ABSTRACT

MITRA, MADHUMI. Paleopalynology of the Tar Heel Formation of Atlantic Coastal Plain of North Carolina, United States (Under the direction of James Earl Mickle.)

Sediments from the Late Cretaceous Tar Heel Formation in the Atlantic Coastal Plain of North Carolina were investigated for occurrence and distribution of palynomorphs. Exposures along rivers at Elizabethtown, Goldsboro, Ivanhoe, Lock, Willis Creek and Tar River in North Carolina were systematically collected. One hundred and three sediment samples were macerated by standard techniques modified by eliminating treatments with nitric acid and potassium hydroxide, and analyzed for palynomorphs. Eighty species of palynomorphs were distributed in 4 form genera of freshwater algae, 3 of dinoflagellates, 9 of fungi, 15 of pteridophytes, 11 of gymnosperms and 24 of angiosperms. Angiosperms were the dominant components in assemblages at all localities. Representatives of the Normapolles pollen group (characteristic angiosperm pollen group of middle and high northern latitudes of eastern North America and Europe) occur throughout the Tar Heel Formation and collectively comprise 29%-54% of the angiosperm assemblages. Palynological age assessment is in concordance with earlier dating determined by other workers based on invertebrate faunas. Minimum variance clustering with squared Euclidean distances in the Q-mode (clustering of samples) indicates that stratigraphically older layers of Ivanhoe, Lock and Willis Creek are similar in palynofloral composition, and one section of the Goldsboro locality is compositionally equivalent to the Tar River locality. Minimum variance cluster analysis in the R-mode (clustering of taxa) indicates the association of Campanian taxa in the same cluster. This reconfirms that localities of the Tar Heel Formation are of Early Campanian age.

Informal biostratigraphic zones of Campanian (CA2-CA4) known from other Atlantic Coastal Plain deposits do not occur in the Tar Heel Formation. Quantitative analysis is consistent with the long-standing hypothesis of diversification and dominance of angiosperm pollen groups during the Campanian. The palynological record of the Tar Heel Formation, based on some indicator taxa with modern equivalents, suggests that subtropical to warm, moist temperate conditions prevailed in the southeastern region of North America during Campanian time.

PALEOPALYNOLOGY OF THE TAR HEEL FORMATION OF ATLANTIC COASTAL PLAIN OF NORTH CAROLINA, UNITED STATES

by

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Chair of Advisory Committee

BIOGRAPHICAL SKETCH

Madhumi Mitra was born in Calcutta, India. She is the only child of Amarendranath Mitra and Aloka Paul Mitra. Madhumi completed her baccalaureate degree with first class honors in Botany from Presidency College, Calcutta, India. She obtained a masters of science degree in Botany with specialization in Phycology from the University of Calcutta, India in December 1989. After four years of absence from academics, Madhumi enrolled in a Ph.D program in Paleobotany at North Carolina State University, Raleigh, North Carolina, in August 1993 under the supervision of Dr. James E. Mickle. She took a leave of absence for two years and moved to Puerto Rico in June 1995 to be with her family. During her stay in San Juan, Puerto Rico, Madhumi worked as a research assistant in the Department of Biology at University of Puerto Rico. She also taught AP (Advanced Placement) Biology at Baldwin School of Puerto Rico from 1996-1997. Madhumi returned to North Carolina State University in August 1997 and continued her doctoral work in Paleopalynology.

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INTRODUCTION

1.1 Importance of the research

The history of angiosperm evolution from Early Cretaceous to modern times can be traced from both pollen and macrofloral records. Fossil leaves and palynomorphs represent different phases of the plant life cycle and have demonstrated their usefulness as independent and parallel indicators of long-term trends in land plant diversity (Muller, 1984; Lovis, 1989; Lidgard and Crane, 1990). Palynofloras have outnumbered macrofloras due to their potential for preservation in a greater variety of environmental settings. Factors that control the supply of palynomorphs in sediments include the production rate of plants and their mode of dissemination, seasonal production, transportation by wind, water and insects, deposition of sediments, weathering, and preservation (Farley, 1988). These factors, either singly or in concert, may contribute to both under- and over- representation of palynomorphs in the fossil record. Knowing their uses and limitations, researchers have used palynofloras in paleofloristics, paleosystematics and biostratigraphic studies.

The fossil record indicates a coordinated increase in diversity and abundance of angiosperm pollen from the Aptian-Albian (mid-Cretaceous) through the Late Cretaceous (Crane and Lidgard, 1990; Lidgard and Crane, 1990). Rapid diversification of angiosperms is apparent from the observation that all major types of apertures (tricolpate, tricolporate and triporate), exine structure, and exine sculpture seen in pollen of living angiosperms had appeared by the end of Cenomanian (Lidgard and Crane, 1990). The angiosperms were not only taxonomically diverse but also dominant in assemblages before the end of Maastrichtian (Lupia, 1996).

Pollen and leaves represent different stages in the life cycle of flowering plants and are parallel indicators of long-term trends in angiosperm evolution. Additional studies of Cretaceous micro and megafossils are needed to refine our knowledge of Mesozoic palynology and help in increasing understanding of the diversification and rise to dominance of angiosperms in the Late Cretaceous.

Records of Upper Cretaceous palynomorphs are derived from Asia, Africa, Australia, Antarctica, North America and South America. In North America, macro and microfossils of floras and faunas have been reported from localities of Alaska, western Canada, Atlantic Coastal Plain, Gulf Coastal Plains, central and Northern Rocky Mountain regions, New Mexico, Arizona, California and Mexico (Srivastava 1978, Baghai, 1996). Late Cretaceous paleobotanical studies both at the macro and micro levels are important in contributing to the knowledge of paleofloristics and paleobiogeography at local, regional and global levels.

The Cretaceous exposures in the Atlantic Coastal Plain are poorly studied and few detailed sedimentological and paleofloristical studies have been undertaken (Crane and Herendeen, 1996). The study of Late Cretaceous palynomorphs from the Tar Heel Formation of southeastern North America attempts to reduce the gap in our knowledge of palynofloras of the Upper Cretaceous of the Atlantic Coastal Plain. An analysis of palynomorphs from samples of Tar Heel Formation will be useful in providing more information on the relative abundance and diversity of various palynomorph groups like freshwater algae and dinoflagellates, fungi, pteridophytes, gymnosperms and angiosperms. This will be useful in testing the hypothesis that angiosperms were the most diverse and dominant among other floral groups during the Late Cretaceous. The palynoflora of the Tar Heel Formation will be compared to other Late Cretaceous (Campanian-Maastrichtian) palynofloras of the Atlantic Coastal Plain, Gulf Coastal Plain and Wetern Interior of North America. The correlational studies could further be applied to compare the extent of similarities and dissimilarities that exist among other contemporary palynofloras in different regions of North America and other parts of the world. This would enhance our understanding of biogeography and distribution of various spore and pollen species in the Upper Cretaceous.

Late Cretaceous floral biogeography is interesting since this period witnessed the rapid radiation of angiosperms along with the development of microfloral provinces termed the Normapolles microfloral province (eastern North America, Europe and western Asia) and Aquilapollenites microfloral province (western North America and eastern Asia) named according for their predominant pollen types (Stanley, 1970; Tschudy, 1975, 1980, 1981; Batten, 1984) (Figure 1a). Pollen of the Normapolles group is characterized by being triporate, having internally complex pore structures and elaborate apertures (Batten, 1981; Tschudy, 1981; Batten and Christopher, 1981). Aquilapollenites is characterized as triprojectate pollen having three prominent sculptured equatorial projections extending radially from a central body and apertures borne on the projections (Jarzen, 1977; Muller, 1984; Jarzen and Nichols, 1996). The north-south trending epicontinental Campanian sea provided a barrier to plant migration (Tschudy, 1980; Srivastava, 1981; Batten, 1984). Although Zaklinskaya (1977) referred eastern United States to be a part of the “Normapolles Province”, there are relatively few detailed paleopalynological studies of this region. Information on various fossil angiosperm pollen types will be useful in further testing the hypothesis of occurrence of diverse morphological Normapolles pollen in the eastern United States.

Many of the Late Cretaceous localities of the Atlantic Coastal Plain of North Carolina have been designated as "Tar Heel beds" based on invertebrate faunal data (Sohl and Christopher, 1983; Sohl and Owens, 1991) (Table 1.1). The age of some of the localities of Tar Heel beds is unknown due to lack of trace fossils (Sohl and Owens, 1991). Palynomorphs, especially dinoflagellates and many angiosperm pollen, have been reliable indicators of age due to their short stratigraphic ranges and can assist in correlating both marine and non-marine rocks of different facies (Traverse, 1988). In non-marine rocks, angiosperm pollen such as many species of Normapolles group, and other tricolpates, tricolporates and triporates have short stratigraphic ranges and have been used to indicate the age of sediments (Wolfe, 1976; Tschudy, 1975; Batten, 1981; Christopher, 1979a; Christopher, personal communication, 1993). This study will investigate whether the ages determined from palynological data and invertebrate faunal data agree or not. It would also be useful in correlating facies among localities based on similar palynomorph assemblages. Exposures of many localities have been assigned to the Tar Heel Formation based on similar lithological characteristics (Sohl and Owens, 1991; Owens and Sohl, 1989). Correlation based solely upon comparison of similar lithofacies could lead to erroneous interpretations of the depositional history and that is why biostratigraphic age control is very necessary (Owens and Sohl, 1989).

1.2 Objectives

The major objectives of this study are: 1) prepare a monograph of the fossil pollen and spores of the Tar Heel Formation of the Atlantic Coastal Plain of North Carolina which will encompass both palynofloristics and palynosystematics; 2) document diversity and relative abundance of various palynomorph groups at six localities of the Tar Heel Formation in order to determine which palynomorph group was the most diverse and dominant in the assemblages; 3) discuss various Normapolles pollen and other characteristic angiosperm palynoflora recovered from the Tar Heel Formation samples; 4) discuss the age of sediments and localities based on palynomorphs of the Tar Heel Formation and determine whether palynological dating agrees with dates based on invertebrates; 5) compare Tar Heel Formation palynoflora with other contemporary floras at the intra and inter-regional levels; 6) correlate stratigraphic sections/localities of the Tar Heel Formation and determine which sections are biostratigraphic or time equivalents; 7) to test the validity of informal biostratigraphic zones of Early Campanian (CA-2, CA-3, CA-4) as stated by Wolfe (1976) for post-Magothy formations and by Christopher (cited as personal communication in Owens and Sohl, 1989) for the Tar Heel Formation; 8) speculate on the climatic conditions that prevailed in the south eastern region of North America based on indicator taxa with modern equivalents.

1.3 Background Information

Classical Studies in the Atlantic Coastal Plain - One of the major phases in angiosperm diversification for the Early Cretaceous has been demonstrated by the Potomac Group megaflora/palynoflora sequence (Doyle and Hickey, 1976, Hickey and Doyle, 1977).

Megafossil and pollen studies of the Aptian-Cenomanian of the Potomac Group of eastern North America are noteworthy since an attempt was made to provide a better resolution of the origin and evolution of flowering plants. Leaf fossils and pollen were described in sedimentological context. The sequence of changes in both leaf architecture and pollen morphology was well documented through Brenner's (1963) six palynological zones (Zones I, IIA, IIB, IIC, III, IV). Angiosperm leaves showed differentiation of lamina and petiole and increasing sophistication of venation in progressively younger strata. As for pollen, monosulcate grains were confined to Zone I. There was an increase in tricolpates and monocolpates in IIB and tricolporoidates increased in the upper sections (Doyle and Hickey, 1976, Hickey and Doyle, 1977).

Previous Late Cretaceous Palynological studies of the Atlantic Coastal Plain of eastern North America

Middle Atlantic States

Brenner (1963), Wolfe (1976) and Wolfe and Pakiser (1971) have proposed pollen assemblage zones for the outcropping Cretaceous system of the Middle Atlantic States. Six major zones were proposed for Campanian to lower Maastrichtian rocks of the Raritan (New Jersey) and Salisbury (Maryland) embayments based on stratigraphic ranges of dicotyledonous pollen. Brenner (1963) earlier proposed ten informal biostratigraphic zones for the Potomac Group and Raritan Formation. These were later revised by Wolfe (1976) and grouped into six, namely CA-1 (Santonian), CA-2, CA-3, CA-4 (Lower Campanian, CA-5 (Upper Campanian), CA-6 (Lower Maastrichtian). Diversity of dicot pollen has been documented by Wolfe (1976) and Christopher (1978, 1979a). Pollen types described by Wolfe (1976) were the Normapolles complex, tricolpates, tricolporates, Proteacidites and miscellaneous pollen types that included Aquilapollenites (in one sample), polycolporates, fragments of syncolpate Trisectoris, and tricoporate pollen of Bombacidites. These studies helped correlate Campanian and Maastrichtian sediments from the Raritan, Salisbury and Okefenokee embayments (Christopher, 1979a).

Evitt (1973) reported the occurrence of two species of Aquilapollenites (characteristic of western North American palynofloral province) from Maastrichtian deposits of Maryland and New Jersey. In Texas, occurrence of other species (occurring also in the Rocky Mountain region) of Aquilapollenites is suggestive of a direct southward extension of the genus from the Rocky Mountain region. In Maryland and New Jersey, long distance wind transport may have brought the western element to the east (Evitt, 1973; Traverse, 1988).

South Carolina

The morphology, taxonomy and biostratigraphy of 24 species of triatrite pollen assigned to seven genera of juglandaceous forms, namely Momipites, Plicatopollis, Platycaryapollenites, Platycarya, Subtriporopollenites, Carya and Casuarinidites were described from cores in Charleston, South Carolina (Fredericksen and Christopher, 1978). Diversity of triatrite pollen increased in the Lower and Upper Eocene rocks (Fredericksen and Christopher, 1978).

Black Creek Group

Cretaceous stratigraphy of the Carolina Coastal Plain has a complicated history (Sohl and Owens, 1991). Brett and Wheeler (1961) and Swift and Heron (1967) divided the stratigraphic column into four formations: Cape Fear (oldest), Middendorf, Black Creek and Peedee (youngest). Absence of distinctive calcareous fossils in the formations of Cape Fear, Middendorf and Black Creek led to erroneous correlations of these units with those of other areas (Sohl and Owens, 1991). The Peedee Formation had uniform lithology throughout its outcrop belt and contained distinctive calcareous fauna (Sohl and Owens, 1991). Sohl and Owens (1991) elevated the Black Creek Formation to a group status that included three formations: Tar Heel, Bladen and Donoho Creek ranging in age from Lower Campanian to Lower Maastrichtian. The age of these formations was based on the presence of invertebrate fossils and the formations were assigned pollen zones CA-2 through CA-6 of Wolfe (1976) (Sohl and Christopher, 1983).

Basal coastal sediments that outcrop along the Cape Fear, Neuse and Tar Rivers in North Carolina are older than Black Creek and have not yielded many productive samples (Christopher, 1979b). Two samples from the Cape Fear locality yielded a well-preserved rich diverse pollen assemblage that can be correlated with the highest units of Magothy Formation (Santonian) of the northern New Jersey Coastal Plain ("Morgan" and "Cliffwood beds"). Rare dinoflagellate cysts and acritarchs suggest some marine influence during deposition of the unit (Christopher, 1979b). Palynomorph assemblages contain pollen of Araucariacites australis, Aequitriradites spinulosus, Inaperturopollenites, spores of Cicatricospisporites sp and four angiosperm pollen species (Complexiopollis sp. A, Complexiopollis sp. C, Porocolpopollenites and a new genus of triporate pollen) (Christopher and Sohl, 1979). Detailed palynological investigations of individual formations of the Black Creek Group have not been conducted to date. Environmental settings under which the sedimentary rocks were deposited were reconstructed from samples collected along the Neuse River in North Carolina (Zastrow, 1982). Reconstruction was based on field observations, sedimentary structures, lithologic composition and grain size analysis of rocks. Analysis of palynomorphs was not included in the study.

Upper Cretaceous series of North Carolina may possibly consist of two to three cycles of marine transgression based on the presence of disconformities between Cape Fear Formation (Santonian) and Black Creek Group (Campanian- Early Maastrichtian) and Black Creek Group and Peedee Formation contacts (Brett and Wheeler, 1961; Heron and Wheeler, 1964; Swift, 1964). Studies by Sohl and Christopher (1983) suggest that the Black Creek and PeeDee Formations comprised distinctly different environments under which the sedimentary rocks were deposited. The disconformity between the two is indicated by poorly sorted coarse-grained sand zone. This zone contains abraded bone and shells, pebbles, teeth and reworked materials. Based on lithologic and paleontologic data, it has been suggested that a major environmental change attributed to marine transgression took place at the disconformity (Christopher, 1979; Sohl and Christopher, 1983).

The paleontological data suggest vertical and lateral facies changes in some of the outcrops of the Black Creek (Owens and Sohl, 1989). The fauna recovered is diverse, and biostratigraphically important invertebrate fossils have been reported from the exposures of the Tar Heel, Bladen and Donoho Formations respectively (Sohl and Owens, 1991). Besides invertebrate fossils, vertebrate fossils have been reported from some of the exposures of the Black Creek (Richards, 1950; Baird and Horner, 1979).

Tar Heel Formation

Earlier studies by Mitra and Mickle (1998, 2000) on samples from Goldsboro and Tar River localities (Tar Heel Formation) revealed diverse species of palynomorphs. Angiosperms were the most diverse group represented by thirty species distributed in 23 genera followed by 12 genera of pteridophytes (15 species), 10 genera of gymnosperms, 8 genera of fungi and 6 genera of algae and dinoflagellates. Relative abundance data of various palynomorph groups at Goldsboro and Tar River localities indicated that angiosperm pollen were the most dominant components among all the other floral groups followed by pteridophytes, gymnosperms, fungi, algae and dinoflagellates. Angiosperm pollen were represented by tricolpates, tricolporates, Normapolles pollen, western Aquilapollenites and other triporates. Two species of Aquilapollenites (Aquilapollenites quadrilobus and Aquilapollenites sp.) were documented from seventeen samples of Goldsboro and eight samples of Tar River localities. Normapolles pollen were comprised about 48% (Goldsboro) and 52% (Tar River) of the total angiospem flora. Aquilapollenites pollen contributed about 4% and 5% of the total angiosperm palynoflora at Goldsboro and Tar River localities. Findings of western Aquilapollenites pollen from Goldsboro and Tar River localities of the Tar Heel Formation led to an extended palynofloristic studies to four different localities (North Carolina) of this formation along with further investigations at both Goldsboro and Tar River localities.

Megafossils

Berry (1907, 1908, 1910) and Stephenson (1912) provided reports of many fossil plants including megafossils of conifers from localities of the Black Creek Group. In most cases placement of taxa in designated families was erroneous. Studies on leaf and branch impressions of Araucaria bladensis Berry from Tar River locality of the Black Creek Group revealed that the material by Berry (1908) called Araucaria bladensis shared characteristics with both Araucariaceae and Podocarpaceae, it was transferred to the genus Pagiophyllum (Mickle, 1993). Studies of conifer megafossils from Tar Heel Formation of the Black Creek Group have been useful in throwing light on different conifer families that were prevalent during the Campanian. Materials from Neuse River Cut Off (Tar Heel Formation) yielded a rich assemblage of conifer twigs that included Androvettia statenensis (Hueber and Watson, 1988), Androvettia carolinensis, Brachyphyllum squammosum, Brachyphyllum sp., Geinitzia reichenbachii and Moriconia cyclotoxon (Raubeson and Gensel, 1991). Numerical analysis of leaf and morphological characters of fossil taxa and modern conifers revealed that Androvettia carolinensis and Brachyphyllum sp. belong to Hirmerellaceae whereas Geinitzia reichenbachii and Brachyphyllum squammosum belong to Araucariaceae (Raubeson and Gensel, 1991).

Three new species belonging of Liriodendroidea were reported from Neuse River locality of the Black Creek Group. The species were established based on well-preserved fruitlets with seeds in both eastern North America and Kazakhstan (Frumin and Friis, 1996). These species were similar to the extant Liriodendron, indicating that the tribe Liriodendrae was established by the mid-Cretaceous and widely distributed by the Late

Cretaceous (Frumin and Friis, 1996). The Neuse River locality was the source of other angiosperm reproductive structures, Spirematospermum chandlerae, (Friis, 1988), Platananthus hueberi and Platanocarpus carolinensis (Friis et al, 1988). Lauraceous fruits assigned to the form-genus Grexlupus carolinensis were reported in abundance from Goldsboro locality (Neuse River cut off) in North Carolina (Mickle, 1996). With more discoveries of megafossils and in situ pollen from the Black Creek Group, some of the problems regarding the affinities of many ancient taxa that are not easily determined from dispersed pollen will be resolved.

MATERIALS AND METHODS

2.1 History, Geology and Distribution of the Tar Heel Formation (Black Creek Group)

The Black Creek Group (named by Sloan in 1907) derived its name from a tributary of the Pee Dee River in Florence and Darlington Counties, South Carolina. Stephenson (1907) suggested the name Bladen Formation based on a similar lithological unit in North Carolina. Later Stephenson (1912) discarded the Bladen nomenclature and redefined Sloan's term. Black Creek has been raised to group status and includes Tar Heel (youngest), Bladen (middle) and Donoho Creek (oldest) Formations respectively (Owens and Sohl, 1989; Sohl and Owens, 1991). The characteristic feature of the Black Creek Group is the presence of thin, interbedded dark clays and light colored sands that fit well into a delta to shelf model of sedimentation (Benson, 1968; Zastrow, 1982; Carter et al, 1988; Owens and Sohl, 1989) (Figure 2a). Black Creek Group is time-transgressive and the formations represent asymmetrical cycles with transgressive marine units at the base (Sohl and Owens, 1991). It ranges from Early Campanian to Early Maastrichtian of the Late Cretaceous and extends from eastern North Carolina into northeastern South Carolina. The age was assessed primarily based on marine invertebrate faunal data and to an extent on palynology (Sohl and Christopher, 1983; Owens and Sohl, 1989; Sohl and Owens, 1991). Correlation of the formations in the Black Creek Group to other Upper Cretaceous formations was primarily based on molluscan range zones that inlcuded species of Exogyra, Anomia, Ostrea, Turritella, Sphenodiscus, Camptonectus, Flemingostrea and Belemnitella. The pollen zonation was after Wolfe (1976) and Christopher (1978).

2.2 Description of the Collecting Sites

This study was confined to localities in North Carolina and documentation of these localities has been facilitated by the use of scale county maps, U.S. Geological Survey topographic maps and consultation with professional geologists. Some of the descriptions of the localities in the literature are obscure and, to locate these areas, the North Carolina Geological Survey and the authors of relevant literature were consulted.

The best exposures of the Black Creek Group of the Carolinas outcrop along the rivers that traverse the Coastal Plain (Tar, Cape Fear, Black, Neuse). Exposures range from a foot to hundred feet in height (Christopher, written communication, 1993). The suite of localities encompassing the Tar Heel Formation was studied for this investigation (Figure 2b). Coordinates for each locality were obtained by a Garmin GPS 12XL.

Tar Heel Formation

The Tar Heel Formation crops out in an area bounded by the Pee Dee River in South Carolina and the Tar River in North Carolina (Owens and Sohl, 1989) (Figure 2c). Shelfal deposits in the northern areas of this formation change to deltaic facies in the southwestern areas (Sohl and Owens, 1991). The bedding characteristics and lack of trace fossils in outcrops of this formation are suggestive of an upper delta plain environment of deposition (Owens and Sohl, 1989).

A total of 103 samples were collected from Willis Creek, Lock and outcrops exposed along the valleys of Cape Fear, Neuse and Tar Rivers. These localities have not been dated due to lack of detailed biostratigraphical studies and have been assigned to Tar Heel Formation based on similar lithological characteristics of outcrops. The Tar Heel

Formation has been assigned an early Campanian age based on invertebrate faunal data (Sohl and Owens, 1991; Sohl, personal communication, 1993). Fossils of Exogyra ponderosa Roemar (Lower Campanian-Upper Campanian) and Ostrea whitei Stephenson (Lower Campanian) have been reported from the Tar Heel localities (Sohl and Christopher, 1983; Sohl and Owens, 1991) (Table 1.1). The samples and their lithological characteristics are outlined in Table 2.1.

Willis Creek – This locality belongs to the basal Tar Heel beds (Owens and Sohl, 1989) and is located on the south of Willis Creek, west of N.C. Highway 87, between Fayetteville and Tar Heel in Cumberland County (Carter et al, 1988). Coordinates are 34^0N 51.57′, 78^0W 51.026'. The outcrop measures 32 feet in thickness. This exposure consists of four zones from lower to upper which are: 1) black clay interbedded with micaceous, medium coarse grained sand 2) black carbonaceous clay interbedded with micaceous white sand 3) grayish-black clay with thin lenses of micaceous, buff colored-sand 4) Laminated sand and carbonaceous clay. Teredolites borings are present in all the zones and marine bivalves occur in the lowermost zone. These features suggest that these deposits represent a delta front with minor marine influence (Owens and Sohl, 1989). Twenty-six samples were collected from this locality (Figure 2d).

Lock Locality – This exposure is located on the side of Glengary Hill Road, near State Route 87, in Cumberland County. The outcrop comprises dark gray clay with fine-coarse grained, micaceous sand. It measures 10.5 feet in thickness and coordinates are 34^0N 48.276', 78^0W 50.003'. Eight samples were collected from the stratigraphic sections of this locality (Figure 2e).

Neuse River Cut Off, Goldsboro – The outcrops are exposed along the bed of the Neuse River Cut Off, southwest of Goldsboro, close to State Route 1222. The lower part consists of medium gray feldspathic sand with lenses of dark clay. The upper part consists of fossiliferous, thinly interbedded dark clays with micaceous silty fine sand (Carter et al, 1988). Coordinates are 35^0N 20.93', 78^0W 1.91'. Samples were collected from both sides of the Neuse River bridge at this locality. A total of 20 samples were collected from both laterally and vertically from sections of this locality (Figures 2f and 2g).

Tar River Locality – This locality is situated close to a bridge across the southern bank of the Tar River about 150 m downstream from the State Route 222 bridge. It is close to 10 miles upstream from Greenville in Pitt County, North Carolina. (Greenville Northwest 7.5′ Quadrangle Pitt County, North Carolina, 1982, SW ¼ SW ¼ NW ¼) (Mickle, 1993). The exposures are rich in megafossils and contain dark gray clayey glauconitic sand. A transect of 41 feet was measured from a reference point and lateral sampling was done as the outcrop was less than 2 feet in thickness. Sampling was done at every 2 feet interval. A total of 21 samples were collected (Figure 2h).

Ivanhoe Locality – Exposures are along the Black River at the town of Ivanhoe, close to State Route 1162 in Sampson County, North Carolina (Owens and Sohl, personal communication, 1993). Coordinates are 34^0N 37.183′, 78^0W 15.556′. Three zones are visible in the exposures: 1) lower black clay interbedded with micaceous, buff colored sand, 2) middle greenish-gray clay with glauconitic sand, 3) grayish-black clay with thin lenses of light brown, coarse sand. The thickness of the section is 30 feet and 24 samples were collected vertically at close intervals (Figure 2i).

Elizabethtown – This locality is situated about 1.5 miles southwest of intersection of U.S. Highway 701 with N.C. Highway 87 in Elizabethtown. The lowermost beds (Black Creek of the Late Cretaceous) consist of lamnated, micaceous, and blue-gray sand with lenses of clay. Bone fragments, shark teeth, lignitized wood and carbonized impressions of plants are common in these sediments. Pliocene sediments overlie the Late Cretaceous beds (Carter et al, 1988). The Late Cretaceous beds have been assigned to the Tar Heel Formation (Vince Schneider, personal communication, 1997). Four samples that were earlier collected by Schneider were processed for palynological studies. Of these, two samples were from laminated dark clayey sand and other two were from micaceous blue-gray clayey sand.

2.3 Materials and Techniques for their collection

A. Pre Laboratory Techniques

Sampling – For Ivanhoe, Lock and Willis Creek localities, sampling was done in vertical profiles following measurement of the outcrop. For Goldsboro and Tar River, lateral sampling was conducted. The stratigraphic section at each level was trenched to expose fresh rock. Sampling interval was dependent on the characteristics of the outcrops.

Outcrops with distinct beds

For outcrops with distinct beds in Willis Creek and Ivanhoe respectively, each distinctive rock layer (bed) was measured and sampled at least once. Multiple samples were taken at several levels where the thickness of the unit (bed) made such a sampling possible.

