornet, 1989a). Pollen referable to the Cheirolepidiaceae (e.g., *Corollina* al. *Classopollis*), however, does not become abundant in the Newark until the late Norian (Cornet and Traverse, 1975; Cornet and Olsen, 1985).

Angiosperm-like pollen first appears in early Carnian strata of the Richmond basin and underwent rapid diversification (Cornet, 1989a). Subsequently, diversity dropped as many early species disappeared by the middle Carnian. At least one of these early species, *Monocrinopollis microreticulatus*, expanded its range during the middle Carnian from the Richmond-Taylorsville basins to the Deep River basin (middle Pekin Formation) of North Carolina, and to the middle-late Carnian Chinle Formation of Arizona (Litwin, 1985). Different species of angiosperm-like pollen appeared in the early Norian of the Newark (Cornet, 1989a and references therein), and show up again in younger Norian, climatically forced cyclic lake sequences (Olsen, 1986), indicating the presence of plants that had to have survived possible extreme fluctuations in rainfall (i.e., tropical monsoons), periodic or cyclic shifts in climate, and/or large fluctuations in population size and density. Evolutionary pressures created by such stress, which progressively increased through the Carnian, may have pre-adapted these plants for surviving in low numbers and for rapidly colonizing new areas when optimum climatic and edaphic conditions arose (Olsen et al., 1978).

COMPARISON OF EUROPEAN AND NEWARK PALYNOFLORAL CHANGE

Simms and Ruffell (1989) compared invertebrate, vertebrate, and floral extinctions and originations during the Carnian and Norian, and claimed that a major episode of floral extinction occurred at the Carnian/Norian boundary in Europe. They hypothesized a pluvial episode during the Carnian, followed by arid conditions in the Norian. They related the cause of the Carnian pluvial episode to the rifting of Pangaea and linked high marine invertebrate turnover at the lower/middle Carnian boundary to the effects of volcanism at the initiation of rifting. If such conditions existed, floral and faunal data from the Newark Supergroup at the center of Pangaea and rifting should confirm the interpretations of Simms and Ruffell (1989).

A careful review of their data, however, reveals a number of errors, such as their placing the Hettangian episode of Newark flood basalts in the early Carnian (interbedded lake sediments produce Jurassic vertebrates and plants: Cornet et al., 1973; Cornet and Traverse, 1975; Cornet and Olsen, 1985; Olsen, 1986; Prévot and McWilliams, 1989). They also incorrectly date the Echo Cove Formation (Founes Head Member) in southern New Brunswick, eastern Canada, as Late Triassic. One of us (Olsen) first discovered fossiliferous plant beds there in 1973, which yielded a well-preserved Anisian (Middle Triassic) palynoflora. Palynofloral data from western Europe and the Alpine Triassic (Mädler, 1964; Brugman, 1983) show high origination and low rates of turnover (extinction) through the Late Triassic with no episode of extinction at the Carnian/Norian boundary. The highest extinction in Europe (16 species) occurred instead at the Triassic/Jurassic boundary (Brugman, 1983).

In comparison, Newark Supergroup palynofloras show a high period of extinction near or at the end of the middle Carnian (Table 8), with the loss of 47 palynomorph species. This extinction and the high (52%) ceratitid ammonoid extinction at the end of the early Carnian (Simms and Ruffell, 1989) may be the result of environmental changes caused by increased geomorphic relief and high geothermal gradients in areas of rifting. The invertebrate extinctions in the Tethyan realm, which began at the end of the Ladinian (Middle Triassic), could be related to higher ocean temperatures cause by a Pangaean heat anomaly (Veevers, 1989). The floral extinctions in eastern North America could be the result of climatic deterioration as uplift and new mountain ranges caused changes in climatic patterns over the center of rifting.

Another Newark episode of floral (palynomorph) extinction occurred at the end of the Triassic with a loss of at least 74 species, followed by a fern spike in the basal Jurassic (Table 8). A corresponding episode of invertebrate extinctions occurred in Europe (Morbey, 1975; Olsen et al., 1987). Only 15 out of 90 palynomorph species in the Newark basin cross the Triassic/Jurassic boundary. The late Carnian and Norian, in contrast, were periods of low extinction in both the Newark Supergroup and Europe. Gradual floral recovery and diversification is evident in the Newark basin following the extinctions in the middle Carnian (the number of palynomorph first occurrences [originations] progressively increased from 5 in the late Carnian to 51 in the late Norian [i.e., Rhaetian] [Table 8]). The percentage of Newark and Culpeper basin pteridophyte (cryptogam) spores also increased through the Norian from 5 species (10%) to 11 species (12.2%).

In conclusion, the Richmond, Taylorsville, and Deep River basins of the Newark Supergroup record a major period of floral extinction from middle to late Carnian. Most of the extinction appears to have occurred near the end of the middle Carnian. A coeval period of floral extinction in Europe is not apparent. Floral composition changed through the Carnian of eastern North America from high-diversity wetland vegetation dominated by pteridophytes and cycadophytes to low-diversity floodplain vegetation dominated by conifers. This change in floral composition appears to have been caused primarily by an increase in aridity through the Carnian, although a decrease in average temperature through uplift may also be a factor. The highest floral diversity occurred in the middle Carnian, midway between climatic extremes at the beginning and end of the Carnian. Middle Carnian megafloras of eastern and western North America closely resemble one another in diversity at the generic or familial level, but differ at the species level (cf. Daugherty, 1941; Ash, 1978; Ash, 1989). Gymnosperm diversification increased through the Norian to the end of the Triassic as the extinction rate declined. A second episode of floral extinction at the Triassic/Jurassic boundary was much more pronounced in North America than it was in Europe (contrary to Ash, 1986). In Europe, numerous Late Triassic taxa persisted into the Early Jurassic before becoming extinct (Harris, 1937; Morbey, 1975; Pedersen and Lund, 1980; Fisher and Dunay, 1981). The differences in floral history between eastern North America and Europe during the Late Triassic may be due in part to differences in paleogeography and in part to a maritime climate around the Tethys Sea, which may have reduced the effects of global climatic change in Europe.

ROAD LOG

Begin Trip—Leave Richmond University campus. Total distance to Stop 1 is about 16.2 miles. Take Three Chopt Road north to Interstate 64 (about 2.2 miles). Take Interstate 64 southeast to Interstate 95 (about 1.6 miles). Take Interstate 94 north to Ashland, Virginia, exiting for VA Route 54 west toward Ashland (about 12.4 miles). Detailed road log commences:

mileage		
total	increment	
00.0	0.00	Cross over Interstate 95 west on VA Route 54.
00.6	0.60	At U.S. Route 1 continue west through traffic light on VA Route 54.
01.15	0.55	Cross Richmond, Fredericksburg, and Potomac Railroad tracks and continue west on VA Route 54.
01.2	0.05	At Ashland Town Hall bear right and continue west on VA Route 54.
01.7	0.50	Bear right and continue west on VA Route 54.
03.6	1.90	Cross Falling Creek. This is the first point in our journey at which

		a stream has incised deeply enough to cut through the Coastal Plain section to expose the underlying Triassic strata.
03.8	0.20	Turn left onto VA Route 666.
04.5	0.70	Turn right onto VA Route 696. Somewhere along this stretch of VA Route 696 we cross the western border of the Taylorsville basin onto Petersburg Granite.
05.3	0.80	Turn right into parking lot for Hanover County Dog Pound.

STOP 1: Hanover Academy Quadrangle (Fig. 12). Lat. 37° 47′ 00″, Long. 77°32′ 40″.

Doswell Formation, Stagg Creek Member and overlying deltaic-lacustrine sequence (Weems, 1981). Park and walk west (in the same direction you were riding on VA Route 696) about 100 ft. (30 m) to bridge over Stagg Creek (Fig. 12). On the near side of the bridge is a foot trail to the right which parallels the creek bank downstream (north). Follow this path along the edge of Stagg Creek, which flows to your left across fault-sheared Petersburg Granite. At 900 ft. (270 m), cross a small gully and begin ascending a steep ridge. At the base of the ridge, Petersburg Granite crops out 20 ft. (6 m) to your right. At 960 ft. (290 m) along the trail, cross over an outcrop of Petersburg Granite on the ridge. The trail crosses the top of the ridge, then descends to a steep-sided ravine at 1,100 ft. (330 m), where the trail crosses the ravine. This gully roughly marks the southern border of the Taylorsville basin in this area. Surface casing for a Poorfarm Park water well can be seen standing to the right; this well reportedly drilled through about 15 ft. (4.6 m) of Stagg Creek sandstone and dark gray siltstone before encountering Petersburg Granite. Dark gray clayey siltstone containing plant cuticle and palynomorphs occurs as lenses within the arkosic sandstone layers exposed in the adjacent bed of Stagg Creek (Cornet, 1977a: palynoflorule P1).

Immediately beyond the ravine (1,150 ft. [345 m]) the trail forks; bear left, and stay beside creek. At 1,200 ft. (360 m), trail skirts creek edge, and Stagg Creek Member sandstone and conglomerate are visible along the creek bed. This arkosic sandstone is very poorly sorted and probably was derived from Triassic uplands immediately to the south, above the eroded stump of Petersburg Granite which we crossed to get here.

Continue along trail; massive to poorly bedded Stagg Creek Member is exposed intermittently along the stream bottom, especially around 1,550 ft. (465 m). At 1,750 ft. (525 m) a large outcrop of Stagg Creek sandstone and conglomerate is visible on the bluff that is near the creek on your right. It is similar to the previous outcrops, except that the pebbles are slightly smaller (less than 1.6 in. or 4 cm). At 1,770 ft. (530 m) the trail forks again; bear left and continue beside the creek. At 1,960 ft. (588 m) the Stagg Creek Member again crops out in the creek bottom. It is poorly sorted, medium- to very coarse-grained sandstone, having mica flakes as much as 1 mm in diameter scattered throughout.

At 2,080 ft. (625 m) cross a small gully, and at 2,100 ft. (630 m) the first exposure of well-bedded sandstones crops out along the creek bed. These sandstones are placed by Weems (1980a) at the base of his Falling Creek Member, which he incorrectly interpreted as overlying his Stagg Creek Member (Weems, 1981, 1982). This exposure is a moderately well-sorted, fine-grained, light yellowish-brown silty sandstone bedded at 0.1–0.4 in. (0.5–1.0 cm) intervals; bedding planes are defined by an abundance of mica flakes. The bedding strikes N80°W and dips about 60°N.

To the east on the adjacent hillside is a small ravine that exposes a 3.3 ft. (1 m) thick, upwards-coarsening swale or overbank sequence just above the base of Weems's Falling Creek Member. Fossilized plant fragments and cuticles occur in a 1 ft. (0.3 m) light-gray, clayey siltstone bed at the base of this sequence. It is the first significant indication of a change in facies (other than an increase in sandstone sorting) above the Stagg Creek Member, and occurs just below the stratigraphic appearance of lacustrine facies in Stratigraphic Section 1 (Fig. 13).

At 2,150 ft. (645 m) cross another small gully, and at 2,170 ft. (651 m) come to the base of a second steep bluff. A good outcrop of well-bedded, fine-grained deltaic sandstones and interbedded lacustrine shales and mudstones (Stratigraphic Section 1: Fig. 13) is present 70 ft. (21 m) to your left where the creek impinges against the base of the bluff. Bedding strikes N75°W and dips 45°N. Stratigraphic Section 1 represents intervals 38-40 in generalized Section 1 of Weems (1980a), and is Outcrop A of Stop 1 in the Eastern Section AAPG Meeting Field Trip 4 Guidebook (Goodwin et al., 1985).

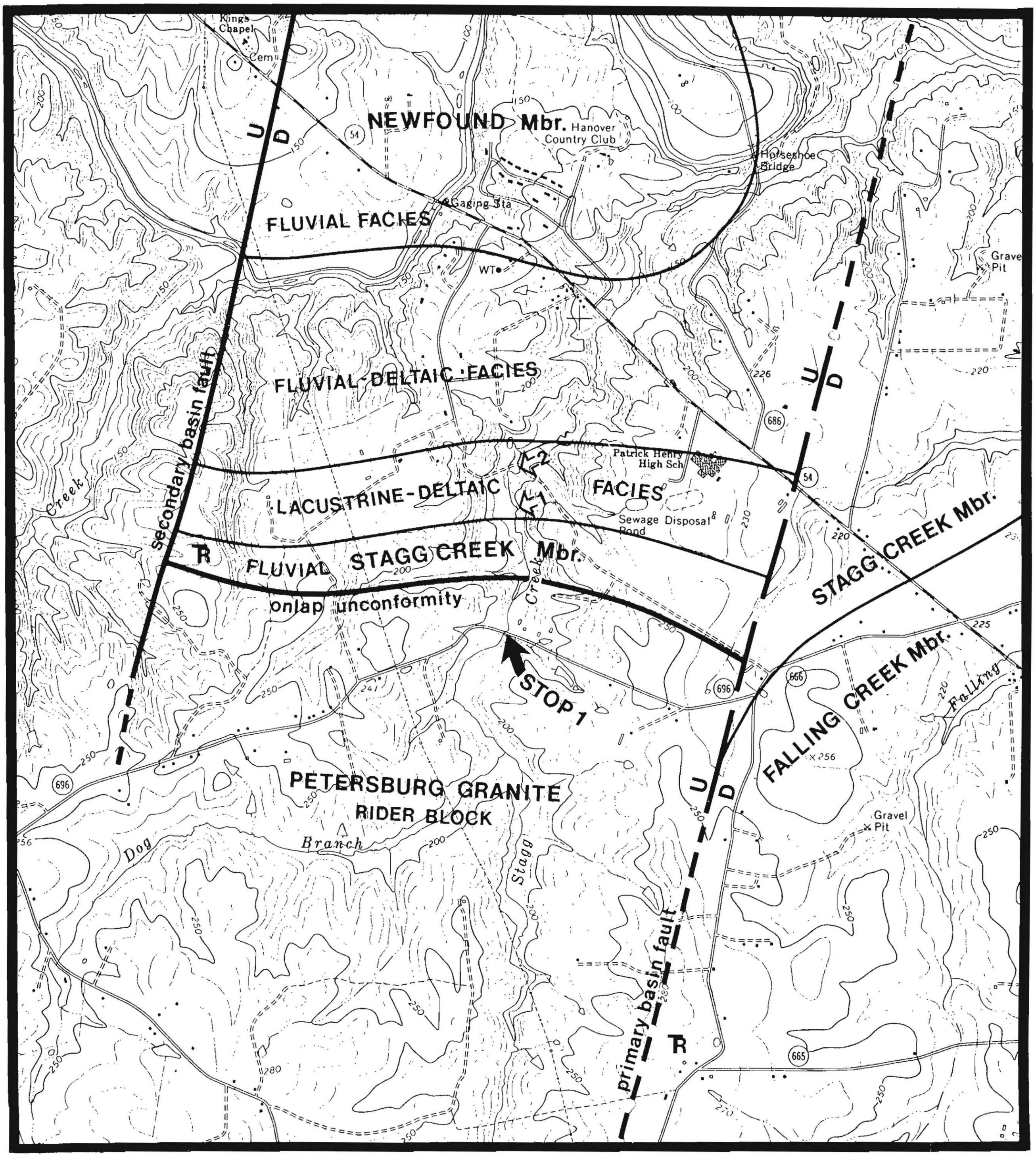

Fig. 12. Stop 1, Hanover Academy 7.5 minute quadrangle, showing major border faults, structural interpretations, and distribution of Triassic sedimentary facies or members of the Doswell Formation in the southern Taylorsville basin outcrop belt. Revised after Goodwin et al. (1985).

Stratigraphic Section 1 at Stop 1 along Stagg Creek: Only three megafossil plant taxa are recorded from this outcrop: *Equisetites rogersii*, *Pterophyllum tenuinervis*, and *Zamites powellii* (Table 6).

This outcrop exposes at least 13 meters of section, and records two major lacustrine intervals separated by a coarsening-upwards sequence of alternating black shales and medium-gray mudstones, and light-gray, fine-grained sandstones at the top (Fig. 13). Above the second, or stratigraphically higher, lacustrine interval is a second coarsening-upwards sequence of black siltstone overlain by dark-gray, fine- to coarse-grained sandstones. Whereas the lower lacustrine interval

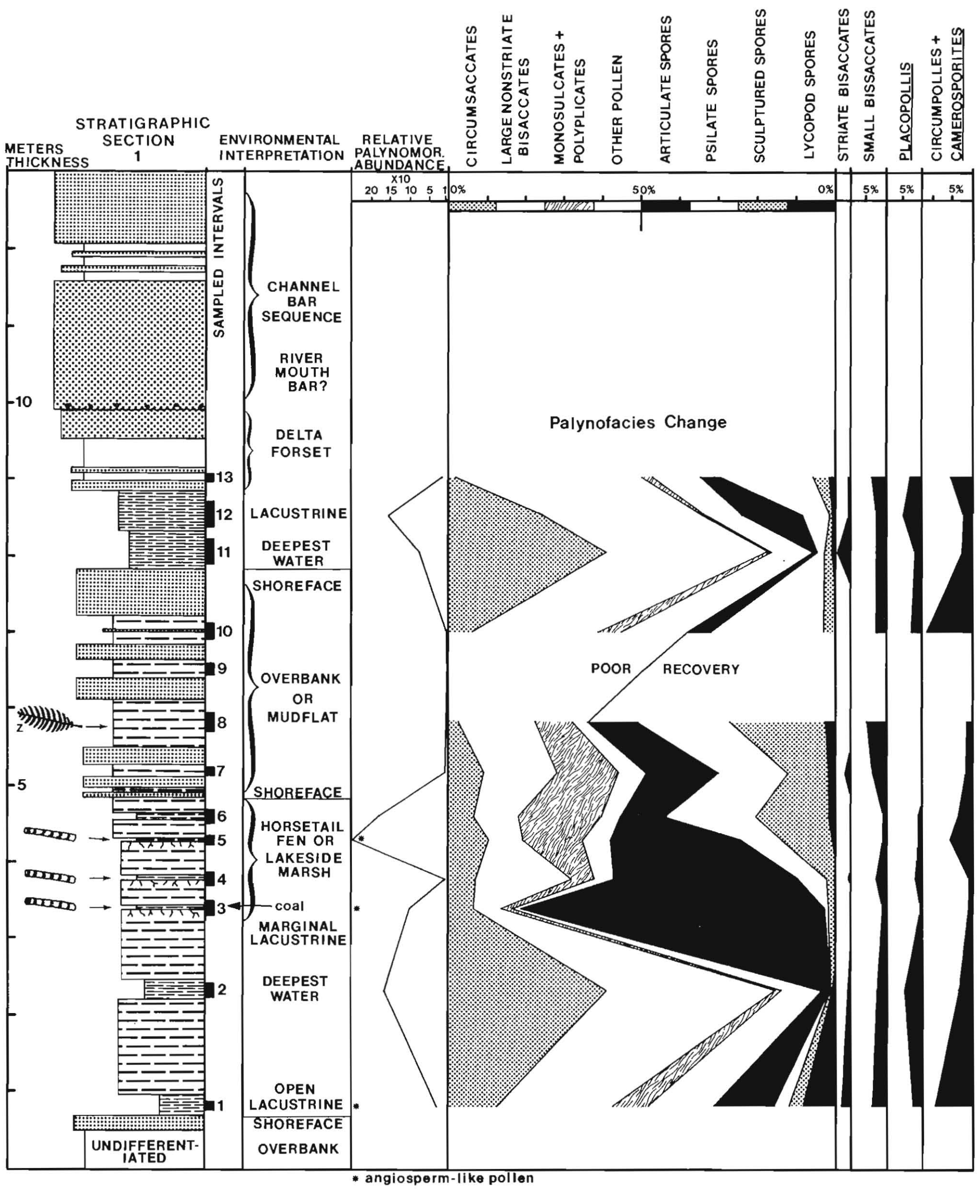

Fig. 13. Stratigraphic Section 1: lithostratigraphy, paleoenvironmental interpretations, megafossil plant locations, relative palynomorph abundances (per traverse of microscope slide), and palynofacies change using palynomorph types. See Fig. 14 for key to the identity of leaf types and lithologies.

is thick (4 m) with a gradual transition to organic-rich black shales, indicating a gradual increase in water depth, the upper lacustrine interval is thinner (2 m) with an abrupt transition to very organic-rich black shales, indicating a more rapid increase in water depth. The transition to fluvial or deltaic conditions above each cycle follows the same pattern, with a gradual transition for the lower lacustrine interval and a rapid transition for the upper interval.

Kerogen residues from the sampled intervals were processed to eliminate amorphous algal debris and to concentrate palynomorphs and woody debris. However, the deeper-water lacustrine shales of sample intervals #2 and #11 contained high amounts of amorphous algal debris, as well as whole *Botryococcus*. Only in the very shallow water environment of the horsetail fen or lakeside marsh does relative palynomorph abundance exceed that of the open lake environments (Fig. 13). The lacustrine intervals stand out palynologically because of their high palynomorph abundance and their high relative content of circumsaccate and bisaccate gymnosperm pollen. These pollen types typically represent the background pollen "rain" from areas around the lake, which entered the lake via either air or rivers draining upland watersheds. In Richmond basin wells, palynoflorules dominated by bisaccate pollen were typically found in either organic-rich lacustrine facies or in organic-poor fluvial facies, while palynoflorules dominated by fern spores and/or circumsaccate pollen were typically found in lake margin or fluvial-deltaic facies (Cornet, 1989a). High-diversity bisaccate pollen assemblages in lacustrine facies imply a regional source, while low-diversity bisaccate assemblages in fluvial facies imply a local source. High circumsaccate pollen abundance (i.e., *Patinasporites* and *Vallasporites*) implies proximity to a lake margin or deltaic facies where the conifers that produced this pollen type lived (cf. Cornet, 1977b; Olsen et al., 1978).

Following the initial establishment of lacustrine conditions near the base of Stratigraphic Section 1, water depth apparently shallowed enough by sample interval #3 for *Equisetites rogersii* (e.g., Plate 1) to establish a rooted colony and accumulate a layer of peat (now a 4-cm-thick coal seam). Rapidly deposited (storm?) muds apparently disrupted or destroyed this colony at least twice, burying the colony quickly enough to preserve these articulates in growth position (Plate 23, nos. 13 and 14). After each episode of burial, the colony became reestablished, but its vitality may have declined because of the progressive drop in articulate spores in palynoflorules from the black shale layers above each root and rhizome layer. Only in the first peat-producing colony are cones commonly preserved in the overlying "killer mud" (*sensu* E. I. Robbins, pers. comm., 1989).

The increase in palynomorph abundance and diversity in sample interval #5 implies that other plant types began to colonize the margins of the lake. Monosulcate pollen and fern spores show a progressive increase upwards, while the amount and diversity of comminuted plant cuticles sharply increase in the kerogen residue from sample interval #6. Although no megafossil whole-leaf beds have been recognized higher than the *Equisetites* layers, pieces of *Pterophyllum tenuinervis* and *Zamites powellii* fronds (e.g., Plate 20) were collected from sample interval #8 (Plate 24, no. 19).

Within the overbank or mudflat environment covered by sampled intervals #7 through #10, both kerogen content of the mudstones and palynomorph content in the kerogen drop sharply, possibly due to an increase in oxidation before fossilization. Some palynomorph recovery was obtained from sample interval #9, but abundance was too low to determine anything more meaningful than a spore-to-pollen ratio. Above this sample interval, preservation improves as the sequence passes through shoreface sandstone into quiet water (i.e., below wave base and anoxic) organic-rich black shale. Silt content of the shale increases upwards as amorphous algal debris decreases and woody plant debris increases in kerogen residues #11 through #13. The palynofloral composition also changes upwards from one dominated by saccate pollen that probably represents background pollen rain to one dominated by nonsaccate pollen and spores that probably represents local vegetation growing on the delta that prograded into the area.

Return to the trail and ascend the bluff. At 2,200 ft. (660 m) the trail begins to rise for a distance of 130 ft. (40 m), then starts to descend. To the left along the trail are ledges of fine to very coarse-grained, well-sorted micaceous sandstone that comprise the body of the deltaic-fluvial complex at the top of Stratigraphic Section 1. Descend bluff to creek bottom at 2,580 ft. (774 m). From 2,580 to 2,910 ft. (774 to 873 m) the trail parallels a deep and murky stretch of Stagg Creek (interval 59 in Section 1 of Weems, 1980a). This interval is probably composed mostly of soft delta-plain shales and coals, as a coal mine once was located about 0.25 mile (0.4 km) to the right along strike (Goodwin et al., 1985). At 2,910 ft. (873 m) the trail swings right around the head of a gully and exits at 2,960 ft. (888 m) onto a dirt road that descends from the hill on your right. A rusty piece of abandoned farm equipment rests in that gulley. To your left the creek again impinges against the edge of its valley and exposes Stratigraphic Section 2 (Fig. 14). Bedding strikes N80°E and dips 50°N. Stratigraphic Section 2 represents intervals 61-63 in generalized Section 1 of Weems (1980a), and is Outcrop B of Stop 1 in the Eastern Section AAPG Meeting Field Trip 4 Guidebook (Goodwin et al., 1985).

Stratigraphic Section 2 at Stop 1 along Stagg Creek: Fourteen megafossil plant taxa have been recorded from this outcrop (Fig. 14; Table 6): *Acrostichites linnaeaefolius*, *Cyathoforma carolinensis*, *Pterophyllum braunianum*, *P. taxinum*, *P. tenuistriatus*, and *Podozamites lanceolatus* (Plate 22, no. 8) from the fine sandstone and siltstone layers interbedded in the fine to coarse sandstones at the base of the outcrop section on the right (south) side of the cove; *Equisetites* sp. (Plate 23, nos. 10 and 11), *Macrotaeniopteris crassinervis*, *M. magnifolia* (Plate 24, nos. 15 and 16), *Neocalamites* cf. *N. delawarensis*, *Phlebopteris* cf. *P. smithii*, *Pterophyllum taxinum* (Plate 24, no. 18), *P. tenuinervis* (Plate 23, nos. 18 and 20), *Sphenobaiera striata* (Plate 22, no. 9), cf. *Sphenopteris sitholeyi* (Plate 24, no. 17), *Sphenozamites rogersianus*, and large cycad-like seeds (Plate 22, no. 7) from the lacustrine claystone and siltstone beds exposed below the natural jetty or bench of sandstone on the left (north) side of the cove; and *Macrotaeniopteris magnifolia* and abundant root and rhizome

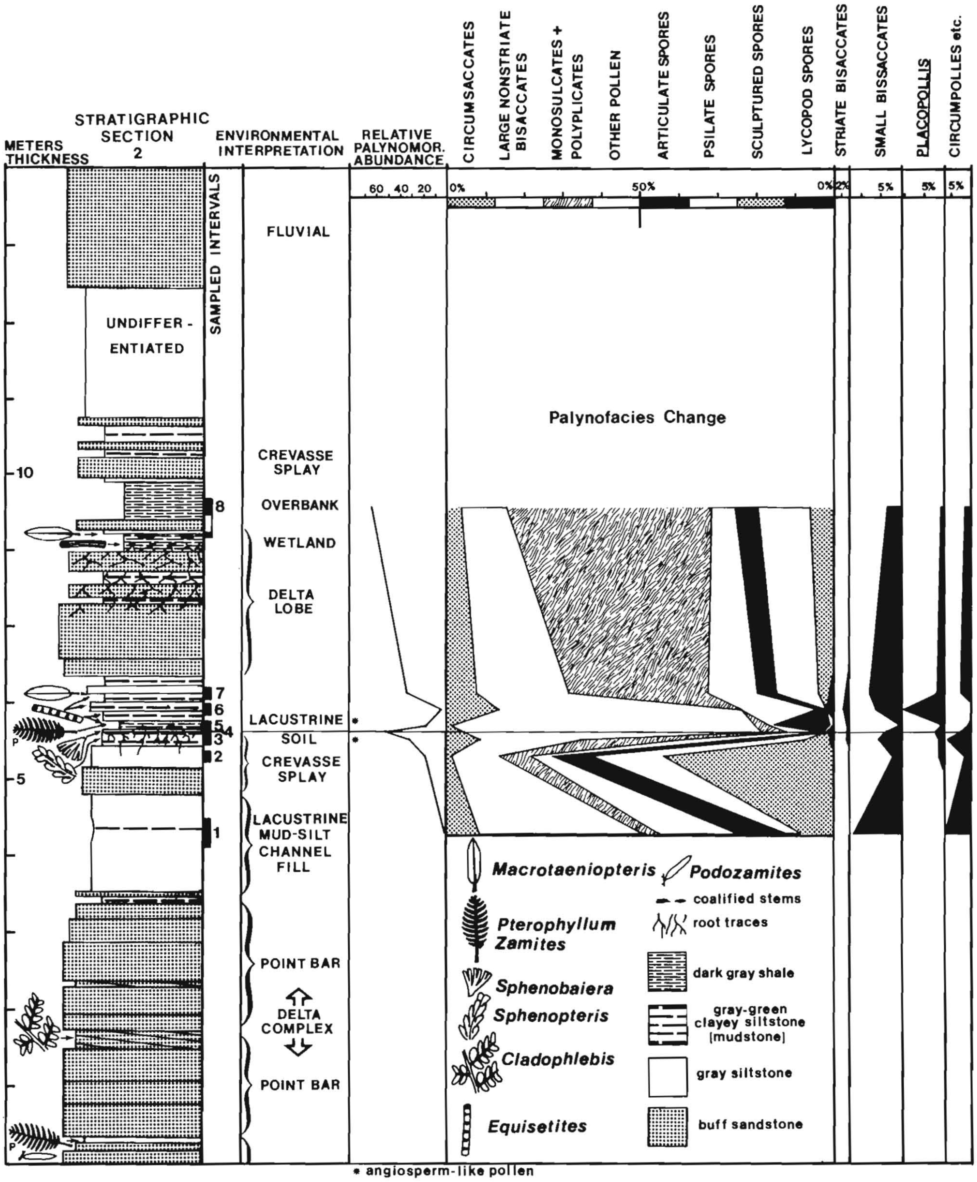

Fig. 14. Stratigraphic Section 2: lithostratigraphy, paleoenvironmental interpretations, megafossil plant locations, relative palynomorph abundances (per traverse of microscope slide), and palynofacies change using palynomorph types.

traces from the claystone and siltstone beds just above that bench of sandstone around the bend in the river. In addition, rare beetle elytra (Plate 23, no. 12) and cockroach wings occur with the megaflora in the middle lacustrine unit (represented by sample intervals #4 through #6 in Fig. 14).

Stratigraphic Section 2 begins with upwards-fining point bar sequences, the tops of which are truncated by the succeeding river channel. Megafossil plants are commonly found in the levee and upper point bar (finer grained) facies, and probably represent plants that grew along the sides of these rivers. The plants include cycadophytes (e.g., *Pterophyllum braunianum*), possible conifers (e.g., *Podozamites lanceolatus*), and probable tree ferns (e.g., *Cyathoforma carolinensis*). Because of the coarse grain size of the matrix, plant preservation is generally poor. Considerable amounts of rounded (river-transported) wood chips and plant stems occur within some of the fine sandstone and siltstone layers.

Above the channel sandstones, the stratigraphic sequence (Fig. 14) records a brief recess in fluvial-deltaic activity. A river channel was probably abandoned and filled with greenish gray muds and silts at sample interval #1. The muds and silts contain very little organic matter (Fig. 14), the result of a low rate of organic accumulation or oxidation in shallow water. No mud cracks are apparent in this deltaic channel fill, indicating that it may have remained connected to a larger lake. The lack of bedding planes and evidence of bioturbation in the mudstone, and a minimum observable depth of 2 meters for the channel (from the thickness of its fill) imply that deposition was never below wave base. Rare fern pinnule impressions can be found near the top of the channel-fill sequence, which ends with an upwards-fining sequence of sandstone and siltstone interpreted as a crevasse splay. The palynoflora shows a change from bisaccate pollen dominance in sample interval #1 to fern spore dominance in sample interval #2, implying a transition from a regional palynomorph source (airborne pollen falling into a lake) to a local source (ferns growing on a levee or river bank).

Root traces at the top of the sequence suggest that a soil developed on top of the channel fill. Pinnule impressions of cf. *Sphenopteris sitholeyi* (Plate 24, no. 17), a possible pteridosperm, occur just below abundant leaf fragments of *Sphenobaiera striata* (Plate 22, no. 9), a possible ginkgophyte, in the clay and silt layers comprising the top of the paleosol. A non-oxidizing wet soil environment is implied by (1) preservation of palynomorphs and leaf cuticles, (2) common fungal bodies and fungal damage on thick reddish-brown cuticles of *Sphenobaiera* leaf fragments, and (3) suspected fungal destruction of veins in most of those leaf fragments. The palynoflorule from this soil (sample interval #3) shows a significant decline in spores and a sharp but transient increase in simple monosulcate pollen compared to the sample interval below (Fig. 14). It is tempting to correlate the increase in monosulcate pollen with the presence of abundant *Sphenobaiera* leaves and to imagine possible ginkgophyte trees as one of the first woody colonizers of this moist soil.

On top of the paleosol is an upwards-coarsening claystone to siltstone sequence containing abundant megafossil leaves and stems of cycadophytes, sphenophytes, and pteridophytes. While fern fronds are rare and fragmentary, whole *Pterophyllum tenuinervis* fronds (Plate 24, nos. 18 and 20) and large segments of *Equisetites* stems are common. Fragments of large *Sphenozamites rogersianus* pinnules (e.g., Plate 19) are scattered throughout some layers. At the top of this sequence whole leaves of *Macrotaeniopteris magnifolia* occur (Plate 24, nos. 15 and 16). The palynoflorules from this sequence (sample intervals #4-6) show a substantial increase in bisaccate gymnosperm pollen, along with the highest relative percentage of circumsaccate gymnosperm pollen for samples from this outcrop.

This information taken together—i.e., abundant plant remains with abundant wind-blown (background) pollen—suggests that the plants may not be *in situ*. This sequence was obviously deposited near the margin of a lake, because it occurs very near the western edge of the basin (Fig. 12). The rapid upwards increase in background pollen rain (from sample interval #3 to #4) may indicate a rapid increase in local water depth—more rapid than one would expect from increased border fault activity or from the compaction of underlying sediments. It would not be unreasonable to suggest that lake level rose as rivers became more active. If the increase in water depth is not due to local subsidence, but instead is due to a rise in lake level throughout the Taylorsville basin, then increased river discharge into the basin is implicated. With increased flow rates, the rivers feeding the lake would have grown in size, cutting more actively into their floodplain deposits. Increased cannibalization of their banks could have increased uprooting and transportation into the lake of plant communities growing along the margins of these rivers.

Following the development of lacustrine conditions, a small upwards-coarsening delta prograded into the area (Fig. 14). Because this area is located on a basement rider block (Fig. 12), which may have subsided at a different rate than that of the rift valley floor to the east, it may not be possible to determine whether deltaic progradation resulted from an increase in sedimentation rate (i.e., accretion) or from a fall in lake level.

Just below the deltaic sandstones, the palynoflora (sample interval #7) rapidly changes from below to one strongly dominated by small psilate monosulcate pollen (Fig. 14). The relative percentage of this pollen in sample intervals #7 and #8 is at its highest level of all sampled intervals along Stagg Creek. Leaf layers of *Macrotaeniopteris magnifolia* (e.g., Plate 12) occur in a swale or depression on top of the sandstone. Abundant large root traces can be found in almost all of the fine sandstone and siltstone layers at the top of this delta (Fig. 14), implying that *Macrotaeniopteris* may have densely colonized such habitats. Palynoflorules from the overbank claystones and siltstones containing these leaves have a monosulcate pollen content of about 53%, similar to that from *Macrotaeniopteris* layers from the Winterpock coal measures of early Carnian age (Stop 4).

Above the deltaic sandstones, possible floodplain and fluvial sandstones appear (Fig. 14). Past this outcrop much of the section along Stagg Creek has not been studied due to poor exposure. Other creeks and streams in the area, however, have yielded examples of younger buff sandstones interbedded with dark-gray to black lacustrine shales containing well-preserved palynomorphs and fish scales (e.g., Cornet, 1977a: M'b). With additional exploration, new lake-margin plant localities will undoubtedly be found.

Return to vehicles by the same path.

Return to Ashland via VA Route 696, VA Route 666, and State Route 54, and proceed to south-bound entrance ramp on Interstate 95. Total distance to Stop 2 is about 22.5 miles. Take Interstate 95 south to the exit for Interstate 295 west (about 6 miles), and take that exit toward Interstate 64 west and Charlottesville. Follow Interstate 295 west until it intersects with Interstate 64 (about 10.3 miles), and take Interstate 64 east toward Richmond to the first exit (about 0.8 miles). Get off Interstate 64 at the first exit (Short Pump), and turn right onto U.S. Route 250 heading west toward Short Pump. The detailed road log commences again at this intersection of Interstate 64 and U.S. Route 250. To the left (east about 1.2 miles) is the Deep Run basin and the Deep Run plant locality.

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mileage total	increment	
00.0	0.00	Proceed west on U.S. Route 250 from its intersection with Interstate 64.
00.7	0.70	Pass through the town of Short Pump, well known to fans of Jeff MacNelly's cartoon series, "Shoe." This area is underlain by the Petersburg Granite, which separates the Deep Run outlier basin and its coal-mining district to the east from the main Richmond basin to the west.
02.2	1.50	Turn left onto VA Route 623 (Gayton Road).
03.6	1.40	Turn right onto Lauderdale Road.
03.85	0.25	Just past Church Road, cross over the contact between Petersburg Granite to the east and the Lower Barren Beds and Productive Coal Measures members of the Richmond basin to the west.
04.25	0.40	Turn left onto Gayton Road. Open pit mines and prospect pits were once common along the exposed coal seams, and waste material from those mines is abundant in the soils of this region. Several mines were formerly operated on both sides of Gayton Road south of this point, and this straight portion of Gayton Road follows the railroad track bed for the Tuckahoe and James River Railroad (1840) that once serviced these coal mines (Wilkes, 1988).
05.5	1.25	East bend in Gayton Rd. At least two thin seams of coal, underclay, and brown sandstone were once exposed here before commercial development.
05.7	0.20	Cross tributary of Tuckahoe Creek, marking approximate contact between Lower Barren Beds sandstone and Petersburg Granite at eastern edge of Richmond basin.
06.2	0.50	Crossing into Tuckahoe outlier basin and coal-mining area, isolated from the Richmond basin by erosion. Outcrop exposures occur along Flat Branch. Much of the developed area here overlies old mine workings. Abandoned but still open mine shafts and tunnels make careful site investigation for the development of this area a necessity.
06.88	0.68	Crossing out of the Tuckahoe basin back onto Petersburg Granite.
08.00	1.18	Turn right to continue on Gayton Road.
09.18	1.18	Turn right onto VA Route 6 (Patterson Avenue), and proceed west.
12.00	2.82	Entering Richmond basin on west side of Tuckahoe Creek.
12.20	0.20	Sandstones of the Lower Barren Beds Member crop out along the hillsides. The Productive Coal Measures Member appears to be mostly faulted out in this region, because exploration pits for coal did not extend the coal mine workings to this area from Gayton Road to the north (Wilkes, 1988).
12.60	0.40	Outcrops of lower Vinita Beds Member occur along the roadside. Black shales containing abundant fossil fish (*Dictyopyge* sp.) are interbedded with deltaic sandstones and conglomerates containing

		plant impressions. When VA Route 6 was widened in 1972, several closely spaced faults could be seen cutting through the fresh outcrop. This outcrop contains two of Cornet's (1977a) palynological sample localities.
12.80	0.20	Fluvial-deltaic sandstones containing common large stems of *Equisetites* sp. crop out on this hillside along the shoulders of the road.
16.10	3.30	Pass through the town of Manakin. This was an old coal-mining center on the western margin of the Richmond basin. Mine shafts were situated both north and south of VA Route 6. These coal measures were mapped by Goodwin (1970) as Productive Coal Measures Member, but unlike the coals from the eastern side of the basin, the coals in this area have yielded only lignitic wood (i.e., vitrinite) with no cuticle or palynomorphs. Palynoflorules from black shales associated with the coals are strongly dominated by gymnosperm pollen and indicate a younger, Vinita Beds Member age. A 557 ft. (169.8 m) continuous core from just north of Manakin (VAGO-1 well: VA Dept. Min. Res.) encountered only black lacustrine shales interbedded with gray siltstones and sandstones of the lower Vinita Beds Member. Coalified logs are common in outcrops of lower Vinita Beds Member exposed at Stop 2, implying the possibility that some of the mined coals in the Manakin area represent allochthonous accumulations of logs and driftwood along the steep and unstable western margin of a large basin lake.
16.70	0.60	Turn left across the center island and onto the road leading into the Boscobel Quarry of the Luck Stone Company. As you go down this road, there is a good view southward across the valley and floodplain of the James River.
17.10	0.40	Check in at Luck Stone office to obtain permission to enter the quarry.
17.40	0.30	After bearing right toward the quarry at the base of the hill, pull off to the right near the high cut banks in sandstone and shale. Beyond these cuts is the deep Boscobel Quarry developed in Cornwallis Hill.

STOP 2: Midlothian Quadrangle (Fig. 15). Lat. 37° 35′ 45″, Long. 77° 43′ 00″

Vinita Beds Member and exposed contact with border fault rider block in Boscobel Quarry (Goodwin, 1970). The Boscobel Quarry exposes metamorphic and adjacent sedimentary rocks of the Richmond basin (Fig. 15) and shows complexities of the border fault region of the rift in unique detail. According to Goodwin et al. (1985), this quarry was opened in 1924, although rock had been obtained for this general area from at least 63 years previously (Gooch et al., 1960), and a quarry was already present in the area by 1922 (Roberts, 1928). The Boscobel Quarry contains the only really good exposures in the basin, and they have been subject to very conflicting geological interpretations (Shaler and Woodworth, 1899; Roberts, 1928; Gooch et al., 1960; Olsen et al., 1982; Goodwin et al., 1986; Ressetar and Taylor, 1989; Olsen et al., 1989).

The main part of the Boscobel Quarry is developed in a gray to pink or white foliated feldspar- and quartz-rich rock having light-colored pegmatitic veins, which has been variously described or mapped as granite gneiss (Shaler and Woodworth, 1899; Roberts, 1928), granitized Wissahickon gneiss (Stose, 1928), Petersburg Granite (Goodwin et al., 1986), Hylas zone mylonite (Ressetar and Taylor, 1989), and granodiorite gneiss (Bobyarchick, 1976). To the immediate west of the quarry lies the Boscobel Boulder Beds Member, which dips to the west and toward the main border fault. Coal-bearing shales and sandstones at Manikin are to the east of the quarry (Fig. 15).

The contact between the Richmond basin sedimentary rocks and the crystalline rocks in the Boscobel Quarry has been traditionally interpreted as a major east-dipping fault (Goodwin et al., 1986; Ressetar and Taylor, 1989). This interpretation is consistent with the intense local small-scale fault deformation (Goodwin et al., 1986) and local core hole data (G. C. Fox [Boscobel Stone Co.], pers. comm., 1990), which demonstrate a very rapid increase in thickness of sedimentary rocks to the immediate east of the sedimentary rock/crystalline rock contact. However, close examination (in 1972

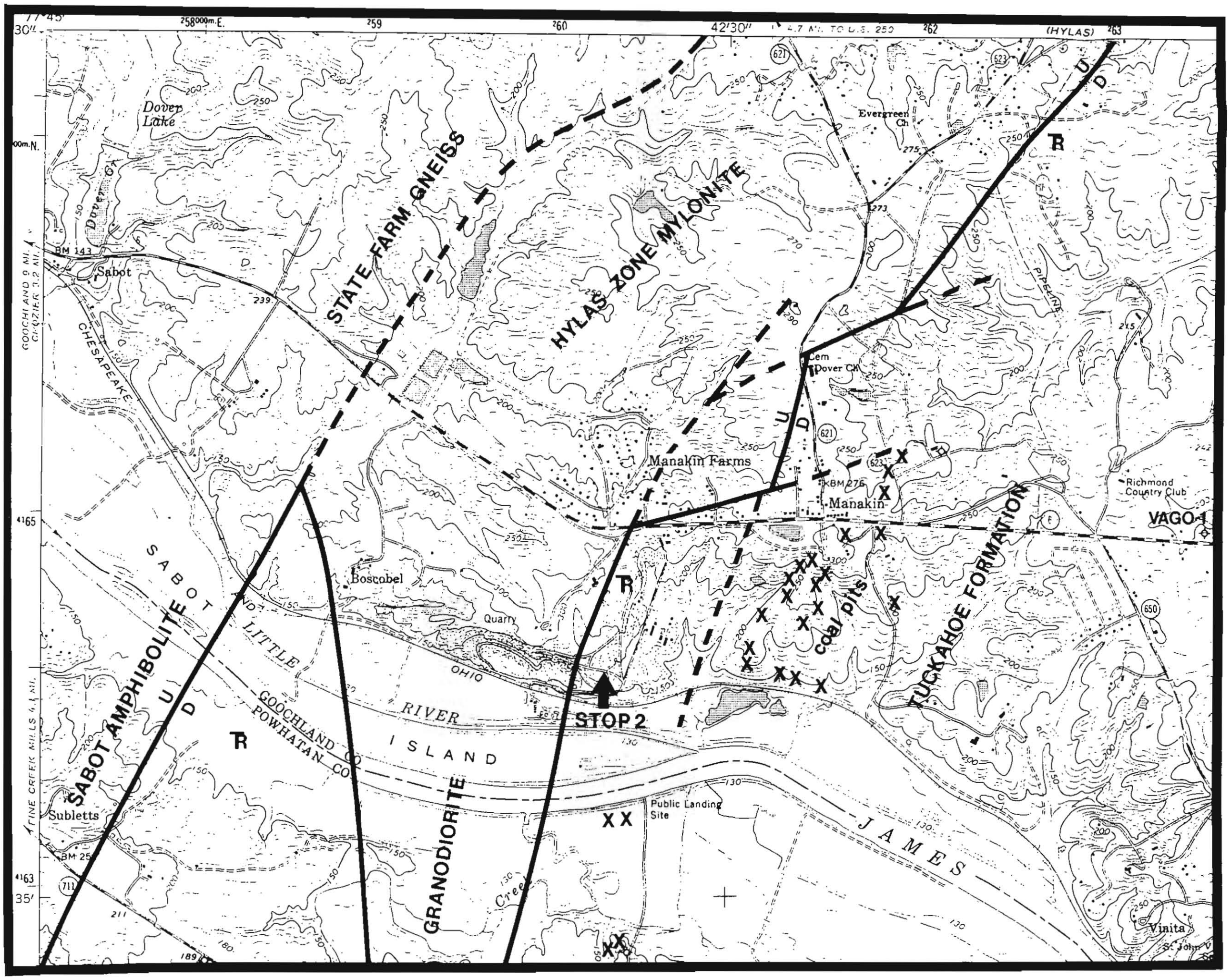

Fig. 15. Stop 2, Midlothian 7.5 minute quadrangle, showing major border faults, structural interpretations, and distribution of metamorphic/igneous rock types and Triassic formations. X = areas of coal mine activity. Well symbols for coreholes (VA Dept. of Min. Res.). After Wilkes (1988) and Ediger et al. (MS).

and 1990) of the contact area shows that a simple fault contact is not present. Instead, the contact consists of an unconformity offset by numerous small, down-to-the-east normal faults. Where bedding-plane-normal-section can be seen, the sequence invariably consists of crystalline rocks overlain (with a welded contact) by a 0.2–1.0 m thick layer of rounded to angular cobbles and boulders with a gray sandstone and gravel matrix, which is in turn overlain by gray and black pebbly sandstone and siltstone. Because of the dense spacing of small normal faults, the sedimentary contact drops off rapidly to the southeast, below the level of exposure. Thus, the sedimentary rocks in the quarry are locally the basal parts of the basin sequence resting on basement (Figs. 16 and 18).

The exposed 30 m thick sedimentary sequence consists of lower pebbly sandstones and interbedded siltstones, resting on the cobble beds, succeeded upward by alternating sandstones and calcareous shales (Fig. 16). The lower beds contain abundant wood debris and large compressed logs identified by Ressetar and Taylor (1989) as thin coal seams. The thicker sandstone beds generally show planar or gently dipping to hummocky lamination or are otherwise massive. Sandstones typically have common shale clasts and woody debris, and some burrows have been observed (Goodwin et al., 1986). The fine-grain rocks are calcareous claystones and siltstones, most of which are microlaminated and contain abundant whole and fragmentary fish (Fig. 17), coprolites, and clam shrimp (Schaeffer and McDonald, 1978; Olsen et al., 1982). Thin (<20 cm) sandstone and non-laminated siltstone beds are interbedded with the shales, and some shale beds show pinch and swell lamination. Many thin sandstones are graded and have load-casts and tool and groove sole marks. Desiccation

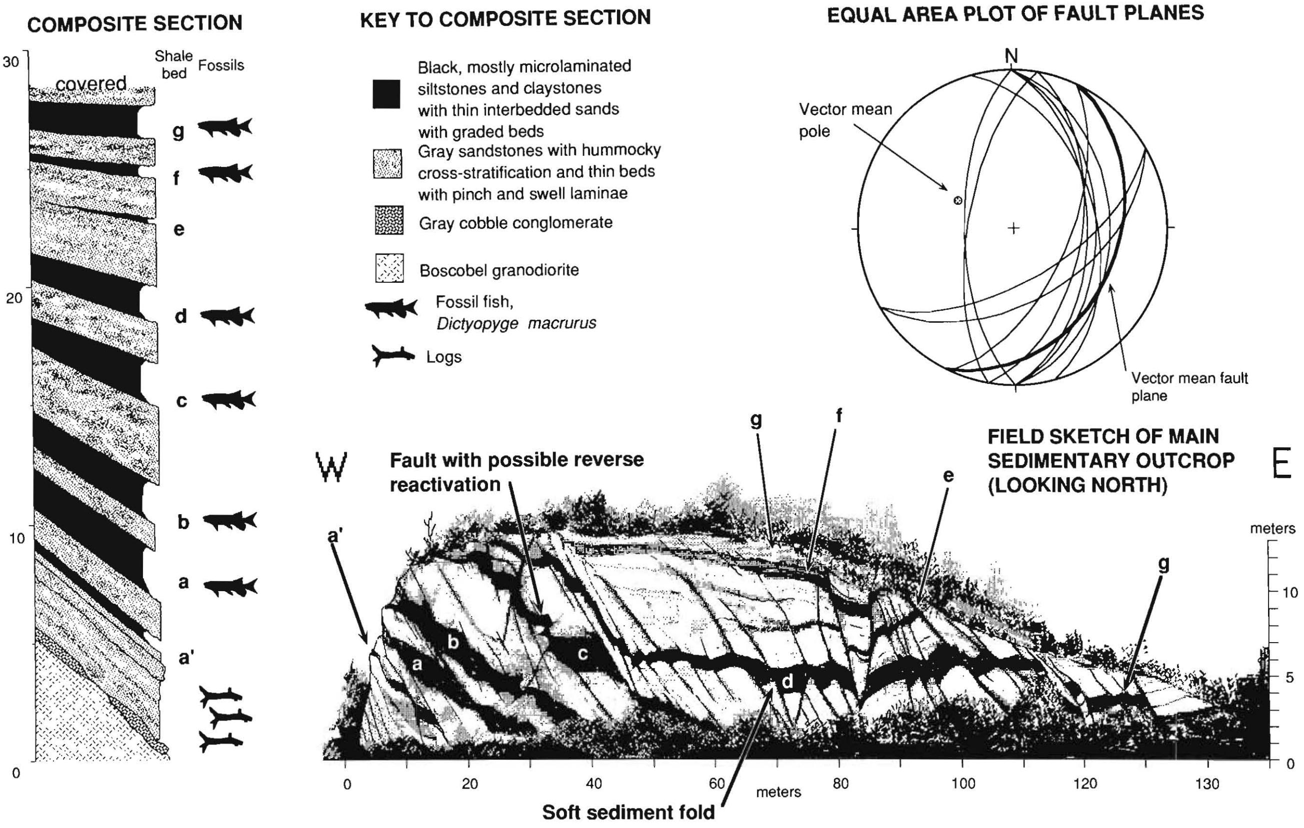

Fig. 16. Boscobel Quarry section and fault attitudes.

cracks and root traces are conspicuously absent.

The very thin calcareous laminations in the shales and common preservation of whole fish in the quarry sequence imply deposition in anoxic, very quiet, possibly deep water. The interbedded graded beds are consistent with small turbidites. The style of lamination in the sandstones and the pinch and swell laminations suggest some wave reworking in shallow-to-moderate water depths. The entire section indicates subaqueous deposition. Although the alternation of wave-reworked sandstones and quiet-water microlaminated shales implies changes in lake depth, there are absolutely no indications of subaerial exposure. In fact, the alternations of low-energy and higher-energy deposits could be the result of changes in wind intensity or storm frequency rather than rising and falling lake levels. This interpretation differs substantially from the swamp and river channel environment cited by Ressetar and Taylor (1989) for these outcrops. The presently exposed coal layers are large carbonized logs oriented parallel to outcrop, rather than accumulations of bedded peat as seen in the Productive Coal Measures Member on the east side of the basin (Stop 4).

Traditionally the Boscobel sedimentary sequence has been regarded as part of the Productive Coal Measures Member (Shaler and Woodworth, 1899; Roberts, 1928; Schaeffer and McDonald, 1978), but the sedimentary contact with basement suggested to Olsen et al. (1982) that the section represents the Lower Barren Beds Member. On the basis of palynology, especially the rarity of articulate and lycopod spores (Table 9), the Boscobel Quarry sequence most closely resembles the Vinita Beds Member or similar facies. The lithology resembles the lower part of the sequence in the VAGO #1 core, which is characteristic of the Vinita Beds. Because shales of the lithology dominant at the Boscobel Quarry are completely unknown in the Lower Barren Beds or Productive Coal Measures members, we conclude they are, in fact, Vinita Beds Member.

Sedimentary strata at the quarry (Fig. 16) appear to be warped into a syncline (Goodwin et al., 1986). On the west side of the outcrops, strata dip to the east and southeast, and on the east, strata dip more to the west. The visual impression gained from the outcrop is one of a syncline, but numerous down-to-the-east normal faults have juxtaposed younger (higher) strata against older (lower) strata from west to east. These faults show

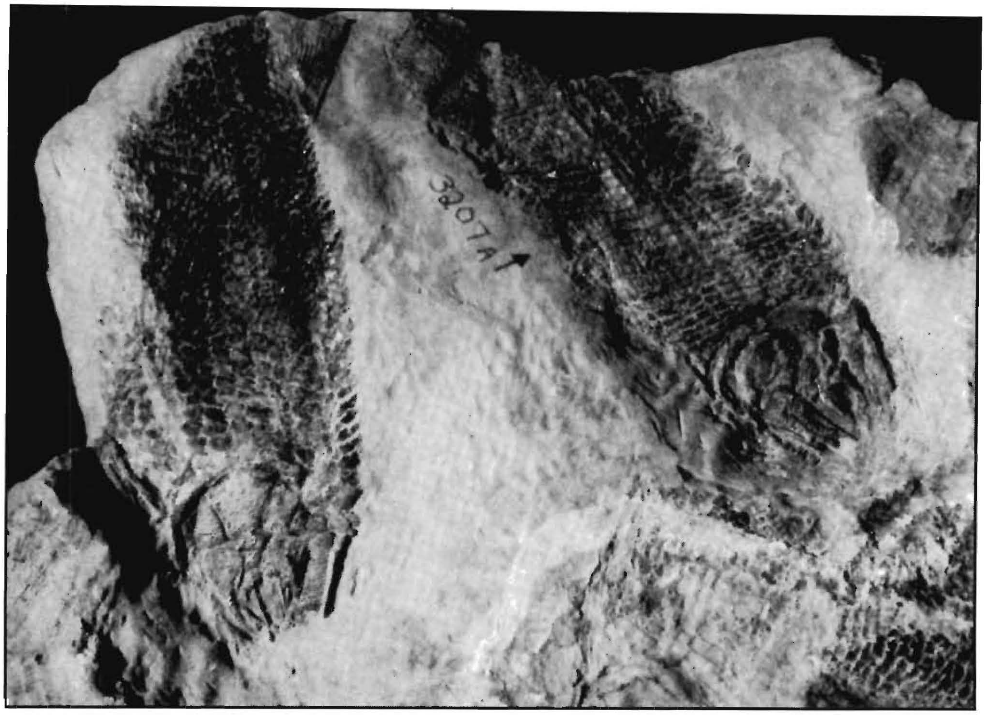

Fig. 17. *Dictyopyge macrurus* in sandstone from an unknown coal mine, Chesterfield Co., VA., collected by W. C. Redfield prior to 1841, presumably from Vinita Beds Member (YPM 3207). Photograph by William Sacco.

only dip-slip slickenlines. Thus, if you sample from west to east from the middle of the outcrop, you are moving up section, not down section as in a synclinal fold.

Within the sedimentary sequence, shale beds consistently thicken to the east (Figs. 16 and 18), which is especially obvious in the upper parts of the sequence. Small-scale, soft sediment folds within sandstones imply transport to the east, in the direction of thickening. The core hole data show that depth to the basement contact is in excess of 60 m (G. C. Fox, pers. comm., 1989), which is twice the observable stratigraphic thickness, again indicating rapid eastward thickening. As the westernmost outcrops represent an unconformity, and the observed section thickens to the east, the sedimentary section at the Boscobel Quarry probably represents a westward onlap of successively younger strata onto basement. The intense faulting, combined with thickening of individual beds to the east, is consistent with onlap onto an active normal fault zone during Vinita Beds time.

The coarse clastics of the Boscobel Boulder Beds Member present to the west of the quarry are often mapped as being separated from the crystalline rocks of the quarry by a fault (Roberts, 1928; Goodwin et al., 1986; Ressetar and Taylor, 1989; Mickus et al., 1989). The contact is probably an onlap, however, as indicated by Shaler and Woodworth (1899) and Roberts (1928). The structure of the block on which the Boscobel Quarry is developed is consistent with a rider block on the main boundary fault (Fig. 18).

The structure and stratigraphy to the east of the Boscobel Quarry are obscure. Strata to the immediate east of the quarry are mapped as Productive Coal Measures Member, and the area was the site of the coal mines of the Manakin area (Shaler and Woodworth, 1899; Goodwin et al., 1986). Shaler and Woodworth (1899) show an anticline bringing coal-bearing rocks to the surface in this region (Fig. 18), and this is in line with the observed dip reversal. The stratigraphic position of these coal-bearing beds remains in question. They could be equivalent to the Productive Coal Measures Member on the east side of the basin, or they could be a coal-bearing facies of the Vinita Beds Member, which is indeed known to have local coal beds of uncertain origin (Shaler and Woodworth, 1899; Goodwin et al., 1986; Ediger et al., in prep.). Gravity and magnetic models by Mickus et al. (1989) of the area along the James River imply that the basin is very shallow at Manakin, and this is consistent with the cross-section of Shaler and Woodworth (1899) and with the coal-bearing units belonging to the Productive Coal Measures Member (Fig. 18).

The Boscobel Quarry exposures produce abundant fossil fish characteristic of the Richmond basin, although none have biostratigraphic utility within the basin. The most abundant fish from

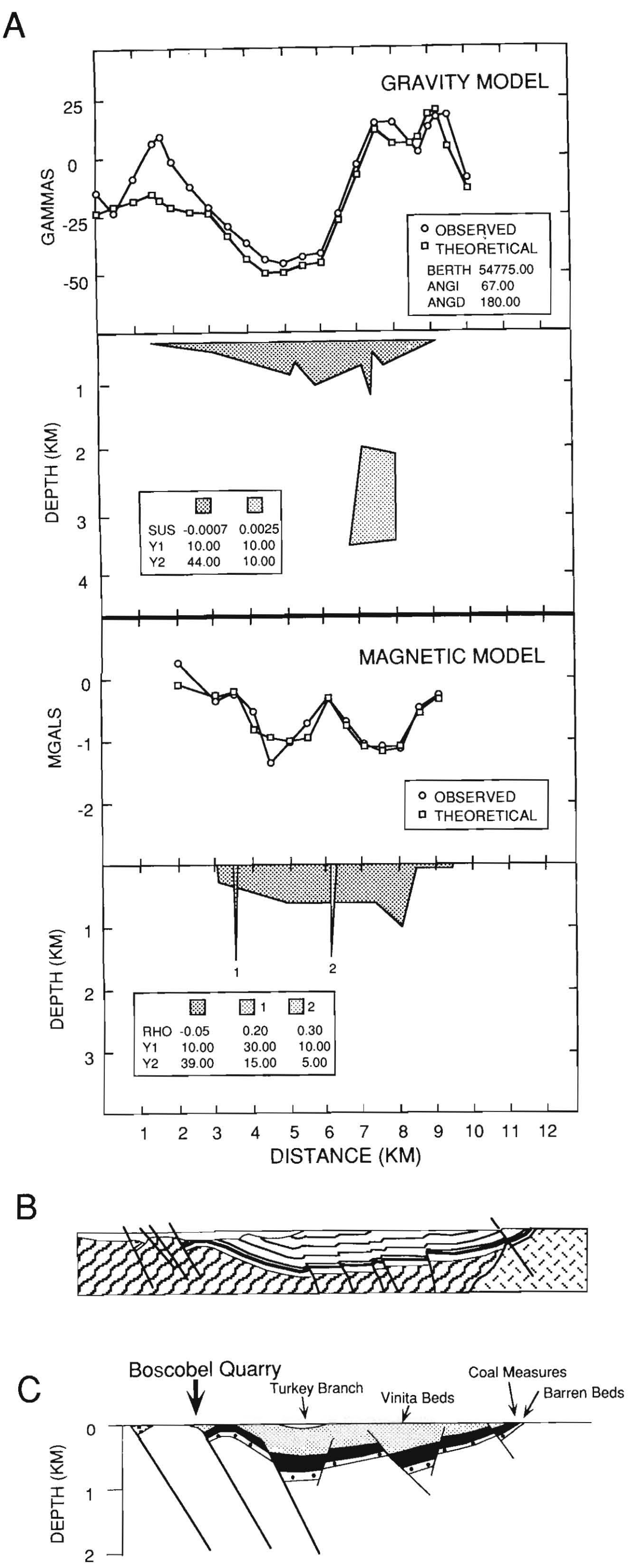

Fig. 18. Cross sections of the Richmond basin near the James River: A, gravity and magnetic models (redrawn from profiles M6 and G5 of Mickus et al., 1988); B, cross-section based on surface outcrops (redrawn from Shaler and Woodworth, 1899); C, cross-section based on surface outcrops, drill records, and proprietary seismic lines (note position of Boscobel Quarry).

the Boscobel Quarry is the ubiquitous redfieldiid paleonisciform *Dictyopyge macrurus* (Redfield) Lyell (Figs. 11 and 17), which is characterized by a graceful, lobate anal fin and a snout that looks like a pile of rice grains. Also present is a small fish named by Schaeffer and McDonald (1978) as *Dictyopyge meekeri*. This fish lacks the typical skull sculpture, lobate anal fin, and rice-grain-like snout of *Dictyopyge*, and appears to show much closer attributes to the genus *Cionichthys*. *D. meekeri* is therefore transferred to *Cionichthys* in Table 1. Probable fish coprolites, perhaps made by a coelacanth (1-5 cm long), are abundant. The only tetrapod material found thus far consists of small, slightly curved conical teeth comparable to the teeth found with *Doswellia* in the Taylorsville basin by Weems (1980b). Invertebrates present include only small clam shrimp, darwinulid ostracodes, and rare burrows. Macroscopic plant remains include abundant woody material and occasional bits of *Equisetites*, *Neocalamites*, and fern pinnae. Finally, the palynoflora is dominated by non-striate bisaccate pollen (Table 9), and organic residues contain much amorphous algal material, as is characteristic of the Vinita Beds Member (Fig. 4).