Outcrops without distinct beds

Outcrops showing an absence of distinctive beds or rock layers in Goldsboro and Lock localities respectively were sampled as closely as possible in vertical profiles. Lateral sampling was done in Tar River locality as the outcrop was less than 2 feet in thickness. **Collection and storage of samples –** About 200-300 grams per sample of clastic (discrete particles like shale, silt, clay) sediments were collected. Heavy plastic freezer bags were used for storing samples to minimize contamination. Sediment samples with high moisture content (common in rocks from the Atlantic Coastal Plain) were air dried and then stored since moisture accelerates fungal growth (Upchurch, 1989).

B. Laboratory Techniques – Maceration and Slide Preparation

Modified Maceration Technique – Samples were processed in the laboratory using modified maceration techniques (Figure 2j). Standard techniques published in literature and patented by United States Geological Survey in Reston, Virginia, were used but later modified in the Palynological Laboratory at North Carolina State University. The modified maceration technique yielded more and identifiable grains with minimum processing. The standard techniques for maceration of clastic rocks (Traverse, 1988) were tested to see whether any disparity exists in the number of palynomorphs or not. Although spores and pollen were of good quality, the standard technique yielded a lower number of palynomophs. Representative samples from each locality were processed for four treatments and it was observed that treatments with potassium hydroxide and nitric acids yielded a lower number of grains compared to the cold treatment where both nitric acids and potassium hydroxide steps were completely eliminated (Table 2.2). For each sample, 25-50g was weighed and pulverized with a mortar and pestle to pea-sized fragments. For muddy or unconsolidated sediment, a stirring rod was used to divide the sediment into smaller pieces. The sample was then placed into 400 ml Tripour beaker and covered with 20 % aqueous HCl overnight for fixation. Once the reaction was completed, the residue was neutralized with repeated water washes. Following this, the sample was covered with 49 % HF and left overnight. After neutralization with water washes, the residue was mixed with dilute detergent to suspend clay-size particles and then centrifuged slowly for one minute. Slow centrifugation in detergent was repeated until most of the clays were removed as supernatant. The clay supernatant was sieved through fabric mesh (8μm) with sieve plate and aspirator to remove clay and isolate organics that may have been poured off. After a water wash to remove the detergent, the residue was mixed with $ZnCl_2$ (specific gravity = 2) and centrifuged to separate organics from mineral matter. Organic material was recovered by pipette, rinsed with 2 % HCl twice and neutralized with distilled water before oxidation with concentrated HNO_3 (nitric acid). The residue was treated with 50 % KOH for 1-5 minutes to remove humic acid and then neutralized with water. However, it has been found that the treatments with nitric acid and potassium hydroxide are potentially damaging to spores and pollen and unnecessary for most of the work with clastics, especially the samples from the Tar Heel Formation (Mitra and Mickle, 1999). The modified palynological preparation method was used to process all 103 samples in order to minimize processing time while obtaining abundant, identifiable palynomorphs from each sample. This deviation from the conventional technique is well suited for processing clastic sediments and is both cost and time effective.

Staining and slide making --- Following distilled water washes for both treated (HNO_3 and KOH, HNO_3 only, KOH only) and untreated residues, the residues were treated with few drops of Safranin O for a minute. After staining, residues were washed with 25 % ethanol two to three times to remove excess stain. Residues were then mixed with glycerin jelly and mounted on microscope slides with coverslips. Slides were kept upside down on toothpicks on a warming table at 40 ^{0} C for 2-3 days for drying the mounting medium. Coverslips were ringed with clear nail polish for a tight seal. For each productive sample, ten to twelve slides were prepared. Unmounted residues were stored in small glass vials with plastic push-in or screw-tops to which glycerol and a couple of drops of phenol were added for preservation and to prevent fungal growth respectively (Batten, personal communication, 1994). Cross contamination of the samples was avoided by use of disposable pipettes, and the careful cleaning and bleaching of all reusable plastic and glassware.

C. Data

Palynomorphs - Slides from each sample were scanned to establish the species of palynomorphs regardless of relative abundance. Palynomorphs were photographed using Kodak Plus-X pan ASA 125 black and white film and a Nikon photomicroscope at 40X and 100X respectively. Length and width measurements for identifiable palynomorph species recognized from the Tar Heel Formation were recorded to the nearest tenth of a micrometer (µm) using an ocular micrometer.

Following completion of the taxonomic portion (identification of palynomorphs) of the study, the relative frequency of palynomorph types was determined. An average of two hundred palynomorphs per sample was counted using a 40X objective lens of a Nikon BT-H compound microscope following standard practice (Traverse, 1988; Willard, 1998; Baghai, 1996). Some samples had fewer than 200 palynomorphs. For those samples, all palynomorphs were counted. Poorly preserved or non-productive samples were not used for palynomorph counts. Percentages for general categories of palynomorphs (dinoflagellates/acritarchs, fresh water algae, fungi, ferns/mosses, gymnosperms and angiosperms) were calculated. Bar graphs illustrated the relative abundance data for each locality.

Cluster analyses in the Q and R modes were conducted following data entry in Microsoft Excel 2000 spreadsheet. Q-mode clustering techniques compared samples as to their species content resulting in the grouping of samples with similar species content. R-mode clustering techniques were used to group palynomorphs based on their occurrence and abundance in the Tar Heel Formation samples. Minimum variance clustering method with log (2) transformation was used for both Q-mode and R-mode analyses. Clustering techniques were carried out with Multivariate Statistical Package (MVSP for windows) version 3.0 (Kovach, 1998).

D. Preservation, documentation and sharing of data

Samples of rocks, slides and residues are deposited in the Paleobotanical and Palynological Collections of the North Carolina State University.

2.4 Identification of Taxa

Palynomorph identifications were done by comparison with published descriptions and illustrations from and consultations with other professional palynologists. Dr. Lucy

Edwards of United States Geological Survey, Reston, Virginia, was consulted for identification of freshwater algae and dinoflagellates. Ioannides's (1986) publication on "Dinoflagellate cysts from Upper Cretaceous-Lower Tertiary Sections, Bylot and Devon Islands, Arctic Archipelago" was helpful in providing detailed descriptions on Upper Cretaceous dinoflagellate taxa. Elsik's (1993) short course "The Morphology, Taxonomy, Classification and Geologic Occurrence of Fungal Palynomorphs" was used for identification of fungal palynomorphs and for information on their geologic range and geographic occurrences. Dr. William Elsik of Mycostrat Connection, Houston, Texas reconfirmed identifications of fungal palynomorphs. Brenner's (1963) "The spores and pollen of the Potomac Group of Maryland" published by Maryland Department of Geology, Mines and Water Resources was a valuable tool for identifying many trilete spores, and gymnosperm and angiosperm pollen from the Tar Heel Formation. Professional palynologists, Dr. Raymond Christopher of Clemson University, South Carolina, Dr. Michael Farabee of Estrella Mountain Community College in Avondale, Arizona, Dr. Norm Frederikson of United States Geological Survey, Reston, Virginia, Dr. Michael Zavada of Providence College, Providence, Rhode Island and Dr, Robert Ravn of Aeon Biostratigraphic Services, Anchorage, Alaska, provided expertise on the identification of various pteridophyte spores, gymnosperm and angiosperm pollen. Batten and Christopher's "Key to the recognition of Normapolles and some morphologically similar pollen genera" was useful in identifying species of Normapolles pollen from the Tar Heel Formation. Various volumes of the serial "Catalog of fossil spores and pollen" were useful for taxonomy and stratigraphic range of various groups of palynomorphs.

The Taxon database (v.3.2, copyright R. L. Ravn, 1998) was a source of information on the taxonomy as well as stratigraphic and geographic occurrences of fossil palynomorphs.

SYSTEMATIC PALEOPALYNOLOGY

Palynomorphs recovered from Tar Heel samples have been described systematically according to their inferred affinity with major taxonomic groups of plants. Palynofloras have been arranged into the following groups:

1. Fresh water algae
2. Dinoflagellates
3. Fungal spores, hyphae and fruiting bodies
4. Bryophyte spores and pteridophyte spores
5. Gymnosperm pollen
6. Angiosperm pollen

Genera and species documented from previously published accounts have been used in the identification of the palynomorphs encountered in this study. The systematic arrangement of the families, orders, classes and divisions has been done from a compilation of various authorities as discussed in section 2.4. Species of pollen and spores have been listed under each of their respective genera. Naming of new species has been refrained from this dissertation and has been designated as sp. following the generic name in most cases. The classifications for each taxonomic group follow Lee (1989) for algal forms, Lentin and Williams (1989) and Fensome et al (1989) for dinoflagellates, Elsik (1993) for fungi and Taylor (1981) for Bryophytes, Pteridophytes, Gymnosperms and Angiosperms.

Genera and species described under each taxonomic category are arranged alphabetically. The palynomorphs of unknown affinity have been treated as *incertae sedis*.

3.1 Distribution of Palynomorphs

A total of 80 species, assignable to 66 form-genera, were recovered from stratigraphic sections of Tar Heel Formation of the Atlantic Coastal Plain. Dinoflagellates and fresh water algae are represented by 7 forms; fungi are represented by 9 genera of spores, hyphae and fruiting bodies; pteridophytes and bryophytes include 15 genera of trilete and monolete dispersed spores; gymnosperms are represented by 11 genera of inaperturate, saccate, bisaccate and nonsaccate pollen grains and angiosperms include 24 genera. Of these 24 genera, 22 are dicots that include tricolpates, triporates, tricolporates and two genera included monocolpate pollen of monocots.

3.2 Classification of palynomorphs

A. Fresh water algae

Division Chlorophyta

Class Chlorophyceae

Order Chlorococcales

Family Botryococcaceae

Genus Botryococcus

Botryococcus braunii

Order Zygnematales

Family Zygnemataceae

Genus Ovoidites

Ovoidites sp.

Genus Tetraporina

Tetraporina sp.

Division Chlorophyta (incertae sedis)

Genus Schizosporis

Schizosporis parvus

B. Dinoflagellates

Division Dinoflagellata

Class Dinophyceae

Order Peridiniales

Family Peridiniaceae

Genus Cerodinium

Cerodinium pannuceum

Genus Isabelidinium

Isabelidinium sp.

Genus Pierceites

Pierceites pentagonus

C. Fungi

Division Fungi

Class Deuteromycetes (Fungi Imperfectae)

Order Sphaeropsidaceae

Subfamily Amerosporae

Genus Inapertisporites

Inapertisporites sp.

Subfamily Didymosporae

Genus Dicellites

Dicellites sp.

Genus Didymoporisporonites

Didymoporisporonites sp.

Subfamily Phragmosporae

Genus Fractisporonites

Fractisporonites sp.

Genus Multicellaesporites

Multicellaesporites sp.

Genus Tetracellites

Tetracellites sp.

Subfamily Scolecosporae

Genus Scolecosporites

Scolecosporites sp.

Subfamily: unknown (hyphae)

Genus Palaeancistrus

Palaeancistrus sp.

Subfamily: unknown (flattened fruting bodies)

Genus Phragmothyrites

Phragmothyrites sp.

D. Bryophyte and Pteridophyte spores

Division Bryophyta

Class Musci

Order Sphagnales

Family Incertae

Genus Stereisosporites

Stereisosporites sp.

Division Lycophyta

Order Lycopodiales

Family Lycopodiaceae

Genus Camarozonosporites

Camarozonosporites sp.

Genus Ceratosporites

Ceratosporites sp.

Genus Hamulatisporites

Hamulatisporites sp.

Order Selaginellales

Family Selaginellaceae

Genus Cingutriletes

Cingutriletes sp.

Genus Echinatisporis

Echinatisporis levidensis

Division Pteridophyta

Subclass Leptosporangiatae

Order Filicales

Family Cyatheaceae

Genus Cyathidites

Cyathidites sp.

Family Dipteridaceae

Genus Dictyophyllidites

Dictyophyllidites sp.

Family Gleicheniaceae

Genus Deltoidospora

Deltoidospora sp.

Family Matoniaceae

Genus Matonisporites

Matonisporites equiexinus

Matonisporites sp.

Family Polypodiaceae

Genus Laevigatosporites

Laevigatosporites ovatus

Laevigatosporites sp.

Genus Leiotriletes

Leiotriletes pseudomesozoicus

Leiotriletes sp.

Family Schizaeaceae

Genus Cicatricosisporites

Cicatricosisporites dorogensis

Cicatricosisporites sp.

Pteridophyta incertae sedis

Genus Undulatisporites

Undulatisporites sp.

E. Gymnosperm pollen

Division Cycadophyta

Order Cycadales

Family Cycadaceae

Genus Cycadopites

Cycadopites carpentieri

Division Coniferophyta

Order Coniferales

Family Araucariaceae

Genus Araucariacites

Araucariacites australis

Araucariacites sp.

Family Cheirolepidiaceae

Genus Classopollis

Classopollis classoides

Genus Inaperturopollenites

Inaperturopollenites sp.

Family Pinaceae

Genus Pinuspollenites

Pinuspollenites sp.

Family Podocarpaceae

Genus Podocarpites

Podocarpites radiatus

Genus Parvisaccites

Parvisaccites radiatus

Genus Piceaepollenites

Piceaepollenies sp.

Family Taxodiaceae

Genus Taxodiaceaepollenites

Taxodiaceaepollenites hiatus

F. Angiosperms

Division Magnoliophyta

Class Magnoliopsida

Subclass Hamamelidae

Order Fagales

Family Fagaceae

Genus Cupuliferoipollenites

Cupuliferoipollenites sp.

Order Juglandales

Family Juglandaceae

Genus Momipites

Momipites spackmanianus

Genus Plicatopollis

Plicatopollis sp.

Subclass Hamamelidae incertae sedis

Genus Complexiopollis

Complexiopollis abditus

Complexiopollis exigua

Complexiopollis funiculus

Complexiopollis sp.

Genus Cyrillaceaepollenites

Cyrillaceaepollenites barghoornianus

Genus Labrapollis

Labrapollis sp.

Genus Oculopollis

Oculopollis sp.

Genus Plicapollis

Plicapollis retusus

Plicapollis sp.

Genus Pseudoplicapollis

Pseudoplicapollis newmanii

Pseudoplicapollis longiannulata

Pseudoplicapollis sp.

Genus Tetrapollis

Tetrapollis validus

Genus Tricolpites crassus

Tricolpites sp.

Genus Tricolpopollenites

Tricolpopollenites williamsoniana

Tricolpopollenites sp.

Genus Trudopollis

Trudopollis variabilis

Subclass Rosidae

Order Cornales

Family Nyssaceae

Genus Nyssapollenites

Nyssapollenites sp.

Order Proteales

Family Proteaceae

Genus Proteacidites

Proteacidites retusus

Dicotyledonae – Incertae sedis

Genus Retitricolpites

Retitricolpites sp.

Genus Tricolporopollenites

Tricolporopollenites bradonensis

Tricolporopollenites sp.

Class Liliopsida

Subclass Arecidae

Order Arecales

Family Palmae (Arecaceae)

Genus Arecipites

Arecipites sp.

Subclass Liliidae

Order Liliales

Family Liliaceae

Genus Liliacidites

Liliacidites variegatus

3.3 Descriptions of Palynomorphs

Freshwater algae

Botryococcus Kützing 1849

Type species: Botryococcus braunii Kützing 1849

Description: Traverse (1955, p. 276); Batten and Grenfell (1996, p. 208, pl. 2, figs. 4, 5-7, 8, 9).

Suggested affinity: Chlorophyta; Chlorococcales, Botryococcaceae (Batten and Grenfell, 1996).

Botryococcus braunii Kützing 1849

Plate I, Figure 4

Description: Traverse (1955, p. 276); Batten and Grenfell (1996, p. 208, pl. 2, figs. 4, 5-7, 8, 9).

Measurements: 50-80 µm in diameter; five specimens measured.

Stratigraphic interval: Found in 14 samples in Goldsboro, 17 samples in Tar River, 10 samples in Willis Creek, 1 in Lock and 2 in Ivanhoe localities.

Previously reported occurrences: Carboniferous-Recent. Fossil forms of Botryococcus braunii have been reported from the Upper Carboniferous of Yorkshire (Marshall and Smith, 1964); basal Cretaceous of southern England (Harris, 1938); Tertiary sediments of Palana, Rajasthan, India (Sah and Kar, 1974); Cenozoic deposits of Australia (Cookson, 1953); Oligocene of Vermont (Traverse, 1955); Miocene of Oregon (Gray, 1960).

Ovoidites Potonié 1951

Type species: Ovoidites ligneolus (Potonié) Potonié 1951, p. 151, pl. 21, fig. 185).

Description: Potonié (1951, p. 151, pl. 21, fig. 185).

Suggested botanical affinity: zygospore or aplanospore of zygnemataceous algae (van Geel and van der Hammen, 1978).

Ovoidites sp.

Plate I, Figure 1

Measurements: 45 to 60 µm in length; 19 to 30 µm in width; eight specimens measured.

Stratigraphic interval: Present in 16, 15, 4, 13, samples of Goldsboro, Tar River, Willis Creek and Ivanhoe localities respectively. Not reported from Lock and Elizabethtown.

Previously reported occurrences: Cretaceous-Miocene. Species of Ovoidites have been reported from various regions worldwide. Some of the reported occurrences are: Cenomanian of southern France (Thiergart, 1954), Campanian of Wyoming (Meyers, 1977); Maastrichtian of North Dakota (Bergad, 1974); Maastrictian of Wyoming (Farabee and Canright, 1986); Paleocene of South Dakota (Stanley, 1965); Oligocene of Poland (Grabowska and Piwocki, 1975); Pliocene and Pleistocene of China (Song, 1988); Upper Maastrictian of South Korea (Yi, 1997); Upper Miocene of Hungary (Nagy, 1969); Upper Miocene of Turkey (Nakoman, 1968).

Schizosporis Cookson and Dettmann, 1959

Type species: Schizosporis reticulatus (Cookson and Dettmann, 1959) p 213, pl.1, figs 1-4.

Description: Cookson and Dettmann, p. 213.

Suggested botanical affinity: Schizosporis has been suggested to have affinities with the fresh water alga, Spirogyra (Zygnemataceae) (van Geel, 1979). Cookson and Dettmann (1959) classified Schizosporis as Pteridophyta incertae sedis and also as inaperturate angiosperm and gymnosperm pollen.

Schizosporis parvus Cookson and Dettmann, 1959

Plate I, Figure 3

Description: Cookson and Dettmann (1959, p.216, pl. 1, figs. 15-19).

Measurements: Length 50 to 88µm; width 20 to 32 µm; 10 specimens measured.

Stratigraphic interval: Occurs in 58 palynomorph samples throughout the Tar Heel Formation. Occurs in 17 samples of each of Goldsboro and Tar River localities, 8 samples of Willis Creek, 13 samples of Ivanhoe and 3 samples of Lock localities. Not reported from Elizabethtown locality.

Previously reported occurrences: Barremian-Paleocene. In the United States, this species has been reported from Cenomanian of Arizona (Romans, 1975); Upper Cretaceous of Wyoming (Griggs, 1970); Lower and Upper Almond Formation, Campanian of Wyoming (Stone, 1973); Paleocene sediments of Alabama (Srivastava, 1972), Texas (Elsik, 1968), Montana (Norton and Hall, 1969), South Dakota (Stanley, 1965); Eocene sediments of Tennessee (Elsik and Dilcher, 1974). Worldwide: reported from Lower Cretaceous in Germany (Dörhöfer, 1977); Albian and Cenomanian (Cookson and Dettman, 1959); Albian to Cenomanian sediments (Cookson and Dettman, 1959).

Tetraporina Naumova 1939 ex Bolkhovitina 1953

Type species: Tetraporina antiqua Naumova 1950

Description: Naumova (1950; p. 106-107, pl. 1, figs 1, 2).

Suggested botanical affinity: zygospores of Zygnemataceae (van Geel and Grenfell, 1996).

Tetraporina sp.

Plate I , Figure 2

Measurements: 40 to 65 µm in length; 39-60 µm in width; three specimens measured.

Stratigraphic interval: Reported from 18, 19, 4, 4 samples of Goldsboro, Tar River, Willis Creek and Ivanhoe localities respectively. Not reported from Elizabethtown and Lock localities.

Previously reported occurrences: Carboniferous-Recent. Upper Devonian of the Russian Platform (Naumova, 1953); Lower Carboniferous of SW China (Gao, 1980); Lower Permian of Western Australia (Foster and Waterhouse, 1988); Lower Permian of Brazil (Ybert, 1975); Tertiary of Rajasthan, India (Sah and Kar, 1974); Cretaceous of the central part of USSR (Bolkhovitina, 1953).

Dinoflagellates

Cerodinium Vozzhennikova 1963

Type species: Cerodinium sibiricum Vozzhennikova 1963.

Description: Vozzhennikova (1963, p. 181, figs. 9-10).

Cerodinium pannuceum (Stanley) Lentin and Williams 1987

Plate I, Figure 5

Description: Stanley (1965, p.220, pl. 22, figs 1-4, 8-10); Lentin and Williams (1987, p.115)

Measurements: Length – 70-120µm, width – 45-90µm. Six specimens measured.

Stratigraphic interval: Present in 8 samples from the lower sections of Ivanhoe locality. This species is also found in 7 and 16 samples of Goldsboro and Willis Creek localities respectively.

Previously reported occurrences: Campanian-Paleocene. Some of the reported occurrences are: USA – Lower Campanian-Lower Maastrichtian of NE Texas (Heine, 1991); Campanian of South Dakota (Lentin and Williams, 1980); Lower-Upper Maastrichtian of Atlantic Coastal Plain, U.S. (Aurisano, 1989); Upper Campanian-lower Maastrichtian of eastern United States (Habib and Miller, 1989). Worldwide- Pliocene-Pleistocene of Mexico (Wrenn and Kokinos, 1986); Paleocene of Manitoba, Canada (Kurita and Mc Intyre, 1995); Upper Paleocene-basal Eocene, NW Germany (Köthe, 1990); Maastrichtian-Danian of NW Tunisia (Brinkhuis and Zachariasse, 1988); Lower Paleocene of Israel (Eshet et al, 1992)

Isabelidinium Lentin and Williams 1977

Type species: Isabelidinium korojonense (Cookson and Eisenack) Lentin and Williams 1977.

Description: Lentin and Williams (1997, p. 167); Cookson and Eisenack (1958, pgs 27-28, plate 4, figs 10, 14).

Isabelidinium sp.

Plate I. Figure 6

Measurements: Total length 55-95µm long, 35-75µm wide. Six specimens measured.

Stratigraphic interval: Found in 9 samples of each of Goldsboro and Tar River localities, 15 , 2, 5 and 3 samples of Willis Creek, Lock, Elizabethtown and Ivanhoe localities respectively.

Previously reported occurrences: Species assigned to Isabelidinium have been reported from Campanian sediments of Australia (Marshall, 1990), Middle Campanian –Lower Maastrichtian of Canada (Cookson and Eisenach, 1958) and Australia (Helby, Morgan and Partridge, 1987) and Maastrichtian sediments of southeast Canada (Bujak and Williams, 1978).

Pierceites Habib and Drugg 1987

Type species: Pierceites schizocystis Habib and Drugg 1987.

Description: Habib and Drugg (1987, p. 761-762; pl.6, fig. 1); Fensome et al (1995; fig.1, pg. 1769).

Pierceites pentagonus May 1980

Plate I, Figure 7

Description: May (1980, p.87-88, pl.10, figs 13-14); Habib and Drugg (1987; p.762).

Measurements: 50-68 μm in diameter; Eight specimens measured.

Stratigraphic interval: Present in 7, 17 and 9 samples of Goldsboro, Willis Creek and Ivanhoe localities respectively. Not reported from Lock, Elizabethtown and Tar River samples.

Comments: Antapical horns are unequally developed and this species was originally placed under Trithyrodinium.

Previously reported occurrences: Campanian-Paleocene. Some of the reported occurrences of this species are:

U.S.—Maastrichtian sediments of Georgia (Firth, 1987), offshore eastern United States (Habib and Drugg, 1987), New Jersey (May, 1980) and Maryland (Whitney, 1984); Worldwide –Upper Campanian sediments of Indian Ocean (Mao and Mohr, 1992); Upper Maastrichtian of eastern France (Gorin and Monteil, 1990); Santonian and Campanian sediments of Arctic Canada (Ionnides, 1986); Paleocene of Morocco (Soncini and Rauscher, 1988).

Fungi

Dicellites Elsik 1993.

Type species: Dicellites infrascabratus Elsik (1993).

Description: Elsik (1993, p. 50).

Suggested affinity: Saccardo Spore Group. Didymosporae (two cells).

Dicellites sp.

Plate II, Figure 1

Measurements: 16-35μm in length; 10-20μm wide. 5 specimens measured.

Stratigraphic interval: Present in many samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Turonian-Recent. Some of the sediments from where this particular type of spore is reported are: Turonian of northeast Ustyurt and the Aral area (Petrosants, 1976); Paleocene of Rockdale Lignite, Milam County, Texas (Elsik, 1968); Eocene sediments of Palana, Rajasthan, India (Sah and Kar, 1974); Eocene of Tennessee (Sheffy and Dilcher, 1971); Miocene of Klodnica near Gliwice (Macko, 1957); Pliocene of East African lake sediments (Wolf and Cavaliere, 1966).

Didymoporisporonites Sheffy and Dilcher (1971) emend. Elsik (1993)

Type species: Didymoporisporonites Sheffy and Dilcher (1971) emend. Elsik (1993).

Description: Sheffy and Dilcher (1971, p.42) and Elsik (1993, p.52).

Suggested affinity: Saccardo Spore Group. Didymosporae (dicellate/two cells).

Didymoporisporonites sp.

Plate II, Figure 5

Measurements: Two celled specimen. The largest cell measures 15-32µm long; 10-16µm wide; and the smallest cell measures 3-7µm in length and 1-2 µm in diameter, 5 specimens measured.

Stratigraphic interval: Present in samples the upper stratigraphic sections of Ivanhoe, Lock and Willis Creek localities. It occurs also in 18 and 13 samples of Goldsboro and Tar River localities respectively. Not reported from Elizabethtown locality.

Previously reported occurrences: Late Cretaceous-Recent. Reported by Baghai from the Aguja Formation of Texas (1996). Since this specimen is also reported from the Tar Heel Formation, the fossil history could go back to the Late Cretaceous. Sheffy and Dilcher (1971) reported this form genus from the middle Eocene sediments of Tennessee.

Fractisporonites Clarke 1965 emend. Elsik (1993)

Type species: Fractisporonites canalis Clarke 1965 emend. Elsik (1993).

Description: Clarke (1965, p. 91, pl. 1, fig. 6); Elsik (1993, p. 82).

Suggested affinity: Saccardo Spore Group. Phragmosporae, Scolecosporae.

Fractisporonites sp.

Plate II, Figure 3

Measurements: 35-50µm long; 16-18µm wide. Six specimens measured.

Stratigraphic interval: Present in many samples of Goldsboro, Tar River, Willis Creek, Lock and Ivanhoe localities. Not recovered from any of the samples of Elizabethtown locality. This has been reported from a total of 18 samples of the above mentioned localities.

Previously reported occurrences: Turonian-Recent. Reported from the Upper Cretaceous of Colorado (Clarke, 1965).

Inapertisporites van der Hammen emend. Sheffy and Dilcher (1971) Elsik (1993)

Type species: Inapertisporites variabilis van der Hammen 1954 emend. Elsik (1993).

Description: van der Hammen (1954), Rouse (1959) and Elsik (1993).

Suggested affinity: Saccardo Spore Group. Amerosporae.

Inapertisporites sp.

Plate II, Figure 8

Measurements: 12-18 µm in diameter; 10 specimens measured.

Stratigraphic interval: Occurs in most samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Early Cretaceous-Recent. USA – Rockdale Lignite (Paleocene) of Texas (Elsik, 1968); Lawrence clay pit in Tennessee (Eocene) (Elsik and

Dilcher, 1974). Worldwide—Maastrichtian sediments of Columbia, South America (van der Hammen, 1954); Middle Eocene of Burrard Formation, Vancouver, Canada (Rouse, 1962).

Comments: Spores reported from Tar Heel Formation are circular to oval in outline and appear as clusters or sometimes as isolated spheres. Spore walls are folded.

Multicellaesporites Elsik 1968

Type Species: Multicellaesporites nortonii Elsik 1968 emend. Elsik (1993).

Description: Elsik (1968, p. 269; 1993, p.77).

Suggested affinity: Saccardo Spore Group. Didymosporae, Phragmosporae.

Multicellaesporites sp.

Plate II, Figure 2

Measurements: 36-45µm long; 10-12µm wide; wall is 0.5-1.0 µm thick; ten specimens measured.

Stratigraphic interval: Present in many samples throughout the Tar Heel Formation. The percentage of Multicellaesporites sp. increases in stratigraphically younger sections at both Ivanhoe and Willis Creek localities. This trend is not observed at other localities of the Tar Heel Formation.

Previously reported occurrences: Late Paleocene-Recent. Species of Multicellaesporites were reported from Paleocene of South East Texas; Middle Eocene of Tennessee (Sheffy and Dilcher, 1971); Lower Tertiary sediments of E. China (Ke and Shi, 1978)

Comments: Spores from the Tar Heel Formation have 5 to 6 cells with smooth to scabrate outer surface. The wall is thick and one-layered.

Palaeancistrus Dennis 1970

Type Species: Palaeancistrus martinii Dennis 1970

Description: Dennis (1970); Elsik (1993, p. 85).

Suggested affinity: Fossil fungal hyphae bearing clamp connections belonging to Basidiomycetes.

Palaeancistrus sp.

Plate II, Figure 7

Measurements: 25-38µm long; 2-3 µm wide; six specimens measured.

Stratigraphic interval: Occurs in 16, 12 samples of Goldsboro and Tar River localities and also in stratigraphically older sections of Willis Creek and Ivanhoe localities. Not found in samples of Lock and Elizabethtown localities.

Previously reported occurrences: Middle Pennsylvanian-Recent. Comminuted hyphae assigned to the group Basidiomycetes have been reported from the British Pennsylvanian rocks (Dennis, 1970).

Comments: Species belonging to Palaeancistrus have clamp cells. But it is sometimes confused with Palaeofibulus, which was described by Osborn et al (1989) from acetate peels of Triassic of Antarctica. It is questionable whether the latter genus has true clamp cells or not (Elsik, 1993).

Phragmothyrites Edwards 1922 emend. Elsik (in prep.)

Type species: Phragmothyrites eocaenicus Edwards 1922 emend. Elsik (in prep.).

Description: Edwards (1922; p.67-71, pl. 8, figs 1-5); Elsik (1993, p. 93).

Suggested affinity: Fungal fruting body with radiate symmetry (Elsik, 1993).

Phragmothyrites sp.

Plate II, Figure 6

Measurements: The fruting body measures 50-90µm in diameter; four specimens measured.

Stratigraphic interval: Present in all the localities (except Elizabethtown) but in low frequency.

Previously reported occurrences: Lower Cretaceous-Recent. Species assigned to Phragmothyrites have been reported from the Lower Cretaceous of Andaman Islands (Singh, 1971); Cretaceous-Tertiary Formations of South India (Banerjee and Misra, 1968); Eocene of Mull, Scotland (Edwards, 1922); Eocene of Garo Hills, Assam (Kar, Singh and Sah, 1972); Oligocene of the Gulf Coast (Scull, Felix, McCaleb and Shaw, 1966); Miocene of Ninetyeast Ridge, Indian Ocean (kemp, 1974); Pliocene of Rumania (Givulescu, 1975); Pleistocene of Imizu Plain, central Japan (Fuji, 1964).

Scolecosporites Lange and Smith 1971 emend. Elsik (in prep)

Type species: Scolecosporites maslinensis Lange and Smith 1971 emend. Elsik (in prep).

Description: Lange and Smith (1971); Elsik (1993, p. 79).

Suggested affinity: Saccardo Spore Group. Scolecosporae.

Scolecosporites sp.

Plate II, Figure 9

Measurements: Length – 30-55μm; Width – 3-4 μm. Five specimens measured.

Stratigraphic interval: Found in 15, 10, 21, 21 samples of Goldsboro, Tar River, Willis Creek and Ivanhoe localities respectively. Not reported from Lock and Elizabethtown.

Previously reported occurrences: Turonian-Recent. Middle Eocene of Australia (Lange and Smith, 1971); Middle Eocene of Tennessee (Elsik and Dilcher, 1974; Sheffy and Dilcher, 1971).

Comments: The width and length ratio of Scolecosporites is 1:15 or greater.

Tetracellites Elsik (1993)

Type species: Tetracellites felixii Elsik (1993)

Description: Elsik (1993, p. 62).

Suggested affinity: Saccardo Spore Group, Phragmosporae.

Tetracellites sp.

Plate II, Figure 4

Measurements: Length 30-45μm, width 15-20μm; three specimens measured.

Stratigraphic interval: Present in all the samples throughout the Tar Heel Formation.

Previously reported occurrences: Campanian-Oligocene. Reported from the Aguja Formation (Campanian) of Texas (Baghai, 1996); Eocene of western Tennessee (Dilcher, 1965; Sheffy and Dilcher, 1971); Oligocene of Montana (Wilson and Webster, 1949).

Comments: The spores are tetracellate, inaperturate, psilate with a uniform wall thickness and fusiform in outline. Tetracellites were reported from rocks not older than Late Paleocene (Elsik, 1993), but their stratigraphic range goes back to the Campanian with reports of this form genus from Aguja Formation (Bagahi, 1996) and Tar Heel Formation.

Bryophyte and Pteridophyte spores

Aequitriradites Delcourt and Sprumont 1955

Type species: Aequitriradites dubius Delcourt and Sprumont 1955

Description: Delcourt and Sprumont (1955, p. 80).

Suggested affinity:

Aequitriradites ornatus Upshaw 1963

Plate III, Figure 5

Description: Upshaw (1963, p. 428, pl. 1, figs 1-6, 9-4; text figure 1).

Measurements: 32-55μ m in diameter; 6 specimens measured.

Stratigraphic interval: Present in all samples of Goldsboro, 13 and 12 samples of Tar River and Willis Creek localities respectively. Not reported from Elizabethtown, Ivanhoe and Lock localities.

Previously reported occurrences: Lower-Upper Cretaceous. USA – Upper Albian of South Oklahoma (Wingate, 1980); Cenomanian of Wyoming (Griggs, 1970); Cenomanian-Coniacian of Wyoming (Upshaw, 1963); Lower Campanian of New Mexico (Jameossanaie, 1987). Worldwide – Lower Cretaceous of N. China (Miao et al, 1984); Upper Turonian of N. Alberta (Sweet and Mc Intyre, 1988); Cenomanian of NW Alberta (Singh, 1983); Mid-Cenomanian of W. Greenland (Koppelhus and Pedersen, 1993); Maastrichtian of Alberta (Srivastava, 1972).

Camarozonosporites Pant, 1954 ex Potonié, 1956; emend. Klaus, 1960

Type species: Camarozonosporites (Rotaspora) cretaceous (Weyland and Kriegar) Potonié 1956.

Description: Pant (1954 p.51, nomen nudum; genus described but not species); Potonié (1956, p.65); Klaus (1960, p.135-136).

Suggested botanical affinity: Lycopodiaceae (Farabee and Canright, 1986).

Camarozonosporites sp.

Plate III, Figure 7

Measurements: Equatorial diameter 25-50µm; exine 2 to 3 µm thick; lumina of reticulum 1-2 µm; five specimens measured.

Stratigraphic interval: Found in the upper stratigraphic sections of Ivanhoe, Lock and Willis Creek localities; occurs also in 11 and 18 samples of Goldsbor and Tar River localities respectively. Not reported from Elizabethtown.

Previously reported occurrences: Species of Camarozonosporites are known to occur throughout the Mesozoic and early Tertiary in the Northern Hemisphere.

Ceratosporites Cookson and Dettman 1958

Type species: Ceratosporites equalis Cookson and Dettmann 1958

Description: Cookson and Dettmann (1958, p.101-102, pl.14, figs 17-20).

Suggested botanical affinity: Selaginallaceae

Ceratosporites sp.

Plate III, Figure 8

Measurements: Equatorial diameter 16-30µm, spines are 3-5µm in length. Five specimens measured.

Stratigraphic interval: 19 samples from Goldsboro and 20 samples from Tar River localities yielded this grain. This was also found in stratigraphically younger sections of Willis Creek locality.

Previously reported occurrences: Triassic-Maastrichtian. Spores assigned to Ceratosporites have been reported from Triassic to Early Jurassic of New Zealand (Raine, 1990); Neocomian-Albian of Queensland, Australia (Cookson and Dettmann, 1958); Maastrichtian of Canada (Srivastava, 1966, 1972); Jurassic of South Dakota and Wyoming (Griffith, 1972); Campanian of Utah (Lohrengel, 1969); Lance Formation, Maastrichtian (Farabee and Canright, 1986); Maastrichtian-Danian of Escarpado Canyon (Drugg, 1967).

Cicatricosisporites Potonié and Gelletich 1933

Type species: Cicatricosisporites dorogensis Potonié and Gelletich 1933

Description: Potonié and Gelletich (1933, p522); Dettmann (1963).

Suggested botanical affinity: Schizaeaceae (Singh, 1964; Farabee and Canright, 1986).

Cicatricosisporites dorogensis Potonié and Gelletich 1933

Plate IV, Figure 7

Description: Potonié and Gelletich (1933, p. 522); and Dettmann (1963)

Stratigraphic interval: Occurs throughout the Tar Heel Formation.

Measurements: Equatorial diameter measures 48-58µm; exine 1-2 µm thick; height of sculpture elements 1µm; five specimens were measured.

Previously reported occurrences: Lower Jurassic-Recent (Burger, 1966). Worldwide in distribution. Some of the reported occurrences are: Aptian of Britain (Couper, 1958); Barremian-Albian of Alberta, Canada (Singh, 1964); Upper Campanian to Maastrichtian sediments of NE Montana (Norton and Hall, 1969); Maastrichtian of Netherlands (Kedves and Herngreen, 1980); Maastrichtian of New Jersey (Waanders, 1974); Late Cretaceous of SE United States (Groot, Penny and Groot, 1961); Oligocene sediments of Germany (Thomson and Pflug, 1953); Eocene of Germany (Potonié and Gelletich); Eocene sediments in the Gulf Coast (Elsik, 1974); Wealden of Belgium (Delcourt and Sprumont, 1955).

Cicatricosisporites sp.

Plate IV, Figure 5

Measurements: 45-55μm, exine 1μm thick; height of sculpture elements 0.5μm; 8 specimens measured.

Stratigraphic interval: Present in most samples throughout the Tar Heel Formation.

Previously reported occurrences: Upper Jurassic-Eocene. Species assigned to this genus have been reported from various localities worldwide. Some of them are: Aptian of Britain (Couper, 1958); Aptian of Alberta, Canada (Singh, 1964); Neocomian to Aptian of South Australia (Cookson and Dettmann, 1958); Santonian to Lower Campanian of Alberta (Jarzen and Norris, 1975); Campanian sediments of Judith River Formation of Montana (Tschudy, 1973); Lower and Upper Eocene sediments of Hungary (Kedves, 1973); Eocene of northwestern Alabama (Frederiksen, 1980).

Comments: Species of Cicatricosisporites have striate sculpturing on both faces of the spores. The species reported from the Tar Heel Formation is relatively smaller in size than Cicatricosisporites dorogensis.

Cingutriletes Pierce 1961

Type species: Cingutriletes congruens Pierce 1961

Description: Pierce (1961, p. 25, pl.1, fig 1).

Suggested Botanical affinity: Selaginellaceae (Pierce 1961).

Cingutriletes sp.

Plate IV, Figure 9

Measurements: 30 to 45 µm in diameter excluding equatorial flange; 1.5 µm wide in interlaesural region; ten specimens measured.

Stratigraphic interval: Occurs in all the samples of Goldsboro and Tar River localities, reported from 16, 15 and 5 samples of Willis Creek, Ivanhoe and Lock localities respectively. Not reported from Elizabethtown.

Previously reported occurrences: Lower-Upper Cretaceous. Species of Cingutriletes have been reported from Turonian of S. N. Sea (Batten and Marshall, 1991); Berriasian-Maastrictian of offshore E. US (Bebout, 1981); Cenomanian of S. Oklahoma (Hedlund, 1966); Lower Campanian of NW New Mexico (Jameossanaie, 1987); Cenomanian of Minnesota (Pierce, 1961); Upper Albanian of Wyoming (Ravn, 1995); Upper Cretaceous of China (Song et al., 1986).

Comments: The species of Cingutriletes from Tar Heel Formation are triradially symmetrical and spherical in shape. Exine is thin and smooth.

Cyathidites Couper 1953

Type species: Cyathidites australis Couper 1953

Description: Couper (1953, p.27, pl.2, figs 11-13).

Distribution: Jurassic to Cretaceous; widesrpread throughout the world.

Cyathidites sp.

Plate IV, Figure 4

Measurements: Equatorial diameter ranges from 33 to 55 µm; ten specimens measured.

Stratigraphic interval: Found in many samples throughout the Tar Heel Formation. Previously reported occurrences: Known to occur throughout the Mesozoic deposits in both northern and southern hemispheres.

Deltoidospora Miner emend. Potonié 1956

Type species: Deltoidospora hallii Miner (1935, p. 618, pl. 24, figs 7, 8).

Description: Miner (1935) and Potonié (1956, p. 13, pl.1, fig.1).

Suggested botanical affinity: Gleicheniaceae; Filicales-incertae sedis. The form genus Deltoidospora is associated with Mesozoic ferns including Gleicheniopsis, Gleichenites and Laccopteris (Miner, 1935).

Deltoidospora sp.

Plate III, Figure 10

Measurements: 42 to 59 µm in equatorial diameter; eight specimens measured.

Stratigraphic interval: Occurs in 14, 7 and 8 samples of Goldsboro, Tar River and Ivanhoe localities respectively; low frequency.

Previously reported occurrences: Jurassic-Eocene. Microspores assigned to undesignated species of Deltoidospora are reported from Upper Jurassic of Kuotenai Formation, Montana (Miner, 1935); Lower Cretaceous of Manville Group, Alberta (Singh, 1964); Santonian to Lower Campanian of Lea Park Formation, Alberta (Jarzen and Norris, 1975); Campanian to Maastrichtian of Judith River Formation, Montana (Tschudy, 1973); Campanian of Aguja Formation, Texas (Baghai, 1996); Cretaceous sediments of Baquero Formation, Argentina (Archangelsky, 1994); Paleocene of Wilcox Formation, Texas (Elsik, 1968); Paleocene of Brightseat Formation (Groot and Groot, 1962); Middle Eocene of Tennessee (Elsik and Dilcher, 1974).

Dictyophyllidites Couper 1958

Type species: Dictyophyllidites harrisii Couper 1958

Description: Couper (1958; p. 140, pl.21, figs. 5, 6); and also Deltoidospora harrissii (Couper) Pocock (1970a; p.29, pl.5, fig.16).

Suggested botanical affinity: Fern Phlebopteris smithii (Ash, Litwin and Traverse, 1982).

Dictyophyllidites sp.

Plate III, Figure 3

Measurements: 34 – 52 µm in diameter; 10 specimens measured.

Stratigraphic interval: Present in many samples of all the localities of Tar River Formation.

Previously reported occurrences: Triassic-Tertiary. Widely distributed. Some of the reported occurences in the United States and worldwide are: US – Upper Triassic of SW United States (Ash, Litwin, Traverse, 1982); Triassic of N.Texas (Dunay and Fisher, 1979); Albian-Cenomanian of Maryland-Delaware (Groot and Penny, 1960); Albian of S. Oklahome (Hedlund and Norris, 1968); Lower Campanian of NW New Mexico (Jameossanaie, 1987), Triassic of North Carolina (Litwin and Ash, 1993); Upper Albian of Central Wyoming (Ravn, 1995); Upper Albian-Upper Cenomanian of NW Iowa (Ravn and Witzke, 1995). Worldwide- Mid Albian-Lower Cenomanian of N. Egypt (Aboul Ela and Mahrous, 1992); Upper Triassic of Switzerland (Achilles and Schlatter, 1986); Upper Triassic-Lower Jurassic, SW China (Bai et al, 1983); Triassic of England (Fisher, 1972); Tertiary of Greenland (Hekel, 1972); Jurassic-Lower Cretaceous of Israel (Horowitz, 1970); Upper Jurassic/Lower Cretaceous (Lachkar, Michaud and Fourcade, 1989); Triassic of Tasmania (Playford, 1965); Maastrichtian of Somalia (Schrank, 1994); Lias of England (wall, 1965); Upper Albian/Lower Cenomanian of SW Ontario (Zippi and Bajc, 1990).

Echinatisporis Krutzsch, 1959

Type species: Echinatisporis longechinus Krutzsch 1959

Description: Krutzsch (1959, p.132).

Suggested botanical affinity: Selaginella (Krutzsch, 1959; Farabee and Canright, 1986).

Echinatisporis levidensis (Balme) Srivastava 1972

Plate IV , Figure 2

Description: Srivastava (1972, p. 12, pl. 7, figs 7-9); Balme (1957, p.18).

Measurements: 25-38μm in diameter; acicular processes about 2-3μm long and 1-1.5μm in diameter.

Stratigraphic interval: Reported from 11, 10, 13, 6 and 10 samples of Goldsboro, Tar River, Willis Creek, Lock and Ivanhoe localities respectively.

Previously reported occurrences: Albian-Lower Paleocene. Some of the reported occurrences are: World: Upper Valanginian-Aptian of Western Australia (Backhouse, 1988); Upper Triassic of South Central China (Lin et al, 1978); Upper Jurassic of Ceylon (Jain and Sah, 1966); Lower Cenomanian of Sarawak (Muller, 1968); Maastrichtian of Alberta (Srivastava, 1972); Maastrichtian of Spain (Ashraf and Erben, 1986).

Hamulatisporites Nakoman 1966

Type species: Hamulatisporites nidus Nakoman 1966

Description: See Nakoman (1966, p. 77, pl. 8, figs 24, 25).

Suggested affinity: Lycopodiaceae (Nakoman, 1966).

Hamulatisporites sp.

Plate IV, Figure 3

Measurements: 37 to 55 μm in diameter; five specimens measured.

Stratigraphic interval: Reported from 15, 17 and all samples of Goldsboro, Willis Creek and Tar River localities respectively. Not found in samples of Elizabethtown. Lock and Ivanhoe localities.

Previously reorted occurences: Species assigned to Hamulatisporites have been reported from Lower-Upper Albian of Venezuela (Sinanoglu, 1984); Maastrichtian of Arctic Canada (Felix and Burbridge, 1973); Oligocene of Turkey (Nakoman, 1966); Pliocene of

France (Méon-Vilain, 1970); Cenomanian of E. Arizona (Canright and Carter, 1980); Upper Campanian of SW Wyoming (Stone, 1973); Maastrichtian of NE Montana (Norton and Hall, 1969); Maastrichtian of Wyoming (Farabee and Canright, 1986); Middle - Upper Eocene of Mississippi-Alabama (1980).

Laevigatosporites Ibrahim 1932, emend. Schopf, Wilson and Bentall, 1944

Type species: Laevigatosporites vulgaris (Ibrahim) Ibrahim, 1933.

Description: Ibrahim, 1932 (p. 448, pl. 15, fig. 16); Schopf, Wilson and Bentall, (1944, p.36-37; pl.1, figs. 5-5b).

Suggested botanical affinity: Polypodiaceae (Singh, 1964).

Laevigatosporites ovatus Wilson and Webster, 1946

Plate III, Figure 1

Description: Wilson and Webster (1946, p. 273, fig. 5).

Measurements: 20-58µm long, 12-39µm wide, monolete suture is almost half the spore length. Ten specimens measured.

Stratigraphic interval: Spores are found in many samples in all the localities of the Tar Heel Formation.

Previously reported occurrences: Upper Jurassic-Paleocene. Worldwide- Upper Mesozoic of Australia (Dettmann, 1963), Jurassic/Cretaceous of Germany (Dörhöfer, 1977); Lower Cretaceous of Canada (Singh, 1964); Middle Campanian of Alberta (Jarzen and Norris, 1975); Maastrichtian of western Scotland (Srivastava, 1975); Paleocene sediments of Ratnagiri beds, India (Saxena and Misra, 1989). USA- Cenomanian of Oklahoma (Hedlund, 1966); Maastrichtian of Montana (Norton and Hall, 1969); Escarpado Canyon, California, Maastrichtian (Srivastava, 1975), Paleocene of Montana (Wilson and Webster, 1946).

Suggested botanical affinity: The spores resemble those found in the extant members of Schizaea (Hedlund, 1966). Norton and Hall (1969) suggested that this species could be related to Polypodiaceae.

Laevigatosporites sp.

Plate III, Figure 2

Measurements: 22-48μm long, 14-36μm wide; five specimens measured.

Stratigraphic interval: Reported from many samples of Goldsboro and Tar River localities; found in four samples of Willis Creek. Not reported from Elizabethtown, Ivanhoe and Lock localities.

Previously reported occurrences: Paleozoic-Tertiary. Species assigned to Laevigatosporites have been reported from Maastrichtian of Wyoming (Farabee and Canright, 1986); Lower Eocene of Hungary (Kedves, 1973), Upper Eocene of Mississippi and Alabama (Frederiksen, 1980).

Leiotriletes Naumova, 1937 emend. Emend. Potonié and Kremp 1954.

Type species: Leiotriletes sphaerotriangulus (Loose) Potonié and Kremp, 1954.

Description: Naumova (1937, p.355), Potonié and Kremp (1954, p.120) and Krutzch (1959, p.56).

Suggested botanical affinity: Spores of Leiotriletes may belong to members of Polypodiaceae or to Lygodium of the Schizaeaceae family (Stanley, 1965).

Leiotriletes pseudomesozoicus Krutzsch 1959

Plate III, Figure 8

Description: Krutzch (1959, p.58)

Measurements: 45 to 70 µm; 5 specimens measured.

Stratigraphic interval: Reported only in 15 and 16 samples of Goldsboro and Tar River localities respectively. Not reported from other locality.

Previously reported occurrences: Jurassic sediments of Germany (Krutzsch, 1959).

Leiotriletes sp.

Plate IV, Figure 1

Measurements: 18-48µm; ten specimens measured.

Stratigraphic interval: Found in all samples of Goldsboro, 9 samples of Tar River, 19 samples of Willis Creek, 5 samples of Ivanhoe, 3 samples of Lock and 2 samples of Elizabethtown.

Previously reported occurrences: Triassic-Oligocene. Some of the occurrences in the United States are from the Paleocene sediments of Oak Hill Member, Naheola Formation in Alabama (Srivastava, 1972). Kedves (1973) has reported from Eocene to Oligocene sediments from Hungary.

Matonisporites Couper 1958 emend. Dettmann 1963

Type species: Matonisporites phlebopteroides Couper 1958.

Description: Couper (1958, p. 139, pl 20, figs. 13-17) and Dettmann (1963, p.58).

Botanical affinity: The spores of Matonisporites have been suggested to resemble those of Phlebopteris (Matoniaceae), a Mesozoic fern genus, or Dicksonia (Dicksoniaceae), the latter an extant fern genus (Farabee and Canright, 1986; Srivastava, 1972, p.24).

Matonisporites equiexinus Couper, 1958

Plate III, Figure 4

Description: Couper (1958, p.140, pl.20, figs. 15-17).

Measurements: The specimens of Tar Heel Formation range from 45-52μm in equatorial diameter; 2-4 μm in thickness; 8 specimens were measured.

Stratigraphic interval: Present in 17, 13, 9, 16, 5 and 3 samples from Goldsboro, Tar River, Ivanhoe, Willis Creek, Lock and Elizabethtown localities respectively.

Botanical affinity: These spores resemble those of the modern Schizaeceous ferns Anemia and Lygodium (Hedlund, 1966, p.13).

Previously reported occurrences: Jurassic to Cretaceous; worldwide.

Matonisporites sp.

Plate III, Figure 6

Measurements: 40-62μm in equatorial diameter; 2-3 μm in thickness; 10 specimens were measured.

Stratigraphic interval: Species of Matonisporites occur in several samples of Goldsboro and Tar River localities, 12 samples of Willis Creek, 9 samples of Ivanhoe and 3 samples Lock localities.

Previously reported occurrences: Jurassic-Cretaceous. Some of the reported occurences are: Jurassic sediments of India (Kumar, 1973); Upper Mesozoic of SE Australia

(Dettmann and Hedlund, 1963); Barremian of Spain (Doubinger and Mas, 1981); Upper Cretaceous of France (Levet-Carette, 1964); Barremian of Maryland (Brenner, 1963); Jurassic-Lower Cretaceous (Couper, 1958); Maastrichtian of Wyoming (Farabee and Canright, 1986); Loer Campanian of New Mexico (Jameossanaie, 1987); Middle-Upper Albian of NW Alberta (Singh, 1971); Basal Jurassic of Arctic Canada (Pocock, 1978).

Stereisosporites Pflug 1953

Type species: Stereisosporites steroides (Potonié and Venitz), Pflug, in Thomson and Pflug 1953.

Description: Pflug (in Thompson and Pflug, 1953, p.53).

Suggested botanical affinity: Sphagnaceae.

Stereisosporites sp.

Plate III, Figure 9

Measurements: 22 to 54 µm in equatorial diameter; ten specimens measured.

Stratigraphic interval: Reported from all samples of Goldsboro and Tar River localities only.

Previously reported occurrences: Cenomanian-Eocene. Species assigned to Stereisosporites are reported from Campanian sediments of Aguja Formation, Texas (Baghai, 1996); Cenomanian sediments of the Tuscaloosa Formation, Mississippi (Phillips and Felix, 1972); Early Campanian sediments of Lea Park Formation, Alberta (Jarzen and Norris, 1975); Eocene of western Mississippi (Frederiksen, 1980a) and middle Eocene of northern Bakony (Kedves, 1973).

Comments: Spores of Stereisosporites recovered from samples of Tar Heel Formation are trilete, semicircular with laesurae extending up to two-thirds or more of the radius. Most of these specimens have faint trilete marks.

Undulatisporites Pflug 1953

Type species: Undulatisporites microcutis Pflug 1953.

Description: Thomson and Pflug (1953; p.52, pl.1, figs. 81, 82); Potonié (1956, p.19).

Suggested botanical affinity: Pteridophyta-incertae sedis.

Undulatisporites sp.

Plate IV, Figure 6

Measurements: 30 to 45 μm in equatorial diameter; with undulate laesurae; eight specimens measured.

Stratigraphic interval: Reported from 14, 13, 18 and 15 samples of Goldsboro, Tar River, Willis Creek and Ivanhoe localities respectively. Not reported from Lock and Elizabethtown.

Previously reported occurrences: Cretaceous-Tertiary. Eocene sediments of Mississippi and northwestern Alabama (Frederiksen, 1980); Wilcox Formation of Texas (Elsik, 1968); Paleogene of northeastern Virginia (Frederiksen, 1979); Upper Cretaceous of Aguja Formation of Texas (Baghai, 1996).

Gymnosperm pollen

Araucariacites (Cookson) Couper 1953

Type species: Araucariacites australis Cookson 1947.

Description: Cookson (1947, p.130. pl.13, figs. 1-4) and Couper, (1953, p. 39)

Botanical affinity: Assigned to the family Araucariaceae. It is also comparable to the Jurassic Araucarian Brachyphyllum mamillare (Couper, 1958, p.151).

Araucariacites australis Cookson, 1947

Plate V, Figure 3

Description: Synonymy same as type species. Specimens are in complete agreement with those described in Couper (1958, p.151) and Cornet and Traverse (1975, p.13).

Measurements: Diameter measures 73- 86μm, 10 specimens measured.

Stratigraphic interval: Present in most of the samples of Goldsboro locality, present in the lower sections of Ivanhoe and Willis Creek. Also found in Tar River and Lock localities but not in abundance. No specimens were reported from Elizabethtown.

Previously reported occurrences: Jurassic-Tertiary. USA – reported from Triassic through Jurassic of Hartford Basin, Conneticut and Massachusetts (Cornet and Traverse, 1975). Worldwide – Jurassic, Cretaceous and Tertiary worldwide localities (Balme, 1957; Dettman, 1963; Norris, 1967; Hopkins, 1974).

Araucariacites sp.

Plate V Figure 5

Measurements: 60-80 μm, 10 specimens measured.

Stratigraphic interval: Present in many samples of Goldsboro, Tar River, Willis Creek and Ivanhoe localities; 4 samples of Lock and 2 samples of Elizabethtown localities.

Previously reported occurrences: Jurassic-Oligocene. Some of the reported occurrences are: Upper Albian (Awad, 1994); Maastrichtian of Spain (Alvarez Ramis and Doubinger, 1994); Aptian-Danian of South India (Banerjee and Misra, 1968); Albian of Delaware (Brenner, 1967); Jurassic to Lower Cretaceous of Britain (Couper, 1958); Barremian - Aptian of Victoria (Dettmann, 1992); Cenomanian of Portugal (Groot and Groot, 1962); Lower Campanian of NW New Mexico (Jameossanaie, 1987); Upper Oligocene of Hungary (Kedves, 1974); Middle Jurassic of Ontario (Norris, 1977); Jurassic of Argentina (Volkheimer, 1968); Upper Albian of Oaklahoma (Wingate, 1980); Lower Cretaceous of China (Zhang, 1988).