In the Boscobel Quarry it is easiest to find fossils in weathered outcrops of the units. When the rock is fresh, it is black in color and tends to fracture along small faults oblique to the bedding. When the rock weathers, it turns milk-chocolate brown and easily splits along bedding planes into thin (<1 mm) sheets, the surfaces of which are often covered with small clam shrimp. In fresh rock, fish bone is hard and black, and tends to fracture with the rock; in weathered rock, the bone is soft and very crumbly, and tends to fall freely out of the rock, leaving extremely detailed impressions. In 1976, excavation of the sedimentary section had just begun in the quarry, and much of the exposed rock was deeply weathered. Most of the specimens on which Schaeffer and McDonald (1977) based their detailed descriptions of *Dictyopyge macrurus* and "*D.*" *meekeri* were impressions collected by Olsen and McDonald in 1976 from weathered rock.

mileage		
total	increment	
18.18	0.70	Retrace route to the intersection of the road from Boscobel Quarry with VA Route 6. Turn right (east) onto VA Route 6.
19.68	1.50	Bear right onto VA Route 650 (River Road).

23.68	4.00	Cross over the approximate contact between the Richmond basin to the west and the Petersburg Granite to the east.
28.28	4.60	Entrance to the University of Richmond is on the left.
28.98	0.70	Turn hard right onto VA Route 147 (Huguenot Road). You are now on the floodplain of the James River. The bridge over the James River is at the western edge of the Fall Zone, and exposures of the Petersburg Granite are found in the bed of the river eastward to the point where Interstate 95 crosses the James River.
31.28	2.30	Cross over the contact between the Petersburg Granite and high-level gravels of probable Tertiary age. The base of the gravels is subhorizontal and gently inclined eastward at about 7 feet per mile.
36.78	5.50	Turn right at traffic light onto U.S. Route 60 (Midlothian Turnpike).
37.38	0.60	Cross the contact between overlying Tertiary gravels and the Petersburg Granite.
37.68	0.30	In the small road cut on the right side of the road is the contact between the Petersburg Granite and Triassic sandstone, shale, and coal. The Triassic rocks here occur within the Union basin, a small outlying basin to the east of the main Richmond basin. Immediately north of the road are waste piles from the old coal mines. Granite lies between the Union basin and the Richmond basin.
37.98	0.30	Cross over the approximate contact between Petersburg Granite and the Richmond basin.
38.08	0.10	Cross over the contact between Triassic sedimentary rocks of the Richmond basin and overlying, nearly horizontal Tertiary gravels, which extend west for the next 4 miles.
38.68	0.60	Drive through first set of traffic lights at the center of the town of Midlothian. This was an active coal-mining center during the late nineteenth century, and mines were situated both north and south of U.S. Route 60. A few of the old shafts can still be seen, although they are rapidly being destroyed and covered due to the growth of the city of Richmond.
38.78	0.10	At second set of lights turn left onto VA Route 754 (Coalfield Road), and travel south to Powhite Parkway, which continues west as Old *Hundred* Road.
42.08	3.30	Turn right onto VA Route 652 (Old Hundred Road), which soon becomes a dirt road.
43.48	1.40	Cross tributary to Little Tomahawk Creek. Highly weathered outcrops of the Tomahawk Creek Member are exposed in the drainage ditches along the sides of the road and on the adjacent hillsides.
43.63	0.15	A highly weathered exposure of sandstone with a black shale interbed crops out on the right just before the road bends sharply to the right (north). The black shale contains fish scales and a middle Carnian palynoflorule.
43.73	0.10	The Tomahawk bone quarry occurs on the right.
43.76	0.03	Slow down and prepare to pull to the side of the road. Park on the right just before reaching Little Tomahawk Creek. This road, despite being unpaved, is heavily traveled. Watch out for traffic, and stay either on the shoulders of the road or off the road.

STOP 3: Hallsboro Quadrangle (Fig. 19). Lat. 77° 40′ 15″, Long. 37° 27′ 45″

Tomahawk Tetrapod Quarry: lower Turkey Branch Formation (by P. E. Olsen and H.-D. Sues). Because of a lack of exposures, the vertebrate paleontology of the early-middle Carnian portion of the Newark Supergroup has been very poorly known. Recently, joint teams from the Smithsonian Institution and Columbia University have been excavating a spectacularly rich reptile assemblage in the Tomahawk Creek Member of the Turkey Branch Formation. The site was originally a very small roadside gully, discovered by P.E. Olsen in July 1981 while visiting B. Cornet, who was "sitting" the Horner #1 well (Figs. 3 and 19). In 1988 Cynthia Banach and P. E. Olsen found a portion of a traversodont cynodont dentary, which indicated that the site was extremely important. Since that time H.-D. Sues and Olsen have been working the site, funded by grants from the National Geographic Society.

The outcrops occur just east of the east branch of Tomahawk Creek on the old Tomahawk Plantation. A sand-filled Civil War trench traverses the outcrop, cutting through the bone-producing unit. Linear depressions identifying other sediment-filled trenches can be followed in the woods to the east. Impressions of modern leaves occur in clay-rich interbeds in the trench, which was dug presumably for controlling traffic on this nineteenth-century road. Shaler and Woodworth (1899) even show a dip symbol at this location on their basin map, indicating that they visited this site.

The section (Fig. 20) consists of a poorly exposed sequence of laminated claystone containing clam shrimp that grades upwards into massive mudstone and nodular limestone containing root structures. The tetrapod bones occur in the massive mudstone. The bones occur as disarticulated but partially associated jaws (Fig. 21), skulls, and skeletons, as well as numerous isolated bones and bone fragments. Unlike most other Newark bone localities, the bone is hard, almost uncrushed, and separates easily from the rock. Very small vertebrate bones are recovered by bulk processing in kerosene and hot water, followed by sieving.

Unlike all other North American Triassic age assemblages, this one is dominated by non-mammalian synapsids ("mammal-like reptiles") and is closely comparable to those known from southern Africa, Brazil, and Argentina. Most common is an advanced traversodont superficially similar to *Massetognathus* from the Middle Triassic Ischichuca Formation of Argentina, but which shows a more detailed resemblance to *Luangwa* from the Anisian Ntawere Formation of Zambia and *Traversodon* from the latest Ladinian or early Carnian Santa Maria Formation of Brazil (Figs. 11C and 21) (Sues and Olsen, in press). It is, however, sufficiently different from all previously described forms to warrant designation as a new genus.

A second synapsid is represented by a nearly complete left dentary containing several postcanine teeth (and an associated, but as yet unprepared, probable cranium), a tiny tooth-bearing right dentary, and isolated postcanine teeth (Fig. 11A). The postcanine teeth closely resemble those of *Microconodon* from the lower Cumnock Formation (Emmons, 1857). Placed in the Mammalia by its original describers, *Microconodon* is actually a pre-mammalian cynodont that has most recently been interpreted as a possible representative of the Chiniquodontidae, which are otherwise known from the Middle to Late Triassic of Argentina and Brazil (Hopson and Kitching, 1972). The material from the Tomahawk locality is much better preserved than the only known specimen (the holotype) of *Microconodon tenuirostris*; upon completed preparation, it should provide much new information on these hitherto poorly documented, very mammal-like synapsids.

A peculiar new archosaurian reptile is represented by parts of the dermal armor and various postcranial bones, all of which may represent a single individual. The distinctive dorsal scutes formed two rows, as in primitive crocodile-like archosaurs (Suchia). The crocodile-like pattern of ornamentation on the scutes confers a superficial resemblance to *Doswellia* from the Falling Creek Member of the Doswell Formation in the Taylorsville basin. However, there are notable differences, particularly the possession of prominent spines in the new form.

The large number of teeth, jaws, and bones also indicate the presence of many additional reptiles and some amphibian taxa. These include possible phytosaurs (teeth and one scute), other archosauromorphs, sphenodontids, lizard-like forms, and possibly salamanders or frogs. A faunal list, complete as of April 1990, is given in Table 1. Thus far absent are any remains of temnospondyl amphibians, particularly Metoposauridae, which were widely distributed throughout North America, Europe, Morocco, and India during the Late Triassic. This preliminary faunal inventory underscores the unique position occupied by this diversified new assemblage of Late Triassic tetrapods from Virginia within the Northern Hemisphere, as well as in the global paleobiogeographic picture. The synapsids indicate very close faunal ties to the Gondwanan realm, specifically South America and southern Africa. With the possible exception of the phytosaurs, the tetrapod fauna from the Tomahawk

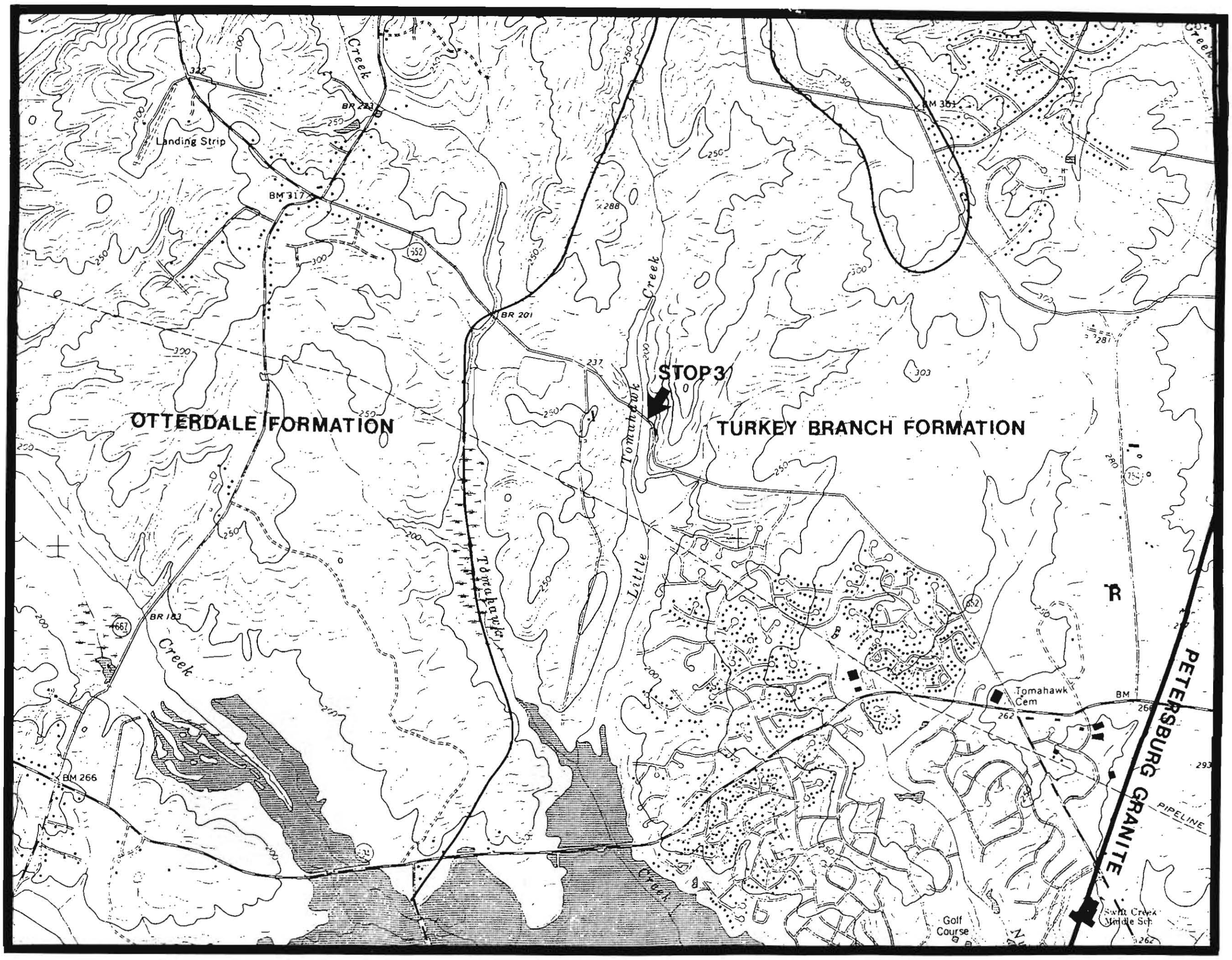

Fig. 19. Stop 3, Hallsboro 7.5 minute quadrangle, showing eastern border fault with distribution of Petersburg Granite and Triassic formations.

locality shows no similarity to the classic assemblages from the Late Triassic Chinle and Dockum formations of the western United States, or to the rest of the Newark Supergroup. Because this new assemblage is slightly older than other well-known Laurasian, Late Triassic assemblages and has close affinities to Gondwanan faunules, it implies that the differences between the Carnian assemblages of Laurasia and Gondwana were probably not caused by geographic isolation.

The bone-producing units have also produced a snail, and the underlying claystones have produced a palynoflora (Table 10) typical of the middle Tomahawk Creek Member of the Turkey Branch Formation in both outcrop and well data. The palynological assemblage indicates a probable middle Carnian age. The only macroscopic plants found thus far include poorly preserved roots, wood scraps, and a single very poorly preserved fern pinnule. It is worth noting that the bone-producing units (or facies) are lithologically similar to those containing *Doswellia* in the Taylorsville basin; both localities contain snail fossils.

The alternation of clam- and shrimp-bearing laminated (but not microlaminated) shales and massive calcareous mudstones containing root traces indicates relatively shallow perennially subaqueous conditions alternating with emergent or near emergent environments. A periodicity in thickness or time is not evident in such alternations.

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mileage		
total	increment	
45.11	1.35	Drive northwest on Old Hundred Road (VA Route 652) to stop sign. Turn left onto Otterdale Road (VA Route 667) and proceed south. Otterdale Road tends to follow a ridge that marks the eastern mar-

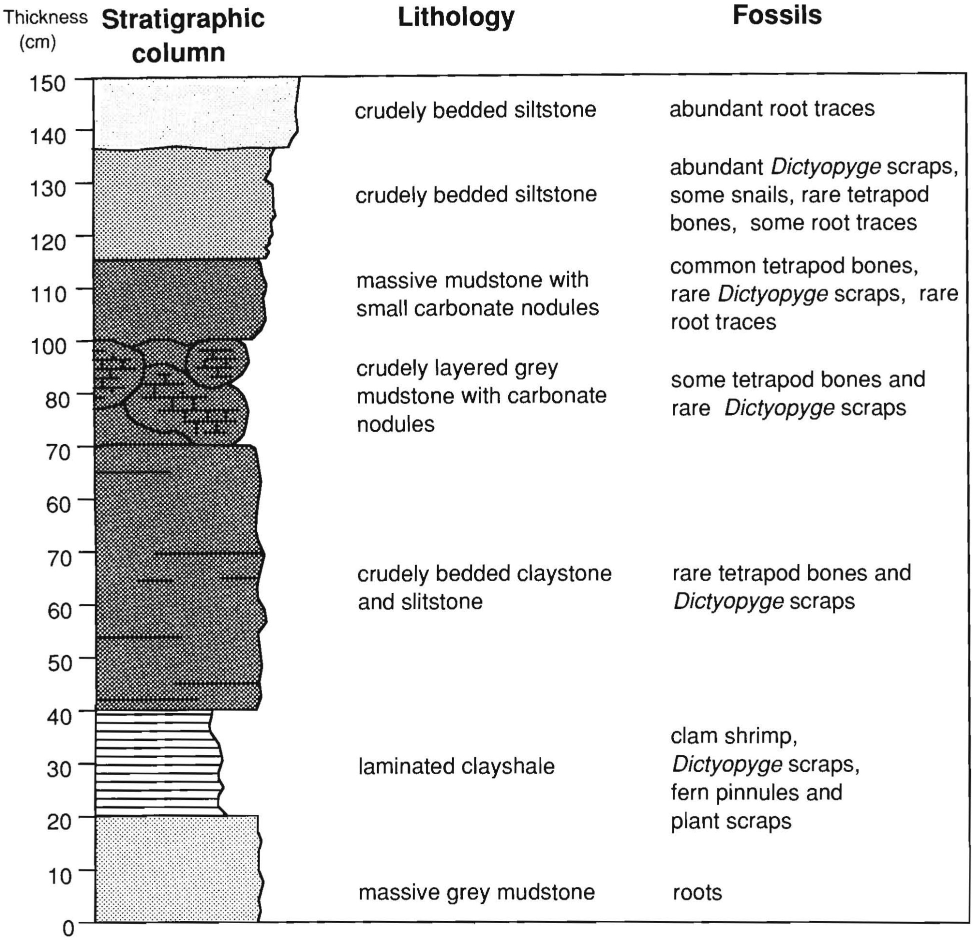

Fig. 20. Section exposed at the Tomahawk tetrapod quarry in the upper Tomahawk Creek Member of the Turkey Branch Formation, Stop 3.

gin of a large, west-dipping basement fault block like that shown on Fig. 5.

46.71 1.60 Cross Swift Creek with its broad floodplain. This floodplain is underlain by an east-west-oriented fault and fracture system that makes the underlying Triassic rocks more susceptible to erosion.

47.01 0.30 Weathered exposures of the Otterdale Formation occur on the left side of the road in a high roadcut. This outcrop exposes some of the youngest Triassic (late Carnian) sediments preserved in the Richmond and Taylorsville basins.

47.31 0.30 Cross Genito Road (VA Route 604). Continue south on Otterdale Road.

48.01 0.70 Cross Otterdale Branch where conglomeratic sandstone containing silicified tree trunks is exposed in the bed of the creek on the right (west) side of the road. Well-preserved, tan to black chunks of silicified wood commonly occur as float further upstream in Otterdale Branch.

48.91 0.90 Three shallow wells drilled by Merrill Natural Resources between 1981 and 1982, and one 4,570 ft. (1,393 m) well drilled to basement by Southeastern Exploration and Production Company (SEPCO) in 1985, are located to the left between Otterdale Road and Deep Creek in the valley to the east. The first well in this series of drill holes, spotted by B. Cornet, contained a reddish-green light oil that flowed to the surface for a short period of time. The valley to the left marks the down-thrown portion of another basement fault block on the eastern side of the Richmond half-graben. A well drilled by Merrill Natural Resources on that easterly fault block in 1982, and

Fig. 21. Right lower jaw and associated partial cranium of new traversodont cynodont synapsid from Tomahawk tetrapod quarry in the upper Tomahawk Creek Member of the Turkey Branch Formation, Stop 3.

		tested by SEPCO in 1985, could have been the first oil-producing well in the basin had oil prices not fallen so drastically in 1986, causing the well to be plugged and abandoned.
50.01	1.10	At "T" junction, turn left and continue to the southeast on Otterdale Road (VA Route 667).
52.81	2.80	Turn left onto U.S. Route 360 (Hull Street Road) and proceed east.
54.91	2.10	Turn right onto VA Route 621 (Winterpock Road) and proceed south to Winterpock.
60.61	5.70	Cross bridge over Winterpock Creek, which marks the eastern edge of the Richmond basin and the outcrop belt of the Productive Coal Measures Member (Fig. 22). Just after the bridge, note coal mine refuse dumps on the left behind the metal fence. These dumps, which belonged to the Beaver Slope coal mine (part of the Brighthope mine), have yielded a low diversity of plant fossils (mostly *Equisetites* and *Neocalamites* stems) compared to the mine dumps at the Clover Hill coal mine of Stop 4.
66.41	5.80	Continue on VA Route 621 to stop sign at intersection with Coalboro Road. The Winterpock general store is on the right.
66.94	0.53	Turn right onto Coalboro Road (VA Route 664) and proceed north to Clover Hill Road. Turn right onto Clover Hill Road. Park on the shoulder of the road. The Lush residence is located further up this road. The house dates to the early part of the nineteenth century, when it was the Cox residence. The house was used by General Lee during the Civil War as a temporary Confederate headquarters because of its secluded location on the coal mine rail line. Coalboro Road was the track bed for the Clover Hill Railroad (1845) and the Brighthope Railroad (1877). Sue Lush has graciously granted us permission to collect fossils on her property.

STOP 4: Winterpock Quadrangle (Fig. 22). Lat. 77° 43′ 00″, Long. 37° 21′ 08″

The fossil plants at this locality come from the shafts and galleries of the Clover Hill mine displayed in Fig. 22. The waste dumps on the east

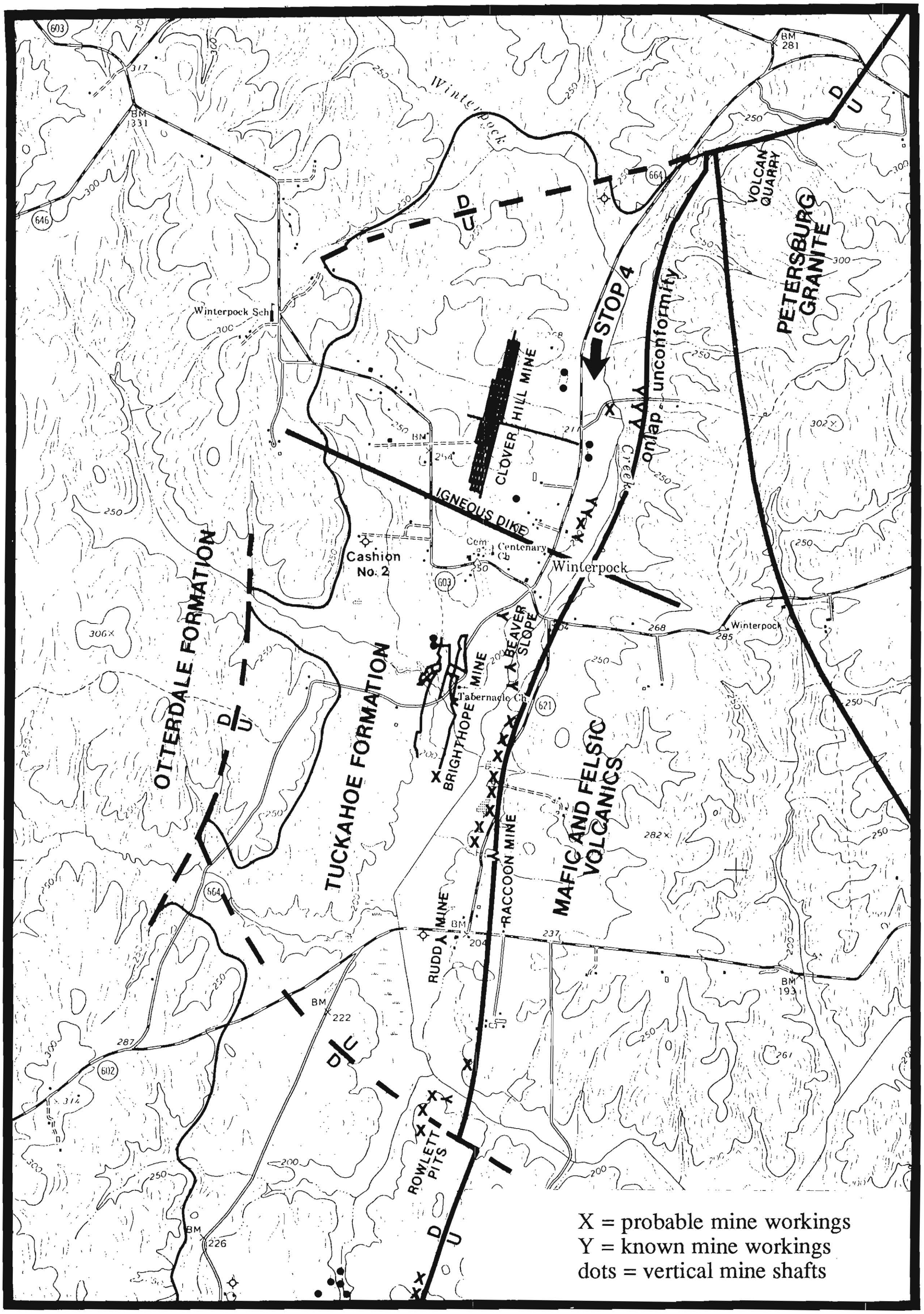

Fig. 22. Stop 4, Winterpock 7.5 min. quadrangle. Compiled from Wilkes (1988).

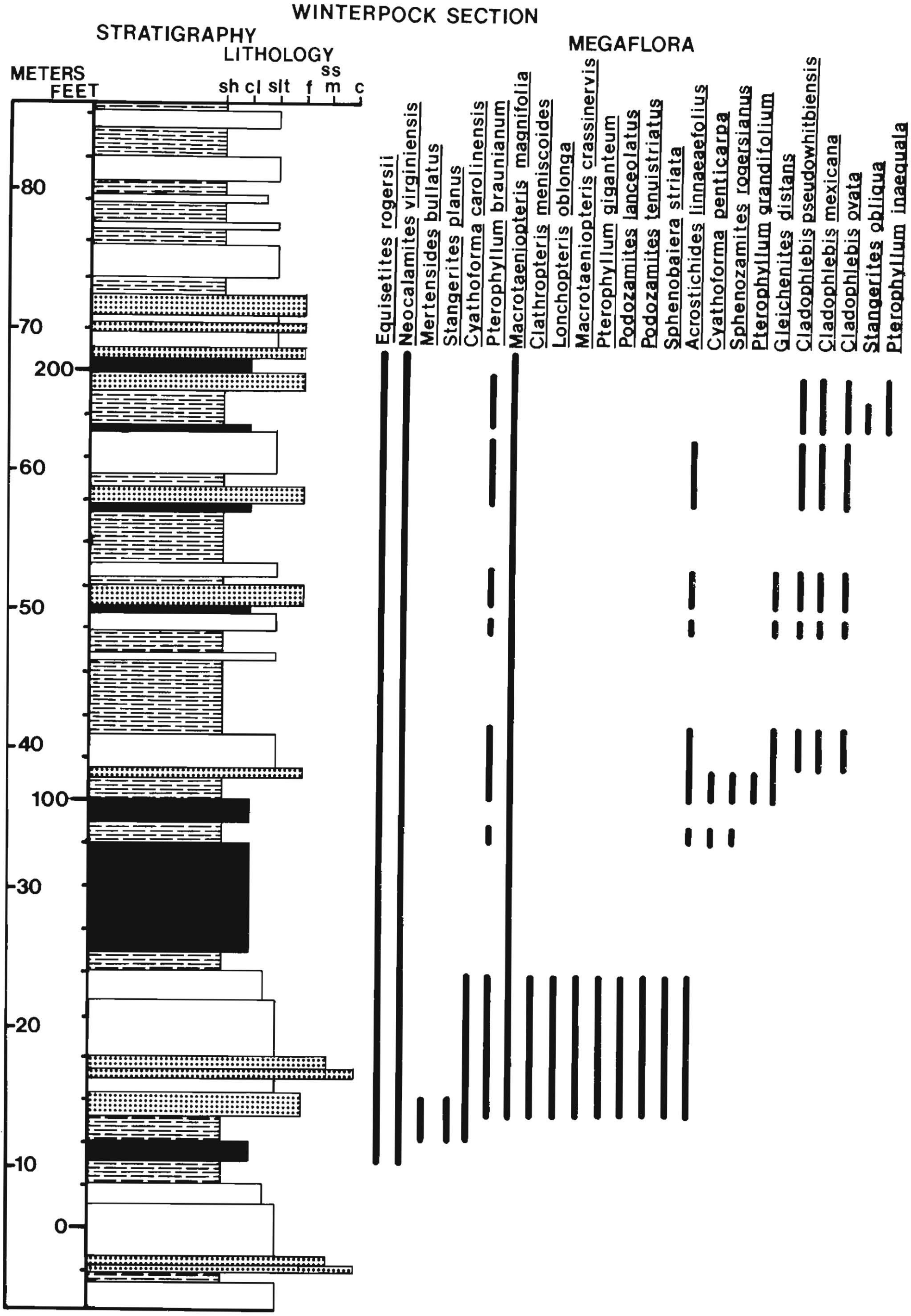

Fig. 23. Winterpock stratigraphic section, based on geologic data from Cashion #2 well and Fontaine (1883), showing possible ranges of megafossil taxa found in the coal mines and access shafts, according to Fontaine (1883). Megafossil nomenclature emended from Bock (1969) and Fontaine (1883); see text.

side of Coalboro Road (Lush property) probably come from the entrance and air shafts that led to the galleries at depth. Because these dumps contain strata above and between the coal seams, they sample a diversity of stratigraphic levels and environments of deposition. Excavation for this field trip has opened up areas in some of the mounds to provide access to less-weathered rocks at their centers.

A record of where various plant taxa were recovered from the Productive Coal Measures Member was kept by Fontaine (1883). Although his information is not very detailed, an attempt is made in Fig. 23, using Fontaine's data, to show the distribution of megafossil taxa through the Winterpock section. The stratigraphic section is revised from information given by Fontaine, using electric log data and cuttings descriptions for the Cashion #2 well (Fig. 22). The Winterpock section is significant in that non-red lithologies predominated, implying reducing conditions for the preservation of organic matter. These lithologies are interpreted as overbank and floodplain deposits, an ideal environment for the growth and preservation of plants. Fluvial sandstones are not as common at Winterpock as they are in correlative strata of the Bailey #1 well (Fig. 8), located due northwest of Winterpock (Fig. 3).

Some taxa are long-ranging (e.g., *Equisetites rogersii, Neocalamites virginiensis*, and *Macrotaeniopteris magnifolia*) and occur at many levels throughout the sequence, while other taxa are more restricted in occurrence (e.g., *Gleichenites distans*). *Cyathoforma penticarpa*, *Pterophyllum grandifolium*, and *Sphenozamites rogersianus* appear to be restricted to the shale parting of the main coal seam and to its roof shale, while *Mertensides bullatus* and *Stangerites planus* are restricted to the roof shale and sandstone above the lowest coal seam (Fig. 23).

At the Clover Hill mine, Bock recovered a high diversity of plants (Table 2) from a quarry in one of the mounds on the Lush property. The quarry was subsequently used for a time as a dump by local residents (S. V. Lush, pers. comm.,1990). This particular mound caught fire because of its high content of coal and burned for many years (A. J. Chalkely, a local resident, pers. comm., 1985), turning most of its dark-gray to black shale and siltstone to a brick-red, hard "porcelainite" suitable for road metal. The fire was extinguished by the time this mound was quarried for road metal in the 1950s. Bock collected at this locality from about 1948 to the late 1960s and reported a number of specimens in red or brown shale (Bock, 1969: 122, 132, 265). Although the heat destroyed all organic matter, it created beautiful and durable casts of plants, many with excellent impressions of cuticle (illustrated in Bock, 1969).