Cedripites Wodehouse 1933

Type species: Cedripites eocenicus Wodehouse 1933

Description: Wodehouse (1933, p. 490, fig. 13)

Cedripites sp.

Plate V, Figure 11

Measurements: 50-65 μm in diameter; central body circular in polar view, 25-30μm in diameter; exine 1μm thick; ten specimens measured.

Stratigraphic interval: Reported from all samples of Goldsboro, 19 samples of Tar River, 8 samples of Willis Creek, 7 samples of Ivanhoe and 4 samples of Lock localities. Not reported from Elizabethtown.

Previously reported occurrences: Lower Cretaceous-Tertiary. Species of Cedripites have been primarily reported from the Tertiary rocks worldwide. Some of the common occurrences are Eocene of Colorado (Wodehouse 1933); Albanian-Santonian of Western Siberia (Chlonova, 1960, 1976); Lower Jurassic- Lower Cretaceous sediments of Hunan, China (Jiang and Hu, 1982); Lower Cretaceous of Northern China (Miao et al, 1984);

Aptian of Inner Mongolia (Song et al, 1986). In North America species of Cedripites have been reported from Maastrichtian of Wyoming (Farabee and Canright, 1986); Lower Paleocene of NE Montana (Norton and Hall, 1969); Upper Campanian of SW Wyoming (Stone, 1973); Upper Campanian of N. Montana (Tschudy, 1973); Maastrichtian-Paleocene of NW Canada (Wilson, 1978).

Classopollis Pflug emend. Pocock and Jansonius 1961

Type species: Classopollis classoides Pflug emend. Pocock and Jansonius 1961.

Description: Plug (1953, p. 91); Couper (1958, p. 156); Pocock and Jansonius (1961, p. 439-449, pl. 1); and Srivastava (1976, p. 442).

Botanical affinity: Affinities with extinct gymnosperms such as Cheirolepis; Pagiophyllum and Brachophyllum (Farabee and Canright, 1986; Gies 1972; Singh, 1964).

Classopollis classoides Pflug 1953

emend. Pocock and Jansonius, 1961

Plate V, Figure 10

Description: Reissinger (1950, p. 114, pl. 14, figs. 15-16); Plug (1953, p. 91); Pocock and Jansonius (1961, p. 443, pl. 1, figs 1-9); Srivastava (1976, p. 442).

Measurements: 35 to 50 μm in diameter; five specimens measured.

Stratigraphic interval: Occurs in all samples of Goldsboro, Tar River and Willis Creek localities of the Tar Heel Formation. Not reported from other localities.

Previously reported occurrences: Rhaetic-Eocene. U. S. A. – Lower Cretaceous of Mt. Laurel, Navesink and Red Band Formations from Monmouth Co., New Jersey

(Waanders, 1974); Maastrichtian of Wyoming (Farabee and Canright, 1986); Upper Cretaceous of Wyoming (Griggs, 1970); Upper Cretaceous of northwestern Colorado (Gies, 1972). Worldwide – Lower Cretaceous of Manville Group, Alberta (Singh, 1964); Late Albian to Cenomanian of Egypt (Beialy, 1993).

Comments: This species has been speculated to be suggestive of nearshore marine sediments (Orlansky, 1971; Pocock and Jansonius, 1961). Cuticles assignable to Pagiophyllum have been reported from the Tar River locality of the Tar Heel Formation (Mickle, 1993).

Cycadopites Wodehouse, 1933 emend. Wilson and Webster, 1946

Type species: Cycadopites follicularis Wilson and Webster 1946

Description: Wodehouse (1933, p. 483); Wilson and Webster (1946, p. 274)

Suggested botanical affinity: Cycadophyta, Cycadaceae (Oltz, 1969).

Cycadopites carpentieri (Delcourt and Sprumont) Singh, 1964

Plate V, Figure 2

Description: Delcourt and Sprumont (1955, p. 54, fig. 14); Singh (1964, p. 104, pl. 14, fig. 3).

Measurements: Length 35 to 50 µm, width 12 to 20 µm; exine 1µm thick; five specimens measured.

Stratigraphic interval: Occurs in 5, 14 and 13 samples of Ivanhoe, Goldsboro and Tar River localities respectively.

Previously reported occurrences: Middle Jurassic-Cretaceous. Middle Jurassic to Cretaceous of England (Couper, 1958), Lower Cretaceous of Alberta (Singh, 1964); Campanian of Aguja Formation of Texas (Baghai, 1996).

Ginkgocycadophytus Samoilovich 1953

Type species: Ginkgocycadophytus caperatus (Luber) Samoilovich 1953.

Description: Samoilovich (1953, p. 30, translation of Elias, 1961, p.35-36).

Suggested affinity:

Ginkgocycadophytus nitidus (Balme) de Jersey 1962

Plate V, Figure 9

Description: (Balme) de Jersey (1962; p. 12, pl. 5, figs 1-3.

Measurements: Length 35-75 µm; width 22-45 µm; five specimes measured.

Stratigraphic interval: Reported from all the localities of the Tar Heel Formation.

Previously reported occurrences: Triassic-Paleocene. USA- Barremian-Albian of Maryland (Brenner, 1963); Upper Albian of S. Oklahoma (Wingate, 1980); Maastrictian of Utah (Lohrengel, 1970). Worldwide - Upper Triassic - Middle Jurassic of SW China (Bai et al, 1983); Upper Jurassic of Sweden (Guy-Ohlson and Norling, 1988) and Queensland, Australia (de Jersey, 1959); Lower Cretaceous of Zhejiang, china (Li, 1989), India (Venkatachal, 1969) and Mongolia (Liu, 1983); Barremian-Aptian of Victoria, Australia (Dettmann et al, 1992); middle Albian of Romania (Baltes, 1967); Middle Cretaceous of Tunisia (Reyre, 1966); Campanian of Alberta, Canada (Jarzen, 1982);

Campanian/Maastrichtian of NW Canada (Mc Intyre, 1974); Paleocene of Chike (Doubinger and Chotin, 1975).

Inaperturopollenites Pflug and Thomson 1953

Type species: Inaperturopollenites dubius (Potonié and Venitz) emend. Thomson and Pflug 1953.

Description: Potonié and Venitz (1934, p. 17; pl.2, fig. 21); and Thomson and Pflug (1953, p. 65; pl. 4; fig. 89; pl. 5, figs 1-3).

Suggested botanical affinity: Larix (Norton and Hall, 1969; Stone, 1973); Cupressaceae or Taxodiaceae (Gies, 1972; Norris, 1967).

Inaperturopollenites sp.

Plate V, Figure 7

Measurements: 35-68μm in diameter; ten specimens measured.

Stratigraphic interval: Reported in 55 samples from all the localities of Tar Heel Formation.

Previously reported occurrences: Jurassic-Paleocene. Species assigned to Inaperturopollenites have been reported from Albian-Turonian of Peru (Brenner, 1963); Magothy and Raritan Formations of New Jersey (Christopher, 1979); Lower Cretaceous Tuscaloosa, Arundel and Patuxent Formations of Maryland and Delaware (Groot and Penny, 1961); Potomac group of Maryland (Brenner, 1968); Coniacian of Utah (Orlansky); Campanian of Utah (Lohrengel, 1969); Menefee Formation (Campanian) of New Mexico (Jameossanaie, 1987); Upper Cretaceous of Wyoming (Griggs, 1970); Lance Formation (Maastrichtian) of Wyoming (Farabee and Canright, 1986).

Comments: The grains reported from the Tar Heel Formation are oval in shape with thin walls and have folds. Exine ornamentation is psilate.

Parvisasaccites Couper 1958

Type species: Parvisaccites radiatus Couper, 1958

Description: Couper (1958, p.154, pl. 29, figs. 5-8, pl. 30, figs. 1-2).

Suggested botanical affinity: Podocarpaceae

Parvisaccites radiatus

Plate V, Figure 1

Description: Couper (1958, p.154, pl. 29, figs. 5-8, pl. 30, figs. 1-2).

Measurements: Length of central body – 38 to 55 µm; breadth of central body- 23 to 46 µm; length of bladders 28 to 31µm; breadth of bladders 16 to 18 µm; 5 specimens measured.

Stratigraphic interval: Occurs in 20, 13, 3, 20 and 2 samples of Goldsboro, Tar, Ivanhoe, Willis Creek and Lock localities.

Previously reported occurrences: Jurassic to Maastrictian. Jurassic – Albian of Holland (Burger, 1966; Couper and Hughes, 1963); Wealden of France (Levet-Carette, 1966); Late Jurassic to Albian of England (Couper, 1958; Norris, 1969; Kemp, 1970); Early Cretaceous to Cenomanian of western Canada (Pocock, 1962, Singh, 1964 and 1971; Norris, 1967); Barremian-Albian of Maryland (Brenner, 1963); Cenomanian of Minnesota (Pierce, 1961); Coniacian of Utah (Orlansky, 1971); Campanian of New Mexico (Jameossanaie, 1987).

Suggested botanical affinity: Related to the extant species Dacrydium elatum.

Piceaepollenites Potonié 1931

Type species: Piceaepollenites microalatus Potonié 1931

Description: Potonié (1931, p.5, fig. 34).

Suggested botanical affinity: Podocarpaceae

Piceaepollenites sp.

Plate V, Figure 4

Measurements:Length of central body – 30-42μm; breadth of central body - 49-68μm; 8 specimens measured.

Stratigraphic interval: Found in many samples throughout the Tar Heel Formation.

Previously reported occurrences: Permian-Miocene. Early Permian of Tarim Basin, China (Wang Hui, 1989); Upper Tertiary of China (Zheng-Ya-hui, 1987); Miocene of Germany (Potonié, 1931).

Comments: Species of Piceaepollenites recovered from Tar Heel Formation are bisaccate with reticulate surface. The sacs protrude more or less widely on the sides and the central body is oval.

Pinuspollenites Raatz, 1937 ex. Potonié, 1958

Type species: Pinuspollepollenites labdacus (Potonié) Raatz, 1937 ex Potonié, 1958.

Description: Potonié (1958).

Suggested botanical affinity: Coniferales – genus Pinus.

Pinuspollenites sp.

Plate V, Figure 8

Measurements: Length of central body – 25-48μm; breadth of central body - 40-66μm; length of bladders – 15-18 μm; breadth of bladders – 28-30 μm. 6 specimens measured.

Stratigraphic interval: Found in all the localities except Elizabethtown of the Tar Heel Formation.

Previous reported occurrences: Cenomanian-Miocene. Some of the localities are as follows: Cenomanian sediments of Dakota Sandstone in Arizona (Romans, 1975); Potomac Group of Maryland, Early Cretaceous (Brenner, 1963); Straight Cliffs Sandstone in Utah (Orlansky, 1971); Miocene of India (Rao, 1986).

Comments: The morphotype recovered from the Tar Heel Formation has reticulate and granular ornamentation on its bladders. The central body also has granular ornamentation.

Podocarpites Bolkhovitina 1956

Type species: Podocarpites acicularis Andrae 1855

Description: Andrae (1855, p.45).

Suggested affinity: Podocarpaceae

Podocarpites radiatus Brenner 1963

Plate V, Figure 6

Description: Brenner (1963, p.82, pl.32, figs 3, 4)

Measurements: Length of the grain – 45-90μm; body length – 36-41μm; body width-25-47μm; bladder length- 38-55μm; bladder width-26-37μm.

Stratigraphic interval: Present in many samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Early Cretaceous-Tertiary. USA - Barremian-Albian, Maryland (Brenner, 1963); Barremian-Lower Albian of western Colorado (Tschudy, Tschudy and Craig, 1984). Cenomanian of Arizona (Romans, 1975); Upper Paleocene of S. California (Gaponoff, 1984). Other countries- Berriasian-Upper Albian of Western Canada (Burden and Hills, 1989); Albian of Portugal (Hasenboehler, 1981); Middle Albian of NW Alberta (Singh, 1971); Maastrichtian of Netherlands (Herngreen, Felder, Kedves and Meessen, 1986).

<u>Taxodiaceaepollenites</u> Kremp 1949 ex Potonié 1958

Type species: <u>Taxodiaceaepollenites</u> <u>hiatus</u> (Potonié) Kremp, 1949 emend. Potonié 1958.

Description: Potonié for <u>Pollenites</u> <u>hiatus</u> (1931, p. 5; fig. 27) and Kremp (1949, p. 59) for <u>Taxodiaceceaepollenites</u> (<u>Pollenites</u>) <u>hiatus</u>.

Botanical affinity: <u>Taxodium</u> (Taxodiaceae) (Stone, 1973) or with <u>Thuja</u> (Cupressaceae) (Stanley, 1965).

<u>Taxodiaceaepollenites</u> <u>hiatus</u> (Potonié) Kremp 1949

emend. Potonié 1958

Plate V, Figure 12

Description: Potonié (1931, p.5, fig.27) for <u>Pollenites</u> <u>hiatus</u>; Wodehouse (1933, p.493-494, fig. 19) regarding <u>Taxodium</u> <u>hiatipites</u>; Kremp (1949, p.59); Potonié (1951, p. 140, 149; 1958, p.79) about <u>Taxodiaceaepollenites</u> <u>hiatus</u>.

Measurements: Specimens fall into the size range of 32-48μm in diameter; 12 specimens were measured.

Stratigraphic interval: Observed in many samples of the Tar Heel Formation, low to abundant frequency.

Previous reported occurrences: Cretaceous-Tertiary. Some of the reported occurrences are as follows: USA: Cenomanian- Senonian – Alabama, Georgia, Delaware, Maryland and New Jersey (Groot, Penny, and Groot, 1961); Campanian – Menefee Formation, New Mexico (Jameossanaie, 1987); Judith River Formation, Montana (Tschudy, B. 1973); Masestrichtian to Danian - California (Drugg, 1967); Maastrichtian - Bearpaw Shale, Fox hills, Hell Creek, Tullock, Lebo Formations, Montana (Stone, 1973); Navesink and Red Bank Formations, New Jersey, (Wanders, 1974), Lance Formation, Wyoming (Farabee and Canright, 1986); Eocene – Green River Formation in Utah and Colorado (Wodehouse, 1933). Worldwide – Canada (Santonian – Campanian) (Jarzen and Norris, 1975); West Greenland (Albian – Cenomanian) (Koppelhus and Pedersen, 1993); Oligocene to Miocene in Germany (Kremp, 1949).

Angiosperm pollen

Arecipites (Wodehouse) emend. Nichols, Ames and Traverse, 1973

Type species: Arecipites punctatus Wodehouse 1933.

Description: Wodehouse (1933, p. 497, nomen nudium); Anderson (1960, p. 18); and Nichols, Ames and Traverse (1973, p. 248).

Botanical affinity: Arecaceae (Farabee and Canright, 1986).

Arecipites sp.

Plate VIII , Figure 12

Measurements: Length 29-35 µm; width 20- 31 µm; four specimens measured.

Stratigraphic interval: Reported from 10 samples of Goldsboro and stratigraphically younger samples of Ivanhoe (4), Lock (2) and Willis Creek (11) localities.

Previously reported occurrences: Upper Cretaceous-Eocene. Species of Arecipites are reported from Late Cretaceous of Sudan (Scrank, 1987); Eocene of Brown-coal Formation (Kedves, 1973), Eocene of Mississippi and northwest Alabama (Frederiksen, 1980).

Clavatipollenites Couper 1958

Type species: Clavatipollenites hughesii Couper emend Kemp 1968 (by designation of Couper, 1958).

Description: Couper emend. Kemp (1968, p. 426-427, pl. 80, figs 9-19);); Couper (1958, p.159, pl.31, figs 19-22).

Suggested botanical affinity: Chloranthaceae (Muller, 1981).

Clavatipollenites hughesii Couper emend. Kemp 1968

Plate VII, Figure 1

Description: Description: Couper emend. Kemp (1968, p. 426-427, pl. 80, figs 9-19); Couper (1958, p.159, pl.31, figs 19-22).

Measurements: 26-40 µm in diameter; ten specimens measured.

Stratigraphic interval: More abundant in samples from the lower stratigraphic (older) sections of the Tar Heel Formation.

Previously reported occurrences: Lower Cretaceous-Oligocene. Clavatipollenites hughesii have been reported from the Cretaceous sediments worldwide. Some of the reported occurrences are Lower Albian of SE Spain (Arias and Doubinger, 1980); Barremian of S. England (Batten, 1996); Barremian/Albian of Israel (Burden, 1984); Lower-Middle Albian, SE Queensland (Burger, 1980); Wealden-Aptian of Britain (Couper, 1968); Lower Aptian of Maryland (Doyle, 1992); Lower Albian–Cenomanian of N. France (Fauconnier, 1979); Cenomanian of Kansas-Nebraska (Farley and Dilcher, 1986); Barremian-Lower Albian of Northern Hebei, China (Gan and Zhang, 1985); Upper Barremian-Lower Aptian of NW Egypt (Ibrahim and Schrank, 1996); Paleocene-Oligocene of Indian Ocean (kemp and harris, 1977); Aptian of offshore Morocco (Kotova, 1988); Upper-Albian-Lower Campanian of New Zealand (Mildenhall, 1994); Lower Cretaceous sediments of Germany (Schulz, 1967); Middle Jurassic of Sweden (Tralau, 1968); Barremian-Lower Albian of Western Colorado and Upper Albian of Utah (Tschudy, Tschudy and Craig, 1984); Aptian of Poland (Waksmundzka, 1981); Albian of Kansas (Ward, 1986).

Complexiopollis Krutzsch 1959 emend Tschudy, 1973

Type species: Complexiopollis praeatumescens Krutzch, 1959.

Description: Krutzch (1959, p. 134).

Suggested botanical affinity: This is considered to be one of the earliest genera of the Normapolles group and has affinities with Hamamelidae.

Complexiopollis abditus Tschudy, 1973

Plate VII, Figure 2

Description: Tschudy (1973. P. C7)

Measurements: 20-30µm long, 23-35µm wide, exine is1-2µm thick. 10 specimens measured.

Stratigraphic interval: Common in all samples of the Tar Heel Formation.

Previous reported occurrences: Widespread during the Turonian-Campanian in the Normapolles province of the United States. Some of localities from where this genus has been reported are: Campanian—post- Magothy Formations in Salisbury and Raritan embayments of New Jersey (Christopher, 1979); Eutaw (Coniacian) and Coffee Sand (Campanian) Formations in the Mississippi embayment (Tschudy, 1973); Coniacian-Campanian in New Mexico (Jameossanaie, 1987); and Turonian- Campanian sediments of the Mid-Atlantic Baltimore Canyon (Bebout, 1981).

Complexiopollis exigua Christopher 1979

Plate VII, Figure 3

Description: Christopher (1979, p. 109-110, plate 8, figs 1-9).

Measurements: Equatorial diameter ranges from 18-35 µm in diameter. 5 specimens measured.

Stratigraphic interval: Common in samples of all the localities of Tar Heel Formation.

Previous reported occurrences: Upper Turonian-Campanian. Christopher (1979) has reported this species from the Upper Cretaceous Raritan and Magothy Formations of New Jersey respectively. It has also been observed in other parts of the Atlantic Coastal

Plain like the Black Creek Group of South Carolina and the Eutaw Formation of the Alabama-Georgia border (Christopher, 1979).

Complexiopollis funiculus Tschudy 1973

Plate VII, Figure 4

Description: Tschudy (1973, p. C4-C5, pl. 1, figs. 1-29).

Measurements: 15-37µm long, 18-34µm wide; six specimens measured.

Stratigraphic interval: Present in most samples of the Tar Heel Formation in moderate frequency.

Previous reported occurrences: This species has been reported from the Upper Albanian-Santonian sediments of the Baltimore Canyon area (Bebout, 1981); Cenomanian-Coniacian of the Southern United States (Tshudy, 1973); Turonian sediments of the Southern North Sea (Batten and Marshall, 1991).

Complexiopollis sp.

Plate VII, Figure 5

Measurements: 20-37µm long, 25-35µm wide (polar view); five specimens measured.

Stratigraphic interval: Present in most samples of the Tar Heel Formation.

Previous reported occurrences: Cenomanian-Paleocene. Has been reported from the Paleocene of China (Chlonova, 1981) and Aguja Formation (Campanian) in Texas (Baghai, 1996).

Cupuliferoipollenites Potonié 1960

Type species: Cupuliferoipollenites (al. Pollenites) pusillus (al. Quisqualis pusillus Potonié 1934, p.71, pl. 3) R. Potonié, 1951b, p.145, pl 20, fig.69.

Description: Potonié (1934 p. 71 and 1960, p.98).

Suggested botanical affinity: Fagaceae, resembles the pollen of Castanea (Potonié, 1960; Chmura, 1973; Groot and Groot, 1962).

Cupuliferoipollenites sp.

Plate VII, Figure 10

Measurements: Polar views 13-18 μm long, 10-13μm wide; eight specimens measured.

Stratigraphic interval: Reported from the upper sections of Willis Creek, Lock and Ivanhoe localities and occurs in 12, 8 and 4 samples of Goldsboro, Tar River and Elizabethtown localities respectively.

Previously reported occurrences: Pollen grains of Cupuliferoipollenites have been reported from Upper Albian to Cenomanian (Jarzen and Norris, 1975); Paleocene of Georgia (Christopher et al, 1980); and Eocene of Mississippi and Alabama (Frederiksen, 1980).

Cyrillaceaepollenites Mürriger and Pflug ex Potonié1960

Type species: Cyrillaceaepollenites megaexactus (Potonié) Potonié 1960.

Description: Potonié (1960, p. 102); Pollenites megaexactus Potonié (1931, p. 26, pl. 1, fig. V42 b).

Suggested affinity: Cyrillaceae (Thomson 1953, in Thomson and Pflug)

Cyrillaceaepollenites barghoornianus (Traverse) Potonié1960

Plate VII, Figure 3

Description: Potonié (1960, p. 102); Cyrilla barghoorniana Traverse (1955, p. 56, fig. 10 (69, 70); p. 80, fig. 13 (150).

Measurements: 18 to 30 µm in equatorial diameter; thickness of exine 2 µm; ten specimens measured.

Stratigraphic interval: Reported from many samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Lower Cretaceous of Potomac Group of Maryland (Brenner 1963); Oligocene of Vermont (Traverse, 1955); Eocene of SE US (Frederiksen, 1988); Maastrichtian of Netherlands (Herngreen et al, 1986); Lower-Middle Eocene of Hungary (Kedves, 1982); Thanetian of France (Kedves, 1982); Oligocene of Egypt (Kedves, 1985).

Holkopollenites Fairchild, in Stover, Elsik and Fairchild, 1966

Type species: Holkopollenites chemardensis Fairchild, in Stover, Elsik and Fairchild, 1966.

Description: Elsik and Fairchild (1966, p. 5-6, pl. 2, figs 8a-d).

Botanical affinity: Tricolporate pollen of unknown affinity.

Holkopollenites chemardensis Fairchild, in Stover, Elsik and Fairchild, 1966.

Plate VIII, Figure 4

Desscription: Elsik and Fairchild (1966, p. 5-6, pl. 2, figs 8a-d).

Measurements: 35-48µm long, 29-46µm wide; 10 specimens measured.

Stratigraphic interval: Reported from upper stratigraphic sections of Willis Creek, Lock and Ivanhoe localities. Occurs in 3 samples of Elizabethtown and 13 samples of each of Goldsboro and Tar River localities.

Previously reported occurrences: Campanian-Paleocene. Upper Campanian and Maastrichtian sediments of Raritan, Salisbury, Okefenokee embayments of the Atlantic Coastal Plain (Christopher, 1978); Wenonah Formation of New Jersey (Upper Campanian) (Wolfe, 1976); Paleocene of Gulf Coast (Fairchild and Elsik, 1969); Paleocene of NW Louisiana (Stover, Elsik and Fairchild, 1966).

Comments: The colpi of Holkopollenites chemardensis are more deeply incised than other species of this genus. There is also a tendency for the sides of these grains to be more convex (Wolfe, 1976).

Holkopollenites sp. A (CP3D-1 of Wolfe, 1976)

Plate VIII, Figure 5

Description: Wolfe (1976; p. 16, pl.4, figs. 6, 7)

Measurements: 21-36µm long, 18-34µm wide; 10 specimens measured.

Stratigraphic interval: Reported in all localities of the Tar Heel Formation in abundance. Not reported from Elizabethtown.

Previously reported occurrences: Campanian-Santonian. Reported from Lower Campanian (Cliffwood beds of Magothy Formation and Merchantville Formation) of Raritan embayment of central and northern New Jersey (Wolfe, 1976); Upper Santonian-Lower Campanian of New Jersey (Litwin et al, 1993).

Comments: This species occurs with Holkopollenites chemardensis in samples from the Tar Heel Formation. The stratigraphic srange of the latter needs to be revised as it was considered to occur only in the Upper Campanian-Paleocene sediments (Wolfe 1976; Christopher, 1978; 1979 a). Holkopollenites sp. A has concave to convex sides (Wolfe, 1976).

Holkopollenites sp. C (CP3E-1 of Wolfe, 1976)

Plate VIII, Figure 6

Description: Wolfe (1976; p. 16, pl.4, fig.11).

Measurements: 32-40μm in diameter; 10 specimens measured.

Stratigraphic interval: Occurs throughout the Tar Heel Formation except Elizabethtown locality.

Previously reported occurrences: Lower-Upper Campanian (Woodbury Clay to Mount Laurel Sand) of Raritan embayment of central and northern New Jersey (Wolfe, 1976).

Comments: The inner wall is chanelled by anastomosing rather than straight grooves and has fine sculpturing (Wolfe, 1976).

Labrapollis Krutzch 1968

Type species: Labrapollis labraferus (Potonié) Krutzsch 1968

Description: Labrapollis labraferus (Potonié) Krutzsch (1968, p. 62, p.1, figs 1-13)

Suggested botanical affinity: This is one of the genera of Normalles group. The Normapolles group has been suggested to have affinities with Hamamelidae and has also been suggested as a heterogeneous assemblage of pollen of uncertain origin (Batten and Christopher, 1981).

Labrapollis sp.

Plate VI, Figure 2

Measurements: 15 to 35μm in diameter; 10 specimens measured.

Stratigraphic interval: Reported from the younger stratigraphic sections of Lock, Willis Creek and Ivanhoe localities. Reported from most samples of Goldsboro and Tar River localities. Not reported from Elizabethtown.

Previously reported occurrences: Maastrichtian to Eocene. Species of Labrapollis have been reported mostly from the Tertiary sediments in many parts of the world. Some of the occurrences are: Maastrichtian of Spain (Alvarez Ramis and Doubinger, 1994); Upper Paleocene of Belgium (Schumacker-Lambry, 1978); Paleocene-Middle Eocene of Germany (Krutzsch and Vanhoorne, 1977); Middle Miocene of Eastern Turkey (Funda, Alisan and Akyol, 1986); Middle-Upper Eocene of Germany (Thomson and Pflug, 1953); Paleocene-Upper Eocene of Virginia (Frederiksen, 1979); Maastrichtian sediments of Raritan, Salisbury and Okefenokee embayments of the Atlantic Coastal Plain (Christopher, 1978; 1979).

Comments: Species reported from the localities of Tar Heel Formation are small in size with circular to sub-circular ambs with three protruding germinals. Occurrences of Labrapollis from Lower Campanian sediments are rare.

Liliacidites Couper 1953

Type species: Liliacidites kaitangataensis Couper (1953).

Description: Couper (1953, p.56, pl. 7, fig. 97); Anderson (1960) and Leffingwell (1971).

Stratigraphic range: Upper Cretaceous to Eocene.

Suggested botanical affinity: Liliales.

Liliacidites variegatus Couper 1953

Plate VI, Figure 4

Description: Couper (1953, p. 56, pl. 7, figs. 98, 99).

Measurements: 40 to 62 μm long, 15 to 27 μm wide, exine 1.5 μm thick, lumen of reticulum 1.5 to 2 μm; ten specimens measured.

Stratigraphic interval: Present in many samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Albian to Middle Miocene. Lower Cretaceous of Magothy and Tuscaloosa Formation, New Jersey (Groot et al, 1961), Albian of northeastern Peru (Brenner, 1968); Santonian of Oldman Formation, Alberta, Canada (Rouse, 1957); Upper Cretaceous and Eocene and Oligocene of of New Zealand (Couper, 1953, 1960); Campanian of Aguja Formation, Texas (Baghai, 1996); Upper Campanian of Judith River Formation, Montana (Tschudy, 1973); Campanian and Maastrichtian of San Joaquin Valley, California (Chmura, 1973); Cenomanian of Wepo Formation, Arizona (Romans, 1975); Maestrictian-Paleocene of former Soviet Union (Samoilovitch and Mtchedlishvili, 1961); Maastrichtian to Danian of Upper Moreno Formation, California (Drugg, 1967), Maastrichtian of Hell Creek Formation, Montana (Norton and Hall, 1969, Oltz, 1969)); Maestrictian of Lance Formation, Wyoming (Farabee and Canright, 1986); Maestrictian of Edmonton Formation, Canada (Srivastava, 1966 and 1969) Upper Cretaceous of Frontier Formation, Wyoming (Griggs, 1970); Upper

Cretaceous of Rocky Mountain region, Colorado (Gies, 1972); Paleocene of Milam County, Texas (Elsik, 1968).

Momipites (Wodehouse) Frederiksen and Christopher, 1978

Type species: Momipites coryloides Wodehouse (1933).

Description: Wodehouse (1933, p. 511), Nichols (1973, p. 106) and Frederiksen and Christopher (1978).

Suggested botanical affinity: Juglandaceae.

Momipites spackmanianus (Traverse) Nichols, 1973

Plate VIII, Figure 10

Description: Nichols (1973, p. 107); Traverse (1955, p. 44, fig. 9).

Measurements: Diameter 25-33µm; thickness of exine 2µm. Ten specimens measured.

Stratigraphic interval: Reported from all the localities of the Tar Heel Formation.

Previously reported occurrences: Lower Cretaceous-Tertiary. Lower Cretaceous of Portomac Group of Maryland (Brenner, 1963); Oligocene of the Brandon lignite of Vermont (Traverse, 1955); Tertiary deposits of Massachusetts (Frederiksen, 1984); Miocene of Bethany Formation and Pliocene of Omar Formation os southern Delaware (Groot et al, 1990).

Nyssapollenites Thiergart 1937 ex Potonié 1960

Type species: Nyssapollenites pseudocruciatus (Potonié) Thiergart 1938

Description: Thiergart (1938; p. 322).

Suggested botanical affinity: Nyssaceae (Thiergart, 1938).

Nyssapollenites sp.

Plate VIII, Figure 7

Measurements: 26-42µm in diameter; ten specimens measured.

Stratigraphic interval: Reported from upper stratigraphic sections of Lock, Ivanhoe and Willis Creek localities. Reported from all the samples of Elizabethtown, Goldsboro and Tar River localities.

Previously reported occurrences: Late Cretaceous-Tertiary. Mid-Eocene to Lower Oligocene, Mississippi-Alabama (Frederiksen 1980a); Lower Oligocene of Mississippi-Alabama (Oboh and Reeves Morris, 1994); Upper Maastrichtian of NE Montana (Norton and Hall, 1969); Paleocene of Georgia (Christopher et al; 1980; Frederiksen 1980b).

Comments: Nyssapollenites spp recovered from Tar Heel Formation is tetrahedral and has subtriangular amb. It is similar to the species of Nyssapollenites reported by Christopher (1979b) reported from the basal Cretaceous units of the Eastern Gulf and Southern Atlantic Coastal Plains.

Oculopollis Pflug 1953

Type species: Oculopollis lapillus Pflug 1953

Description: Pflug (1953, p.110, pl. 19, figs 53-56).

Suggested botanical affinity: Hamamelidae-incertae sedis, Normapolles group (Pfug, 1953).

Oculopollis sp.

Plate VIII, Figure 1

Measurements: 19 to 25 μm long, 22-34μm wide; ten specimens measured.

Stratigraphic interval: Occurs in most samples throughout the Tar Heel Formation.

Previously reported occurrences: Campanian-Paleocene. Reported from Lower Campanian of Germany (Pflug, 1953); Campanian-Maastrictian of Azov Sea area, USSR (Mikhelis, 1981); Upper Cretaceous of Romania (Mogos, 1992); Paleocene of NW Siberia (Zaklinskaya, 1963).

Plicapollis (Pflug, 1953) emend. Tschudy, 1975

Type species: Plicapollis serta Pflug, p. 97, pl. 11, figs. 17-20.

Description: Pflug (1953, p.97) and Tschudy (1975, p.17).

Stratigraphic range: Cenomanian to Late Eocene.

Suggested botanical affinity: Hamamelidae-incertae sedis, Normapolles group. Plicate (Kedves and Herngreen, 1980).

Plicapollis retusus Tschudy 1975

Plate VII, Figure 6

Description: Tschudy (1975, p. 18).

Measurements: 15 to 30 μm long, 17-38μm wide; ten specimens measured.

Stratigraphic interval: Occurs in many samples in all the localities of Tar Heel Formation.

Previously reported occurrences: Campanian-Maastrichtian. Campanian of Tennessee (Tchudy, 1975); Campanian-Maastrichtian (Peedee Formation) of Charleston, South Carolina (Christopher, 1978); Cenomanian-Maastrichtian of Baltimore Canyon area (Bebout, 1981).

Plicatopollis Krutzch 1962 emend. Frederiksen and Christopher, 1978

Type species: Plicatopollis plicatus Potonié (1934).

Description: Krutzch (1962, p.277); Jansonius and Hills (1976, p.2044); and Frederiksen and Christopher (1978, p. 133-134).

Synonyms: Maceopolipollenites Leffingwell (1971).

Suggested botanical affinity: Juglandaceae, Platycarya (Frederiksen and Christopher, 1978).

Plicatopollis sp.

Plate VI, Figure 6

Measurements: 30 to 34 µm long; 26 to 30 µm wide; eight specimens measured.

Stratigraphic interval: Species of Plicatopollis are present in samples of upper stratigraphic sections of Ivanhoe (8), Lock (3) and Willis Creek localities respectively.

Previously reported occurrences: Upper Cretaceous-Tertiary. Reported from Crossroads core, South Carolina, Maastrichtian-Paleogene (Frederiksen and Christopher, 1978); Lower to Middle Eocene of Hungary (Kedves, 1973); Campanian of Aguja Formation, Texas (Baghai, 1996); Campanian and Maastrichtian sediments of Raritan, Salisbury znd Okefenokee Embayments of Atlantic Coastal Plain (Christopher, 1979).

Comments: Specimens of Plicatopollis found in the Tar Heel Formation samples are triangular with triradiate structures similar to plicae extending toward poles and are triporate.

Proteacidites Cookson ex Couper 1953

Type species: Proteacidites adenanthoides Cookson 1950

Description: Cookson (1950; p. 172-173, pl.2, fig. 21).

Suggested botanical affinity: Proteaceae.

Proteacidites retusus Anderson 1960

Plate VIII, Figure 8

Description: Anderson (1960, p. 21, pl. 2, fig. 5-7); Sarmiento (1957, figs 3, 4).

Measurements: 20 to 33 µm long, 25-33 µm wide; exine 1.5 µm thick; lumina approximately 0.5 µm; ten specimens measured.

Stratigraphic interval: Occurs in moderate to high frequency in many samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Albian to Paleocene. Maastrictian of Wyoming (Farabee and Canright, 1986); Campanian of Aguja Formation of Texas (Baghai, 1996); Maastrichtian of New Jersey (Wanders, 1974); Lea Park Formation, Alberta, Albian to Campanian (Jarzen and Norris, 1975); Upper Campanian to Danian of New Mexico (Anderson, 1960); Maastrichtian of Utah (Lohrengel, 1969); Late Cretaceous of Wyoming (Stone, 1973); Upper Moreno Formation, California, Maastrichtian to Danian (Drugg, 1967); Hell Creek Formation, Montana, Maastrichtian (Norton and Hall, 1969; Lofgren et al 1990; Tschudy, 1970).

Comments: The apertures of Proteacidites retusus appear to be circular.

Suggested botanical affinity: Proteaceae; Petrophila (Dettmann and Jarzen, 1991).

Pseudoplicapollis Krutzch in Goczan and others, 1967 emend. Christopher, 1979.

Type Species: Pseudoplicapollis palaeocaenicus

Description: Krutzch in Goczan et al (1967, p. 496, pl. 14, figs, 26-31).

Pseudoplicapollis newmanii Nichols and Jacobson, 1982

Plate VII, Figure 7

Description: Nichols and Jacobson (1982, p. 140, pl. 4, figs. 5 and 6).

Measurements: Equatorial diameter range 18-39 μm. 16 specimens measured.

Stratigraphic interval: Observed in most samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Lower-Upper Campanian. In the USA, it has been reported from middle to upper Campanian localities in Colorado (Newman, 1964; 1965) and Wyoming (Stone, 1973; Rubey et al, 1975; Tschudy, 1980).

Pseudoplicapollis longiannulata Christopher 1979

Plate VII, Figure 8

Description: Christopher (1979, p 114, pl9, figures 1-9).

Measurements: 17-38 μm in equatorial diameter; annuli 3μm in thickness; 10 specimens measured.

Stratigraphic interval: Common in many samples from the Tar Heel Formation.

Previously reported occurrences: Coniacian-Campanian. This species was reported from the Upper Cretaceous (Magothy Formation) of New Jersey (Christopher, 1979); Upper Cretaceous Marine Unit at Cheesequake, New Jersey (Litwin et al, 1993).

Comments: This species has been reported from sediments older than the Campanian. The most striking feature that helps to distinguish this species from others are the long protruding annuli (Christopher, 1979).

Pseudoplicapollis sp.

Plate VI, Figure 1

Measurements: 22 to 36 µm in equatorial diameter; exogerminals are 2 to 2.5 µm long and 0.5 µm wide; ten specimens measured.

Stratigraphic interval: Occurs in 19 samples of each of Goldsboro and Tar River localities, 15, 5, 3 and 2 samples of Willis Creek, Ivanhoe, Lock and Elizabethtown respectively.

Previously reported occurrences: Upper Cretaceous rocks of Raritan embayment (Central and northern New Jersey) and Salisbury embayment (Maryland, Delaware, southern New Jersey) (Wolfe, 1976, Christopher, 1979); Upper Cretaceous of Eagle Ford of Texas (Christopher, 1982).

Comments: Specimens assigned to Pseudoplicapollis sp from the Tar Heel Formation resemble Pseudoplicapollis sp. A of Christopher (1979) (NC-1 of Wolfe, 1976) in having a thickened wall surrounding the exospore. All specimens are triangular in outline with convex sides and protruding corners. Conspicuous endoplicae present terminating as points within the germinals. Exine is composed of two wall layers; inner layer consists of short radial bacula.

Retitricolpites Hammen, 1956 emend. Pierce, emend. Hammen and Wymstra 1964, emend. Srivastava, 1966

Type species: Retitricolpites ornatus Hammen, 1956.

Description: Hammen (1956); Pierce (1961); Hammen and Wymstra (1964) and Srivastava (1966).

Stratigraphic range: Albian to Eocene.

Suggested botanical affinity: Some species have been suggested to have affinities with Bombacaceae (Hammen and Mutis, 1966). The genus Retitricolpites includes a number of species, which are reticulate, and tricolpate (Guzmán, 1967).

Retitricolpites sp.

Plate VI, Figure 8.

Measurements: 15 to 39 μm long, 12 to 31 μm wide; ten specimens measured.

Stratigraphic interval: Observed in many samples associated with the Tar Heel Formation.

Previously reported occurrences: Albian-Eocene. Unassigned species of Retitricolpites are reported from Early Cretaceous sediments of Potomac Group of Maryland (Brenner, 1968); Upper Albian to Cenomanian of Alberta, Canada (Jarzen and Norris, 1975, Norris, 1967); Upper Cretaceous of Wyoming (Griggs, 1970); Campanian of Aguja Formation of Texas (Baghai, 1996); Paleocene of Colombia (Hammen and Mutis, 1966); Lower to Middle Eocene of Los Cuervos and Mirador Formations, Colombia (Guzmán, 1967).

Spheripollenites Couper 1958

Type species: Spheripollenites scabratus Couper 1958

Description: Couper (1958, pl. 31, figs. 12-14).

Spheripollenites perinatus Brenner 1963

Plate VIII, Figure 9

Description: Brenner (1963, p. 89, pl. 37, figs 3-6).

Measurements: Diameter 15-20 μm; six specimens measured

Stratigraphic interval: Reported from most samples of Goldsboro, Tar River, Willis Creek localities and also from 15 samples of Ivanhoe locality. Not reported from Elizabethtown and Lock.

Previously reported occurrences: Lower-Upper Cretaceous. Barremian-Albian of Maryland (Brenner, 1963); Middle-Upper Albian of Portugal (Hasenboehler, 1981).

Tetrapollis Pflug 1953

Type species: Tetrapollis validus (Pflug) Pflug 1953

Description: Plug (1953; p.113, pl. 24, figs. 72, 74, 76-79).

Suggested botanical affinity: Hamamelidae-incertae cedis, Normapolles group (Batten and Christopher, 1981).

Tetrapollis validus (Pflug) Pflug 1953

Plate VII, Figure 9

Description: Plug (1953; p.113, pl. 24, figs. 72, 74, 76-79).

Measurements: 22 to 32 μm long; 28 to 40 μm wide; outer wall layer 4 to 4.5 μm thick and inner wall layer 1.5 to 2 μm thick; eight specimens measured.

Stratigraphic interval: Reported from upper stratigraphic sections of Willis Creek (17), Ivanhoe (8) and Lock (5) localities; 18 samples from Goldsboro, 4 samples from Tar River and 4 samples from Elizabethtown localities.

Previously reported occurrences: Cretaceous-Paleocene. Mid Paleocene-Eocene of Germany (Plug, 1953; Thomson and Pflug, 1953); Mid Paleocene-Eocene of Central Europe (Góczán, Groot, Krutzch and Pacltová, 1967); Lower Tertiary of Inner Mongolia (Song, 1996); Upper Cretaceous of Meghalaya, India (Nandi, 1979).

Tricolpites Cookson ex Couper, 1953; emend. Potonié 1960 emend. Srivastava, 1969

Type species: Tricolpites reticulatus Cookson, 1947.

Description: Cookson ex Couper (1953, p. 61); Potonié (1960, p. 95) and Srivastava (1969, p. 55-56).

Suggested botanical affinity: Hamamelidaceae: Corylopsis, Hamamelis, Fothergila (Srivastava, 1969, 1975). Saxena and Misra (1989) suggested affinities of some members to Lamiaceae. It has been suggested by Leffingwell (1971) that Tricolpites reticulatus is comparable to the pollen of Gunnera.

Tricolpites crassus Frederiksen 1979

Plate VI, Figure 9

Description: Frederiksen (1979; p.139, pl.1, figs 7-11); Christopher et al (1980; p.117, pl.2, fig. 16).

Measurements: 20-36 μm in size; colpi 2-3 μm deep, exine of intercolpium 2.5-3 μm thick; ten specimens measured.

Stratigraphic interval: Reported from 13, 18, 9, 5 samples of Goldsboro, Willis Creek, Ivanhoe and Lock localities respectively. Not reported from Tar River and Elizabethtown localities.

Previously reported occurrences: Paleocene of Georgia (Christopher et al, 1980); Upper Paleocene of Gulf Coast of US (Frederiksen, 1979); Upper Paleocene of South Carolina (Frederiksen, 1980).

Comments: Specimens of Tricolpites crassus recovered from the Tar Heel Formation are larger in size compared to previously reported specimens from other localities. This species is tricolpate with short, shallow colpi with exine composed of two layers in the intercolpium region. Exine is less than 1 μm thick at colpi.

Tricolpites sp.

Plate VI, Figure 5

Measurements: 15 to 40 μm long; 12 to 38 μm wide; ten specimens measured.

Stratigraphic interval: Very abundant in many samples from all the localities of Tar Heel Formation.

Previously reported occurrences: Upper Cretaceous-Tertiary. Species of Tricolpites have been reported throughout the world. Some of the reported occurrences in the United States are: Coniacian of Utah (Orlansky, 1971); Cenomanian to Campanian of mid-Atlantic Baltimore Canyon area (Bebout, 1981); Coniacian-Campanian of New Mexico (Jameossanaie, 1987), Campanian-Maastrichtian of Utah (May, 1972), Paleocene of New Mexico (Fassett et al, 1987); Paleogene of northeastern Virginia (Frederiksen, 1979).

Tricolpopollenites (Potonié) 1934 emend. Pflug and Thomson 1953

Type species: Tricolpopollenites (Pollenites) parmularis (Potonié) Thomson and Pflug, 1953, p.97.

Description: Potonié (1934, p.52) for the description on Pollenites parmularis; Pflug (1953, Pflug in Thomson and Pflug, p. 95) on Tricolpopollenites.

Botanical affinity: Dicotyledonae-incertae sedis.

Tricolpopollenites williamsoniana (Traverse) Gruas Cavagnetto 1968.

Plate VII, Figure 11

Description: Traverse (1955, p. 49, fig. 10 (45) for the description on Quercus williamsoniana); Gruas Cavagnetto (1968; p. 64, pl. 6, figs 20-22).

Measurements: 38-45µm long; 20-29µm wide. Thickness of exine is 2µm. Eight specimens measured.

Stratigraphic interval: Reported from many samples of the Tar Heel Formation, not found in Elizabethtown locality.

Previously reported occurrences: Barremian-Oligocene. This species has been reported from Barremian-Albian of Maryland (Brenner, 1963); Oligocene of Vermont (Traverse, 1955); Lower Cretaceous of France (Gruas-Cavagnetto, 1968).

Comments: This pollen has pronounced longitudinal furrows and the sculpture is scabrate.

Tricolpopollenites sp.

Plate VI, Figure 7

Meaurements: 15-20 µm long, 10-12 µm wide; ten specimens measured.

Stratigraphic interval: Occurs in abundance throughout the Tar Heel Formation.

Previously reported occurrences: Upper Cretaceous-Tertiary. Upper Cretaceous of Atlantic Coastal Plain of Maryland and Delaware (Groot and Penny, 1961); Maastrichtian of Mt. Laurel Formation of New Jersey (Gray and Groot, 1966); Maastrichtian to Danian of Escarpado Canyon, California (Drugg, 1967); Campanian of Aguja Formation, Texas (Baghai, 1996); Paleocene of Silverado Formation, California (Gaponoff, 1984).

Comments: Pollen grains of Tricolpopollenites sp. from the Tar Heel Formation are tricolpate, radially symmetrical, and oval in shape. Colpi are distinct, simple and extending to the poles.

Tricolporopollenites Potonié, 1931

Description: Potonié (1931) and Thomson and Pflug (1953).

Type species: Tricolporopollenites kruschii Pflug and Thomson 1953.

Suggested botanical affinity: Dicotyledonae-incertae sedis.

Tricolporopollenites bradonensis Traverse 1994

Plate VIII, Figure 11

Description: Traverse (1994, p. 285, p. 290).

Measurements: 22-35μm in diameter, exine 2-2.5μm in thickness, ten specimens measured.

Stratigraphic interval: Not common in Tar Heel localities except Goldsboro where 14 samples yielded this grain. Reported from 8, 4 samples of Willis Creek and Ivanhoe respectively.

Previously reported occurrences: The species has been previously reported from Brandon Lignite of Vermont (Traverse, 1994).

Comments: It has been suggested that this species might have affinities to extant members of Rosaceae since the large circular equatorial furow structure and the striate sculpture distinguishes this species from the rest. This is a characteristic feature of many genera of Rosaceae (Traverse, 1994).

Tricolporopollenites sp.

Plate VII, Figure 12

Measurements: 20-55 µm long; 10- 28 µm wide; ten specimens measured.

Stratigraphic interval: Distributed throughout the Tar Heel Formation; reported from all the localities.

Previously reported occurrences: Lower Cretaceous-Tertiary. Species belonging to Tricolporopollenites have been reported from Lower Cretaceous of Maryland and Delaware (Groot and Penny, 1961); Santonian to Campanian of Mid-Atlantic Baltimore Canyon area (Bebout, 1981); Campanian-Maastrichtian of Utah (May, 1972); Maastrichtian (Kairparowits Formation) of Utah (Lohrengel, 1969); Eocene of Texas Gulf Coast (Elsik, 1974); Turonian to Lower Senonian of Alberta (Jarzen and Norris, 1975).

Triplanosporites Pflug ex Thomson and Pflug 1953

Type species: Triplanosporites sinuosus Pflug 1953

Description: Plug (1953, p.58).

Suggested affinity: Magnoliopsida

Triplanosporites sinuatus Takahashi 1964.

Plate VI, Figure 3

Description: Takahashi (1964, p.211-212, pl 28, figs. 12-14).

Measurements: 24-40 µm long; 18-33 µm wide.

Stratigraphic interval: Found in samples of all the localities of Tar Heel Formation.

Previously reported occurrences: Lower-Upper Cretaceous. Barremian-Albian of Maryland (Brenner, 1963); Campanian of Northern Japan (Takahashi, 1964).

Trudopollis Pflug emend. Krutzsch in Goczan et al., 1967

Type species: Trudopollis pertrudens Pflug (1953).

Description: Pflug (in Thomson and Pflug, 1953 p. 98).

Suggested botanical affinity: Hamamelidae-incertae sedis, Normapolles group. (Kedves and Herngreen, 1980).

Trudopollis variabilis Tschudy 1975

Plate VIII, Figure 2

Description: Tschudy (1975, p.25, pl. 16, figs. 13-22).

Measurements: 25-33µm long; 25-34µm wide; eight specimens measured.

Stratigraphic interval: Reported from all the samples of Tar Heel Formation.

Previously reported occurrences: Reported from the Lower-Campanian to Lower Maastrichtian sediments of the southeastern United States (Tschudy, 1975).

DESCRIPTIVE STRATIGRAPHY AND PALEOFLORISTICS

4.1 Descriptive Stratigraphy of Localities of Tar Heel Formation

4.1 A Elizabethtown Samples

Four palynological samples from Elizabethtown locality were studied. ET-1a (lower) and ET-1b (upper) represent samples from laminated, dark clayey sand zone. ET-2a (lower) and ET-2b (upper) are samples from micaceous blue-gray clayey sand zone. Freshwater algal forms are not recovered from any of these samples. Isabelidinium is the only dinoflagellate species that is found. Isolated fungal spores of Dicellites, Inapertisporites, Multicellaesporites and Tetracellites are recognized. Spores of fern genera such as Cicatricosisporites, Cyathidites, Dictyophyllidites, Laevigatosporites and Matonisporites occur in these samples. Conifer pollen of Araucariacites, Inaperturopollenites, Piceaepollenites, Podocarpites and Taxodiaceaepollenites are reported. Normapolles pollen of Complexiopollis, Oculopollis, Plicapollis, Pseudoplicapollis, Tetrapollis and Trudopollis are very well represented. Besides Normapolles pollen, various tricoplates, tricoplorates and triporates are also present. Angiosperms are the most common palynomorph component comprising about 76% of the total palynoflora followed by pteridophytes (10%), fungal forms (7%), gymnosperms (6%) and dinoflagellates (1%) (Figure 4a).

4.1 B Goldsboro Samples

Twenty samples were collected from Neuse River Cut Off, Goldsboro locality. A bridge spans the locality and sampling was done from both sides of the bridge. On one side of the bridge four samples were collected from medium-gray feldspathic sand with lenses of dark clay and six samples were collected from thinly interbedded dark-gray clays with sand zones. On the other side of the bridge, two were collected from the intercalated black clay zone, five samples were collected from medium-gray feldspathic sand with lenses of dark clay zone and three were collected from thinly interbedded dark-gray clays with sand zones. Fresh water algal forms along with marine dinoflagellates such as Cerodinium, Isabelidinium and Pierceites are present in samples of Goldsboro. Fungal spores are very diverse including fungal hyphae of Palaencistrus and fruiting body of Phragmothyrites. Assortment of dark brown dicellate, tetracellate and multicellate fungal spores are associated with the abundance of degraded organic matter. Well preserved trilete fern spores are reported from many samples of this locality. Gymnosperm pollen characteristic of low paleolatitudes such as Taxodiaceaepollenites and Cycadopites are found besides other conifers. Angiosperms are well represented and comprise about 44% of the total palynoflora. Pteridophytes, gymnosperms, fungi, fresh water algae and dinoflagellates constitute 22%, 20%, 10% and 4% of the total palynoflora respectively (Figure 4b). The presence of marine dinoflagellates suggests a possible marine influence in this environmental setting.

4.1C Ivanhoe Samples

Twenty four palynology samples were analyzed from the Ivanhoe locality. Most samples collected from the older black clay bed are rich in megafossils of leaves and stems. Fresh water algal remains and dinoflagellates were reported from black clay interbedded with buff sand bed. Specimens of Ovoidites and Schizosporis parvus were reported from greenish-gray clay bed. Dinoflagellate species of Cerodinium, Isabelidinium and

Pierceites are present in some samples of the lower most black clay bed but are not found in samples from greenish-gray clay and grayish black clay beds. Fungi spores are well represented and spores of Multicellaesporites show a trend in increased relative abundance from stratigraphically older to younger strata. Well preserved trilete fern spores of Camarozonosporites, Cicatricosisporites dorogensis, Cyathidites, Dictyophyllidites, Laevigatosporites ovatus, Undulatisporites and Deltoidospora are well represented. Pollen of conifers such as Pinuspollenites, Piceaepollenites, Taxodiaceaepollenites are common in most samples. Angiosperm pollen represents the most dominant palynofloral group, accounting for 59% of the total palynoflora followed by fungal and pteridophyte groups, each constituting 13% of the total palynomorph count. Gymnosperms, algae and dinoflagellates comprise 12% and 3% of the total palynoflora respectively (Figure 4c).

4.1D Lock Samples

Exposures spanning stratigraphic section of the Lock locality range from 10-12 feet in thickness. Eight palynological samples were processed from the dark gray clay bed. Sampling was done at 1 to 2 feet intervals. Some samples had abundant plant fragments (cuticles) and dark organic matter. Three samples yielded one freshwater algal specimen of Schizosporis parvus. Specimens of Isabelidinium sp. were recovered from two stratigraphically older samples (LK1 and LK2). Assorted ferns, fungi, gymnosperms and angiosperms were reported from many samples. Angiosperms dominate the assemblages representing about 63% of the total palynoflora. Pteridophyte spores are more common than gymnosperm pollen (11%) and fungal spores (10%) and comprise about 15% of the palynomorph count (Figure 4d).

4.1E Tar River Samples

Twenty one palynomorph samples were analyzed from the Tar River locality of the Tar Heel Formation. Sampling was done laterally at every 2 feet interval from dark gray clayey sediments. Megafossil fragments of twigs and leaves are found in some samples. Fresh water algal remains of Botryococcus, Ovoidites, Schizosporis, Tetraporina and dinoflagellate Isabelidinium represent 4% of the total palynoflora. Gymnosperms pollen represent 21% of the palynomorph component. Angiosperms represent the most common palynomorphs accounting for 51% of the total palynoflora (Figure 4e). Cycads, conifers and genera associated with Normapolles complex, tricolporates, triporates and tricolpates are reported from most samples.

4.1F Willis Creek Samples

Twenty six samples (seven from black clay interbedded with micaceous coarse sand bed, six from black carbonaceous clay bed, five from grayish-black clay bed and eight from laminated sand and carbonaceous clay bed) were collected from the Willis Creek locality and processed for palynological analyses. Algal remains of Botryococcus braunii, Ovoidites sp., Schizosporis parvus were found from black clay and grayish-black clay beds. These freshwater algae were not found in other beds of the locality. The dinoflagellates Cerodinium sp., Isabelidinium sp. and Perceites pentagonus occur in many samples from all four beds of this locality. The algae and dinoflagellates constitute

4% of the total palynomorph count. The occurrence of Teredolites borings, microforaminiferal linings and marine bivalves indicate a marine influence that may be due to transgression with rapid sea-level rise (Owens and Sohl, 1989; Sohl and Owens, 1991; Stancliffe, 1996). Two morphological types (trochospiral and planispiral) of microforaminiferal linings have been found in fourteen samples of Willis Creek. In the trochospiral form (Plate IX, Figure 1), a whorl overlaps on one side of the previous whorl making a trochospiral form. Planispiral forms (Plate IX, Figure 2) have only one whorl (Stancliffe, 1996). Assorted fungal spores/hyphae represent 10% of the total palynoflora. The form genus Multicellaesporites shows a similar trend in its relative abundance (as seen also in Ivanhoe locality). The number of grains of Multicellaesporites increases from stratigraphically older to younger strata. This could be correlated with the progressive high yield of angiosperm pollen in the stratigraphically younger sediments. Different kinds of fern spores are also found and account for 16% of the total palynoflora. Gymnosperm pollen represent 14% of the palynomorph component. Common constituents include Classopollis classoides, Ginkgocycadophytus nitidus, Parvisaccites radiatus, Pinuspollenites sp., Piceaepollenites sp., Podocarpites sp. and Taxodiaceaepollenites sp. Angiosperms represent the most common palynomorph (56%) and include taxa associated with the Normapolles and Postnormapolles complex and other triporates, tricolpates and tricolporates (Figure 4f).