Mine waste dumps on the west side of Coalboro Road appear to have come primarily from the galleries of the mine. A 14 ft. (4.2 m) thick coal containing a 3 ft. (1 m) shale parting was mined from two parallel drifts that were connected at various intervals. These drifts were inclined 30° to the west (Wilkes, 1988). The shale parting is the primary source of plant fossils in the waste mounds on the west side of Coalboro Road and contains a low-diversity flora dominated by *Equisetites*, *Macrotaeniopteris*, and *Isoetodendron*. Other taxa do occur there (e.g., *Pterophyllum grandifolium*), but they are less common.

A slope mine was initially constructed from the outcrop west through the "Garrett Trouble" zone, but was soon abandoned because the coal dipped at 40°W, creating a slope too steep for mules to haul coal in carts out of the mine (Wilkes, 1988). It was necessary to dig vertical shafts, both for ventilation and for lifting coal and water by bucket hoist using a steam engine. The diagram of the Clover Hill mine in Fig. 22 is based on a map made before the mine was expanded northward. An additional pair of shafts was added to service that extension; their position is shown on the map.

A diabase dike crosses the coal field from east to west (Fig. 22). Mine records show that the dike turned the coal to coke at the southern end of the Clover Hill mine. The Cashion #2 well, located near the dike (Fig. 22), penetrated a 150 ft. (46 m) thick diabase sill, the top of which is at 100 ft. (30 m) below ground level (BGL). The top of the main coal seam is at about 1,180 ft. (360 m) BGL in the Cashion well, and at 6,654 ft. (2,029 m) BGL in the Bailey #1 well, located 3 miles (4.8 km) due northwest of Winterpock.

After a gas explosion in the Clover Hill mine in April 1867, the mines were temporarily closed. Because of primitive and unsafe methods of venting coal gas from the mines, methane gas explosions in the coal mines at Winterpock were frequent and deadly. The Clover Hill Coal Mining and Manufacturing Company's mines and railroad were sold in foreclosure to the Brighthope Mining Company in 1877 and continued to operate until the late 1800s (Wilkes, 1988).

Most Winterpock plant fossils are at a coal rank maturity of low volatile bituminous, unlike Carnian plants in the Santa Clara Formation of Mexico (Weber, 1985a-c), which are preserved as silver impressions in shales associated with anthracite coals. Excellent cuticle preservation after oxidation and clearing in basic solutions allow some fossils to be dissected or embedded in wax and sectioned. Whole rock maceration and transfer preparation have the potential of revealing reproductive structures critical to understanding early bennettitalean (e.g., *Triassiflorites*), cycadalean (e.g. *Zamiostrobus*), and anthophyte (e.g., *Primaraucaria*) evolution.

End of field trip.

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TABLE 1

VERTEBRATES AND INVERTEBRATES OF THE RICHMOND AND TAYLORSVILLE BASINS

Mollusca
  Gastropoda
    undetermined snails (Tf,Rt)
  Pelecypoda
    Unionidae
    undetermined clams (Tf)

Arthropoda
  Crustacea
    Diplostraca
      Cyzicus (Tfc, Ts, Rc, Rv, Rt)
    Ostracoda
      Darwinula spp. (Tfc, Ts, Rc, Rv, Rt)

Osteichthyes
  Actinopterygii
    Palaeonisciformes
      Cionichthys meekeri (Schaeffer and McDonald 1978) nov. comb. (Rv)[basionym: *Dictyopyge meekeri* Schaeffer and McDonald 1978]
      Dictyopyge macrurus (Tf, Ts, Rc, Rv, Rt)
      Tanaocrossus (Rc)
  Sarcopterygii
    Coelacanthiformes
      unidentified bones (Rt)

"Lissamphibia"
  ?Urodela?
      unidentified jaws (Rt)

?Procolophonia
  ?Procolophonidae
      unidentified form (Rt)

Synapsida
  Tritylodontoidea
      new genus cf. *Luangwa* (Rt)
  ?Chiniquodontidae
      new genus cf. *Microconodon* (Rt)

Diapsida
  Lepidosauromorpha
    Sphenodontida
      unidentified form (Rt)
    ?"Lacertilia"
      several undetermined forms (Rt)
  Archosauria
    ?Crocodylomorpha
      new genus (Rt)
    Phytosauridae
      undetermined teeth and scute (Rt)
    Doswelliidae
      Doswellia kaltenbachi (Tf)
  Archosauria indet.
      several new forms (Rt, Rv, Tf)

Basins and Formations: Rc) Richmond basin, Productive Coal Measures member; Rt) Richmond basin, Turkey Branch Formation; Rv) Richmond basin, Vinta Beds member; Tf) Taylorsville basin, Falling Creek member; Ts) Taylorsville basin, Stagg Creek Member.

TABLE 2

THE FONTAINE AND BOCK RICHMOND-TAYLORSVILLE FLORA

Stop 4 Richmond basin, Winterpock area
Ferns, Articulates, and Lycopods
21 taxa

Acrostichites linnaeaefolius (Bunbury) Fontaine. Plates 7 and 11.
  A.l. var. *rhombifolius* Fontaine
  A.l. var. *microphyllus* Fontaine
  A.l. var. *densifolius* Fontaine
Auriculophora acrostichoides Bock, found only at Winterpock. Plate 9.
Cladophlebis mexicana (Newberry) Bock (= *C. microphylla* Fontaine).
  possible synonyms:
  Cladophlebis ovata Fontaine. Plates 10 and 11.
  Cladophlebis pseudowhitbiensis Fontaine. Plate 11.
Clathropteris meniscoides (Brongn.) Brongniart. Plate 3.
Cyathocaulis carolinensis Bock, stem of a tree fern; found only at Winterpock. Plate 6.
Cyathoforma carolinensis (Emmons) Bock (= *Asterocarpus virginiensis* Fontaine and *A. platyrachis* Fontaine). Plates 4, 5, and 9.
Cyathoforma minuta Bock, found only at Winterpock. Plate 2.
Cyathoforma penticarpa (Fontaine) Bock, found only at Winterpock. Plate 5.
Danaeopsis virginiensis Bock, a marattialian fern; found only at Winterpock. Plate 9.
Dicranopteris sp., found only at Winterpock. Not illustrated.
Equisetites richmondensis Bock, distinguished by its broad leaf base; found only in Racoon mine dump at Winterpock. Plate 1.
Equisetites rogersii (Bunbury) Bock. Plate 1.

Gleichenites distans (Fontaine) Bock, found only at Winterpock. Plate 8.

Isoetodendron striata Bock, large stem associated with megaspores and *Macrotaeniopteris;* found only at Winterpock. Not illustrated.

Leptocyclotes americana Bock, associated with *Neocalamites;* found only at Winterpock. Plate 2.

Lonchopteris oblonga (Emmons) Bock (= *L. virginiensis* Fontaine), associated only with *Clathropteris;* found only at Winterpock. Similar to *Cynepteris,* but reticulate venation distinct (Ash, 1969). Plates 9 and 10.

Mertensides bullatus (Bunbury) Fontaine. Plates 8 and 9.

Neocalamites virginiensis (Fontaine) Berry (= *Schizoneura planicostatus* [Rogers] Fontaine and *Calamites arenaceus* Brogniart). Plate 1.

Osmundites winterpockensis Bock, stem with leaf scar impressions; found only at Winterpock. Plate 6.

Pteridocaulis rhombiformis Bock, stem of a tree fern; found only at Winterpock. Plate 6.

Pteridocaulis facialis, stem of a tree fern; found only at Winterpock. Plate 6.

Cycadophytes, Conifers, and Other Gymnosperms
19 taxa

Macrotaniopteris crassinervis (Rogers) Schimper, also found in York County, PA. Plate 12.

Macrotaniopteris magnifolia (Rogers) Schimper, also found in York County, PA. Plate 12.

Plicarizamites lanceolatus Bock, found only at Winterpock. Not illustrated.

Podozamites lanceolatus Lindley & Hutton (= *P. emmonsi* Fontaine), associated with *Clathropteris* and *Pterophyllum braunianum.* Plate 20.

Podozamites tenuistriatus (Rogers) Fontaine, associated with *Clathropteris* and *Pterophyllum braunianum;* also found in Deep Run basin. Plate 20.

Primaraucaria wielandii Bock, possibly related to anthophytes and angiosperms (Cornet, 1986). Plate 13.

Pterophyllum braunianum Goeppert (= *C. truncatum* Fontaine), also found in York County, PA, and in Deep Run basin. Plates 16 and 17.

Pterophyllum inaequale Fontaine, also found in York County, PA. Plate 17.

Pterophyllum giganteum (Fontaine) nov. comb. [basion. *Ctenophyllum giganteum* Fontaine 1883], associated with *Clathropteris;* found only at Winterpock. Plate 17.

Pterophyllum grandifolium (Fontaine) nov. comb. [basion. *Ctenophyllum grandifolium* Fontaine 1883], also found in York County, PA. Plate 18.

Sagenopteris rhoifolia? Found only at Winterpock. Not illustrated.

Sphenobaiera striata (Emmons) Bock (= *Baiera multifida* Fontaine). Plate 14.

Sphenopteris sitholeyi Bock. Plate 2.

Sphenozamites rogersianus Fontaine, also found in York County, PA. Plate 19.

Stangerites obliqua Emmons (= *Pseudodanaeopsis nervosa* Fontaine). Plate 15.

Stangerites planus Emmons (= *Pseudodanaeopsis reticulata* Fontaine). Plate 15.

Taeniopteris diminuta Bock, found only at Winterpock. Plate 12.

Triassiflorites grandiflora Bock, possible reproductive structure of *Macrotaniopteris magnifolia;* found only at Winterpock. Plate 13.

Zamiostrobus lissocardius Bock, found only at Winterpock. Not illustrated.

TABLE 3:

THE FONTAINE AND BOCK RICHMOND-TAYLORSVILLE FLORA

Northern Richmond basin flora
6 taxa

Cladophlebis auriculata Fontaine, found at Carbon Hill. Plate 11.

Cladophlebis mexicana (Newberry) Bock (= *C. microphylla* Fontaine). Possible synonym: *Cladophlebis subfalcata* Fontaine, found at Manakin. Plate 10.

Pecopteris rarinervis Fontaine, found at Manakin and Carbon Hill. Not illustrated.

Primaraucaria wielandii Bock (= *Zamiostrobus virginiensis* Fontaine), found near Midlothian. Plate 13.

Pterophyllum affine Nathorst, found at Midlothian. Plate 17.

Pterophyllum taxinum (Lindley & Hutton) nov. comb. [basion. *Ctenophyllum taxinum* (Lindley & Hutton) Fontaine 1883], found at Midlothian. Illustrated by Gensel (1986) in Deep River flora. Plate 20.

Southern Richmond basin, Otterdale Formation?

Zamiostrobus triasiccus Bock, found near Winterpock in roadside outcrop. Not illustrated.

Cumberland area west of Richmond, Virginia

Pterophyllum decussatum (Emmons) Fontaine, found only in Cumberland area, Virginia (Farmville basin). Not illustrated.

TABLE 4

THE FONTAINE AND BOCK RICHMOND TAYLORSVILLE FLORA

Deep Run basin flora
15 taxa

Acrostichites linnaeaefolius (Bunbury) Fontaine. Plates 7 and 11.
Clathropteris meniscoides (Brongn.) Brongniart. Plate 3; Plate 21, no. 3.
Cyathoforma carolinensis (Emmons) Bock (= *Asterocarpus virginiensis* Fontaine and *A. platyrachis* Fontaine). Plates 4, 5, and 9.
Dictyophyllum sp., found only in Deep Run basin. Not illustrated.
Equisetites milleri Bock, also found in Bucks County, PA. Not illustrated.
Equisetites richmondensis Bock, distinguished by its broad leaf base. Plate 1.
Equisetites rogersii (Bunbury) Bock. Plate 1.
Macrotaeniopteris crassinervis (Rogers) Schimper. Plate 12.
Macrotaeniopteris magnifolia (Rogers) Schimper. Plate 12.
Mertensides bullatus (Bunbury) Fontaine. Plates 8 and 9.
Neocalamites knowltonii Berry. Plate 21, no. 2; Plate 22, no. 6.
Neocalamites virginiensis (Fontaine) Berry (= *Schizoneura planicostatus* (Rogers) Fontaine and *Calamites arenaceus* Brogniart). Plate 1.
Podozamites tenuistriatus (Rogers) Fontaine, associated with *Clathropteris* and *Pterophyllum braunianum* at Winterpock. Plate 20; Plate 21, no. 4; Plate 22, no. 5.
Pterophyllum braunianum Goeppert. Plates 16 and 17
Sanmiguelia-like leaves, large leaf fragments which resemble *Neocalamites* stems, but which have several sizes of veins randomly distributed between plications or primary veins, and no internodes. Plate 21, no. 1.

TABLE 5

SECTION BENEATH MAIN COAL BED AS EXPOSED ALONG DEEP RUN

Thickness (cm)	Assemblage, Lithology, and Environmental Interpretation:
30	Coal, representing accumulated wetland peat, terminated by rising water and/or flood deposits.
35	Common rhizome and root compressions in coaly dark gray siltstone and interbedded black shale, representing the re-establishment of wetland vegetation following a drop in water level, possibly due in part to clastic accretion.
7	Coal with claystone partings, composed of mostly *Macrotaeniopteris* leaves and occasional compressions of slender stems, terminated by rising water and/or clastic deposition.
5	Seven layers of large *Macrotaeniopteris* spp. leaves (e.g., 12 cm wide by est. 40+ cm long) in a dark gray-brown silty claystone, representing a dense stand of deciduous bennettitalean "shrubs" in a wetland environment. Lower part of interval contains *Macrotaeniopteris* leaves, *Neocalamites* stems, and rare *Pterophyllum braunianum* fronds.
28	Upper half containing mainly *Equisetites* spp., *Neocalamites* spp. (Plate 21, no. 2), large *Sanmiguelia*-like leaves (Plate 21, no. 1), and roots/rhizomes in a coaly dark gray siltstone unit, representing a submergent floodplain wetland or shallow lake; Lower half containing abundant frond fragments of *Acrostichites linnaeaefolius*, *Cyathoforma carolinensis*, *Mertensides bullatus*, *Dictyophyllum* sp., and small to large *Sanmiguelia*-like leaves, with *Neocalamites* spp. and *Equisetites* spp. becoming more common upwards in a thinly bedded, dark gray, clayey siltstone unit, representing silts and muds energetically deposited on a vegetated, tree-fern dominated, wet flood-plain.
5	Abundant, mostly dismembered *Podozamites tenuistriatus* leaves (Plate 21, no. 4) mixed with common small male cones (Plate 22, no. 5) in a gray siltstone layer, representing a gymnosperm-vegetated floodplain adjacent to a river channel.

35 *Clathropteris meniscoides* and *Equisetites* sp. (Plate 21, no. 3) in brown clay drapes interbedded within massive light gray sandy siltstone layers, representing a fern and horsetail vegetated levee and/or swale facies marginal to a river channel.

TABLE 6

THE FONTAINE AND BOCK RICHMOND-TAYLORSVILLE FLORA

Stop 1 Taylorsville basin flora, Stagg Creek area
16 taxa

Acrostichites linnaeaefolius (Bunbury) Fontaine. Plates 7 and 11.

Cyathoforma carolinensis (Emmons) Bock (= *Asterocarpus virginiensis* Fontaine and *A. platyrachis* Fontaine). Plates 4, 5, and 9.

Equisetites rogersii (Bunbury) Bock. Plate 1; Plate 23, nos. 13 and 14.

Equisetites sp., with broad short leaves, wide stems. Plate 23, nos. 10 and 11.

Macrotaeniopteris crassinervis (Rogers) Schimper. Plate 12.

Macrotaeniopteris magnifolia (Rogers) Schimper. Plate 12; Plate 24, nos. 15 and 16.

Neocalamites cf. *N. delawarensis* Bock. Not illustrated.

Phlebopteris cf. *P. smithii* (Daugherty) Arnold, isolated fertile pinnae. Plate 9.

Podozamites lanceolatus Lindley & Hutton (= *P. emmonsi* Fontaine), associated with *Clathropteris* and *Pterophyllum braunianum* at Winterpock. Plate 20; Plate 22, no. 8.

Pterophyllum braunianum Goeppert (= *C. truncatum* Fontaine). Plates 16 and 17.

Pterophyllum taxinum (Lindley & Hutton) nov. comb. [basion. *Ctenophyllum taxinum* (Lindley & Hutton) Fontaine 1883]. Illustrated by Gensel (1986) in Deep River flora. Plate 20; Plate 24, no. 18.

Pterophyllum tenuinervis (Fontaine) nov. comb. [basion. *Cycadites tenuinervis* Fontaine 1883]. Plate 20; Plate 24, nos. 18 and 20.

Sphenobaiera striata (Emmons) Bock (= *Baiera multifida* Fontaine). Plate 14; Plate 22, no. 9.

cf. *Sphenopteris sitholeyi* Bock. Plate 2; Plate 24, no. 17.

Sphenozamites rogersianus Fontaine, as distinctive pinna fragments. Plate 19. Large seed possibly belonging to *S. rogersianus*. Plate 22, no. 7.

Zamites powellii Fontaine (in Fontaine and Knowlton, 1890), found only in Hanover County (Stagg Creek). Plate 20; Plate 24, no. 19.

TABLE 7

FLORAL EVOLUTION THROUGH THE NEWARK CARNIAN STAGE

	E.C.	M.C.1	M.C.2	L.C.
1. *Auriculophora acrostichoides*	C			
2. *Cladophlebis auriculata*	C			
3. *Cyathoforma minuta*	C			
4. *Cyathoforma penticarpa*	C			
5. *Cyathocaulis carolinensis*	C			
6. *Dicranopteris* sp.	C			
7. *Equisetites richmondensis*	C			
8. *Gleichenites distans*	C			
9. *Isoetodendron striata*	C			
10. *Mertensides bullatus*	C			
11. *Osmundites winterpockensis*	C			
12. *Pecopteris rarinervis*	C			
13. *Plicarizamites lanceolatus*	G			
14. *Primaraucaria wielandii*	G			
15. *Pteridocaulis rhombiformis*	G			
16. *Pteridocaulis facialis*	G			
17. *Pterophyllum affine*	G			

		E.C.	M.C.1	M.C.2	L.C.
18.	_Sanmiguelia_-like leaves	G			
19.	_Stangerites obliqua_	G			
20.	_Taeniopteris diminuta_	G			
21.	_Triassiflorites grandiflora_*	G			
22.	_Sphenopteris sitholeyi_	G	cf.		
23.	_Pterophyllum taxinum_	G	G	G	
24.	_Cyathoforma carolinensis_	C	C	C	
25.	_Equisetites rogersii_	C	C	C	
26.	_Clathropteris meniscoides_	C		C	
27.	_Danaeopsis virginiensis_	C		cf.	
28.	_Cladophlebis mexicana_	C		C	
29a.	_Cladophlebis ovata_	C			
29b.	_Cladophlebis pseudowhitbiensis_	C			
29c.	_Cladophlebis subfalcata_	C			
30.	_Podozamites tenuistriatus_ _(=Striatotaxus "wherryi"?)_	G			cf.
31.	_Leptocyclotes americana_*	C		C	
32.	_Acrostichites linnaeaefolius_	C	C	C	C
33.	_Podozamites lanceolatus_	G	G	G	G
34.	_Pterophyllum braunianum_	G	G	G	G
35.	_Sphenobaiera striata_	G	G	G	G
36.	_Sphenozamites rogersianus_	G	G	G	G
37.	_Macrotaeniopteris crassinervis_	G	G		G
38.	_Macrotaeniopteris magnifolia_	G	G		G
39.	_Equisetites milleri_	C			C
40.	_Dictyophyllum_ sp.	C			C
41.	_Lonchopteris oblonga_	C			C
42.	_Sagenopteris rhoifolia?_	G			G
43.	_Pterophyllum giganteum_	G			cf.
44.	_Zamiostrobus lissocardius_*	G			cf.
45.	_Neocalamites knowltonii_	C		C	C
46.	_Pterophyllum inaequale_	G		G	
47.	_Pterophyllum grandifolium_	G		G	
48.	_Stangerites planus_	G		G	
49.	_Neocalamites virginiensis_	C		C	
50.	_Pterophyllum decussatum_	?		G	
51.	_Pterophyllum tenuinervis_		G		
52.	_Equisetites_ sp.		C		
53.	_Neocalamites delawarensis_		cf.		C
54.	_Phlebopteris smithii_		cf.	C	C
55.	_Zamites powellii_		G	G	G
	_Compsostrobus neotericus_*			G	cf.
	Cynepteris cf. _C. lasiophora_			C	
	Pekinopteris auriculata			C	
	Wingatea sp.			C	
	Ischnophyton iconicum			G	
	_Leptocycas gracilis_* _(= I. iconicum)_			G	
	_Metridiostrobus palissyaeoides_*			G	
	_Millerostrobus pekinensis_*			G	
	_Florinostrobus andrewsii_*			G	
	Pagiophyllum "Walchia" brevifolia			G	

		E.C.	M.C.1	M.C.2	L.C.
	Otozamites hespera			G	
	Williamsonia sp.*			G	
	Westersheimia sp.*			G	
	Pelourdea sp.			G	
	Phoenicopsis sp.			G	
	Striatotaxus longifolia			G	G
	Striatotaxus triassica			G	G
	Eoginkgoites sectoralis			G	G
	Dinophyton sp.* (pinwheels + branches)			cf.	G
	cf. *Grammaephloios* sp.*				C
	Cladophlebis reticulata				C
	Isoetes graminoides				C
56.	*Zamiostrobus triassicus**				G
	cf. *Dechellyia* sp.*				G
	Striatotaxus diffusa				G
	Brachyphyllum yorkense				G
	Brachyphyllum conites				G
	Elatocladus wanneri				G
	Glyptolepis spp.* (2 taxa)				G
	Pagiophyllum simpsonii				G
	Pagiophyllum diffusum				G
	Pagiosphyllum sp. A				G
	Pagiosphyllum sp. B				G
	Pagiosphyllum sp. C				G
	"Palissya" sphenolepis (+ cone)				G
	Podozamites distans				G
	Pterophyllum carnallianum				G
	Zamites occidentales				G
	Zamites yorkensis				G
	Otozamites (Zamites) dentalina				G

Numbered taxa occur in Richmond and/or Taylorsville basins.
* = reproductive organs
C = cryptogam (pteridophyte, sphenophyte, or lycophyte)
G = gymnosperm (affinity assumed in absence of any other evidence)

E.C. = early Carnian Richmond basin flora
M.C.1 = middle Carnian Taylorsville basin flora
M.C.2 = middle Carnian Deep River basin flora
L.C. = late Carnian Gettysburg-Newark basin + Dan River basin floras

References: Emmons (1856; 1857); Fontaine (1883); Wanner and Fontaine (1900); Hope, Delevoryas, et al. (1969-1987); Cornet (1977b); Olsen et al. (1978); Axsmith and Kroehler (1989); R. C. Hope (pers. comms., 1990).

TABLE 8

SUMMARY OF MEGAFOSSIL AND PALYNOFLORAL CHANGE THROUGH THE NEWARK SUPERGROUP CARNIAN

MEGAFOSSIL FLORAL EVOLUTION

	#CRYPTOGAM TAXA	#PHANEROGAM TAXA	%CRYPTOGAM TAXA	%PHANEROGAM TAXA	TOTAL #TAXA
E.C.	24(23)	25(22)	49.0(51.1)	51.0(48.9)	49(45)
M.C.1	6(6)	10(10)	37.5(37.5)	62.5(62.5)	16(16)
M.C.2	13(12)	26(19)	33.3(38.7)	66.7(61.3)	39(31)
M.C.	13(12)	29(22)	31.0(35.3)	69.0(64.7)	42(34)
L.C.	10(9)	36(29)	21.7(23.7)	78.3(76.3)	46(38)

Key: leaf/vegetative + reproductive taxa (leaf or vegetative taxa only)

PALYNOFLORAL EVOLUTION

	#SPORE SPECIES	#POLLEN SPECIES	%SPORE SPECIES	%POLLEN SPECIES	TOTAL #SPECIES	#FIRST OCCURRENCE	#LAST* OCCURRENCE
E.C.	27	50	35.1%	64.9%	77	65	10
M.C.	39	60	40.6%	59.4%	99	28	47
L.C.	10	37	22.7%	77.3%	47	5	20
N.	5	45	10.0%	90.0%	50	27	18
R.	11	79	12.2%	87.8%	90	51	82
B.J.	15	3	83.3%	16.7%	18	6	9
H.	12	13	48.0%	52.0%	25	15	10

E.C. = early Carnian Richmond basin megaflora/palynoflora.
M.C.1 = middle Carnian Taylorsville basin megaflora/palynoflora.
M.C.2 = middle Carnian Deep River basin megaflora/palynoflora.
M.C. = middle Carnian Taylorsville basin + Deep River basin megaflora/palynoflora.
L.C. = late Carnian Gettysburg-Newark basin + Dan River basin megaflora/palynoflora.
N. = early-middle Norian Culpeper, Gettsburg, and Newark basins palynoflora.
R. = late Norian (Rhaetian) Culpeper, Gettysburg, and Newark basins palynoflora.
B.J. = basal Jurassic Newark basin (fern spike singularity and coal) palynoflora.
H. = Hettangian Culpeper and Newark basins palynoflora.
* = Number last occurrences within or at the end of each epoch; in other words, these species are not present in the succeeding (younger) epoch.

TABLE 9

	PALYNOMORPH GROUP	RELATIVE PERCENTAGES	RANGE AND AVERAGE %		
	PALYNOMORPH GROUP	BOSCOBEL	L.P.C.M.	U.P.C.M.	L.V.B.M.
	( ) = number of palynoflorules		(7)	(7)	(53)
1	STRIATE BISACCATES	0.8%	0.0-0.6	0.0-1.1	0.0-5.5*
			0.1 av.	**0.2 av.**	**0.7 av.**
2	LARGE BISACCATES	60.3%	2.7-8.7	5.9-15.4	7.1-64.8**
			5.8 av.	**10.9 av.**	**31.7 av.**
3	SMALL BISACCATES	12.8%	0.0-2.3	0.0-4.5	0.9-9.7*
			1.4 av.	**1.3 av.**	**2.8 av.**
4	CIRCUMSACCATES	5.8%	1.6-4.0	2.5-10.8*	1.3-72.7
			2.8 av.	**5.0 av.**	**20.1 av.**
5	MONOPORATE TETRADS	11.3%	0.0-1.4	0.0-3.1	0.0-17.6**
	and *Placopollis*		**0.4 av.**	**1.0 av.**	**4.8 av.**
6	MONOSULCATES and	1.9%	14.9-25.0	0.0-18.2	0.0-29.6*
	POLYPLICATES		**18.9 av.**	**9.4 av.**	**6.9 av.**
7	CIRCUMPOLLES and	2.3%	0.0-3.0	0.0-8.1	0.0-16.1*
	Camerosporites		**1.2 av.**	**1.5 av.**	**2.6 av.**
8	ARTICULATE SPORES	0.0%	3.5-21.4	7.2-22.4	0.0-41.7**
			11.7 av.	**15.2 av.**	**7.0 av.**
9	LYCOPOD SPORES	1.2%	23.1-41.5	17.5-50.5	0.0-49.1**
			30.0 av.	**36.5 av.**	**6.2 av.**
10	PSILATE SPORES	3.1%	3.5-7.2	0.0-9.8*	0.0-19.2
			5.0 av.	**4.6 av.**	**6.6 av.**
11	SCULPTURED SPORES	0.4%	15.4-34.1	9.2-18.8	0.0-33.9**
			22.9 av.	**14.4 av.**	**8.0 av.**
12	RELATIVE ABUNDANCE	51.4	11.5-34.7	1.3-24.7	1.1-195.0*
	(number of palynomorphs per		**21.8 av.**	**10.0 av.**	**19.4 av.**
	traverse of slide)		0 areas	2 areas	10 areas

Number of areas of correlation:
* = Areas of closest compositional correlation.
** = Areas of significant (obvious) correlation.
L.P.C.M. = lower Productive Coal Measures Member.
U.P.C.M. = upper Productive Coal Measures Member.
L.V.B.M. = lower Vinita Beds Member.

TABLE 10

PALYNOMORPH GROUP	RELATIVE PERCENTAGES		RANGE AND AVERAGE %	
	BONE #6	**O.H.#2**	**L.T.C.M.**	**M.T.C.M.**
( ) = number of palynoflorules			(18)	(13)
Palynofloral Zone (Cornet, 1989a):			2C	3C
1 STRIATE BISACCATES	0.8%	3.2%	0.0-0.7 **0.1 av.**	0.0-5.3* **0.7 av.**
2 LARGE BISACCATES	33.5%	82.6%	12.4-39.6 **22.5 av.**	20.0-73.0** **50.7 av.**
3 SMALL BISACCATES	6.1%	2.2%	0.0-4.5 **1.8 av.**	0.0-12.2* **4.5 av.**
4 CIRCUMSACCATES	0.8%	2.2%	0.0-17.3* **6.1 av.**	0.0-47.4 **25.1 av.**
5 MONOPORATE TETRADS and *Placopollis*	55.8%	5.4%	0.0-2.7 **0.2 av.**	0.0-12.4** **2.1 av.**
6 MONOSULCATES and POLYPLICATES	1.3%	0.0%	0.0-4.5* **1.1 av.**	0.0-15.8 **2.2 av.**
7 CIRCUMPOLLES and *Camerosporites*	0.0%	1.1%	0.0-4.1 **0.9 av.**	0.0-4.4 **0.9 av.**
8 ARTICULATE SPORES	0.4%	1.1%	27.3-75.0 **50.4 av.**	0.0-10.7** **4.5 av.**
9 LYCOPOD SPORES	0.0%	0.0%	0.0-13.6 **2.4 av.**	0.0-3.3* **0.3 av.**
10 PSILATE SPORES	1.3%	2.2%	0.0-13.6* **3.9 av.**	0.0-16.7 **5.7 av.**
11 SCULPTURED SPORES	0.0%	0.0%	0.0-40.2 **10.7 av.**	0.0-18.2* **4.0 av.**
12 RELATIVE ABUNDANCE (number of palynomorphs per traverse of slide)	23.3	8.4	1.1-25.9 **11.2 av.**	1.3-43.6* **14.4 av.**
Total number of areas of correlation:			3 areas	8 areas

* = Areas of closest compositional correlation.
** = Areas of significant (obvious) correlation.
L.T.C.M. = lower Tomahawk Creek Member.
M.T.C.M. = middle Tomahawk Creek Member.

The Bone #6 sample location occurs directly below the Tomahawk bone bed in a gray shale layer containing rare fern pinnules and unidentifiable but common plant fragments. The O.H. #2 sample location occurs about 480 feet due south of the Tomahawk bone bed at a bend in Old Hundred Road in a black shale layer containing fish scales. It stratigraphically occurs below Bone #6, and is separated from that layer by an interval of sandstone.