4.2 Paleofloristics

4.2 A Freshwater algae

Fossil spores of Ovoidites and Schizosporis parvus recovered from Tar Heel Formation samples have been compared to the extant Spirogyra. Mougeotia has been suggested to be the Recent generic analogue for Tetraporina (van Geel and Grenfell, 1996). These spores are indicators of shallow, stagnant, freshwater habitats (van Geel and van der Hammen, 1978; Sangheon, 1997). Studies in Florida Bay, Harney River and Okefenokee Swamp sites suggest that Ovoidites is more closely associated with freshwater marsh habitats (Rich, Kuehn and Davies, 1982). The fossil genus, Botryococcus braunii recovered in this study, is not of much use in biostratigraphic studies and environmental interpretations (Batten and Grenfell, 1996). The modern Botryococcus is widely distributed in wide array of habitats (freshwater pools to regions of variable salinity) in both temperate and tropical regions and could withstand seasonally cold climates (Batten and Greenfell, 1996).

4.2B Dinoflagellates

Three species, Cerodinium pannuceum, Isabelidinium sp. and Pierceites pentagonus belonging to the family Peridiniaceae are reported from Tar Heel Formation samples. The lower diversity of dinoflagellates compared to other palynofloras in sediments indicates little marine influence on the deposition of Tar Heel sediments (Fensome, Riding and Taylor, 1996).

4.2C Fungi

Fungi have a long geological history and the importance of this group in relation to their roles in the past ecosystem throw light on interactions between fungi and both plants and animals along with their environment (Taylor, 1990). Fungal palynomorphs including spores, hyphae and fruiting bodies were recovered. The morphological types exhibited variations in their cell number, size and arrangement of septa. The diversity is shown by the presence of monocellate (Inaperturopollenites), dicellate (Dicellites, Didymosporiporonites), tetracellate (Tetracellites) and multicellate (Fractisporonites, Multicellaesporites and Scolecosporites) forms. Fruiting bodies of Phragmothyrites and hyphae of form-genus Palaencistrus sp. were also found. The form-genus Multicellaesporites shows a general trend of increased abundance from stratigraphically older to younger strata at Ivanhoe and Willis Creek localities. Changes in diversity and relative abundance of fungal palynomorphs could reflect changes of paleoclimate (Elsik, 1980; 1993). Studies by Jansonius (1976) and Staplin et al. (1976) showed increase in abundance and diversity of Neogene fungal palynomorphs in sediments of the cyclic warm periods. It could also be speculated that changes in relative abundance could possibly reflect the changes in relation to parasitism and saprophytism (Traverse, 1988). Fungal spores of Multicellaesporites were previously unknown from Campanian sediments as these are reported from Late Paleocene to Recent sediments.

4.2D Pteridophytes

Spores of tree ferns of Cyatheaceae (Cyathidites), herbaceous ferns Schizaeceae (Cicatricosisporites), Polypodiaceae (Laevigatosporites, Leiotriletes, Psilatriletes and

Matonisporites) and Selaginellaceae (Cingutriletes and Echinatisporis) are reported from samples of the Tar Heel Formation. These fern families have been associated with moist subtropical or moist warm temperate regions (Hochuli, 1981; Rouse, 1962). Spores of Lycopodiaceae (Camarozonosporites, Ceratosporites, Hamulatisporites) have a wide range of geographical range and are indicative of moist regions (Lohrengel, 1969). Fern spores are important constituents of both Jurassic and Cretaceous sediments (Traverse, 1988). Studies of Late Cretaceous sediments by Hughes and Moody - Stuart (1969) and Hughes and Croxton (1973) in Britain reveal a large diversity of fern spores suggesting that they were important components of palynofloral assembleages during the Cretaceous.

4.2E Gymnosperms

Cretaceous gymnosperm pollen tends to be less diverse and less abundant in sediments as compared to pteridophytes and angiosperms due to gradual decline in the diversity of conifers during the Cretaceous (Lidgard and Crane, 1990). Gymnosperm pollen reported from the Tar Heel Formation samples includes bisaccates (Pinuspollenites, Podocarpites and Parvisaccites), circumpolles (Classopollis), monosulcates (Cycadopites), and inaperturates (Araucariacites, Inaperturopollenites and Taxodiaceaepollenites). Conifers including cheirolepidiaceous, podocarpaceous and taxodiaceous forms were represented well in the samples. Taxodiaceaepollenites (Taxodiaceae) are associated with swampy topography (Lohrengel, 1969; Orlansky, 1971). Cheirolepidiaceous conifers producing Classopollis pollen have been speculated to occupy upland slopes and lowlands close to the coast. Classopollis pollen have been speculated to be indicators of warm climate and representatives of coastal forests in floodplain communities (Srivastava, 1976; Alvin, 1982; Watson, 1982). Cheirolepidiaceae underwent declined in the Cretaceous and became extinct as a group during the Cretaceous/Tertiary boundary (Thomas and Spicer, 1987).

4.2F Angiosperms

Angiosperms are the most diverse and dominant components among the palynomorph groups recovered from Tar Heel Formation. The reproductive success of angiosperms could be attributed to vegetative and reproductive innovations that include the capabilities of angiosperms to set seeds quickly, outgrowing and outnumbering the slower-reproducing seedlings of gymnosperms, seeds protected by carpels from fungal infection, dessication and invasion by insects and double fertilization and having pollen with multiple (tricolpate) apertures with complexly structured exines. Floral complexity documented through diversity in the Cretaceous (Friis and Pedersen, 1996) gave the angiosperms an advantage to wide range of adaptations to insect - pollination strategies. Pollen assigned to Proteaceae, Nyssaceae, Juglandaceae, Fagaceae, Betulaceae, Palmae, Liliaceae and Normapolles group are reported from the Tar Heel Formation. Pollen of other dicotyledons such as Tricolpites, Tricolpopollenites and Tricolporopollenites are abundant and these forms are not classified to particular taxonomic families. The Lower Cretaceous (Barremian) monoaperturate, reticulate Clavatipollenites hughesii, characteristic of dicotyledonous magnoliid angiosperms (Walker, 1984) is represented well in the sediments and are of high abundance in stratigraphically older sections of Tar Heel Formation. Studies by Hickey and Doyle (1977) support that tricolpate pollen pollen arose in the Southern Hemisphere in Aptian time, spread to mid latitudes during Albian and spread rapidly to other regions including the poles in the Cenomanian. Tricolpates (Middle Albian) arose first, followed by tricolporates (Upper Albian) and then triporates (middle Cenomanian) (Brenner, 1963; Doyle, 1969; Lidgard and Crane, 1990). Rapid diversification of angiosperms is apparent from the observation of all major types of apertures, tricolpate, tricolporate and triporate. Tricolpate and ticolpate – derived pollen are common in hamamelididean and rosidean taxa (Friis and Pedersen, 1996). Normapolles pollen exhibit morphological and structural variation and dispersed forms have been compared to wind pollinated forms of Betulaceae, Casuarinaceae, Juglandaceae, Myricaceae and Rhoipteleaceae (Friis and Pedersen, 1996). Triporate and tetraporate Normapolles pollen genera recovered from the Tar Heel Formation are discussed in chapter 6.

4.3 Tar Heel Formation and Other Campanian Floras in the US

Published palynological studies on Campanian localities in the western US include the Judith River (Tschudy, B; 1973), Clagett Formation (Nichols et al., Tschudy and Leopold, 1970), Cokedale Formations (Tschudy and Leopold, 1970), Almond Formation (Stone, 1973), Point of Rocks Formation of the Rock springs Uplift (Stone, 1973), Coal beds of the Mesaverde and Blackhawk Formations (May, 1972), Isles Formation of northwestern Colorado (Newman, 1964, 1965), Mancos Shale of Southern Colorado (Thompson, 1969, 1972); Lewis Shale (Anderson, 1960); Fruitland Formation (Tshudy, 1976) and Menefee Formation (Jameossanaie, 1987). Baghai (1996) conducted a detailed palynological investigation on the Campanian rocks of Aguja Formation, Texas.

Campanian studies of southern and eastern United States include those Tschudy (1975, 1973, 1965) from the Cuesta Sand Member, Ripley Formation, Alabama, Coffee Sand Formation, Tennessee and the Pond Bank deposit in Chambersburg, Pennsylvania. The post-Magothy Formations of Salibury and Raritan Embayments in Maryland and New Jersey were studied by Wolfe and Pakiser (1971), Wolfe (1976) and Christopher (1979) (Figure 4g).

Palynomorphs from the Tar Heel Formation were compared with those of post-Magothy formations (Wolfe, 1976, Christopher, 1979) (Table 4.1) and Aguja Formation (Table 4.2) to determine the similarities that exist among Campanian palynofloras at the intra- regional (post Magothy formations-Atlantic Coastal Plain) and inter-regional levels (Aguja Formation-Gulf Coastal Plain). Amongst the intra-regional Campanian floras of the Atlantic Coastal Plain, angiosperm palynolfloras of post-Magothy formations are well studied compared to other contemporary regional floras. The Aguja Formation was selected for comparison between Campanian floras at the inter-regional level as it documents detailed paleofloristics investigation that includes palynomorph groups of algae, fungi, bryophytes, pteridophytes, gymnosperms and angiosperms. Comparative studies show that the Tar Heel Formation has many genera that are in common with the Aguja Formation. Similar spores and pollen that are characteristic of these two regions include Cerodinium, Ovoidites, Schizosporis (dinoflagellates and algae), Didymoporisporonites, Inapertisporites, Tetracellites (fungi), Sterisosporites (bryophytes), Camarozonosporites, Ceratosporites, Cicatricosisporites, Cingutriletes, Cyathidites, Deltoidospora, Echinatisporis, Laevigatosporites, Leiotriletes, Matonisporites (pteridophytes), Classopollis, Cycadopites, Inaperturopollenites, Parvisaccites, Pinuspollenites, Podocarpites, Taxodiaceaepollenites (gymnosperms), Arecipites, Complexiopollis, Cupuliferoipollenites, Cyrillaceaepollenites, Holkopollenites, Liliacidites, Momipites, Nyssapollenites, Plicapollis, Plicatopollis, Proteacidites, Retitricolpites, Tricolpites, Tricolpopollenites, Tricolporopollenites and Trudopollis (angiosperms). Findings of fungal spores of Didymoporisporonites and Tetracellites from Campanian sediments of Tar Heel and Aguja Formations support the range extension of these form-genera of fungi to the Campanian

In the intra-regional comparison of palynofloras, the angiosperm palynoflora was compared with that of post-Magothy formations. Studies on the pollen of the Magothy and post-Magothy Upper Cretaceous deposits of the Middle Atlantic States have been conducted (Wolfe, 1976; Christopher, 1978, 1979). Six palynologic zones designated by Wolfe (1976) were established based on dicotyledon pollen. The post-Magothy formations include Merchantville (zone CA-2 of Wolfe, 1976), Woodbury (CA-3 of Wolfe, 1976), Englishtown (CA-4 of Wolfe, 1976), Marshalltown and Wenonah (zone CA-5 of Wolfe, 1976). Zones CA-2 to CA-4 correspond to Lower Campanian and zone CA-5 is Upper Campanian (Christopher, 1979). The angiosperm pollen genera common to both the Tar Heel Formation and post-Magothy formations are Complexiopollis, Holkopollenites, Labrapollis, Plicapollis, Plicatopollis, Proteacidites, Pseudoplicapollis, Retitricolpites and Trudopollis. Taxonomic lists are incomplete from post-Magothy formations as data for other palynomorph groups such as algae, fungi, bryophytes, pteridophytes, gymnosperms are lacking. Further (or more complete) studies on these formations would give a better picture of the regional palynoflora during the Campanian.

Comparison of paleofloras between Tar Heel Formation and Aguja Formation reveals more similarities in the angiosperm floras (sixteen genera) than between Tar Heel Formation and post-Magothy formations (twelve genera). This suggests that Tar Heel Formation and Aguja Formation are more contemporary in age and could also reflect similar ecological conditions.

4.4 Climatic Implications

An accurate reconstruction of the climatic and vegetational characteristics of the Tar Heel Formation based solely on the study of palynomorphs is not possible as many extinct form-genera cannot be assigned to families due to lack of modern equivalents. Extrapolation of ecological preferences of extinct taxa with no modern equivalents should not be undertaken at all. In this study, some form-genera have been identified only to the family level, allowing a broad discussion in terms of paleoecological context. Other palynomorphs are difficult to assign to appropriate families due to lack of their modern equivalents.

Climatic data from National Center for Atmospheric Research indicates that the Campanian was warm with very low thermal gradients (Deconto, 1996). Spores of tree ferns of Cyatheaceae (Cyathidites), Schizaeaceae (Cicatricosisporites), Polypodiacese (Laevigatosporites, Leiotriletes, Matonisporites), Selaginellaceae (Cingulatisporites, Echinatisporis) recovered from Tar Heel samples are indicators of moist subtropical to warm and moist temperate regions (Hochuli, 1981; Rouse, 1962). Gymnosperm pollen of Podocarpites, Parvisaccites (Podocarpaceae), Taxodiaceaepollenites (Taxodiaceae), Inaperturopollenites (Cheirolepidiaceae) are associated with low-relief and swampy topography (Herngreen et al. 1986; Lohrengel, 1969). Pollen of Cycadopites (Cycadaceae), Arecipites (Palmae), Proteacidites (Proteaceae) are ecological indicators attributed to subtemperate to subtropical climates. (Herngreen et al. 1986; Lohrengel, 1969; Norton and Hall, 1969; Oltz, 1969). Spores of Stereisosporites (Sphagnum) indicate quiet freshwater ponds, lakes, bogs and swamps (Herngreen et al. 1986).

The Tar Heel palynomorph record, based on the recovery of some indicator form-genera with modern equivalents, suggests a subtropical to warm, moist temperate climate during the Campanian in the southeastern region of North America.

NORMAPOLLES PROVINCE AND AGE OF THE TAR HEEL FORMATION

5.1 Background

During the Late Cretaceous two distinct land floras were present in the Northern Hemisphere. The regions containing these floras were named according to their predominant pollen types. The Normapolles province extends eastward from the Mississippi embayment to eastern United States into western Europe. The Aquilapollenites province extends westward from the Mississippi embayment area through the western United States, Canada, and Alaska into eastern Asia. The north-south trending epeiric sea provided a barrier to plant migration (Stanley, 1970; Tschudy, 1975, 1980, 1981; Batten, 1984).

The name "Normapolles" was proposed by Pflug (1953) and included morphologically distinct pollen of various angiosperms of uncertain origin. Normapolles are "oblate, mostly triporate or brevitricolp(or)ate pollen having complex, commonly protruding apertures and typically a triangular amb, although some are more or less circular in polar view" (Batten and Christopher, 1981). The development of pore structures in which annuli, atria, vestibula and radial bacula make up a complex germinal and the presence of plicae, endoplicae, polar thickenings, oculi, and other elaborations of the wall structure distinguish most Normapolles from other pollen types (Batten, 1981). Many of the taxa have short stratigraphic ranges and are useful for biostratigraphic age determinations in Cretaceous and early Tertiary rocks (Batten, 1981; Srivastava, 1981). This group encompasses more than 86 genera with several hundreds of species (Christopher, 1995).

Normapolles plants may have evolved first in Europe based on number of genera and degree of differentiation of both genera and species (Tschudy, 1981; Herngreen et al, 1996). The oldest record of Normapolles from Europe is from Lower Cenomanian sediments (Herngreen et al, 1996; Srivastava, 1981). The earliest record of Normapolles from the eastern United States is from the Middle Cenomanian (Singh, 1975; Srivastava, 1981). This group reached its peak of diversification in Europe during the Santonian and in North America during the Santonian to Campanian (Batten, 1981, 1984; Tschudy, 1981; Zaklinskaya, 1977, Retallack and Dilcher, 1986). The group declined gradually during the Maastrichtian and Paleocene and became extinct in Europe in early Oligocene, and in North America by the Eocene (Tschudy, 1981; Batten and Christopher, 1981).

The western Aquilapollenites province is separated from the Normapolles province by longitudinal boundaries at 80^0 in West Siberia and 95-100^0 in the Western Interior of North America (Batten, 1981; Srivastava, 1981; Thomas and Spicer, 1987). This group is represented by distinctly different morphological pollen types that are characterized by triprojectate pollen with three equatorial protrusions, each bearing a meridional colpus (Herngreen and Chlonova, 1981). Although provincialism has been established during the Late Cretaceous, there have been reports of mixed floral assemblages / interfloral mixing of both eastern and western elements (Batten, 1984; Lehman, 1997). A few species of Normapolles pollen of Plicapollis, Pseudoplicapollis, Trudopollis, Extratriporopollenites, Thomsonipollis and Vacuopollis have been reported from western United States (Arizona, California, Colorado (Romans, 1975; Drugg, 1967; Chmura, 1973). Other records of occurrences of Normapolles beyond their provincial boundaries are documented from the Canadian Arctic (McIntyre, 1974), Inner Mongolia

(Sun et al., 1979) China (Zhao et al., 1981) and India (Nandi, 1980). Species of Aquilapollenites have been recorded from the Atlantic Coastal plain of North America (Evitt, 1973; Mitra et al., 1998), Brazil (Regali et al., 1974), West Africa (Boltenhagen, 1980), Malaysia (Muller, 1968). The occurrence of both pollen types beyond their known boundaries has been explained in terms of long distance transport (especially the triprojectate pollen that could actually be transported long distances owing to the presence of projections) (Traverse, 1988; personal communication, 1998) and erroneous identifications / contamination (Batten, 1984). It could also be speculated that the epeiric seas were not totally effective in confining the pollen types to their respective provinces. Towards the end of the Maastrichtian, land connections were established during marine regressions (Batten, 1984) that could have aided in intermixing of the pollen types. Most of these studies have not reported relative abundance of various pollen types and at this stage, its too early to question the integrity of the Late Cretaceous floral provinces.

In North America, the distribution of Normapolles genera in three geographical areas namely, North Atlantic Coastal Plain, Mississippi Embayment and west of the epeiric Cretaceous Seaway was recognized by Tschudy (1981). The Normapolles pollen province has since been extended to include the northeastern part of Mexico (Medus and Almeida-Leñero, 1982). Studies show that some Normapolles genera are common among the three areas whereas other genera are confined to specific regions (Tschudy, 1981; Batten and Christopher, 1981; Singh, 1975). More intensive and detailed stratigraphic studies of Late Cretaceous and Early Tertiary rocks would help in throwing light on the distribution of different species of Normapolles.

The heterogeneous Normapolles group has been speculated to be closely related to members of Hamamelideae and in particular the Myricales and Juglandales (Friis, 1983). The discovery of fossil flowers with in situ pollen from Upper Cretaceous sediments of southeastern North America suggests that some members of the Normapolles complex are closely related to "higher hamamelids comprising of Juglandaceae, Rhoipteleaceae, Myricaceae and Betulaceae (Sims et al., 1999). Normapolles pollen types have been linked with both insect and wind pollination. The multilayered exine and complicated germinals of many of the members may have been adapted to insect pollination (Wolfe, 1975). Batten (1981) speculated that the reduced sculpture, porate apertures and diminutive size of some Normapolles grains (especially Complexiopollis) are contrivances for wind pollination. The pollen of Normapolles group, although abundant in non-marine strata, have also been found in marine facies. This evidence could support wind pollination of several Normapolles taxa (Pacltová, 1978). Anemophily is associated with plant communities in temperate regions with seasonality (Whitehead, 1969).

Normapolles pollen have been linked to both arid and humid climates (Batten, 1981). Pacltová (1978) has found them associated with mangrove niches and other authors (Lubiromova and Samoilovich, 1975) associate their occurrence with uplands in the southern Urals.

5.2 Normapolles Pollen from Tar Heel Formation

Seven genera (Complexiopollis, Labrapollis, Oculopollis, Plicapollis, Pseudoplicapollis, Tetrapollis and Trudopollis) representative of the Normapolles group occur throughout the Tar Heel Formation. The Normapolles component comprises about 54%, 48%, 52%, 48%, 50% and 29% of the total angiosperm assemblage in Elizabethtown, Goldsboro, Ivanhoe, Lock, Tar River and Willis Creek localities, respectively. The relatively high abundance of Normapolles pollen indicates that these plants were important components of the vegetation in these Late Cretaceous environments. Four of these seven genera, Complexiopollis, Plicapollis, Pseudoplicapollis and Trudopollis have been collected from all three North American provinces (North Atlantic Coastal Plain, Mississippi Embayment region and Western Interior) designated by Tschudy (1981). A summary of various Normapolles genera has been presented in Table 5.1.

The stratigraphic range of Trudopollis extends from the Early Campanian through the Early Eocene. Trudopollis has been used to define segments of stratigraphic column in both eastern and western North America (Jarzen and Norris; Tschudy, 1981). Complexiopollis is a common genus present in almost all Upper Cretaceous samples from eastern North America. It has a shorter stratigraphic range than Trudopollis, extending from the Late Cenomanian through the Early Maastrichtian (Pacltová, 1981). As a result, species of Complexiopollis have been used to define biostratigraphic zones (Doyle, 1969; Wolfe and Pakiser, 1971; Wolfe, 1976, Christopher, 1979). Complexiopollis abditus, a component of the Tar Heel microfossil flora, is an index fossil of the Campanian. Wolfe (1976) reported this species from basal Merchantville through Englishtown Formations of Raritan and Salisbury Embayments of the Middle Atlantic States. This species has been also reported from Aguja Formation (Campanian) of Texas (Baghai, 1996), Merchantville and Englishtown Formations (Zones CA-C4 of Wolfe (1976) corresponding to Lower Campanian) Salisbury and Raritan Embayments of

Maryland and New Jersey (Christopher, 1979), Coffee Sand Formation (Campanian) of Mississippi (Tschudy, 1973), Meneffee Formation (Coniacian-Campanian) of New Mexico (Jameossanaie, 1987) and San Miguel Formation of Mexico (Medus and Almeida-Leñero, 1982). Besides Complexiopollis abditus, Complexiopollis exigua has biostratgraphic value and has been reported from Turonian – Campanian sediments of Raritan and Magothy Formations, Black Creek samples of South Carolina and Eutaw Formation of Albama-Georgia border (Christopher, 1979). Complexiopollis funiculus has been mostly reported from Cenomanian – Coniacian sediments (Tschudy, 1973) and Santonian sediments (Bebout, 1981). Occurrence of this species in the Tar Heel Formation suggests that its stratigraphic range needs to be extended to the Campanian.

Plicapollis and Pseudoplicapollis extend in stratigraphic range from Late Cenomanian through Early Eocene (Tschudy, 1981) and are present in most Cretaceous and Paleocene samples of eastern North America (Tschudy, 1981). Plicapollis retusus, another index fossil of the Campanian occurs in many samples of all the localities of Tar Heel Formation. This species has been previously reported from the Aguja Formation (Campanian) of Texas (Baghai, 1996), Campanian-Maastrichtian sediments of Charleston, South Carolina (Christopher, 1978), Coffee Sand and Coon Creek Tongue Members, Ripley Formation (Campanian) of Tennessee (Christopher, 1978) and San Miguel Formation of Mexico (Medus and Almeida-Leñero, 1982). Pseudoplicapollis newmanii is restricted to the Campanian and has been used extensively in biostratigraphic studies (Nichols, Perry and Harley, 1985; Nichols et al., 1993).

The genus Labrapollis has a stratigraphic range from Maastrichtian-Eocene. Species of Labrapollis have been reported mostly from the Tertiary sediments in many parts of the world (Alvarez Ramis and Doubinger, 1994; Thomson and Pflug, 1953; Frederiksen, 1979; Christopher, 1978; 1979). Labrapollis has been reported from the Upper Campanian-Maastrichtian of Raritan and Salisbury embayments of the Atlantic Coastal Plain (Christopher, 1978, 1979). This genus is known to occur mostly in the Tertiary sediments and has never been reported from Lower Campanian sediments. The occurrence of Labrapollis in Tar Heel Formation samples indicates a longer range of the genus that could be extended to Lower Campanian.

The genera Oculopollis and Tetrapollis have not been documented previously from Cretaceous strata in North America. Until this study, Oculopollis was recognized mostly in the Campanian-Paleocene sediments of Germany (Pflug, 1953), Romania (Mogos, 1992) and USSR (Mikhelis, 1981). Tetrapollis, a tetraporate Normapolles has been reported from younger sediments than the Campanian. It has been reported from Maastrichtian (Nandi, 1979) and Paleocene-Eocene sediments (Góczán, Groot, Krutzch and Pacltová, 1967) and and Upper Cretaceous of India (Nandi, 1979). Findings from this study support that the range of Tetrapollis could go back to the Campanian.

5.3 Other Angiosperm Palynoflora

Although Normapolles pollen group forms an important component of the Tar Heel Flora, other triporates, tricolpates and tricolporates are present throughout the localities of Tar Heel Formation. Arecipites and Lilacidites are the only monocot genera present in samples of Tar Heel Formation. Postnormapolles form-genera, Momipites and Plicatopollis are found associated with Normapolles genera. Postnormapolles pollen, like Normapolles have been speculated to be from amentiferous trees and shrubs (Traverse,

1988) and this group has been classified by Pflug (in Thomson and Pflug, 1953) as a suprageneric unit for fossil pollen that are triaperturate, porate and lacking special features of Normapolles (Kedves, 1981). Although Postnormapolles represent pollen of angiospermous plants associated with early Neogene to Recent terrestrial floras (Zaklinskaya, 1981), these pollen have also been reported from Late Cretaceous sediments of the United States and Mexico (Baghai, 1996). Plicatopollis has been reported from the Upper Cretaceous of the Navesink Formation and Red Bank Sand of the Raritan Embayment of Atlantic Coastal Plain (Wolfe, 1976) and from the Campanian of Aguja Formation of Texas (Baghai, 1996) and Upper Cretaceous and Paleogene sediments of South Carolina (Frederiksen and Christopher, 1978). Species of Momipites have been found in Campanian through Eocene sediments as documented in palynological studies of Campanian of Mexico (Medus and Almeida-Leñero, 1982) and Aguja Formation of Texas (Baghai, 1996); Maastrichtian of Montana (Farabee and Canright, 1986), California (Drugg, 1967), Atlantic Coastal Plain (Frederiksen and Christopher, 1978); Paleocene of South Carolina (Frederiksen, 1980), Texas (Elsik, 1968) and Mississippi (Nichols and Stewart, 1971); Eocene of Virginia (Frederiksen, 1979) and Mississippi (Nichols and Stewart, 1971).

The genus Holkopollenites, a tricolporate, is well represented in all the localities of the Tar Heel Formation. Palynological studies by Wolfe (1976) and Christopher (1979) reveal that Holkopollenites sp. A (CP3D of Wolfe, 1976) is restricted to zone CA-2 (Merchantville Formation of Raritan and Salisbury Embayments corresponding to basal part of Lower Campanian) of Wolfe (1976). Holkopollenites sp. C (CP3E of Wolfe, 1976) is restricted to zones CA-3 to CA-5 (Woodbury-Wenonah Formations of Salisbury and Raritan Embayments and corresponding to Lower-Upper Campanian) of Wolfe, 1976. Holkopollenites chemardensis has been reported from Upper Campanian-Maastrichtian (Marshalltown, Wenonah and Navesink Formations of Salisbury and Raritan Embayments, corresponding to zones CA-5 through CA-6 of Wolfe, 1976). Studies from the Tar Heel Formation show that the three species of Holkopollenites, H. chemardensis, H. sp. A (CP3D-1 of Wolfe, 1976) and H. sp. C (CP3E-1 of Wolfe, 1976) have been found to occur together in many samples, suggesting that the range of Hokopollenites chemardensis may include Lower Campanian. Holkopollenites sp. A is known to have a short stratigraphic range and since it has been reported from the Lower Campanian sediments of Salisbury and Raritan embayments of the Middle Atlantic States (Wolfe, 1976), it is an important biostratigraphic marker species. Another stratigraphically important palynologic marker that is a reliable indicator of Campanian age is Proteacidites retusus (Campanian-Maastrichtian). Tricoporopollenites bradonensis, Miocene pollen from Brandon Lignite of Vermont (Traverse, 1994) has been reported in some stratigraphically younger samples of Tar Heel Formation.

Angiosperm taxa such as Labrapollis, Holkopollenites chemardensis, Tetrapollis validus, Tricolporopollenites bradonensis have not been recorded previously from strata older than Upper Campanian / Maastrichtian or early Paleogene. Species like Tetrapollis and Oculopollis are known from Europe and have not been documented from North America. These occurrences extend the total stratigraphic range of various form-genera and form-species to the Early Campanian and indicate more extended ranges than suggested in the literature.