THE FONTAINE AND BOCK RICHMOND-TAYLORSVILLE FLORA

Alphabetical Listing with Plate References

Acrostichites linnaeaefolius (Bunbury) Fontaine	Plates 7 and 11
Auriculophora acrostichoides Bock	Plate 9
Cladophlebis auriculata Fontaine	Plate 11
Cladophlebis mexicana (Newberry) Bock	Plate 11
possible synonyms:	
Cladophlebis ovata Fontaine	Plate 10 and 11
Cladophlebis pseudowhitbiensis Fontaine	Plate 11
Cladophlebis subfalcata Fontaine	Plate 10
Clathropteris meniscoides (Brongn.) Brongniart	Plate 3
Cyathocaulis carolinesis Bock	Plate 6
Cyathoforma carolinensis (Emmons) Bock	Plates 4, 5, 9
Cyathoforma minuta Bock	Plate 2
Cyathoforma penticarpa (Fontaine) Bock	Plate 5
Danaeopsis virginiensis Bock	Plate 9
Dicranopteris sp.	Not illustrated
Equisetites richmondensis Bock	Plate 1
Equisetites rogersii (Bunbury) Bock	Plate 1
Equisetites milleri Bock	Not illustrated
Gleichenites distans (Fontaine) Bock	Plate 8
Isoetodendron striata Bock	Not illustrated
Leptocyclotes americana Bock	Plate 2
Lonchopteris oblonga (Emmons) Bock	Plates 9 and 10
Macrotaeniopteris crassinervis (Rogers) Schimper	Plate 12
Macrotaeniopteris magnifolia (Rogers) Schimper	Plate 12
Mertensides bullatus (Bunbury) Fontaine	Plates 8 and 9
Neocalamites cf. *N. delawarensis* Bock	Not illustrated
Neocalamites knowltonii Berry	Not illustrated
Neocalamites virginiensis (Fontaine) Berry	Plate 1
Osmundites winterpockensis Bock	Plate 6
Pagiophyllum sp. (Walchia brevifolia Emmons)	Plate 20
Pecopteris rarinervis Fontaine	Not illustrated
Phlebopteris cf. *P. smithii* (Daugherty) Arnold	Plate 9
Plicarizamites lanceolatus Bock	Not Illustrated
Podozamites lanceolatus Lindley and Hutton	Plate 20
Podozamites tenuistriatus (Rogers) Fontaine	Plate 20
Primaraucaria wielandii Bock	Plate 13
Pteridocaulis rhombiformis Bock	Plate 6
Pteridocaulis facialis Bock	Plate 6
Pterophyllum affine Nathorst	Plate 17
Pterophyllum braunianum Goeppert	Plates 16 and 17
Pterophyllum inaequale Fontaine	Plate 17
Pterophyllum decussatum (Emmons) Fontaine	Not illustrated
Pterophyllum giganteum (Fontaine) nov. comb.	Plate 17
Pterophyllum grandifolium (Fontaine) nov. comb.	Plate 18
Pterophyllum taxinum (Lindley & Hutton) nov. comb.	Plate 20
Pterophyllum tenuinervis (Fontaine) nov. comb.	Plate 20
Sagenopteris rhoifolia?	Not illustrated
possible *Sanmiguelia*-like leaves.	Not illustrated
Sphenobaiera striata (Emmons) Bock	Plate 14
Sphenopteris sitholeyi Bock	Plate 2
Sphenozamites rogersianus Fontaine	Plate 19
Stangerites obliqua Emmons	Plate 15
Stangerites planus Emmons	Plate 15
Taeniopteris diminuta Bock	Plate 12
Triassiflorites grandiflora Bock	Plate 13
Zamiostrobus lissocardius Bock	Not illustrated
Zamiostrobus triassicus Bock	Not illustrated
Zamites powellii Fontaine	Plate 20

LIST OF PLATES

Specimen size indicated adjacent to illustration. Illustrations are reduced from Fontaine (1883) and Bock (1969).

Plate 1
Equisetites richmondensis
Equisetites rogersii
Neocalamites virginiensis

Plate 2
Cyathoforma minuta
Leptocyclotes americana
Sphenopteris sitholeyi

Plate 3
Clathropteris meniscoides

Plate 4
Cyathoforma carolinensis

Plate 5
Cyathoforma carolinensis
Cyathoforma penticarpa

Plate 6
Cyathocaulis carolinensis
Osmundites winterpockensis
Pterocaulis facialis
Pterocaulis rhombiformis

Plate 7
Acrostichites linnaeaefolius

Plate 8
Mertensides bullatus
Gleichenites distans

Plate 9
Auriculophora acrostichoides
Cyathoforma carolinensis
Cyathoforma penticarpa
Danaeopsis virginiensis
Lonchopteris oblonga
Mertensides bullatus
Phlebopteris cf. *P. smithii*

Plate 10
Cladophlebis ovata
Cladophlebis subfalcata
Lonchopteris oblonga

Plate 11
Acrostichites linnaeaefolius
Cladophlebis auriculata
Cladophlebis mexicana
Cladophlebis ovata
Cladophlebis pseudowhitbiensis

Plate 12
Macrotaeniopteris crassinervis
Macrotaeniopteris magnifolia
Taeniopteris diminuta

Plate 13
Primaraucaria wielandii
Triassiflorites grandiflora

Plate 14
Sphenobaiera striata

Plate 15
Stangerites obliqua
Stangerites planus

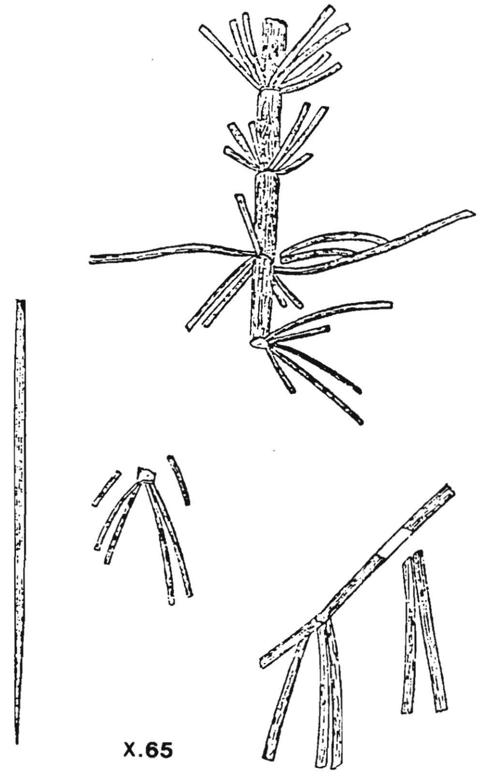
Plate 16
Pterophyllum braunianum

Plate 17
Pterophyllum affine
Pterophyllum braunianum
Pterophyllum giganteum
Pterophyllum inaequale

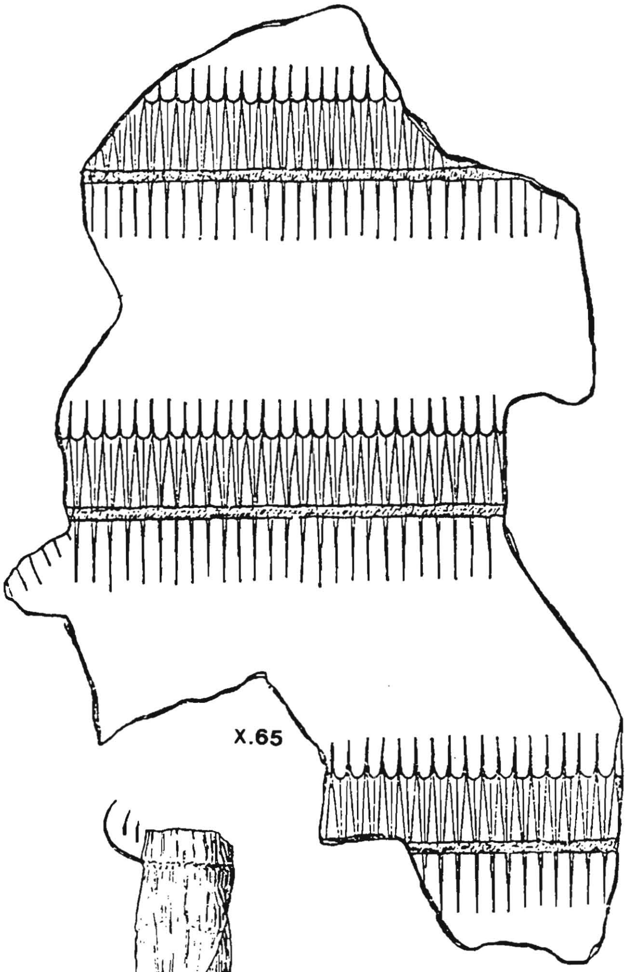
Plate 18
Pterophyllum grandifolium

Plate 19
Sphenozamites rogersianus

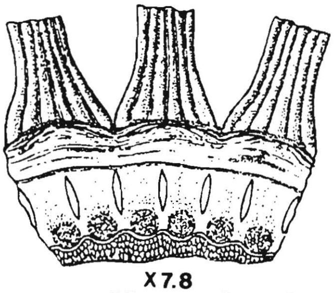
Plate 20
Leaves similar to those associated with *Compsostrobus neotericus* female conifer cones.
Male cone associated with *P. tenuistriatus.*
Pagiophyllum sp. (*Walchia brevifolia* Emmons)
Podozamites lanceolatus
Podozamites tenuistriatus
Pterophyllum taxinum
Pterophyllum tenuinervis
Zamites powellii

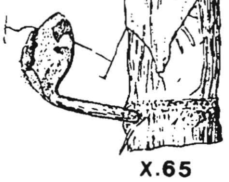


Neocalamites virginiensis

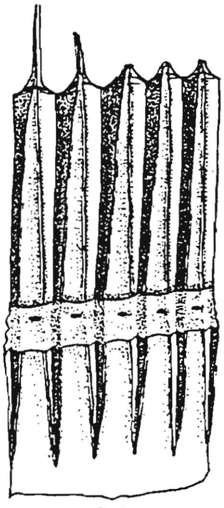


Equisetites rogersii

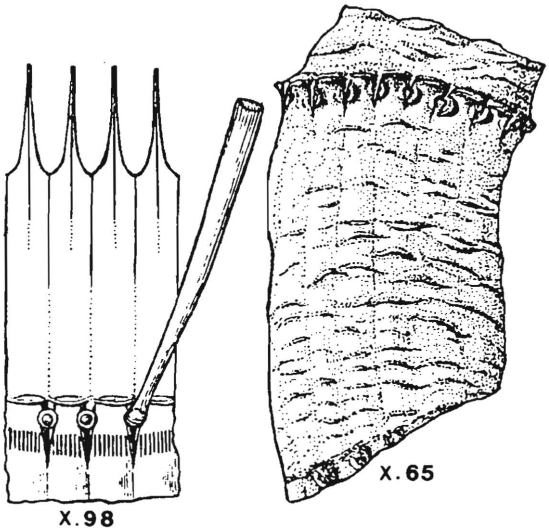




Neocalamites virginiensis

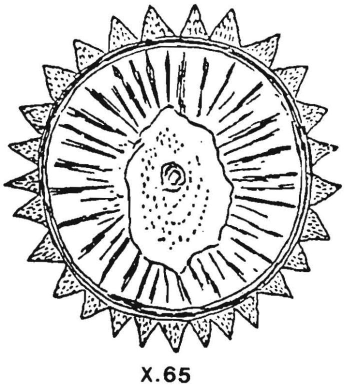


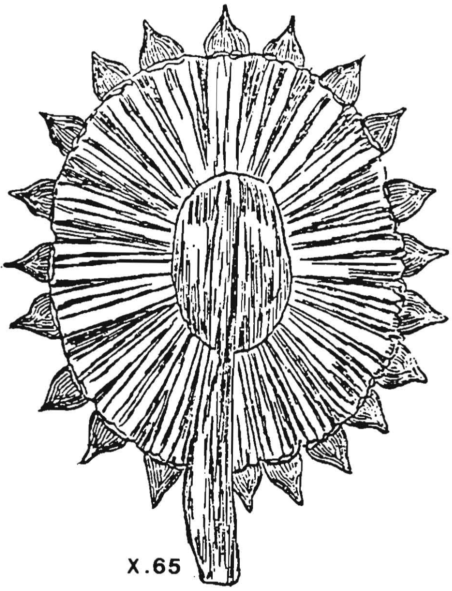
Equisetites rogersii

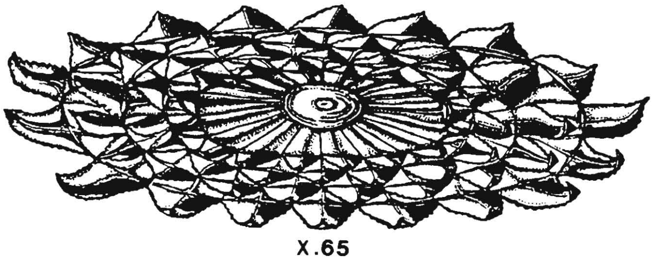


Equisetites richmondensis

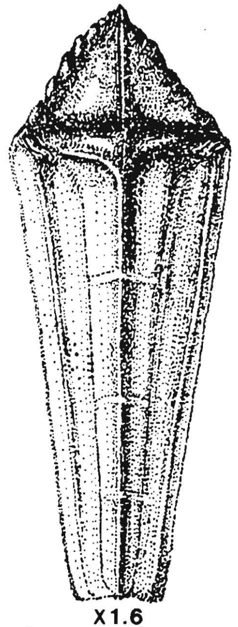
Plate 1



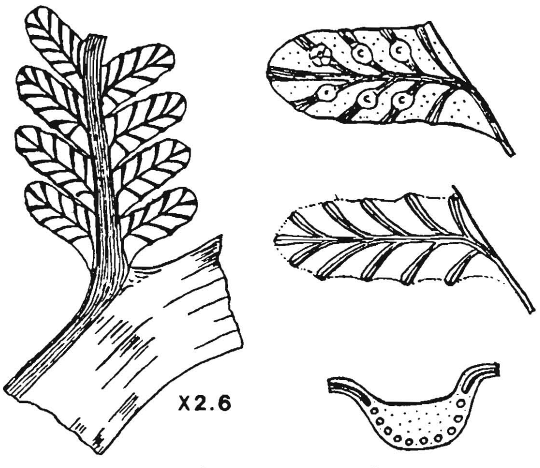




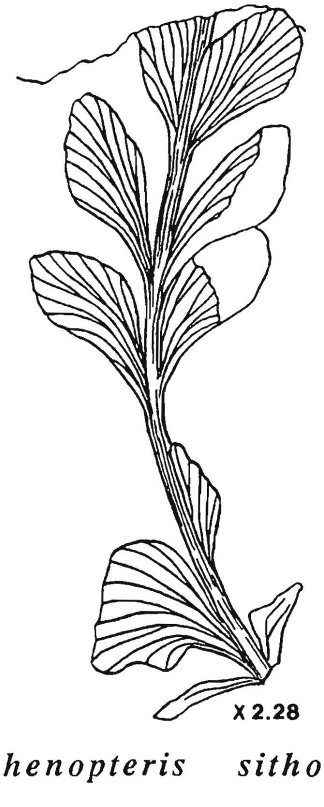
Leptocyclotes americana



Leptocyclotes americana

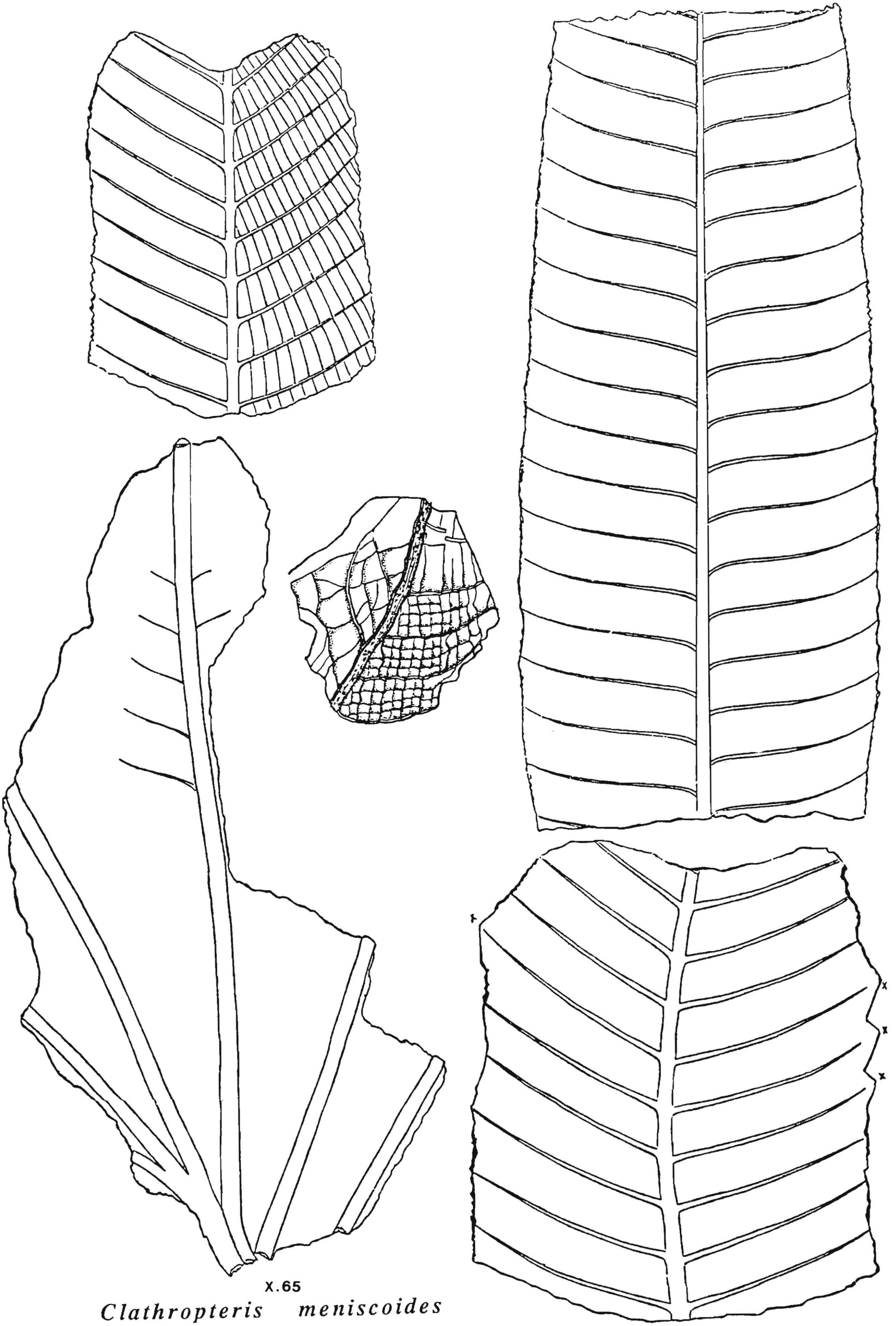


Cyathoforma minuta



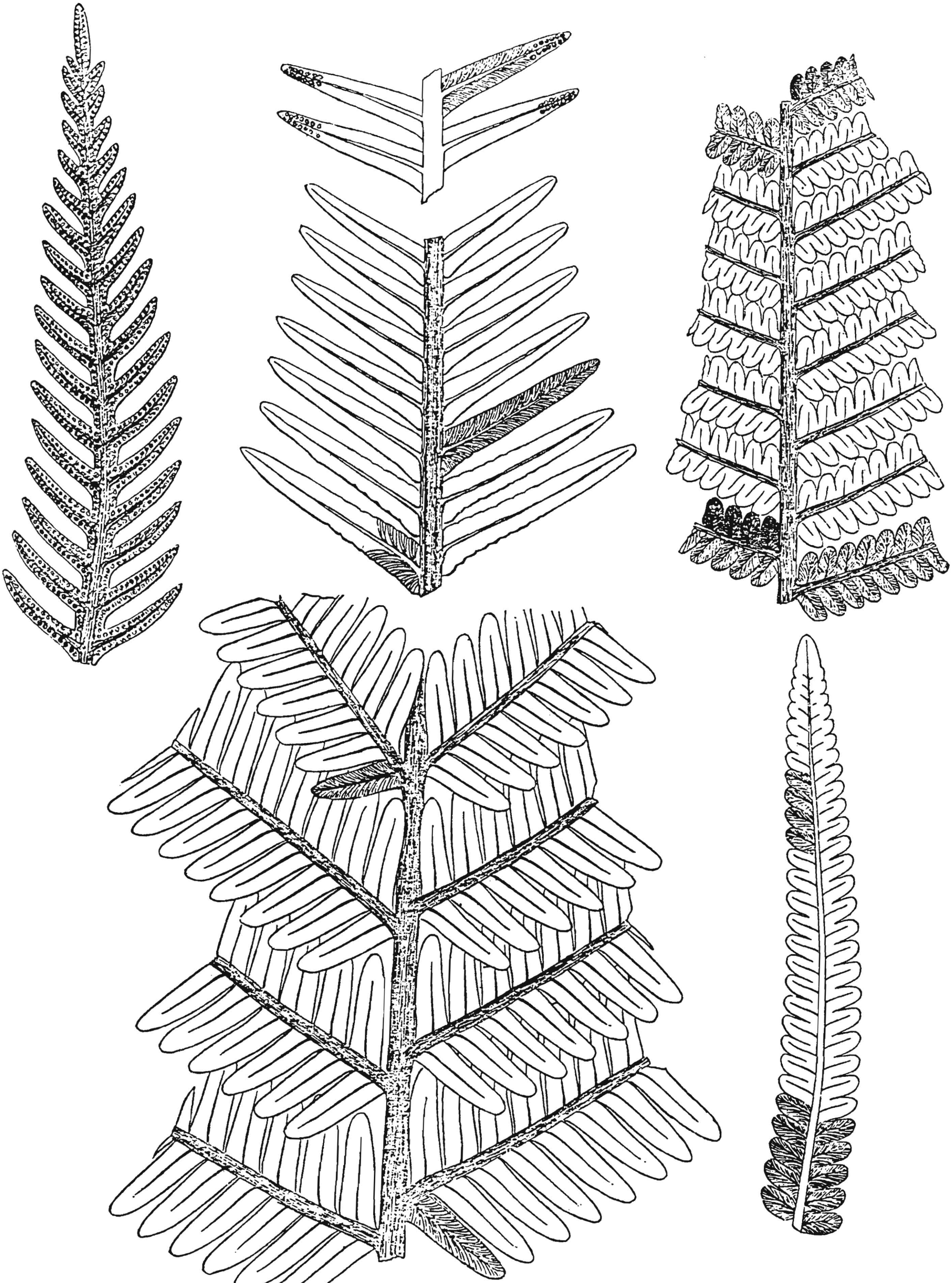
Sphenopteris sitholeyi

Plate 2



Clathropteris meniscoides

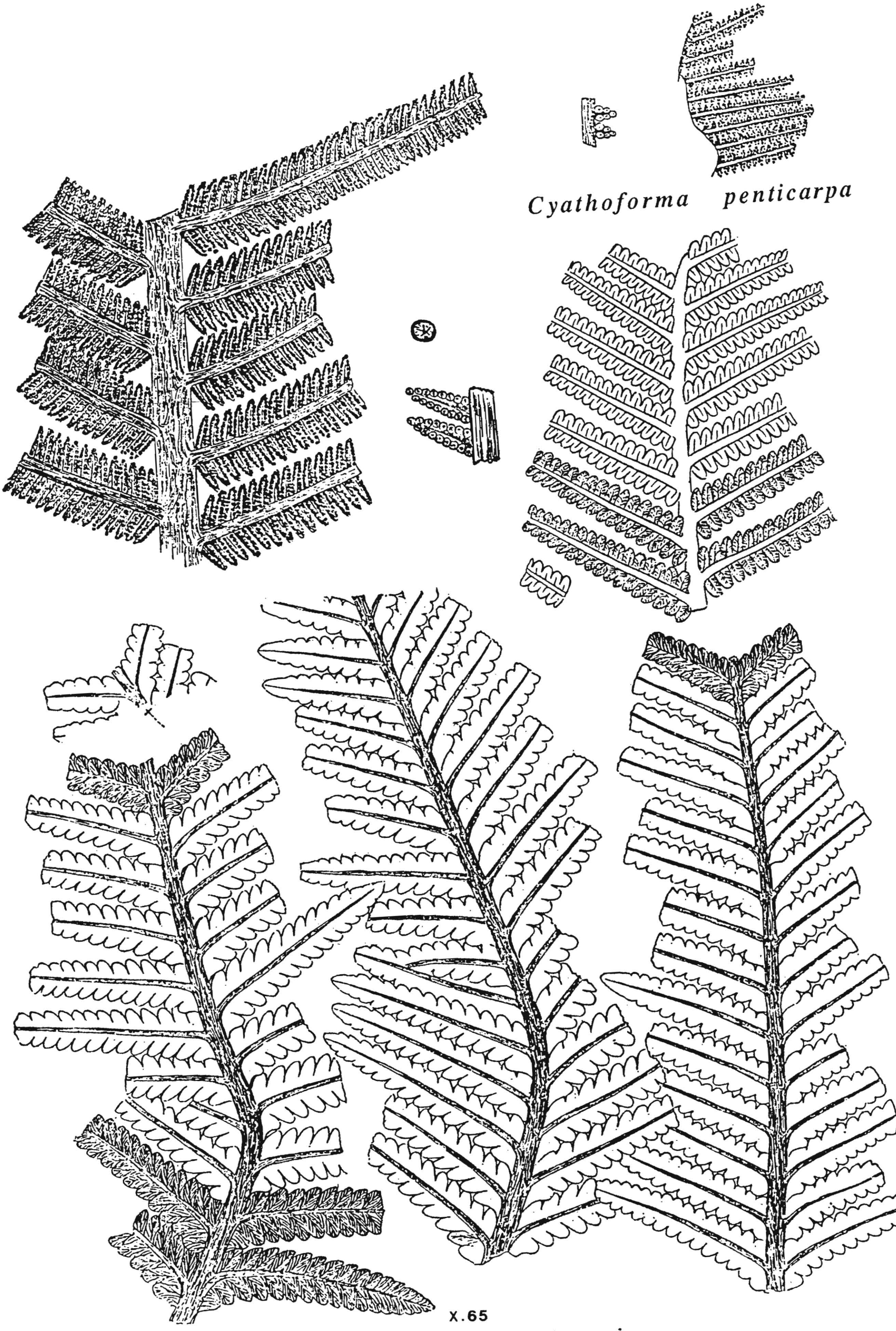
Plate 3



X.65

Cyathoforma carolinensis

Plate 4

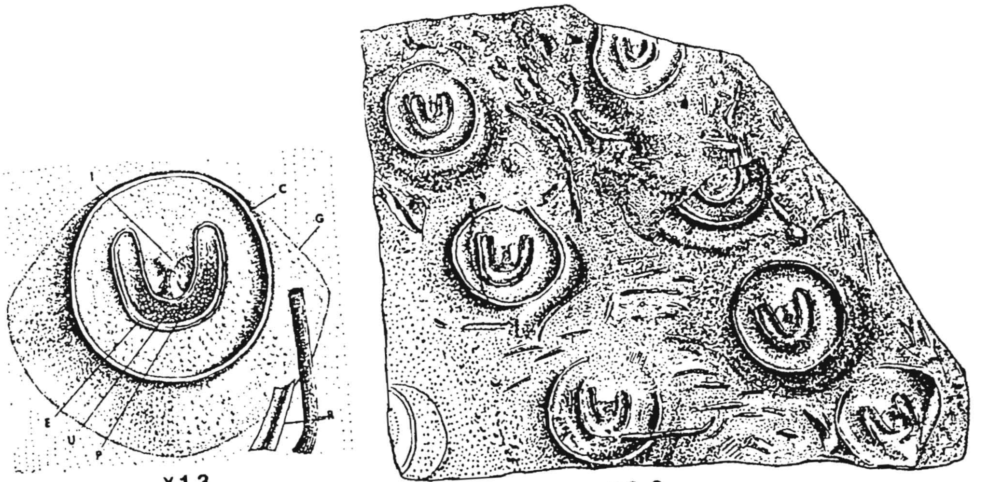


Cyathoforma penticarpa

X.65

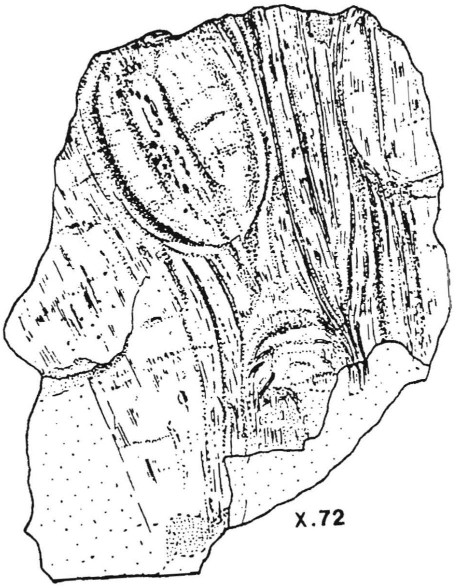
Cyathoforma carolinensis

Plate 5



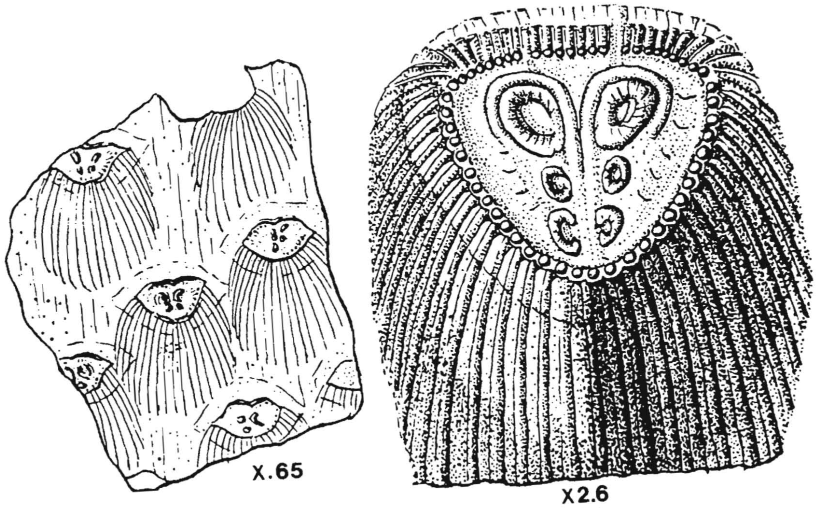
X1.3 X2.6

Osmundites winterpockensis



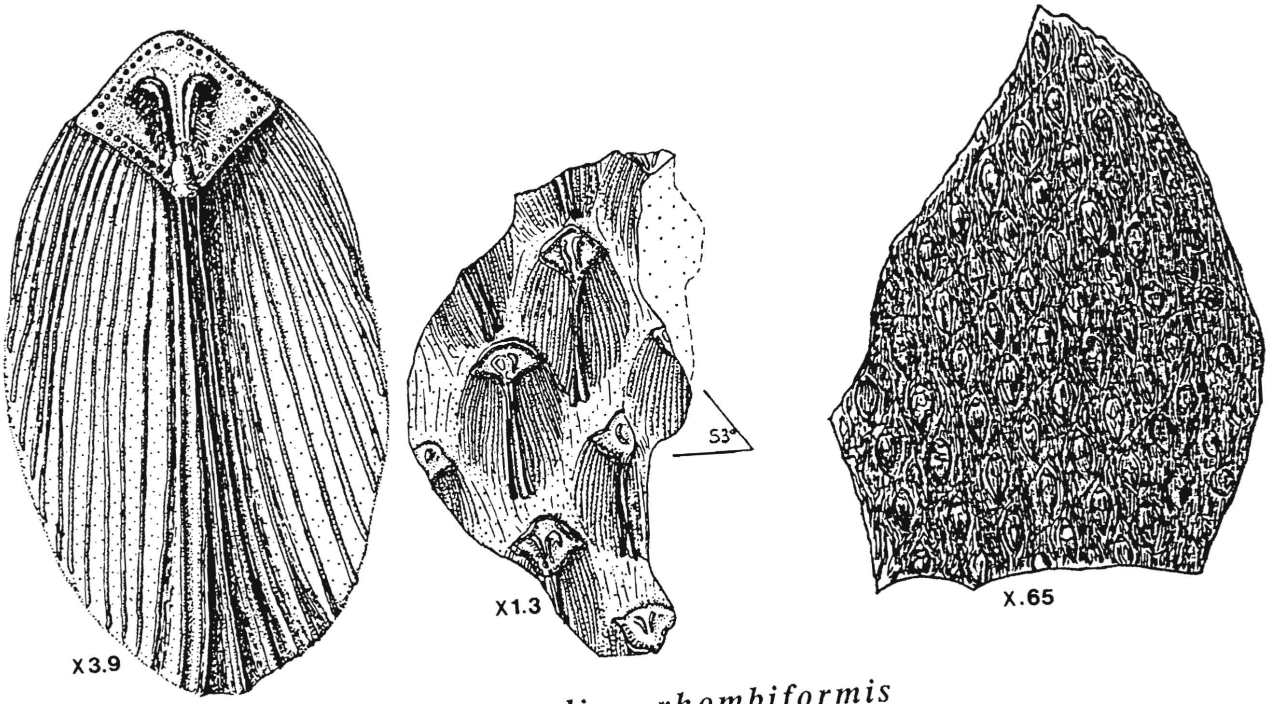
X.72

Cyathocaulis carolinensis



X.65 X2.6

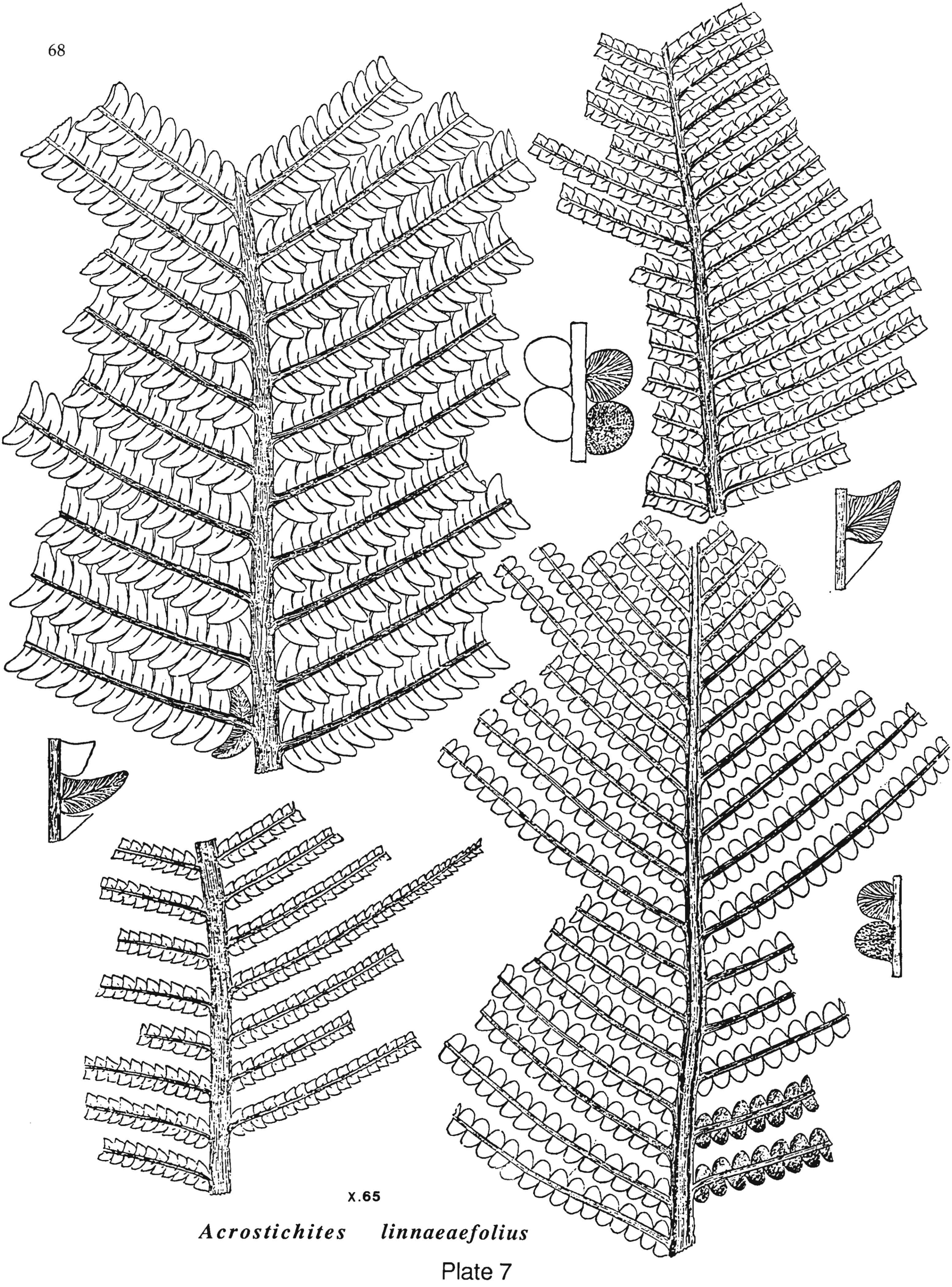
Pteridocaulis facialis



X3.9 X1.3 X.65

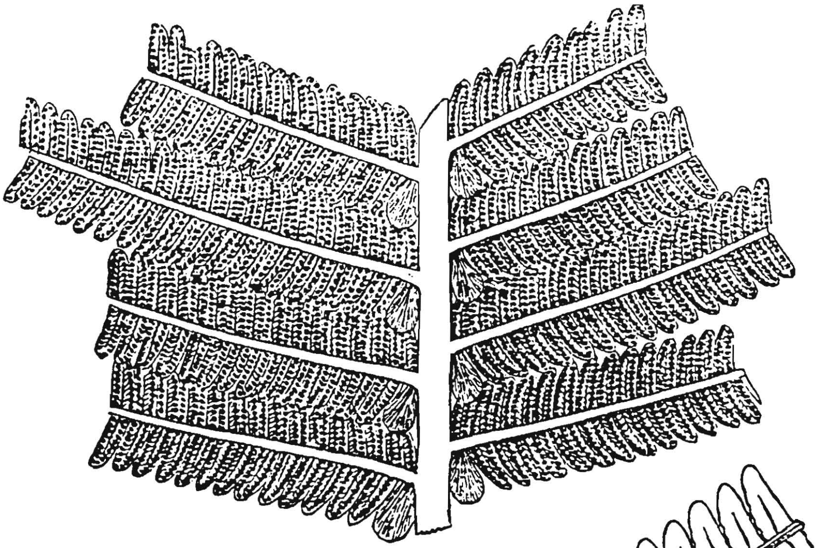
Pteridocaulis rhombiformis

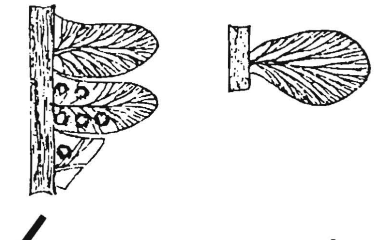
Plate 6

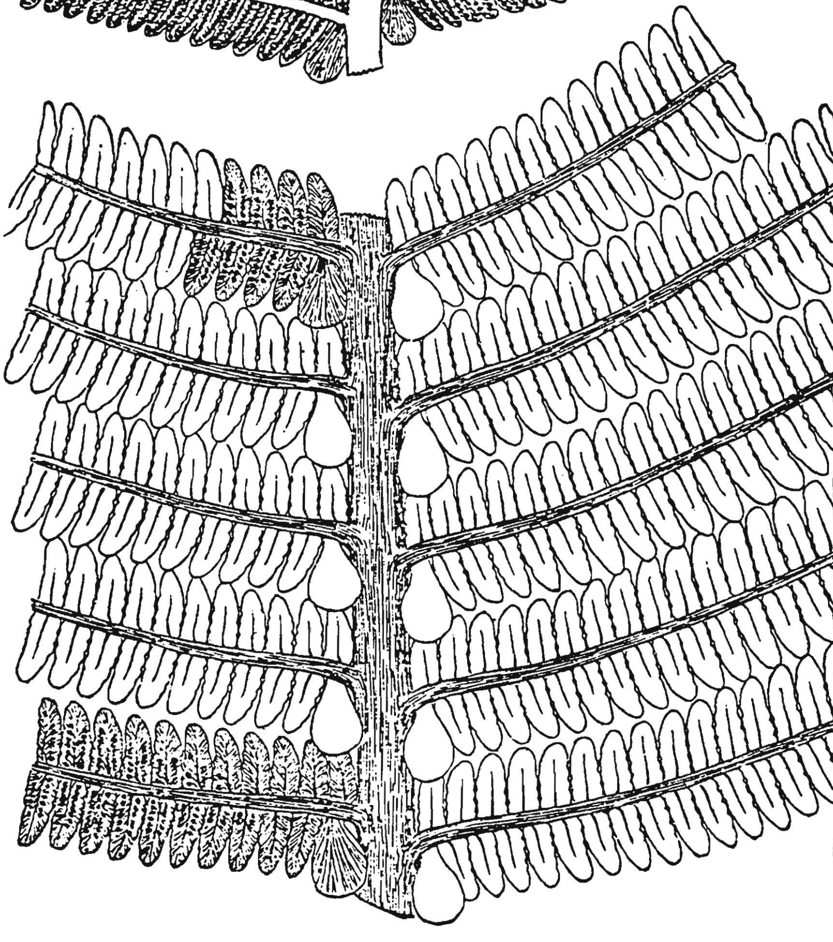


Acrostichites linnaeaefolius

Plate 7

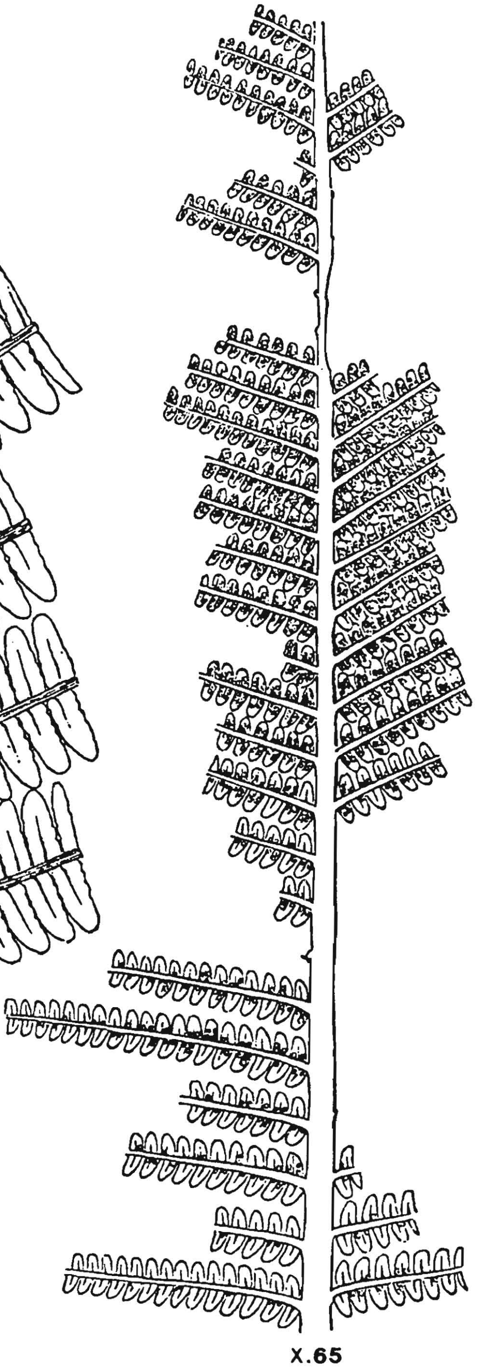






X.65

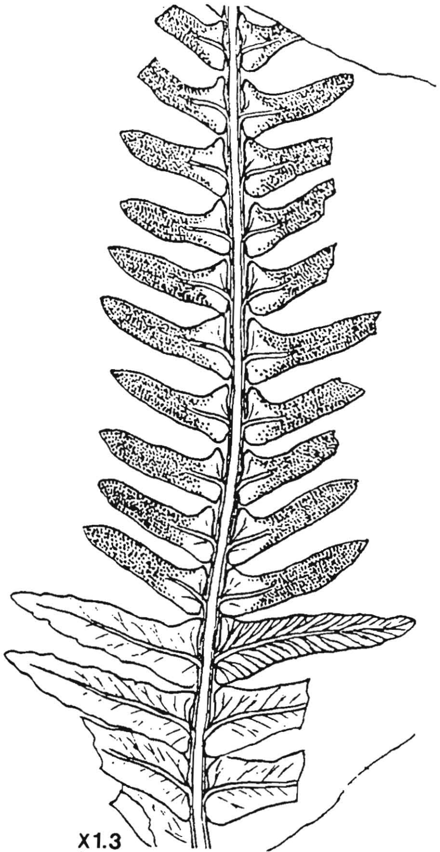
Mertensides bullatus



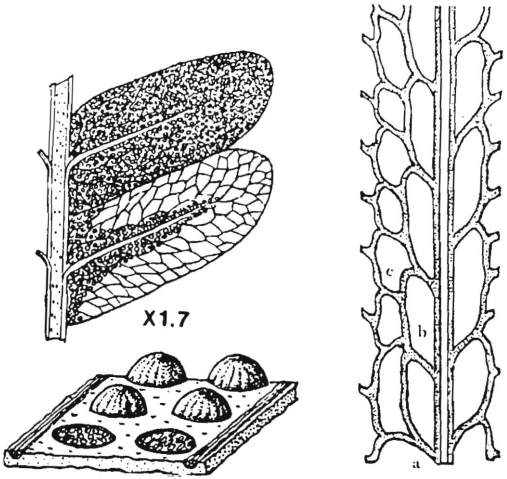
X.65

Gleichenites distans

Plate 8

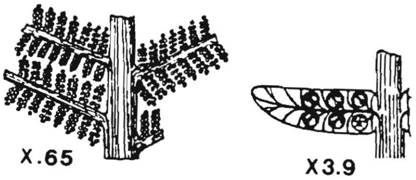


Auriculophora acrostichoides

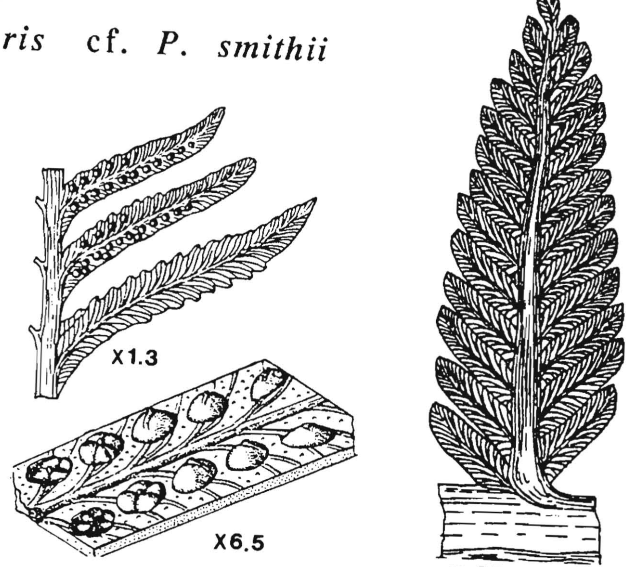


Lonchopteris oblonga

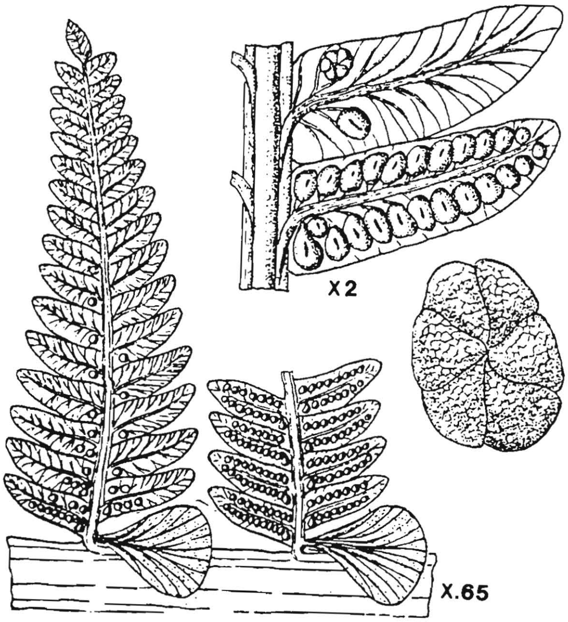
Phlebopteris cf. *P. smithii*



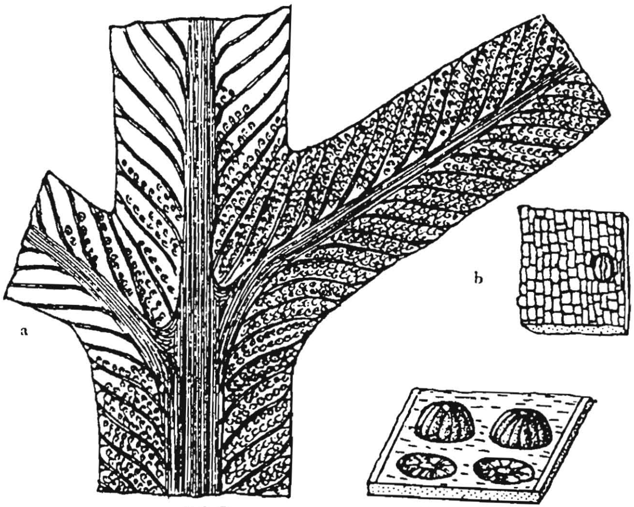
Cyathoforma penticarpa



Cyathoforma carolinensis

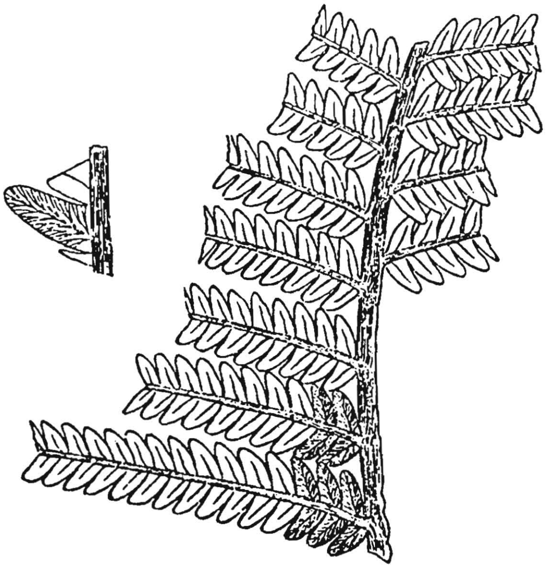


Mertensides bullatus

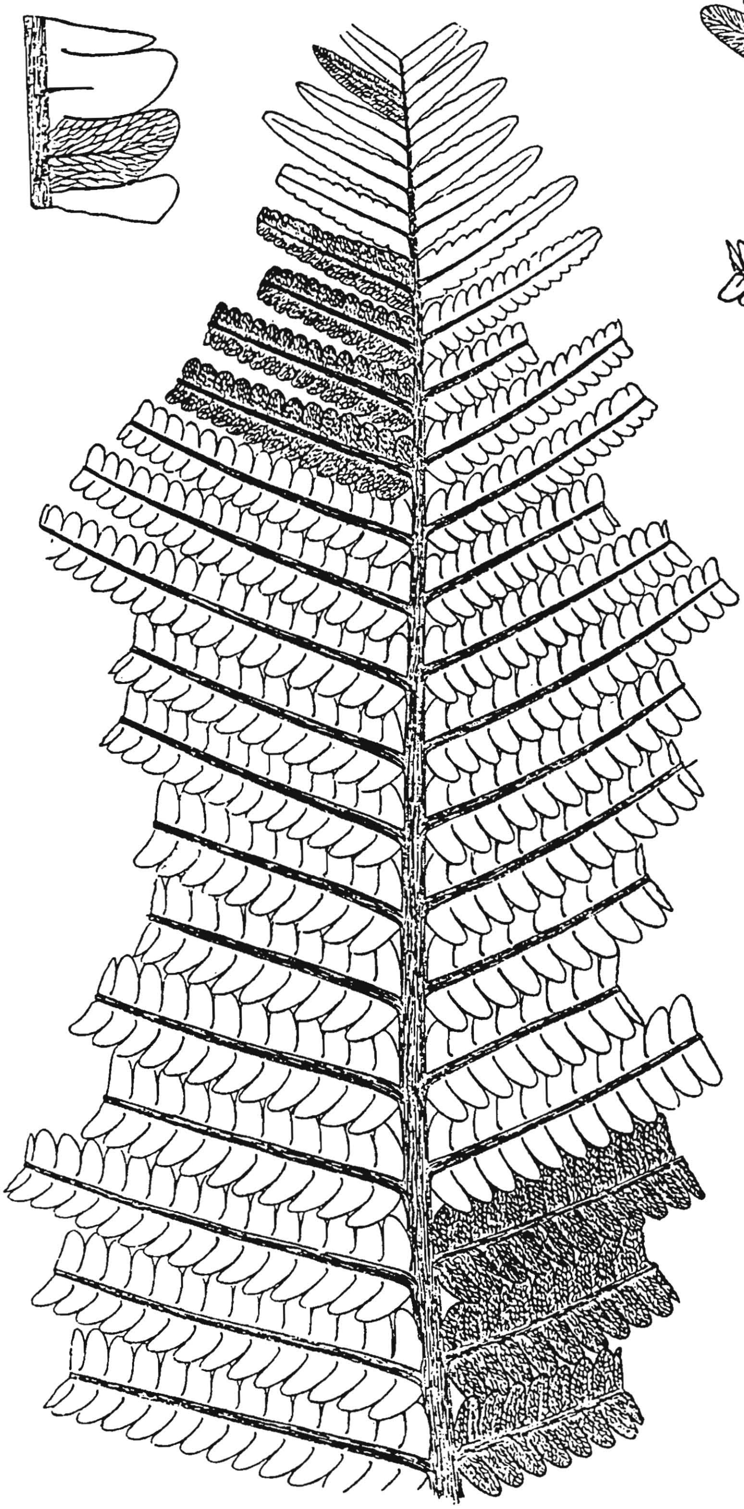