5.4 Age of the Tar Heel Formation

Evidence from poorly identified leaf floras by Berry (1914) and Dorf (1952) led to a late Campanian to Turonian age assignment to the Tar Heel Formation. Studies by Stephenson (1923) on marine invertebrate faunas from some localities suggested that the Tar Heel Formation was of much younger age. Reports of Ostrea whitei (Stephenson, 1923) from Blue Banks Landing on the Tar River and at Snow Hill on Contentnea Creek indicated an Early Campanian age for this formation. Analyses of ostracode assemblages by J. E. Hazel and G. Gohn (in Owens and Sohl, 1989; Owens and Sohl, 1991) included the Early Campanian ostracode assemblage of Fissocarinocythere pittensis, Fissocarinocythere gapensis, Haplocytheridea plumeria from localities of Tar Heel Formation. Exogyra ponderosa, a gryphaeid, is reported from Tar Heel sediments, suggesting an Early Campanian age (Sohl and Owens, 1991). Palynological studies by Christopher (unpublished, stated as written communication in Owens and Sohl, 1989) on a few samples from Tar Heel Formation yielded a flora assignable to pollen zones CA2 through CA4 of Wolfe (1976), which correspond to Lower Campanian.

The palynological age assessment of the Tar Heel Formation was based primarily on the recovery of palynomorph taxa that have been recorded previously in Campanian palynological studies in North America. Observed ranges of key palynomorphs are based on Cretaceous and Tertiary palynological studies (Farabee and Canright, 1986; Drugg, 1967; Chmura, 1973; Thompson and Pflug, 1953, Tschudy, 1970; 1975; Wolfe, 1976; Christopher, 1978, 1979). Stratigraphically important palynologic markers, which are reliable indicators of a Campanian age, include the dinoflagellates Cerodinium pannuceum (Campanian-Paleocene) and Pierceites pentagonus (Campanian-Paleocene), angiosperm pollen of Complexiopollis abditus (Turonian-Campanian), Plicapollis retusus (Campanian-Maastrichtian), Proteacidites retusus (Cenomanian-Campanian), Holkopollenites sp.A (Lower Campanian), Holkopollenites sp.C (Lower-Upper Campanian), Pseudoplicapollis newmanii (Lower-Upper Campanian) and Trudopollis variabilis (Lower Campanian-Lower Maastrichtian). These taxa are represented well in many samples of the Tar Heel Formation. Taxonomic zonations are not recognized in the Tar Heel Formation. Many form-genera and species extend throughout in varying percentages as found in many samples.

STATISTICAL ANALYSIS OF TAR HEEL FORMATION SAMPLES

A total of 80 palynomorphs was recovered from 103 sample-units at 6 different locations. These six locations belong to the Lower Campanian of the Late Cretaceous. Samples were collected vertically from Elizabethtown, Goldsboro, Ivanhoe, Lock and Willis Creek localities. Lateral sampling was done at Tar River site. The two research questions that are addressed here are:

1) Which stratigraphic sections are similar in composition? The Tar Heel Formation was time-transgressive with many cycles of marine transgression (Sohl and Owens, 1991) and correlated stratigraphic sections would indicate similar cycle of marine transgression.

2) Do species of palynomorphs that are indicators of Campanian age tend to form an association? This question would also help in answering the validity of informal biostratigraphic divisions of Early Campanian (zones CA-2, CA-3 and CA-4) for the Tar Heel Formation as proposed by Christopher (cited as personal communication in Owens and Sohl, 1989 and Sohl and Owens, 1991). Similar informal biostratigraphic zones were also proposed by Wolfe (1976) for Campanian and Maastrichtian sediments of the middle Atlantic States. If indicator species occur together, it would suggest that there are no distinct zones of the Campanian for the Tar Heel Formation.

The multivariate statistical methods used here are cluster analyses. Cluster analyses in Q-mode (clustering of samples) and R-mode (clustering of species) were carried out with the Multivariate Statistical package version 3.0. Data were analyzed using both metric and non-metric measures to compare results. The results of the cluster analyses are presented in dendrograms for both the analyses of species and analyses of samples.

6.1 Cluster Analysis Q-mode

Cluster analysis in the Q-mode, a community-approach, was used to determine similarity of samples based on palynomorph content (Stone, 1973). This method establishes a cluster from existing clusters and/or entities by determining the pairing that would result in the minimum variance about its centroid. Agglomerative clustering starts with all objects separate, then successively combines the most similar objects and clusters until all are in a single hierarchial group (Kovach, 1988).

Metric measures

Minimum Variance Clustering – Unlike other techniques, minimum variance clustering (also called Ward's method) is restricted to using a matrix of Euclidean distances (Orloci, 1978). This method focuses on determining how much variation is within each cluster. In this way clusters tend to be as distinct as possible. Minimum variance clustering is considered a good clustering technique, particularly when there is redundancy in the data matrix so that some of the sample-units are very similar and represent repeated sampling of the same community (Kovach, 1988).

Data set of the Tar Heel Formation was first log transformed to reduce the absolute differences between abundances. This reduces the skewness of the distributions, thus bringing the distribution closer to normality, which is assumed by the Euclidean distance measure. A minimum variance clustering of log transformed data could give interpretable results (Kovach, 1988). Analysis of the Tar Heel Formation data set shows seven clusters (Figure 6a). Sample-units from the lower stratigraphic layers of Lock locality (LK1-LK4), first bed (IV1) of Ivanhoe and first bed of Willis Creek (WC1) are placed in one cluster (cluster 1). Cluster 2 contains sample-units of WC2 (second bed of

Willis Creek locality) and WC3 (third bed of Willis Creek locality). The upper stratigraphic sections of Lock (LK5-LK8) form an association with sample-units from the third bed of Ivanhoe (IV3) in the third cluster. Sample-units from stratigraphically youngest bed of Willis Creek (WC4) form a separate cluster (Cluster 4). Elizabethtown locality samples also form a separate cluster (Cluster 5). Sample-units from one stratigraphic section of Goldsboro (GBa, GBb and GBc) are placed in one cluster with all sample-units of Tar River locality. In the seventh cluster some sample-units of Willis Creek (WC3-third bed from the bottom of Willis Creek locality) are placed with a different stratigraphic section of Goldsboro locality (GBw, GBx, GBy and GBz) (Figure 6a).

Sources of noise in palynological data could result from taphonomic processes. Factors such as differential production of pollen by different species of plants, seasonal variation in pollen and spore production, transportation distances of pollen and spores and their preservation in sediments can cause distribution of palynomorphs which depart from the normal distribution (Farley, 1988). Non-metric quantitative measures are sometimes used to minimize noise in the data. Spearman rank-order correlation coefficient, a non-metric quantitative measure based on the rank-order of the abundances rather than on the actual abundances, and binary measures using Sorenson's coefficient were used to compare results between metric and nonmetric clustering strategies. Both these methods did not give any interpretable results.

The choice of the best method depends on the structure of data (variability of relative and actual abundances, occurrence of rare species, diversity of species in localities), specific questions asked in the research and philosophical attitudes of the investigator in emphasizing on characteristics of the data such as absolute abundance, relative abundance, presence and absence (Kovach, 1988). Minimum variance clustering technique gave best results with Tar Heel Formation data indicating that actual abundances of different taxa seemed to be important in this data set. Some taxa like Multicellaesporites showed increased abundance from stratigraphically younger to older sediments at Ivanhoe and Willis Creek localities. Leiotriletes pseudomesozoicus was confined to Goldsboro and Tar River localities and taxa like Tricolporopollenites bradonensis was found in stratigraphically younger strata. Data set from a paleoecological study of megaspore assemblages from the Cenomanian Dakota Formation of Texas was analyzed by various clustering techniques and minimum variance clustering technique gave good results (Kovach, 1987) along with Spearman-rank order correlation. Multivariate methods such as clustering techniques are valuable tools in interpreting paleopalynological data and different methods can give varying results with the same data.

6.2 Cluster Analysis R-Mode

Cluster analysis in the R-mode, a population approach, is used to group palynomorphs on the basis of their comparable occurrence (Stone, 1973; Oltz, 1969). The presence or absence of palynomorphs is documented for each sample using the minimum variance clustering method with log (2) transformation. The dendrogram (Figure 6b) shows five clusters. Spores of Tetraporina, Botryococcus braunii and Ovoidites form a cluster reflecting ecological conditions rather than age. These freshwater algal taxa are indicators of shallow, stagnant and freshwater habitats (van Geel and van der Hammen, 1978; Sangheon, 1997). Campanian dinoflagellate indicators such as Pierceites pentagonus and

Cerodinium pannuceum are associated with Isabelidinium, suggesting marine influence during deposition of sediments. Lower Campanian palynological tricolporate markers, Holkopollenites sp.A and Holkopollenites sp.C form a separate association with bisaccate Pinuspollenites. Lower Campanian Normapolles markers such as Complexiopollis abditus, Complexiopollis funiculus, Pseudoplicapollis newmanii, Plicapollis retusus, Trudopollis variabilis form a cluster with triporate Campanian marker, Proteacidites retusus. These Campanian markers occur with bisaccates (Podocarpites, Piceaepollenites) and other gymnosperm pollen (Araucariacites, Inaperturopollenites). Holkopollenites chemardensis tends to be closely associated with Arecipites, Cupuliferoipollenites, Nyssapollenites, Tricolporopollenites bradonensis, Normapolles pollen Tetrapollis validus, Labrapollis and post Normapolles Plicatopollis. This indicates that these pollen have overlapping ranges and are more contemporaneous. Although these are found in sediments of the Tar Heel Formation, they are more abundant in stratigraphiclly younger sediments.

Cluster analysis on the R-mode using non-metric quantitative measures such Spearman-rank order correlation coefficient and binary measures with Sorensen's coefficient did not give any interpretable results.

6.3 Discussion

Minimum variance clustering technique proved the best method for both Q-mode and R-mode analyses giving interpretable clusters. Results from the minimum variance clustering technique indicate that stratigraphic section of Goldsboro (right side of the bridge) is similar in composition to Tar River locality. Lower stratigraphic layers (younger) of Lock locality have compositional similarity to those of Ivanhoe and Willis

Creek. Stratigraphically older layers of Lock locality are similar in composition to samples from IV3 (third bed from bottom of Ivanhoe locality). Elizabethtown is different from rest of the localities. It could be speculated that Elizabethtown belonged to a marine transgressive cycle that is separate from rest of the localities. Similarly the uppermost bed (stratigraphically youngest) of Willis Creek also belongs to a different marine transgressive cycle. Compositionally equivalent sections could be speculated to indicate similar transgressive cycles of the Early Campanian. The hypothesis that sample units similar in composition are time equivalents requires further testing.

In the R-mode analysis the Normapolles Campanian markers form a cluster along with triporate Proteacidites retusus confirming that the Tar Heel Formation samples are of Early Campanian age. Palynological age assessment agrees with the age assessment based on invertebrate faunal data. Normapolles are represented well throughout the stratigraphic sections. There is no trend of increased abundance of Normapolles pollen stratigraphically. Fluctuations in the relative abundance of bisaccate coniferous pollen are not evident in this study supporting that climate was warm with very low thermal gradients during the Campanian.

Informal biostratigraphic zones for the Early Campanian (CA2-CA4) proposed by Wolfe (1976) are not applicable here as many taxa specific to zones CA-2 through CA-4 (CA=Campanian) are not found from the Tar Heel Formation samples. Campanian indicators such as Complexiopollis abditus (CA2-CA3), Plicapollis retusus (Zone CA3), Trudopollis variabilis (CA2-CA4) occur with Proteacidites, the latter being characteristic of Zone CA-4.

CONCLUSIONS

Palynological analyses of one hundred and three samples from six different localities reveal the presence of 80 different species of palynomorphs. The suite of form-genera of palynomorphs includes four freshwater algae, three dinoflagellates, nine fungal resistant parts, fifteen pteridophytes, eleven gymnosperms and twenty four angiosperms. Angiosperms exhibit the maximum diversity with thirty-three species distributed in twenty-four genera. Relative abundance data of various palynomorphs from all six localities reveal the dominance of angiosperm pollen in the assemblages. The palynological evidence derived from the Tar Heel Formation further confirms the diversification of flowering plants and indicates their dominance in pollen assemblages during the Late Cretaceous.

The modified maceration technique developed in the Palynological Laboratory at North Carolina State University was employed to recover good quality and abundant palynomorphs from samples of Tar River Formation. Although the conventional technique of maceration yielded identifiable palynomorphs, the number of grains obtained was always lower than obtained with the modified technique. The cost and time effective modified technique is a valuable tool for processing clastic sediments.

Fungi are saprophytes or parasites and many are known to have angiosperms as hosts. Recovery of morphologically diverse fungal palynomorphs in the Tar Heel Formation samples, along with the increased abundance of the form-genus Multicellaeasporites from stratigraphically older to younger strata at Ivanhoe and Willis Creek localities, are suggestive of changes in requirements to adaptations to parasitism and saprophytism of fungal groups like Multicellaesporites. Increased abundance data could also reflect changes in the paleoclimate as fungal abundance has been correlated to warmer periods.

Angiosperm pollen components recovered from samples of the Tar Heel Formation include the Normapolles group that is well represented in assemblages of Tar Heel Formation. The recovery of seven different genera of Normapolles pollen and their relative abundances in localities support that these plants were important components of the vegetation. The presence of structurally simpler types of Normapolles like Pseudoplicapollis, Trudopollis, Plicapollis and Tetrapollis indicates that plants producing these pollen could have been wind pollinated and may have been components of open woodlands in seasonally variable climates.

Extended palynofloristic studies on the Tar Heel Formation, especially at Goldsboro and Tar River localities did not report any Aquilapollenites pollen. It could be speculated that pollen of this western form-genus were minor components in Early Campanian assemblages and flora of the Tar Heel Formation could have been mixed in some specific regions where Normapolles and Aquilapollenites occur together as reported from earlier studies at Goldsboro and Tar River localities. Such occurrences of Aquilapollenites in a Normapolles province could also reflect long distance transport of this western genus to eastern North America (Traverse, 1988). The Cretaceous epeiric seas were not totally effective in confining the Normapolles and Triprojectacites to their respective provinces. Aquilapollenites pollen reached their pinnacle of diversification in the Late Campanian through the Maastrichtian (Srivastava, 1978). Investigations on Late Campanian to Early Maastrichtian sediments of Eastern North America may be able to throw some light on our understanding of the Late Cretaceous phytogeography and distribution of various angiosperm pollen groups.

The palynological age assessment of the Tar Heel Formation is in concordance with earlier dating techniques determined from invertebrate faunas. Stratigraphically important palynological markers that are reliable indicators of a Campanian age are represented in these sediments by dinoflagellates *Cerodinium pannuceum*, *Pierceites pentagonus* and angiosperms of *Complexiopollis abditus*, *Complexiopollis exigua*, *Complexiopollis funiculus*, *Holkopollenites* sp. A, *Holkopollenites sp*. C., *Plicapollis retusus*, *Pseudoplicapollis newmanii*, *Proteicidites retusus* and *Trudopollis variabilis*. These taxa are well represented in the palynomorph count.

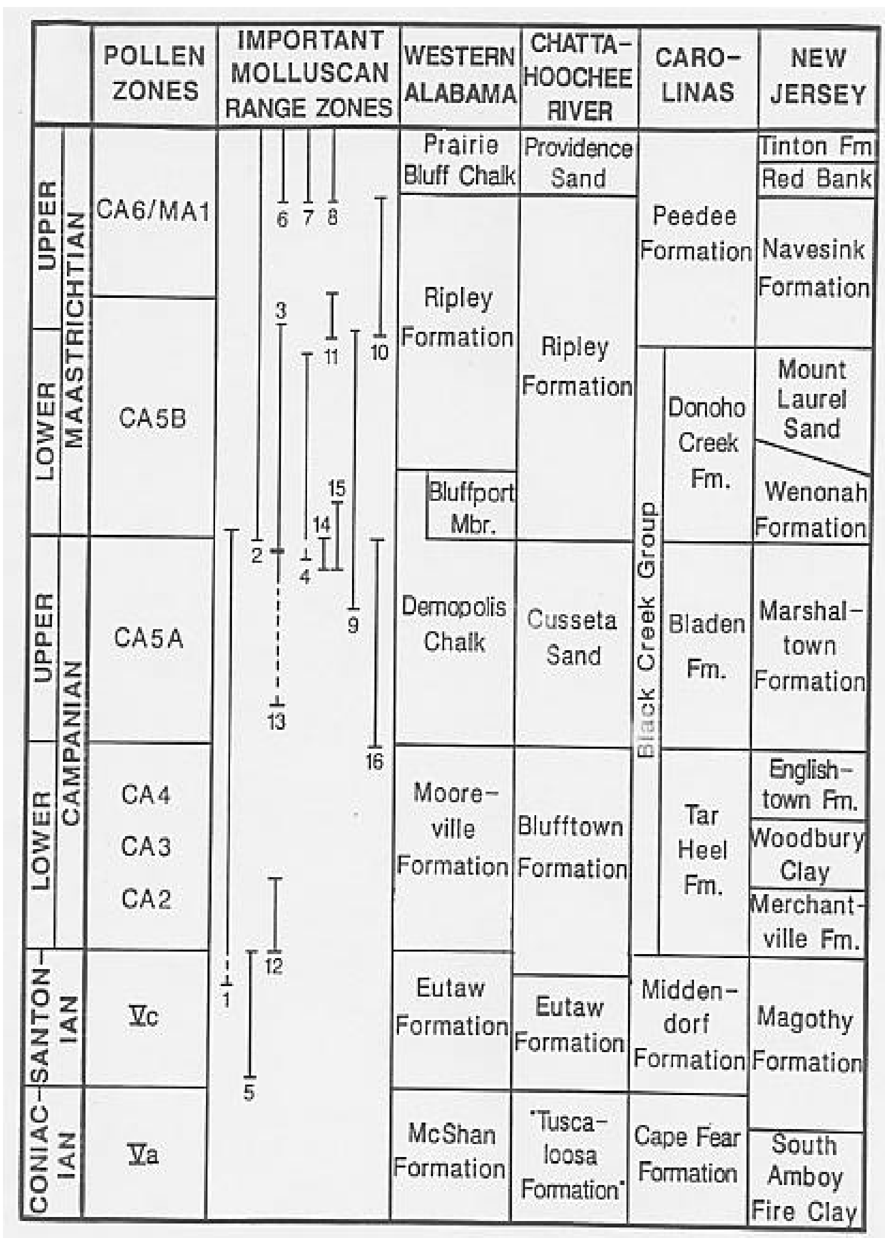
Three angiosperm pollen and one fungal spore discovered in the Tar Heel Formation have not been reported previously from strata older than the Maastrictian or Tertiary. These include fungal spore of *Multicellaesporites*, Normapolles pollen of *Labrapollis*, tricolporates *Holkopollenites chemardensis* and *Tricolporopollenites bradonensis*. These occurrences extend the total stratigraphic range of these form genus/species to the Campanian. Normapolles pollen of *Oculopollis* and *Tetrapollis* were not reported in previous studies from North America.

Minimum variance cluster analysis in the Q-mode reveals that a high correlation exists between Goldsboro and Tar River localities based on composition of palynofloras and their relative abundances. Stratigraphically younger beds at Ivanhoe are correlated to those at Willis Creek and Lock localities. Similarly the older beds of Lock and Ivanhoe are correlated to each other. This correlation suggests that Goldsboro and Tar River localities similar palynofloristic composition. Similarly the younger and older beds of

Willis Creek are equivalent in palynofloral composition to those of Lock and Ivanhoe. The biostratigraphically important pollen markers of the Campanian also tend to form an association as reflected in the R-mode analysis, further confirming that the Tar Heel Formation is of Early Campanian age. Informal biostratigraphic zones for the Early Campanian (CA2-CA4) as proposed by Wolfe (1976) do not occur at localities of the Tar Heel Formation. Correlation between facies among different localities based on biostratigraphy is a more reliable indicator than correlation based solely upon comparison of similar lithofacies as the latter could create an erroneous picture of depositional history (Owens and Sohl, 1989).

The Tar Heel palynomorph record, based on the recovery of some indicator form-genera with modern equivalents, suggests a subtropical to warm, moist temperate climate during the Campanian in the southeastern region of North America. Paleopalynological studies of the Tar Heel Formation have reduced a gap in the fossil record regarding paleofloristics and distribution of palynomorphs of Campanian deltaic depositional units along the Atlantic Coastal Plain of US.

Table 1.1. Correlation of the Carolina Upper Cretaceous formations. The pollen zonation is after Wolfe (1976) and Christopher (1977), and numbers in the column of molluscan range zones refer to the following species: 1) Exogyra ponderosa Roemar; 2) Exogyra costata Stephenson; 3) Exogyra cancellata Stephenson; 4) Anomia tellinoides Morton; 5) Ostrea cretacea Morton; 6) Turritella (Sohlitella bilira) Stephenson; 7) Sphenodiscus spp.; 8) Camptonectes bubonis Stephenson; 9) Flemingostrea subspatulata (Forbes), early form; 10) F. subspatulata (Forbes), normal form; 11) Belemnitella americana (Morton); 12) Ostrea whitei Stephenson; 9) Flemingostrea pratti (Stephenson); 14) Crenella mitchelli Stephenson; 15) Ostrea sloani (Stephenson); 16) Flemingostrea blackensis (Stephenson). (Sohl and Owens, 1991).



Palynomorph sample	Lithology
ELIZABETHTOWN	
ET1a	Laminated, dark clayey sand with carbonized impressions of plants.
ET1b	Laminated, dark clayey sand with carbonized impressions of plants.
ET2a	Micaceous blue-gray clayey sand with bone and plant fragments.
ET2b	Micaceous blue-gray clayey sand with bone and plant fragments.
IVANHOE	
IV1a (Base)	Black clay interbedded with micaceous, buff colored sand containing large plant fragments.
IV1b (1ft)	Black clay interbedded with micaceous, buff colored sand containing large plant fragments.
IV1c (2ft)	Black clay interbedded with micaceous, buff colored sand containing large abundant dark plant fragments.
IV1d (3ft)	Black clay interbedded with micaceous, buff colored sand containing abundant megafossils of leaves and stems.
IV1e (4ft)	Black clay interbedded with micaceous, buff colored sand containing black plant debris.
IV1f (5ft)	Black clay interbedded with micaceous, buff colored sand with lignitized fragments.
IV1g (6ft)	Black clay interbedded with micaceous, buff colored sand with few plant fragments.
IV1h (7ft)	Black clay interbedded with micaceous, buff colored sand with abundant fossils of leaves.
IV1i (8ft)	Black clay interbedded with micaceous, buff colored sand with plant fragments
IV1j (9.5ft)	Black clay interbedded with micaceous, buff colored sand containing abundant plant fragments
IV2a (11ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2b (12ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2c (13ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2d (14ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2e (15ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2f (16ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV2g (17ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV-2h (18ft)	Greenish-gray clay with glauconitic sand containing plant fragments.
IV-2i (19ft)	Greenish-gray clay with glauconitic sand containing plant fragments.

Table 2.1 Descriptions of palynological rock samples from six localities of Tar Heel Formation

Palynomorph sample	Lithology
IV3a (21ft)	Grayish-black clay with thin lenses of light brown, coarse sand containing no plant fragments.
IV3b (23ft)	Grayish-black clay with thin lenses of light brown, coarse sand containing no plant fragments.
IV3c (25ft)	Grayish-black clay with thin lenses of light brown, coarse sand containing plant fragments.
IV3d (27ft)	Grayish-black clay with thin lenses of light brown, coarse sand containing plant fragments.
IV3e (30ft--top)	Grayish-black clay with thin lenses of light brown, coarse sand containing plant fragments.
LOCK	
LK1 (0.5 ft)	Dark gray clay with fine –coarse grained micaceous sand. No plant fragments.
LK2 (1 ft)	Dark gray clay with fine –coarse grained micaceous sand. No plant fragments.
LK3 (2 ft)	Dark gray clay with fine –coarse grained micaceous sand. No plant fragments.
LK4 (4 ft)	Dark gray clay with fine –coarse grained micaceous sand. No plant fragments.
LK5 (6ft)	Dark gray clay with fine –coarse grained micaceous sand. Dark brown plant matter present.
LK6 (7.5 ft)	Dark gray clay with fine –coarse grained micaceous sand. Dark brown plant matter present.
LK7 (9 ft)	Dark gray clay with fine –coarse grained micaceous sand. Dark brown plant matte present.
LK8 (10.5 ft)	Dark gray clay with fine –coarse grained micaceous sand. Dark brown plant matter present.
WILLIS CREEK	
WC1a (0.5 ft)	Black clay interbedded with micaceous, medium coarse sand. Lignite fragments are scattered in thin layers.
WC1b (1ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of marine bivalves and Teredolite borings.
WC1c (2ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of marine bivalves and Teredolites borings.

Palynomorph sample	**Lithology**
WC1d (3ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of marine bivalves and Teredolites borings.
WC1e (4ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of dark plant debris.
WC1f (5ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of seeds and leaves.
WC1g (6ft)	Black clay interbedded with micaceous, medium coarse sand. Presence of seeds and leaves.
WC2a (8ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of Teredolites borings.
WC2b (10 ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of lignitized wood, seeds and leaves.
WC2c (11 ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of lignitized wood, seeds and leaves.
WC2d (12ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of Teredolites borings.
WC2e (14ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of lignitized wood, seeds and leaves.
WC2f (15.3ft)	Black carbonaceous clay interbedded with micaceous, white sand. Presence of lignitized wood, seeds and leaves.
WC3a (18ft)	Grayish-black clay with thin lenses of micaceous, buff-colored sand. Presence of megafossils of seeds and leaves.
WC3b (19ft)	Grayish-black clay with thin lenses of micaceous, buff-colored sand. Presence of lignitized wood and megafossils of leaves
WC3c (20 ft)	Grayish-black clay with thin lenses of micaceous, buff-colored sand. Presence of lignitized wood and megafossils of leaves.
WC3d (21ft)	Grayish-black clay with thin lenses of micaceous, buff-colored sand. Teredolites borings present.
WC3e (23 ft)	Grayish-black clay with thin lenses of micaceous, buff-colored sand. Teredolites borings present.
WC4a (25ft)	Laminated sand and carbonaceous clay. Teredolites borings present.
WC4b (26.5 ft)	Laminated sand and carbonaceous clay. Teredolites borings present
WC4c (27ft)	Laminated sand and carbonaceous clay. Teredolites borings present.
WC4d (28ft)	Laminated sand and carbonaceous clay. Megafossils of leaves and fruits present.

Palynomorph sample	Lithology
WC4e (29ft)	Laminated sand and carbonaceous clay. Lignited wood and megafossils of leaves and fruits present.
WC4f (30ft)	Laminated sand and carbonaceous clay. Lignited wood and megafossils of leaves and fruits present.
WC4g(31ft)	Laminated sand and carbonaceous clay. Lignited wood and megafossils of leaves and fruits present.
WC4h (top-32ft)	Laminated sand and carbonaceous clay. Black plant debris present.
TAR RIVER	
TR0 (Reference point)	Dark gray, clayey, fine-grained, glauconitic quartz sand.
TR2 (2ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR4 (4ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR6 (6ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR8 (8ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR10 (10ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR20 (20ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR22 (22ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Megafossils of leaves present.
TR24 (24ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR26 (26ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR28 (28ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR30 (30ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR32 (32ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.

Palynomorph sample	Lithology
TR34 (34ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR36 (36ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Lacks visible plant debris.
TR38 (38ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
TR40 (40ft)	Dark gray, clayey, fine-grained, glauconitic quartz sand. Dark plant fragments present.
NEUSE RIVER CUT OFF, GOLDSBORO	
GBA1 (14ft from river bottom: reference point)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBA2 (14ft from river bottom; 6 inches from GBA1)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBA3 (14ft from river bottom; 2.5ft from GBA1)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBA4 (14ft from river bottom; 5ft from GBA1)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBB1 (28ft from river bottom; reference point)	Thinly interbedded, dark gray clays and yellow, coarse grained sand. Megaofossils of leaves present.
GBB2 (28ft from river bottom; 1.5 ft from GBC1)	Thinly interbedded, dark gray clays and yellow, coarse grained sand. Megaofossils of leaves present.
GBB3 (28ft from river bottom; 2.5 ft GBB1)	Thinly interbedded, dark gray clays and yellow, coarse grained sand. Megaofossils of leaves present.
GBC1 (42ft from river bottom; reference point)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles.
GBC2 (42ft from river bottom; 2.5ft from GBC1)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles.
GBC3 (42 ft from river bottom; 5ft from GBC1)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles.
Other side of the bridge	
GBW1 (14ft from river bottom)	Intercalated black clay with lignitized wood.
GBW2 (14 ft from river bottom; 2 feet from GBW1)	Intercalated black clay with lignitized wood.