Danaeopsis virginiensis

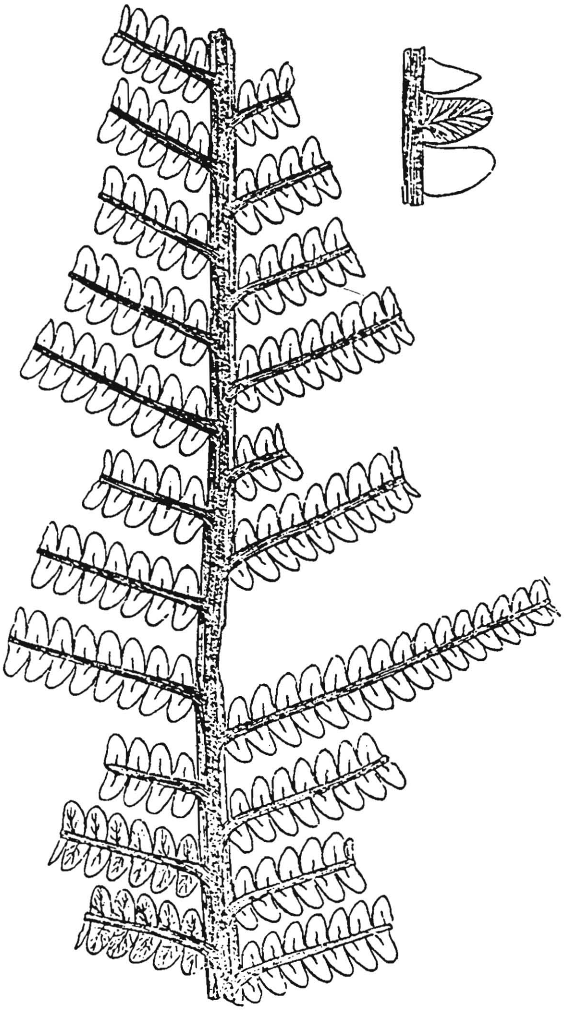
Plate 9



X.65
Cladophlebis subfalcata

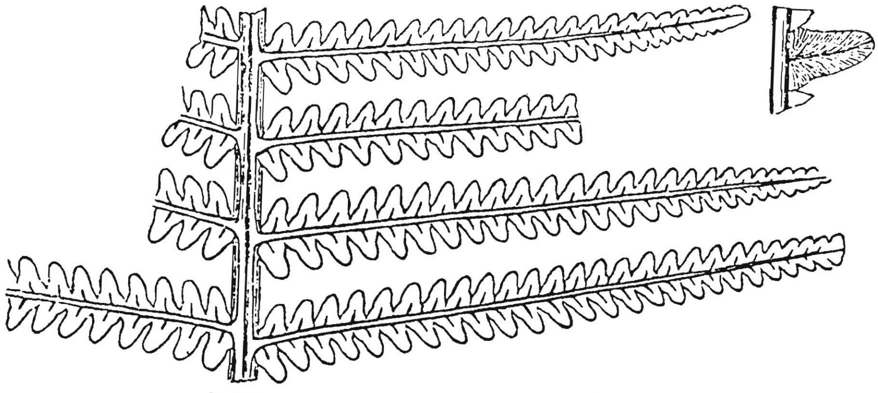


X.65
Lonchopteris oblonga

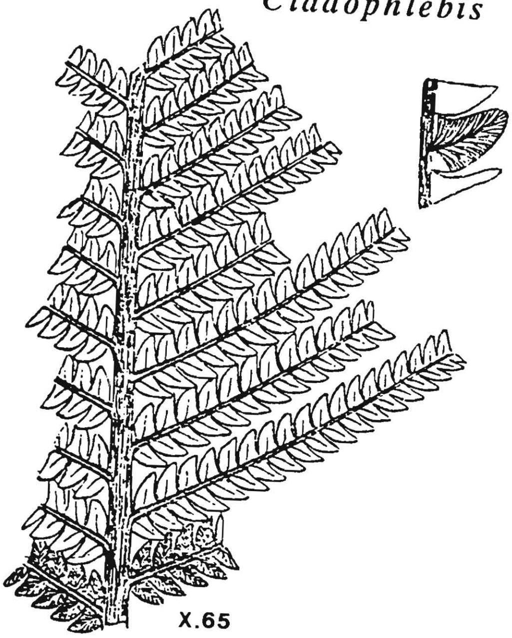


X.65
Cladophlebis ovata

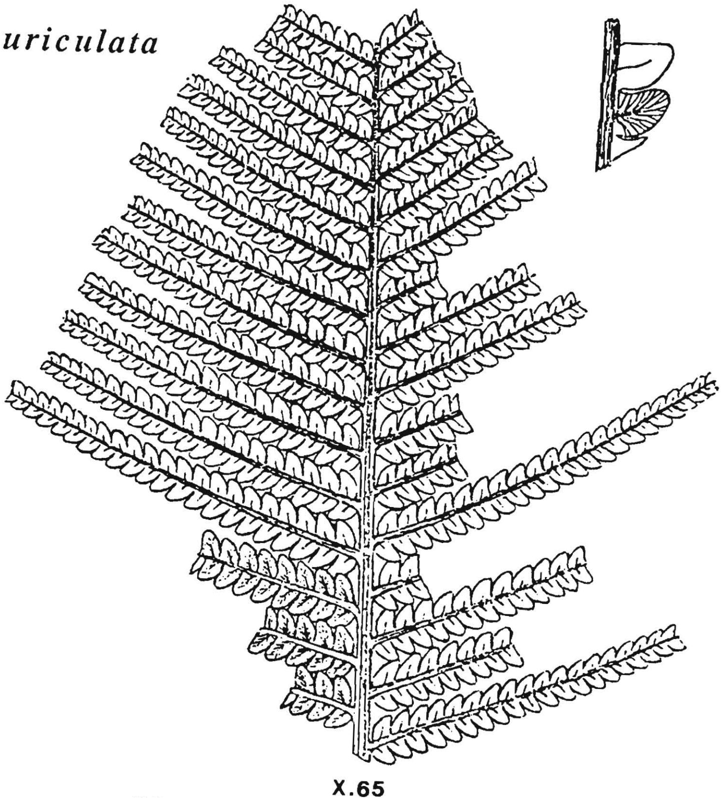
Plate 10



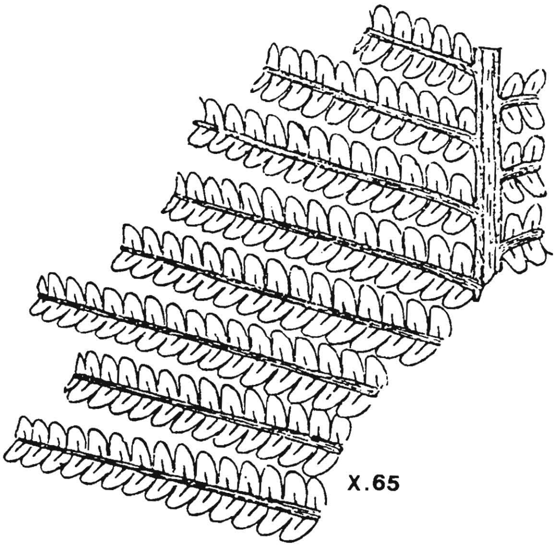
Cladophlebis auriculata



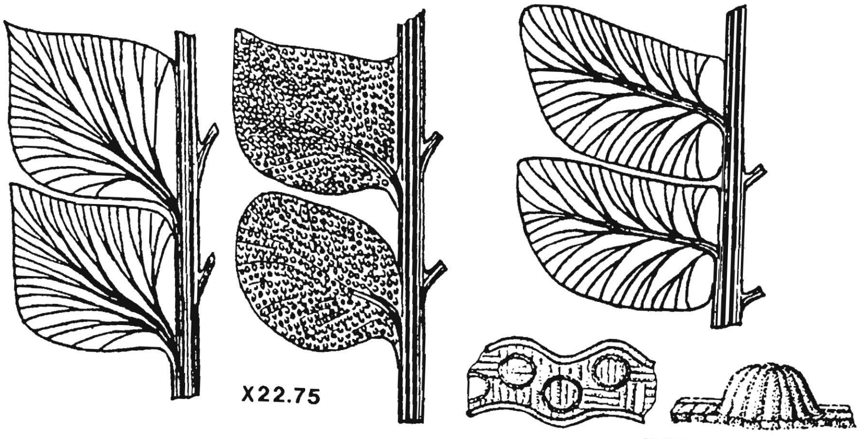
Cladophlebis pseudowhitbiensis



Cladophlebis mexicana

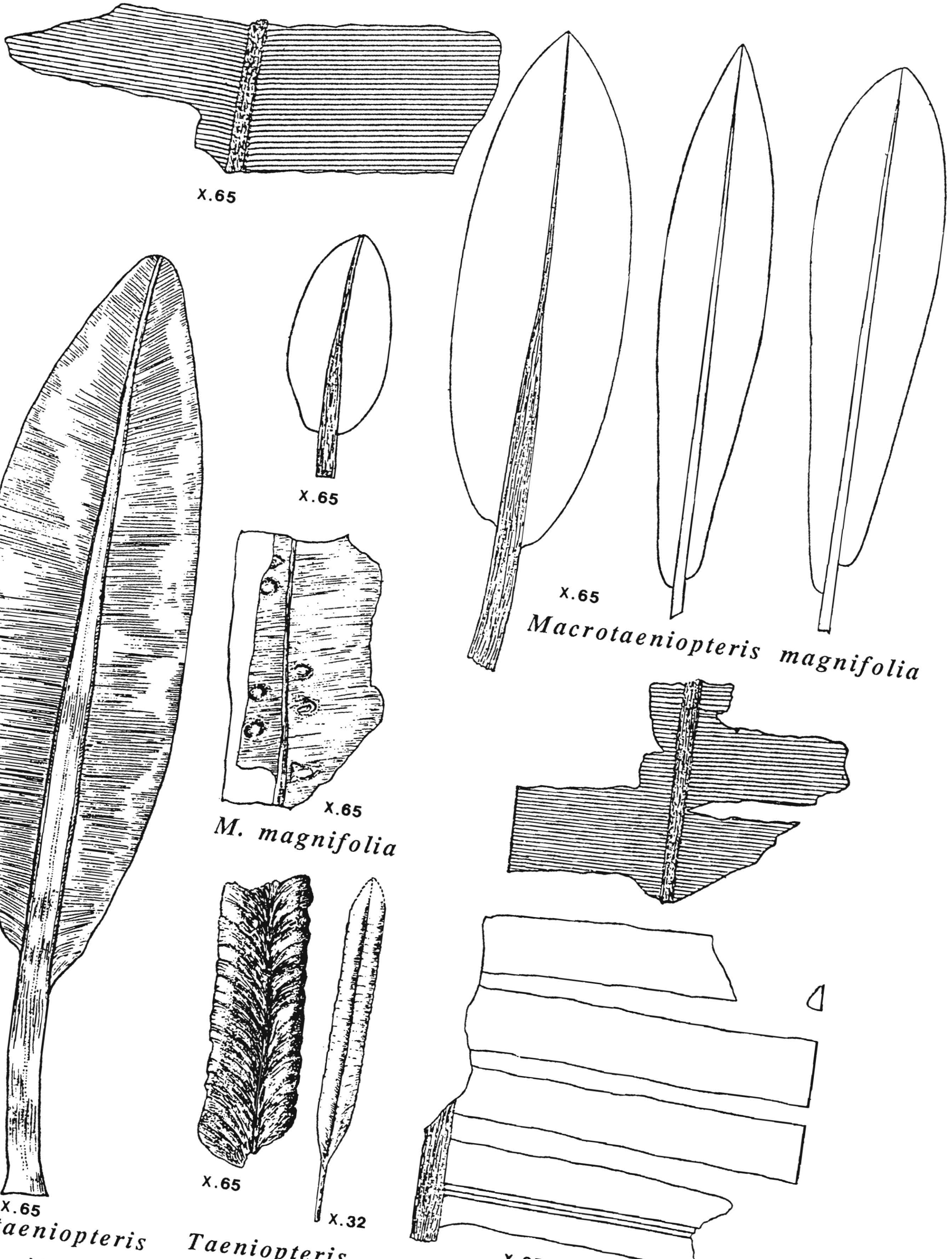


Cladophlebis ovata



Acrostichites linnaeaefolius

Plate 11



Macrotaeniopteris magnifolia

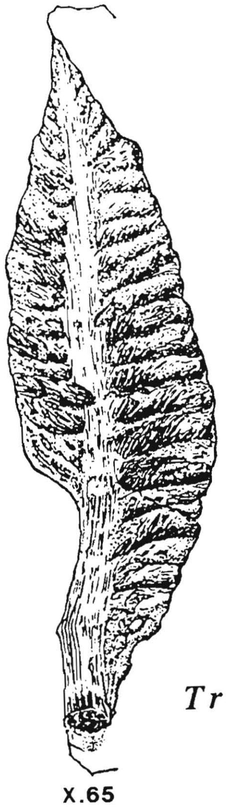
M. magnifolia

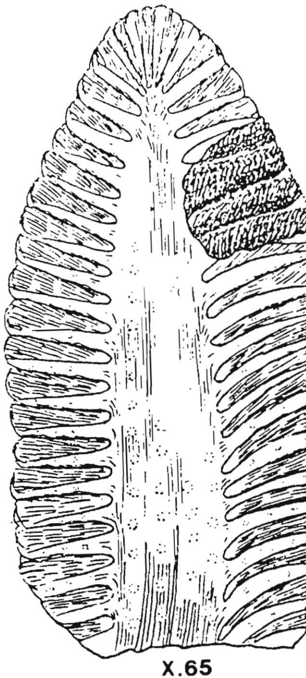
Macrotaeniopteris magnifolia

Taeniopteris diminuta

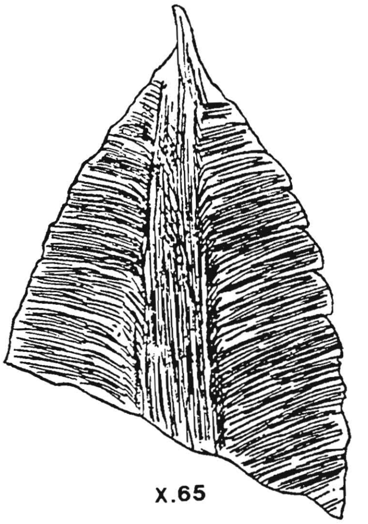
Macrotaeniopteris crassinervis

Plate 12

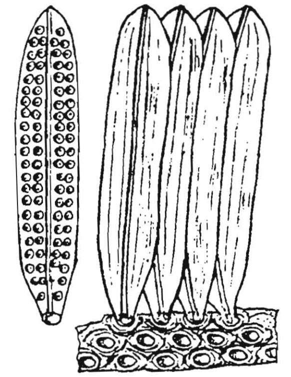


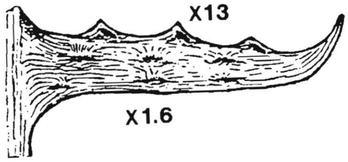


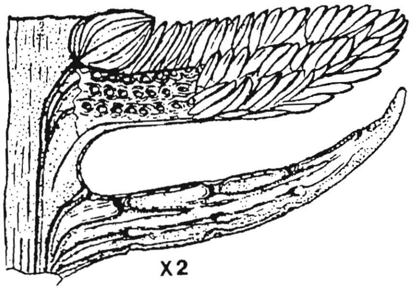
Triassiflorites grandiflora

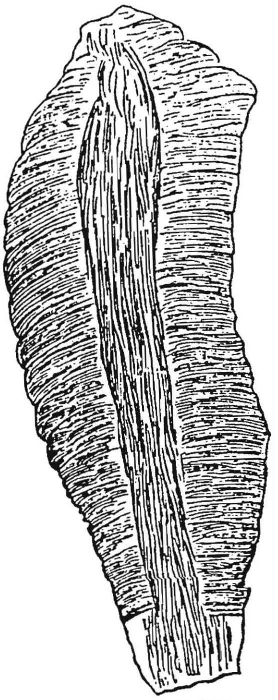


Triassiflorites grandiflora

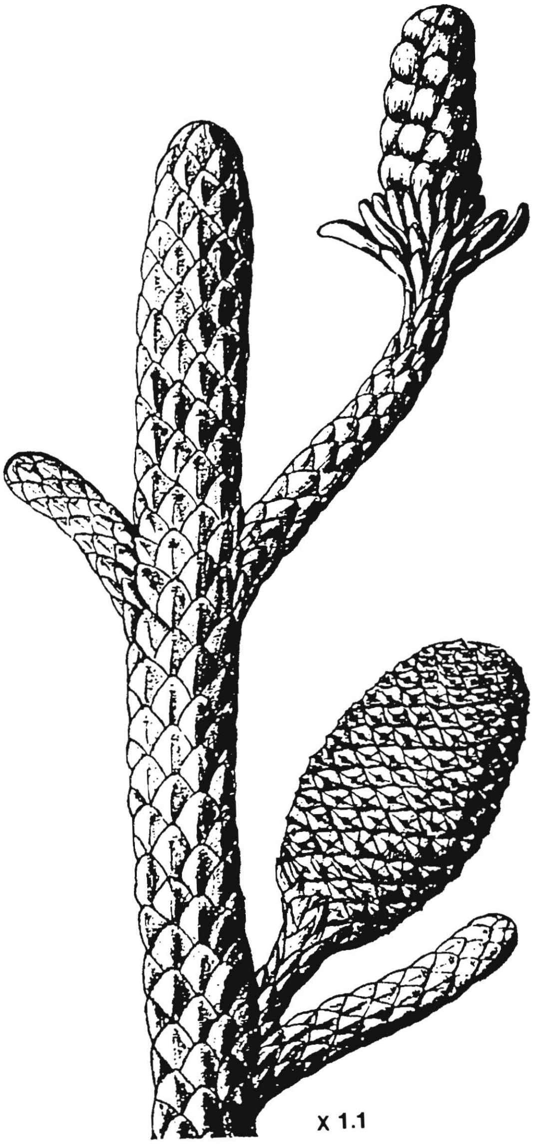






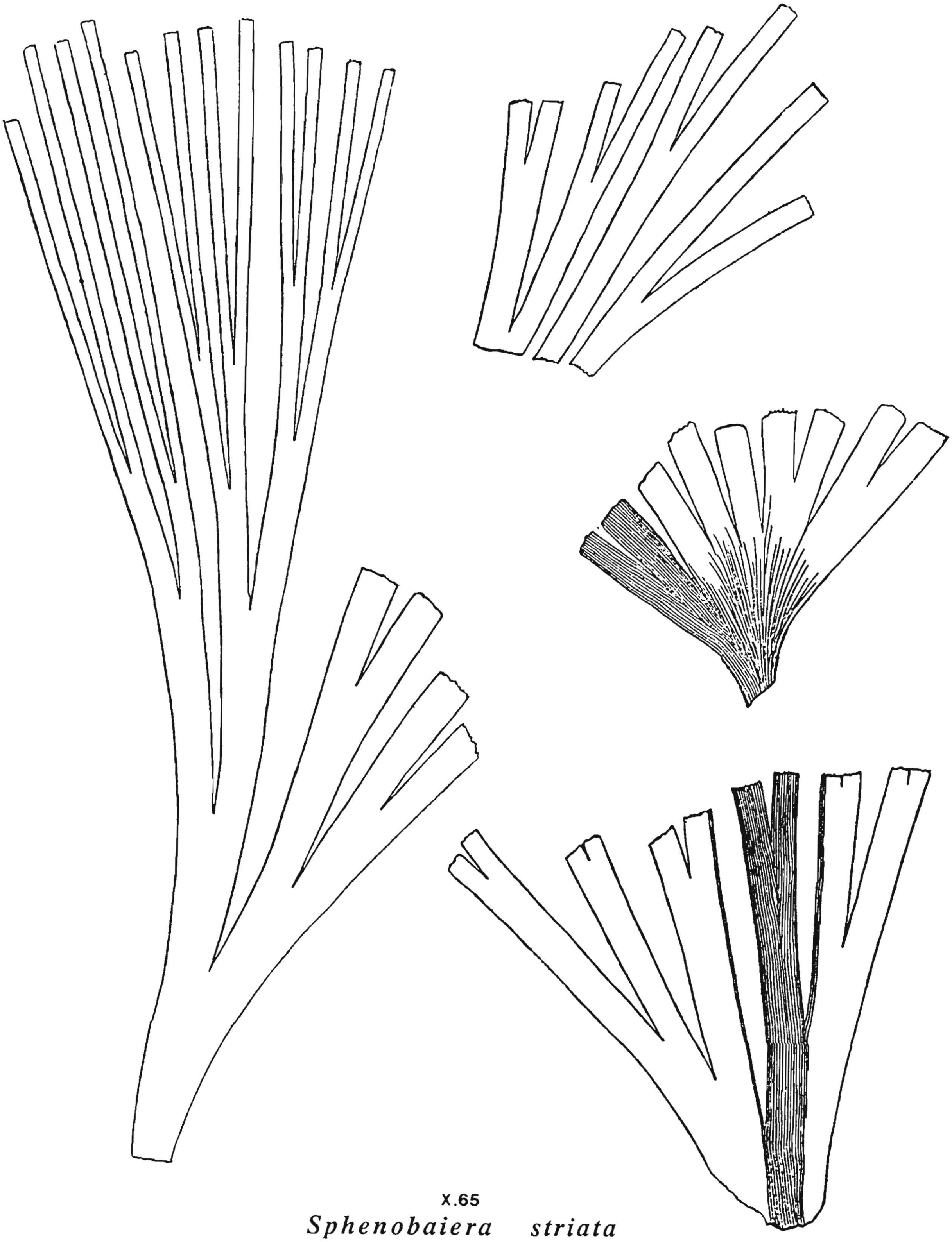


Triassiflorites grandiflora



Primaraucaria wielandii

Plate 13

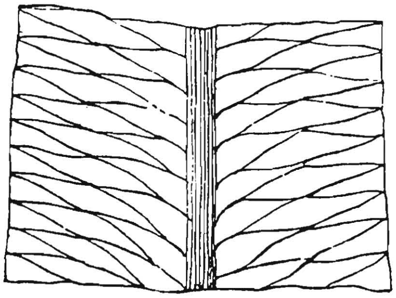


X.65

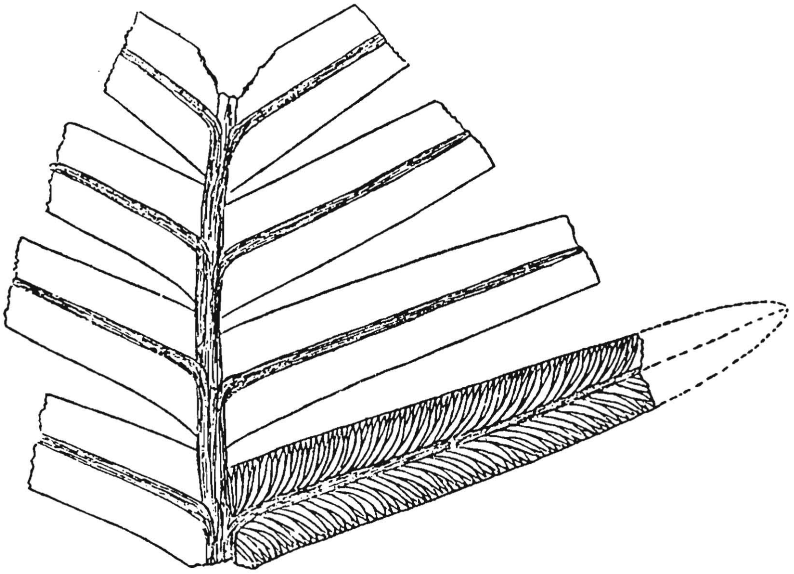
Sphenobaiera striata

Plate 14

X.65
S. obliqua

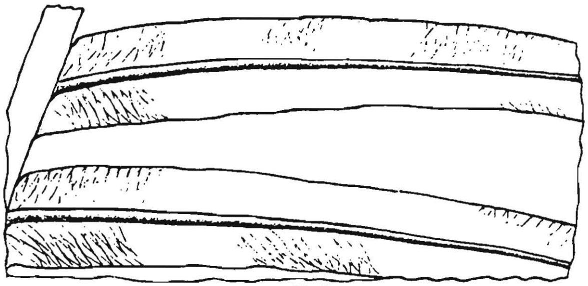


X1.7

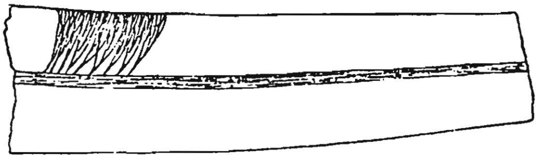


X.65

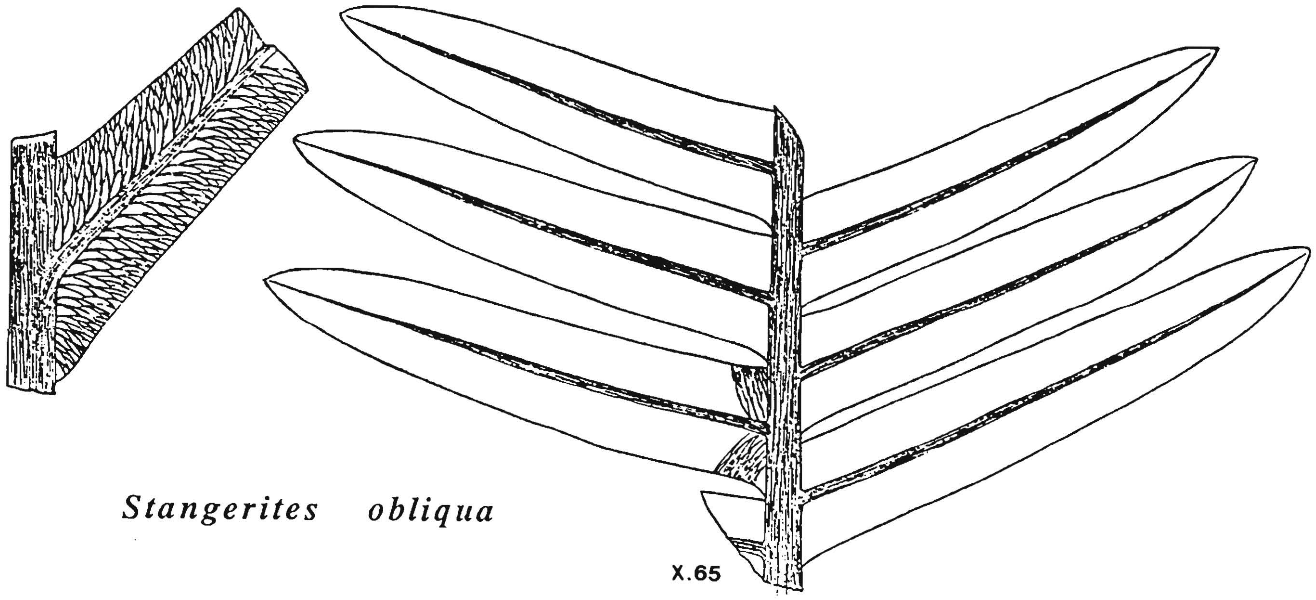
Stangerites planus



X.65
Stangerites planus



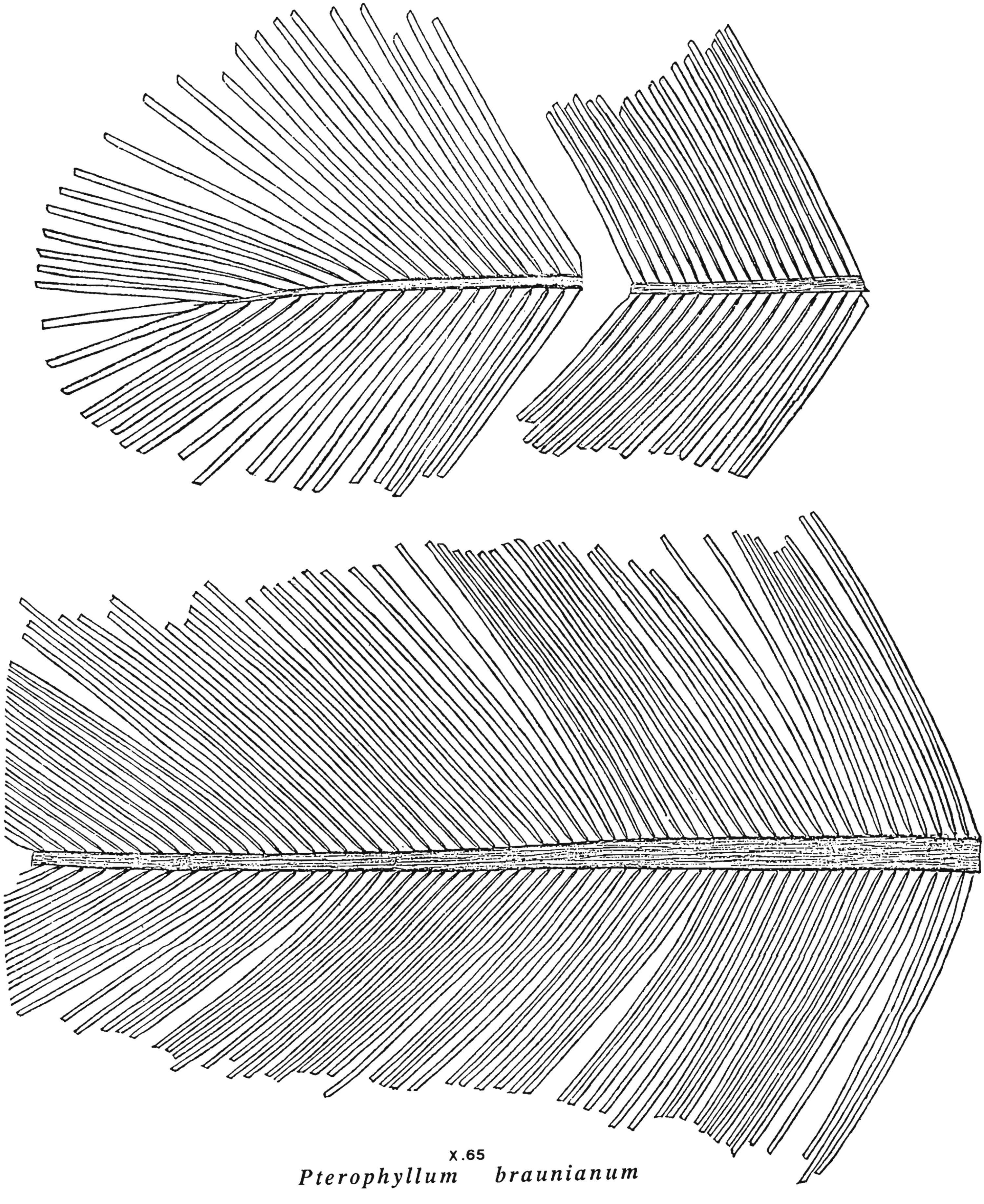
X.65
Stangerites obliqua



Stangerites obliqua

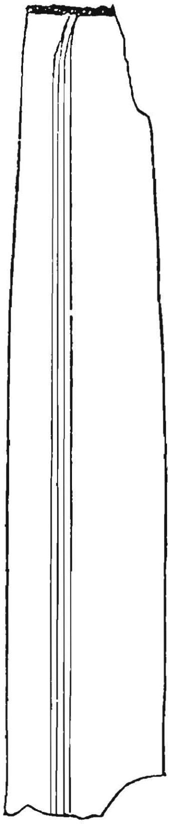
X.65

Plate 15

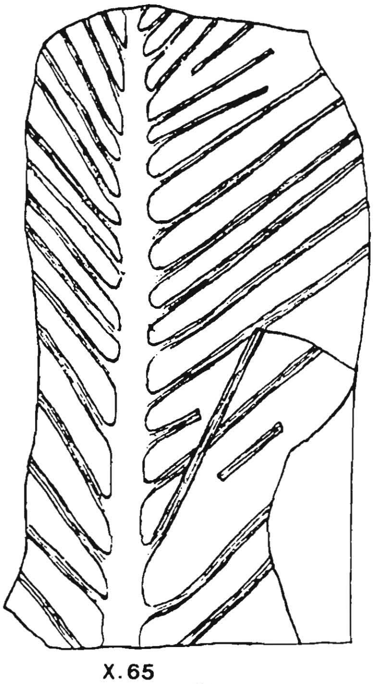


x .65
Pterophyllum braunianum

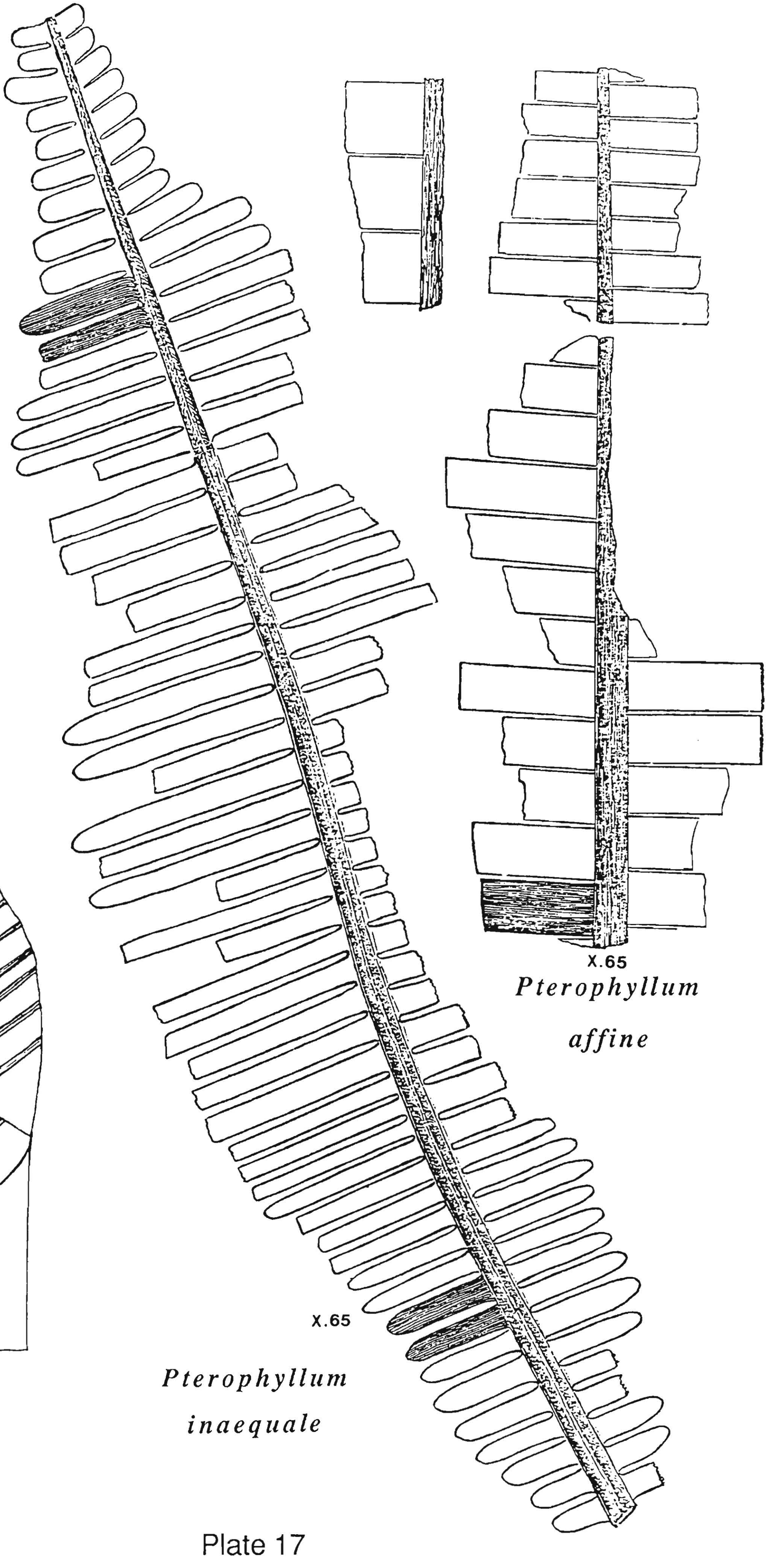
Plate 16



X.65
Pterophyllum giganteum



X.65
Pterophyllum braunianum



X.65

Pterophyllum inaequale

X.65
Pterophyllum affine

Plate 17

Pterophyllum grandifolium

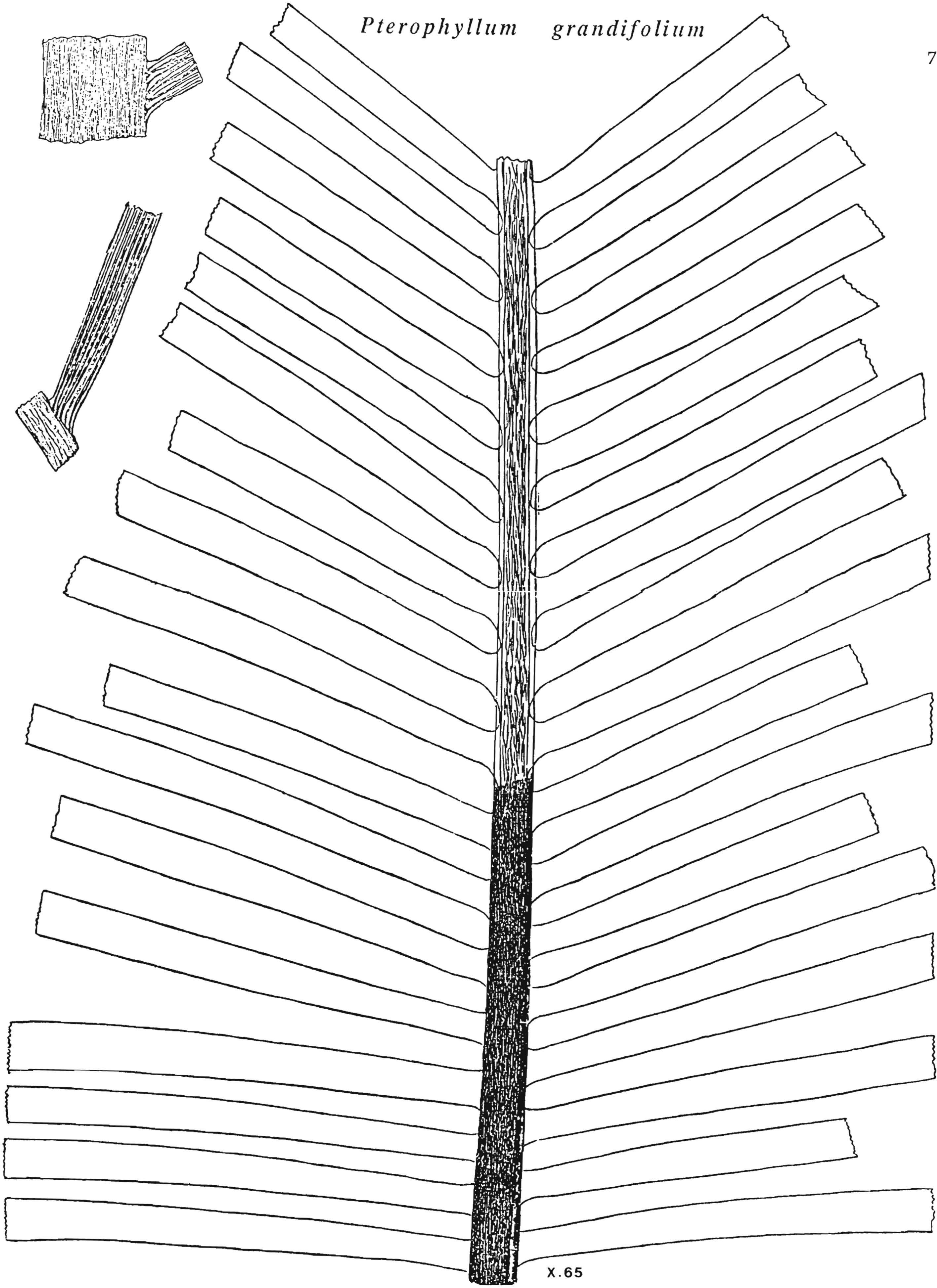
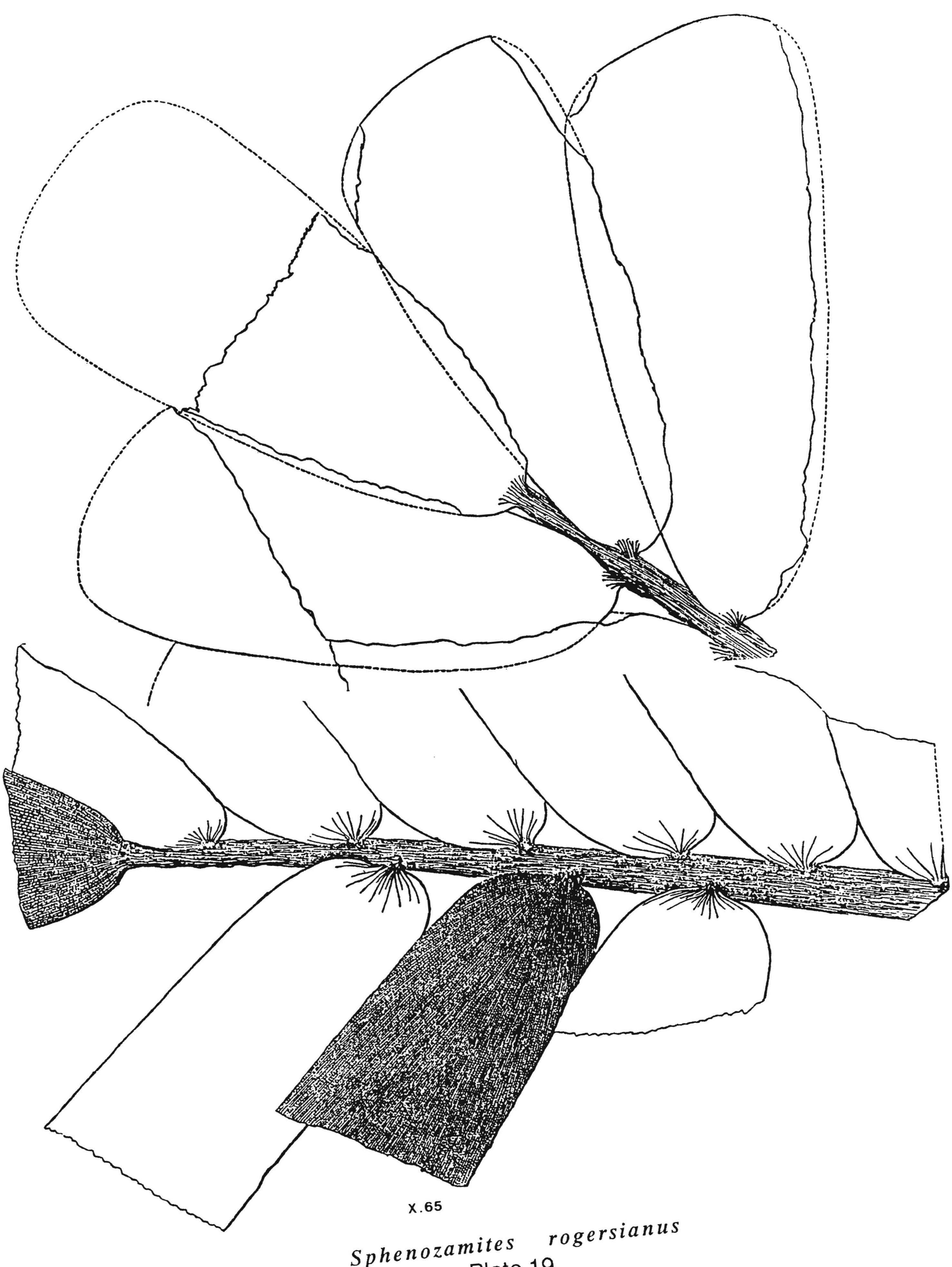


Plate 18

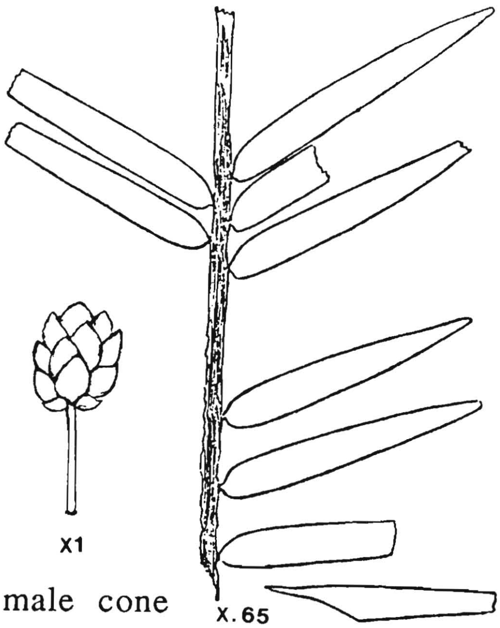


X.65

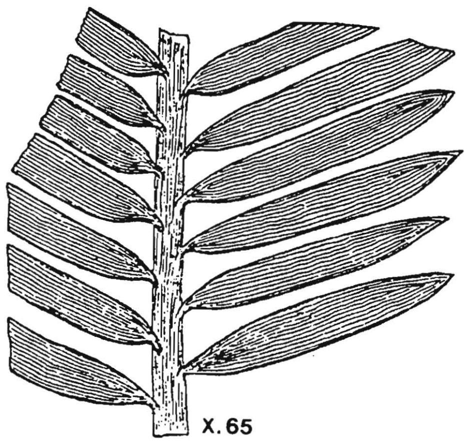
Sphenozamites rogersianus

Plate 19

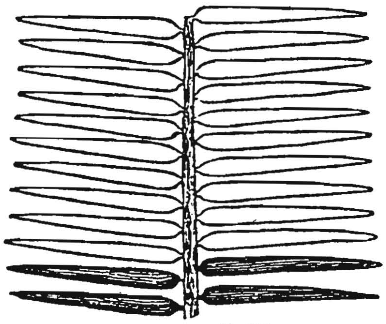
male cone



Podozamites lanceolatus

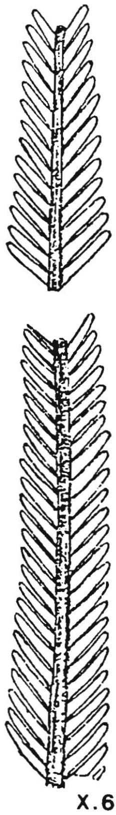


Podozamites lanceolatus

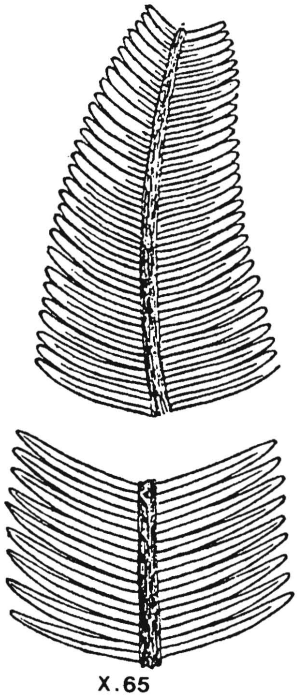


Podozamites tenuistriatus

Similar to leaves associated with *Compsostrobus neotericus*

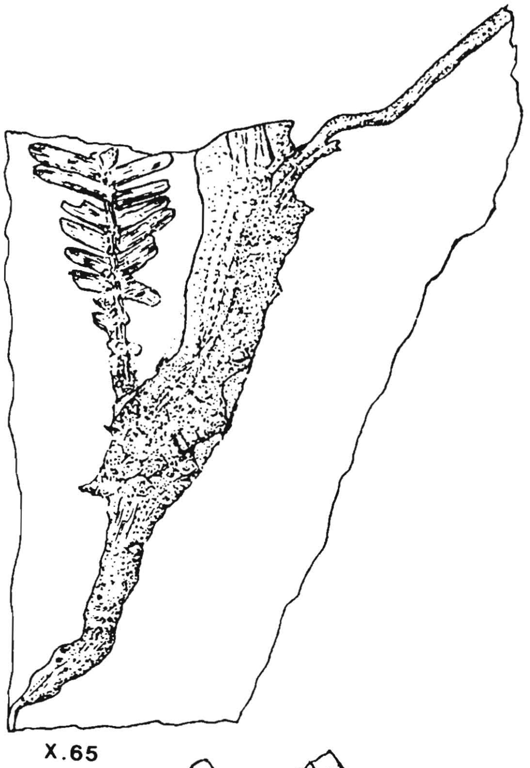


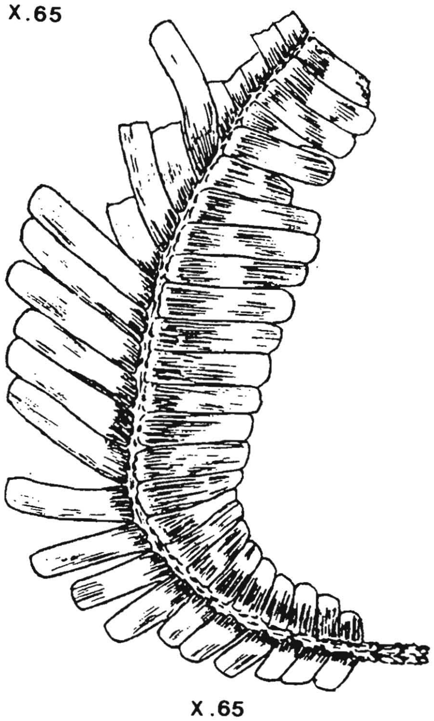
Pterophyllum taxinum



Pterophyllum tenuinervis

Pagiophyllum sp.





Zamites powellii

Plate 20

PHOTOGRAPHIC PLATES

Plate 21

No. 1. *Sanmiguelia*-like leaf. Deep Run plant locality; upper half of *Neocalamites/Sanmiguelia* interval in Table 5. Parallel 0.5 centimeter-wide plications were subdued by compaction, and are more obvious in low-angle lighting.

No. 2. *Neocalamites* stem (rotted) associated with rhizomes and roots. Deep Run plant locality; same interval containing *Sanmiguelia*-like leaf in Figure 1.

No. 3. *Clathropteris meniscoides*. Deep Run plant locality; basal interval in Table 5. Courtesy of N. Robbins; found by R. Weems.

No. 4. *Podozamites tenuistriatus*. Deep Run plant locality; second interval from bottom in Table 5.

Plate 22

No. 5. *Podozamites tenuistriatus* leaves and associated pedicelate cone. Deep Run plant locality; second interval from bottom in Table 5.

No. 6. *Neocalamites knowltonii*. Deep Run plant locality; *Neocalamites/Sanmiguelia* interval in Table 5. Main stem with secondary branches and whorled leaves.

No. 7. Large cycad-like seed. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #5 or #6 (Figure 14). The flat chalaza with small hilum scar (left) probably indicates attachment to a peltate cone scale; this seed associated with common fragments of large *Sphenozamites rogersianus* pinnules (e.g. Plate 19), which is the only cycadophyte plant from the Richmond-Taylorsville basin floras large enough to have borne such a large seed.

No. 8. *Podozamites lanceolatus*. Stagg Creek plant locality, Stratigraphic Section 2, from base of section (Figure 14). *Podozamites* leaf crosses an incomplete specimen of a very large leaf belonging to either *Podozamites* sp. or possibly *Pelourdea* sp.

No. 9. *Sphenobaiera striata*. Stagg Creek plant locality, Stratigraphic Section 2, from paleosol at sample intervals #3 and #4 (Figure 14). Cuticle a reddish brown rather than black; long undivided distal portions of digitate leaves more common than basal dichotomizing portions in photograph.

Plate 23

No. 10. *Equisetites* sp. (new). Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #5 or #6 (Figure 14). Compressed stem cast showing an internode (top) with circular branch bases (three additional bases preserved on opposite side).

No. 11. *Equisetites* sp. (new). Stagg Creek plant locality, Stratigraphic Section 2, from paleosol at sample interval #3 and #4 (Figure 14). A disarticulated node showing whorl of short, very wide, and strongly pointed leaves (larger than on any other *Equisetites* species from the Richmond-Taylorsville basin floras).

No. 12. Paired beetle elytra. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #5 (Figure 14). From deepest water facies containing common *Pterophyllum tenuinervis* and *P. taxinum* fronds.

No. 13. *Equisetites rogersii*. Stagg Creek plant locality, Stratigraphic Section 1, from mudstone layer between sample intervals #3 and #4 (Figure 13). Stem cast preserved in growth position on top of 4 cm-thick coal seam; note numerous narrow leaves typical of this species, and closely spaced internodes near base of stem.

No. 14. *Equisetites rogersii*. Opposites side to specimen in Figure 13. Note collapsed irregular top and relatively undistorted shape of stem cast at base.

Plate 24

No. 15. *Macrotaeniopteris magnifolia*. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #7 (Figure 14). Leaf and central vein impression; counterpart preserved cuticles. For some unknown reason leaf veins or their impressions do not preserve well at this plant bed.

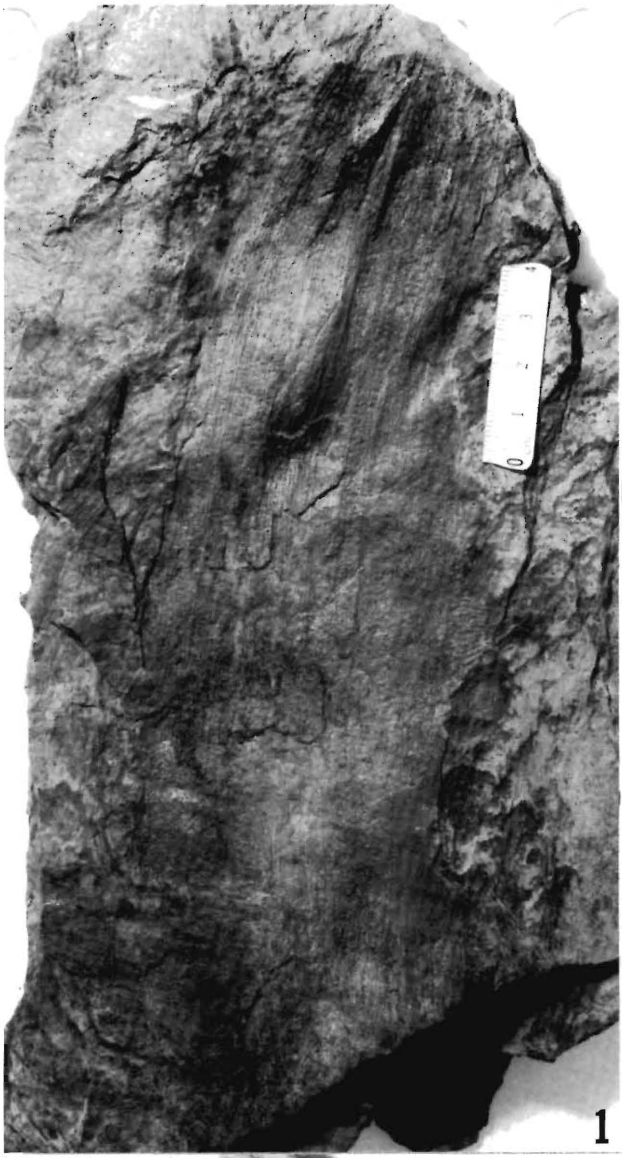
No. 16. *Macrotaeniopteris magnifolia*. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #7 (Figure 14). Lamina and petiole compression from basal part of a small leaf; note absence of secondary vein impressions, which are typically preserved at Winterpock.

No. 17. cf. *Sphenopteris sitholeyi*. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #2 (figure 14). Faint impressions of pinnule fragments from this layer do not show narrow pinnule bases with diverging veins typical of this species at Winterpock.

No. 18. *Pterophyllum taxinum* (left) and *P. tenuinervis* (right). Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #5 (Figure 14). Cuticle typically black without indication of venation.

No. 19. *Zamites powellii*. Stagg Creek plant locality, Stratigraphic Section 1, from sample interval #8 (Figure 13). Specimen shows rachis (right) with attached, wide non-tapering pinnules typical of this species. Associated with *Pterophyllum tenuinervis*.

No. 20. *Pterophyllum tenuinervis*. Stagg Creek plant locality, Stratigraphic Section 2, from sample interval #5 (Figure 14). Specimen shows rachis (right) with pinnules that taper to a point and are distinctly narrower than those of *Z. powellii*.



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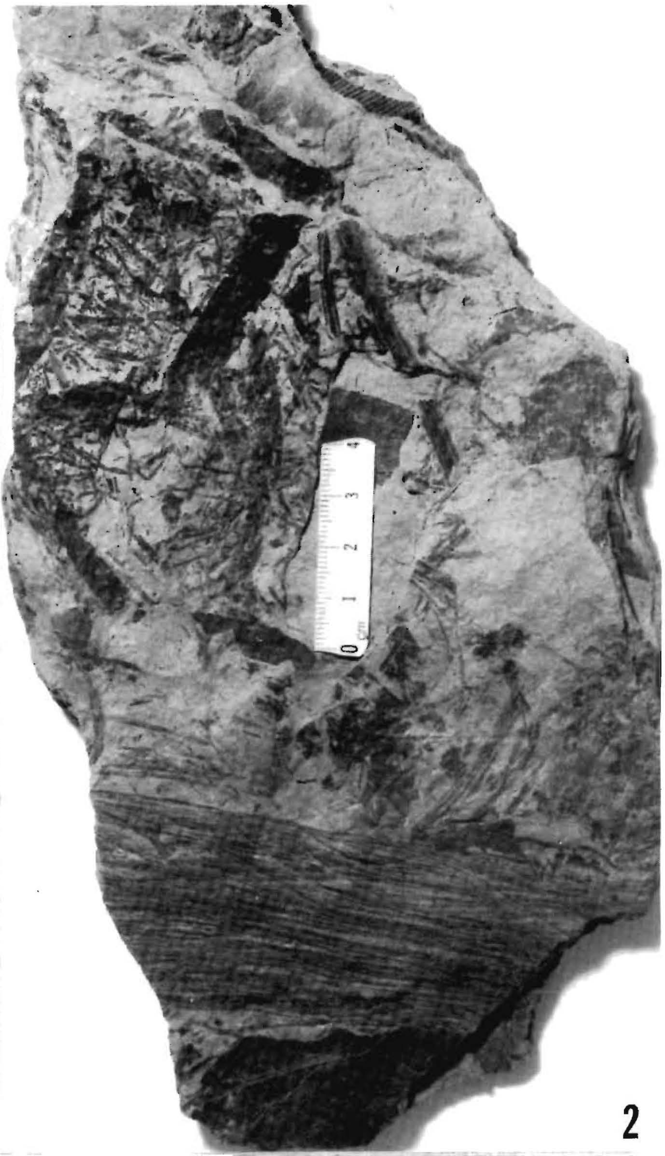

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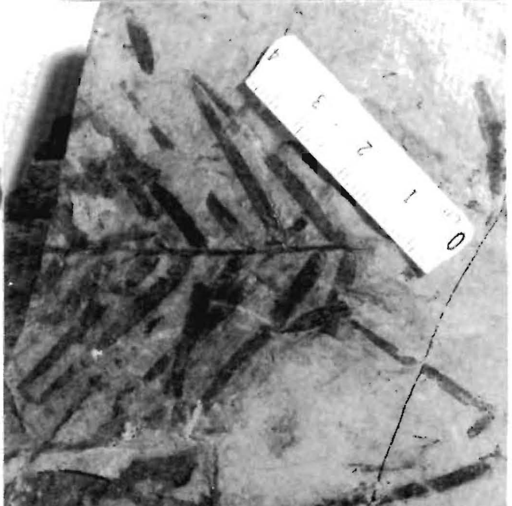

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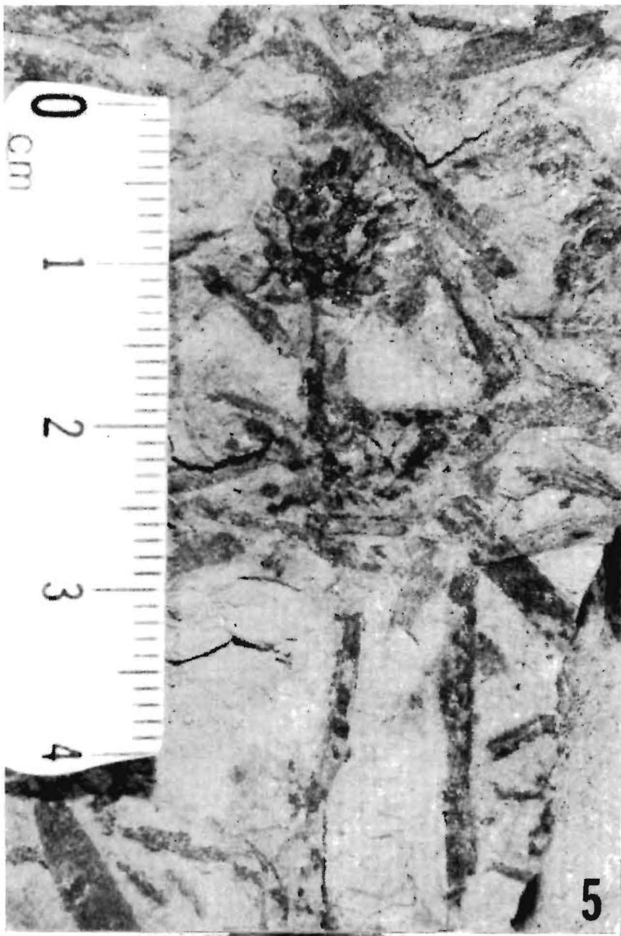

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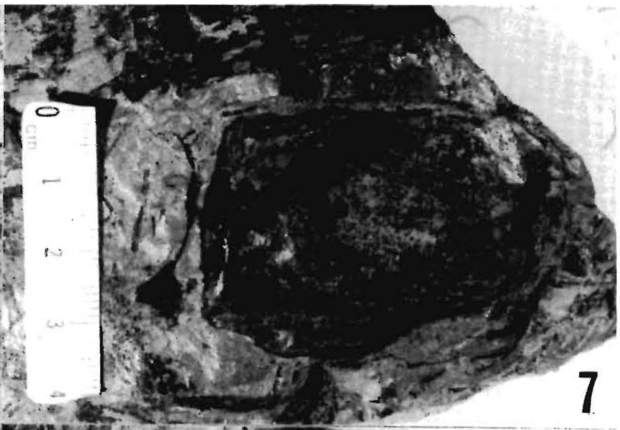

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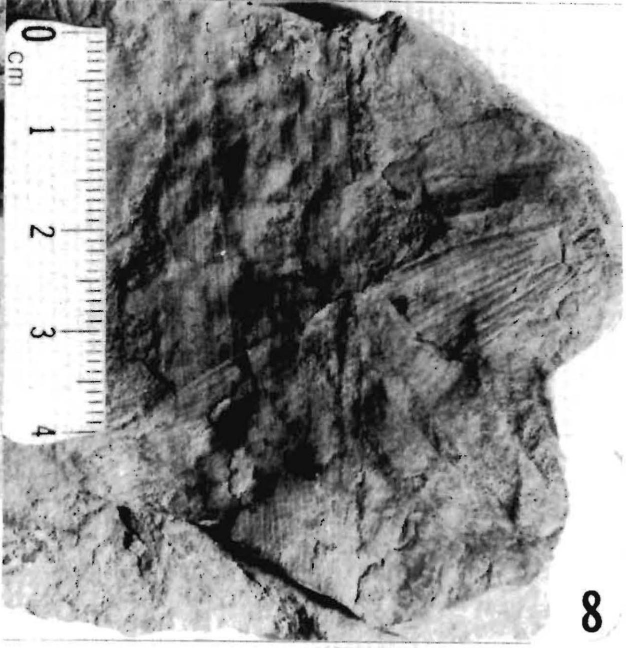

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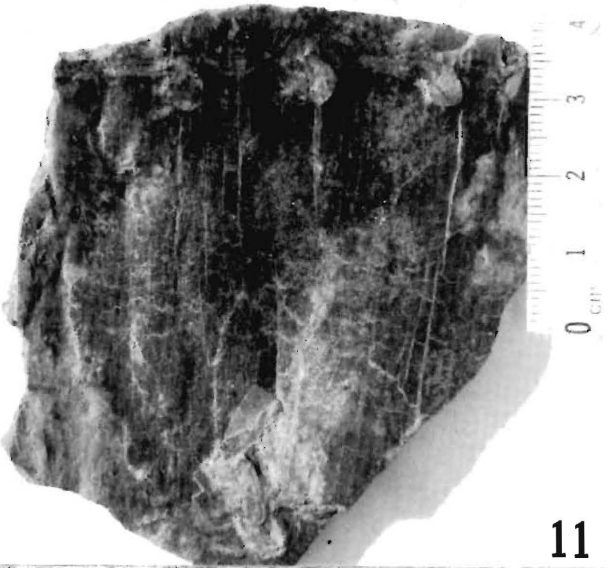

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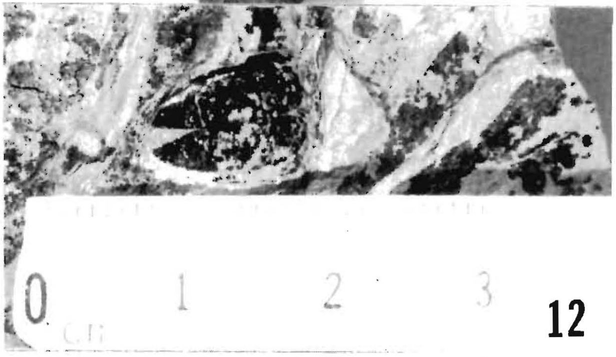

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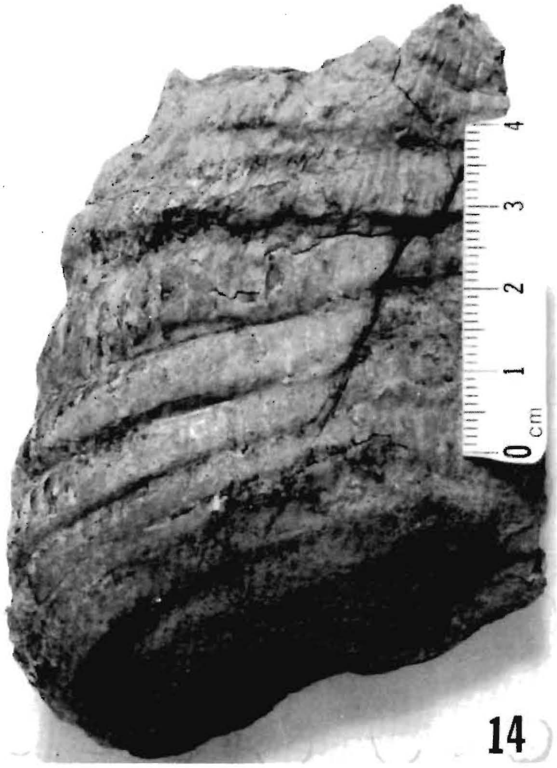

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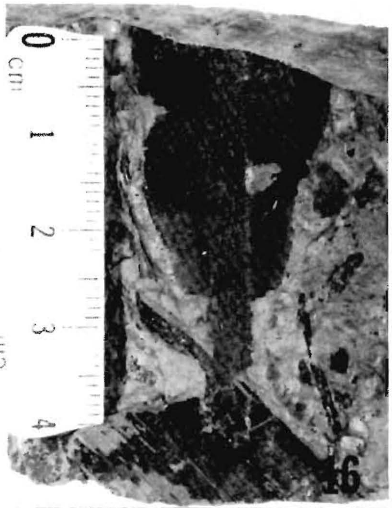

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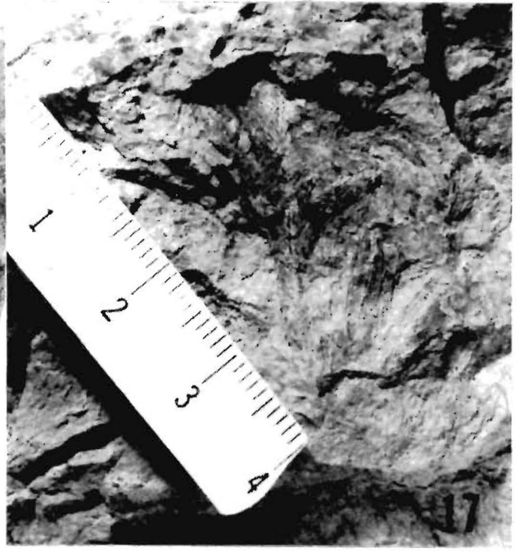

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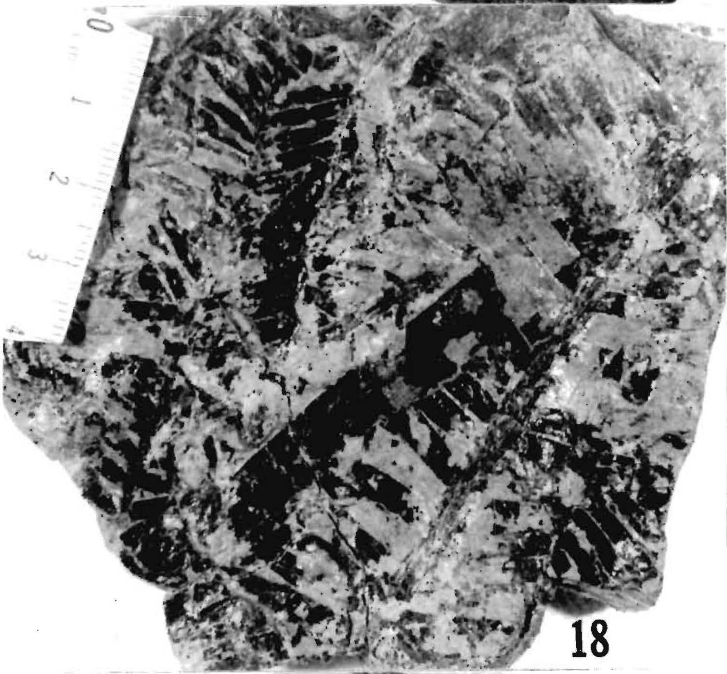

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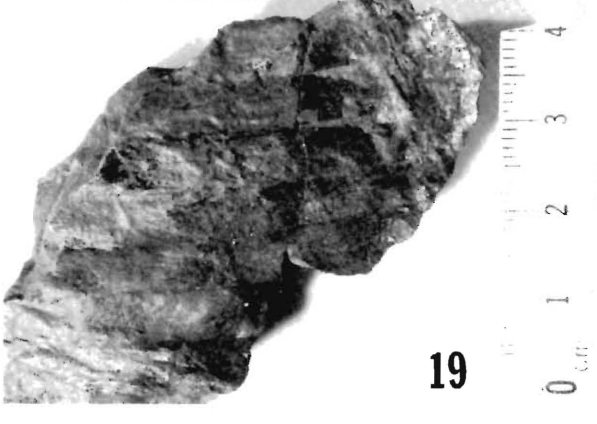

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Early to Middle Carnian (Triassic) Flora and Fauna of the Richmond and Taylorsville Basins, Virginia and Maryland, U.S.A.

Bruce Cornet and Paul E. Olsen

The coal measures and associated shales and sandstones from the Newark Supergroup in the Richmond and Taylorsville basins provide the best documented Late Triassic wetland flora from eastern North America. This flora contains diverse ferns, giant sphenopsids, lycopsids, possible ginkgophytes, diverse Bennettitales and Cycadales, and conifers. Insects and mammal-like reptiles also have been collected from these basins.

This volume provides a comprehensive overview of the flora and fauna of the Richmond basin and the exposed part of the Taylorsville basin, while also giving information on the megaflora of the Deep Run basin, which lies just northeast of the Richmond basin. Together, the flora and fauna provide a view of equatorial conditions during the Carnian, a time when floral diversity was the highest for any Newark Supergroup assemblage.

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