Palynomorph sample	**Lithology**
GBX1 (28ft from river bottom)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBX2 (28ft from river bottom; 0.5ft from GBX1)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBX3 (28ft from river bottom; 2.5ft GBX1)	Medium gray feldspathic sand with lenses of dark clay. Presence of lignitized fragments.
GBY1 (48ft from river bottom)	Medium gray feldspathic sand with lenses of dark clay. Presence of abundant dark brown plant matter.
GBY2 (48ft from river bottom; 2ft from GBY1)	Medium gray feldspathic sand with lenses of dark clay. Presence of abundant dark brown plant matter.
GBZ1 (51ft from river bottom)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles and megafossils.
GBZ2 (51ft from river bottom; 1ft from GBZ1)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles.
GBZ3 (51ft from river bottom; 2.5 ft from GBZ1)	Thinly interbedded, dark gray clay with micaceous silty fine sand. Presence of abundant plant cuticles.

Table 2.2. Number of palynomorphs obtained from standard and modified maceration palynological techniques.

Locality	Sample Number	Standard Technique With both nitric acid and potassium hydroxide treatments	Standard Technique With nitric acid only	Standard Technique With potassium hydroxide only	Modified Technique With no nitric acid and potassium hydroxide
Elizabethtown	ET1a	120	110	85	225
Goldsboro	GBA1	88	130	55	205
Ivanhoe	IV1d	95	98	80	240
Lock	LK1	110	115	75	230
Tar River	TR2	105	152	72	235
Willis Creek	WC1a	130	145	60	210

Table 4.1 Summary of angiosperm taxa (genera) occurring in the Tar Heel Formation of Atlantic Coastal Plain and post-Magothy Upper Cretaceous Formations (Merchantville-Wenonah Formations) of Salisbury and Raritan Embayments. (X=presence).

Taxa	Tar Heel Formation	Post-Magothy Formations
Arecipites	X	
Aquilapollenites		X
Baculostephanocolpites		X
Brevicolporites		X
Bohemiapollis		X
Casuarinidites		X
Clavatipollenites	X	
Choanopollenites		X
Complexiopollis	X	X
Cupanieidites		X
Cupuliferoipollenites	X	
Cyrillaceaepollenites	X	
Endoinfundibulapollis		X
Extremipollis		X
Holkopollenites	X	X
Labrapollis	X	X
Liliacidites	X	
Momipites	X	X
Nyssapollenites	X	X
Oculopollis	X	
Osculapollis		X
Plicapollis	X	X
Plicatopollis	X	X
Praecursipollis		X
Proteacidites	X	X
Pseudoplicapollis	X	X
Retitricolpites	X	X
Spheripollenites	X	
Tetrapollis	X	
Triatriopollenites		X
Tricolpites	X	X
Tricolpopollenites	X	
Tricolporites		X
Tricolporopollenites		X
Triplanosporites	X	
Trudopollis	X	X

Table 4.2 Summary of genera of palynomorphs that occur in Tar Heel and Aguja Formations.

Genera	Aguja Formation	Tar Heel Formation
Freshwater Algae and Dinoflagellates		
Apteodinium	X	
Baltisphaeridium	X	
Botryococcus		X
Canningia	X	
Caligodinium	X	
Cerodinium	X	X
Chatengiella	X	
Deflandrea	X	
Dinogymnium	X	
Hystrichosphaera	X	
Hystrichosphaeridium	X	
Isabelidinium		X
Leptodinium	X	
Micrhystidium	X	
Ovoidites	X	X
Palaeohystrichophora	X	
Paleostomocystis	X	
Pediastrum	X	
Phledinium	X	
Pierceites		X
Phelodinium	X	
Schizosporis	X	X
Spinidinium	X	X
Subtilisphaera	X	
Tetraporina		X
Fungi		
Dicellites		X
Didymoporisporonites	X	X
Foveodiporites	X	
Fractisporonites		X
Hyphites	X	
Hypoxylonites	X	
Inapertisporites	X	X
Microthyrites	X	
Multicellaesporites		X
Multilineanites	X	
Palaencistrus		X
Phragmothyrites		X

Genera	Aguja Formation	Tar Heel Formation
Pluricellaesporites	X	
Portalites	X	
Psiladisporonites	X	
Sephohyphites	X	
Striadisporites	X	
Scolecosporites		X
Staphlosporonites	X	
Tetracellites	X	X
Bryophytes/Pteridophytes		
Aequitriradites		X
Apiculatisporis	X	
Appendicisporites	X	
Camarozonosporites	X	X
Ceratosporites	X	X
Cicatricosisporites	X	X
Cingutriletes	X	X
Concavisporites	X	
Cyathidites	X	X
Deltoidospora	X	X
Dictyophyllidites		X
Echinatisporis	X	X
Granulatisporites	X	
Hamulatisporites		X
Hymenozonotriletes	X	
Kuylisporites		X
Laevigatosporites	X	X
Leiotriletes	X	X
Lusatisporis	X	
Lycopodiumsporites	X	
Lygodiumsporites	X	
Matonisporites	X	X
Microreticulatisporites	X	
Neoraistrickia	X	
Osmundacidites	X	
Polycingulatisporites	X	
Psilatriletes	X	
Punctatisporites	X	
Seductisporites	X	
Sphagnumsporites	X	
Stereisporites	X	X
Taurocusporites	X	
Todisporites	X	
Triporoletes	X	
Undulatisporites	X	X

Genera	Aguja Formation	Tar Heel Formation
Verrucatosporites	X	
Verrucingulatisporites	X	
Zlivisporis	X	
Gymnosperms		
Araucariacites		X
Callialasporites	X	
Cedripites		X
Classopollis	X	X
Cycadopites	X	X
Equisetosporites	X	
Excesipollenites	X	
Ginkgocycadophytus		X
Gnetaceaepollenites		
Inaperturopollenites	X	X
Monosulcites	X	X
Parvisaccites	X	X
Pinuspollenites	X	X
Podocarpites	X	X
Taxodiaceaepollenites	X	X
Angiosperms		
Arecipites	X	X
Clavatipollenites		X
Caryapollenites	X	
Casuarinidites	X	
Complexiopollis	X	X
Corsinipollenites	X	
Cupuliferoipollenites	X	X
Cyrillaceaepollenites	X	X
Holkopollenites	X	X
Interpollis	X	
Intratriporopollenites	X	
Labrapollis		X
Liliacidites	X	X
Margocolporites	X	
Momipites	X	X
Monocolpopollenites	X	
Nyssapollenites	X	X
Oculopollis		X
Palmaepollenites	X	
Plicapollis	X	X
Plicatopollis	X	X
Proteacidites	X	X

Genera	Aguja Formation	Tar Heel Formation
Pseudolasopollis	X	
Pseudoplicapollis		X
Psilatricolporites	X	
Rectosulcites	X	
Retipollenites	X	
Retitricolpites	X	X
Rhoipites	X	
Sabalpollenites	X	
Scabritricolpites	X	
Spheripollenites	X	
Subtrudopollis	X	
Syncolporopollenites	X	
Tetrapollis		X
Triatriopollenites	X	
Tricolpites	X	X
Tricolpopollenites	X	X
Tricolporites	X	
Tricolporopollenites	X	X
Triporopollenites	X	
Trivestibulopollenites	X	
Triplanosporites		X
Trudopollis	X	X
Ulmoideipites	X	
Verrutricolpites	X	
Vitipites	X	
Wilsonipites	X	

Table 5.1 Distribution of Normapolles genera in three geographic regions of North America: North Atlantic Coastal Plain, Mississippi Embayment region and Western Interior (modified after Pacltova, 1981).

Normapolles genera	Atlantic Coastal Plain	Mississippi Embayment region	Western Interior
Atlantopollis	X	X	
Basopollis	X	X	X
Bohemiopollis	X		X
Complexiopollis	X	X	X
Choanopollenites	X	X	
Enscheripollis	X		
Endoinfundibulapollis	X	X	
Extremipollis	X	X	
Heidelbergipollis	X		
Interpollis	X	X	X
Kyandopollenites	X	X	
Labrapollis	X		
Loganulipollis	X		
Megatripollis	X	X	
Minorpollis	X	X	X
Nudopollis	X	X	X
Oculopollis	X		
Pecakipollis	X	X	
Piolencipollis	X		
Plicapollis	X	X	X
Pompeckjoidaepollenites	X	X	
Praebasopollis	X		
Pracursipollis	X		
Primipollis	X		
Pseudatlantopollis	X	X	
Pseudoculopollis	X	X	
Quedlinburgipollis	X		
Semioculopollis	X	X	
Tetrapollis	X		
Thomsonipollis	X	X	X
Trudopollis	X	X	X
Vacuopollis	X	X	
Interporopollenites		X	
Montanapollis			X
Siberiapollis			X

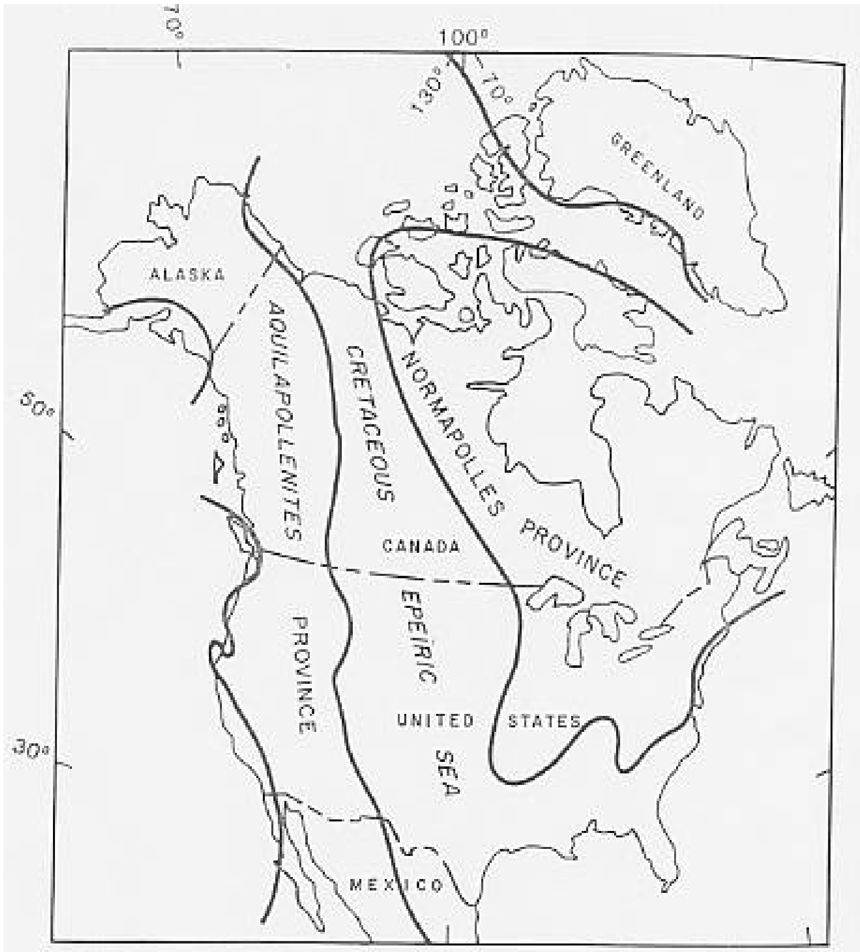


Figure 1a. Probable distribution of land and sea in North America during Campanian time showing Normapolles and Aquilapollenites microfloral provinces (Tschudy, 1980).

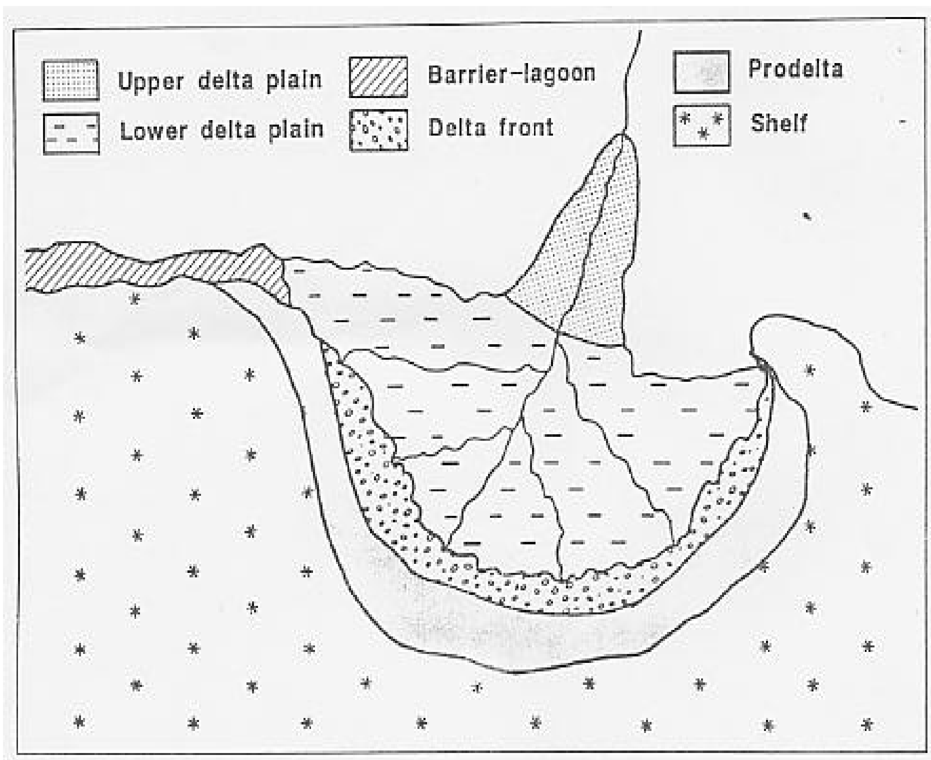


Figure 2 a. Generalized model of the delta to shelf lithofacies used in the analysis of Cretaceous formations in the Carolinas (Sohl and Owens, 1991).

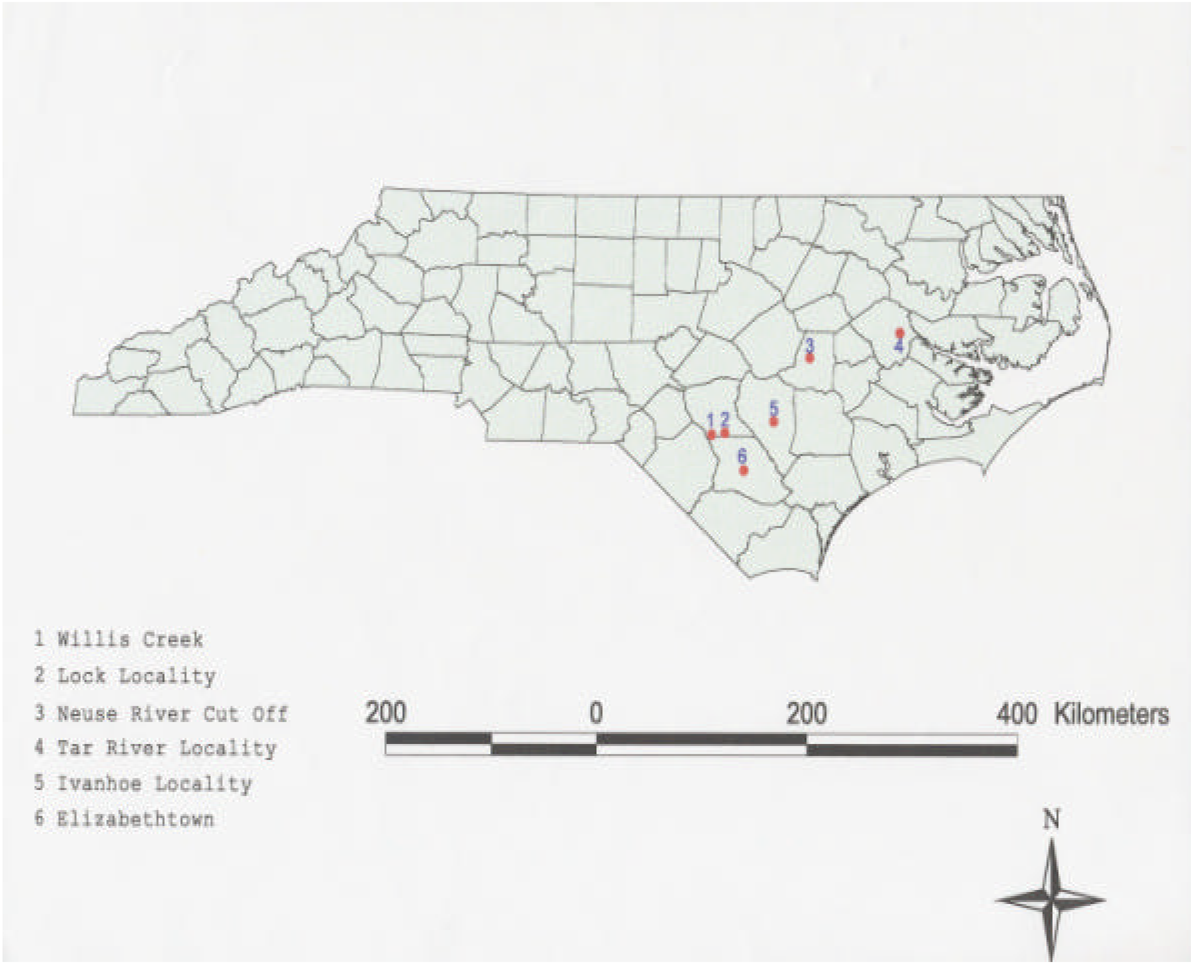


Figure 2b. Map of North Carolina showing the localities of Tar Heel Formation.

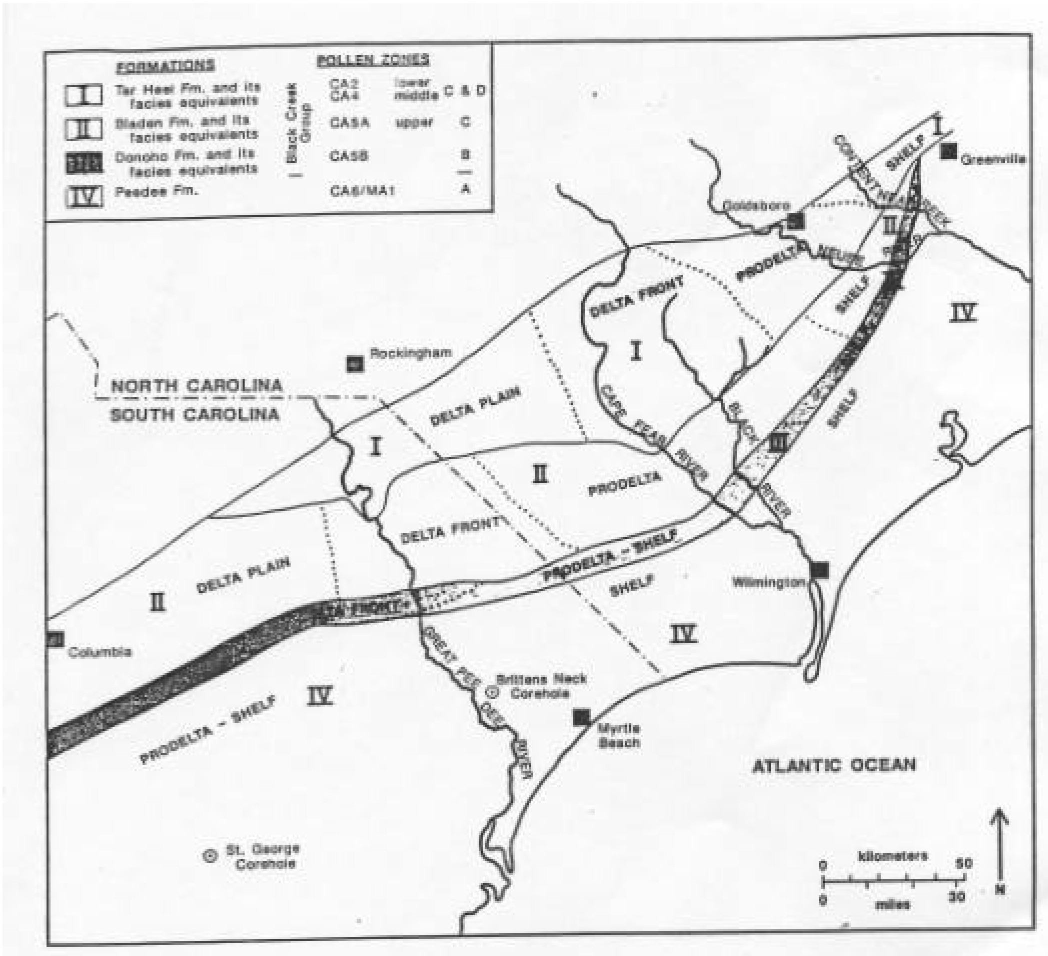


Figure 2c. Outcrop distribution of the lithofacies of the formations in the Black Creek Group and Pee Dee Formation (Sohl and Owens, 1991).

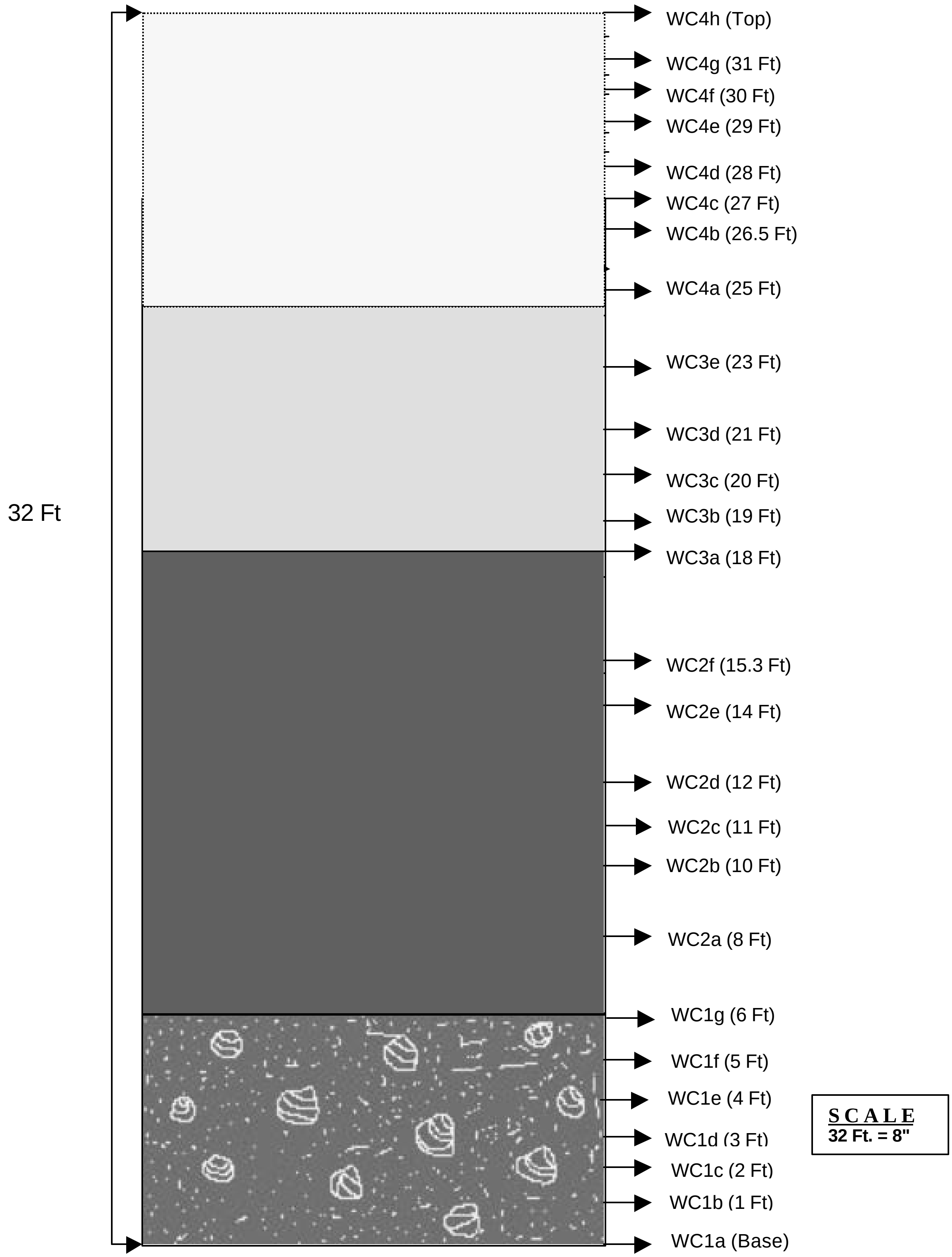


Figure 2d. Samples from the stratigraphic section of Willis Creek locality.

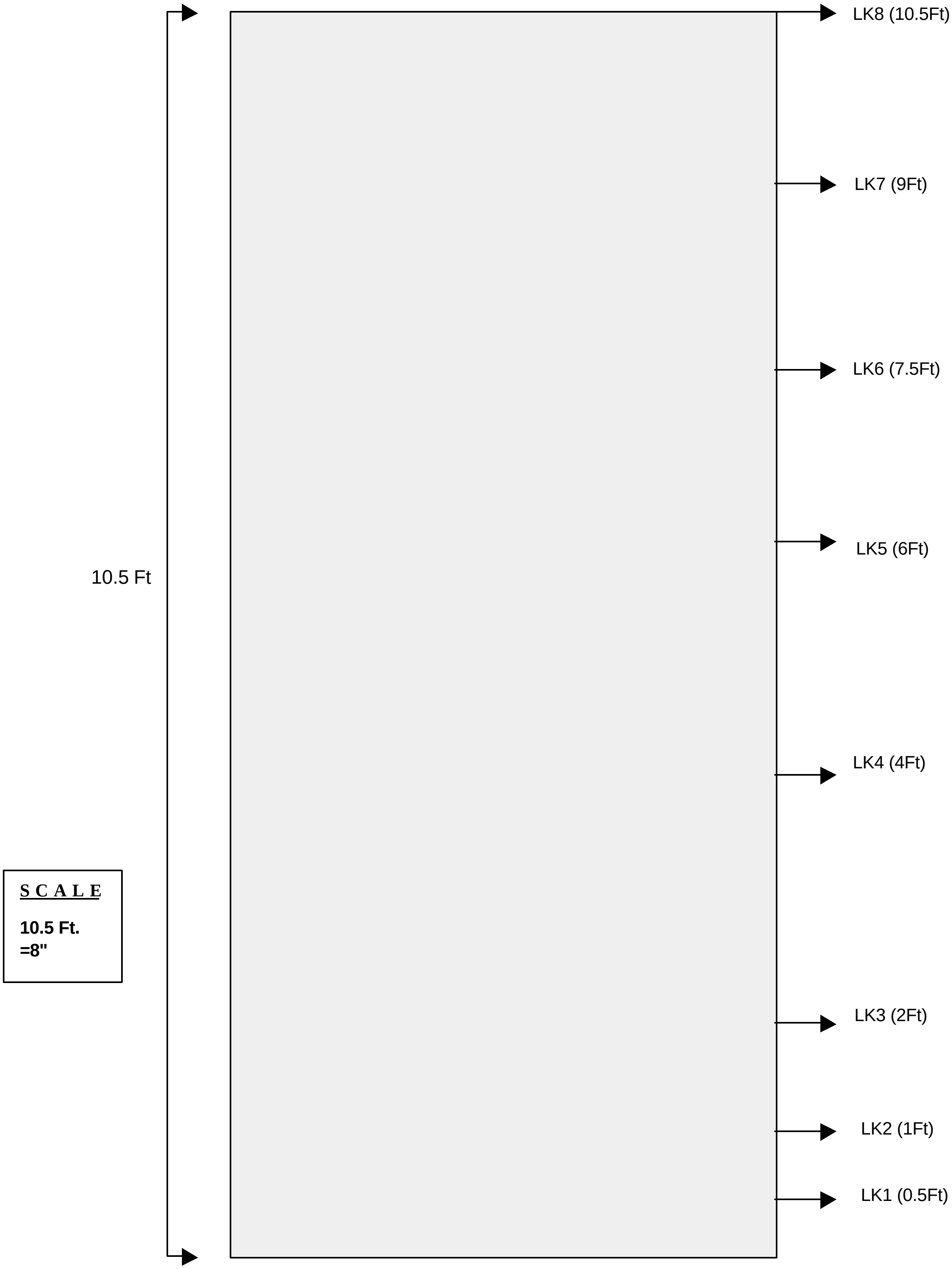
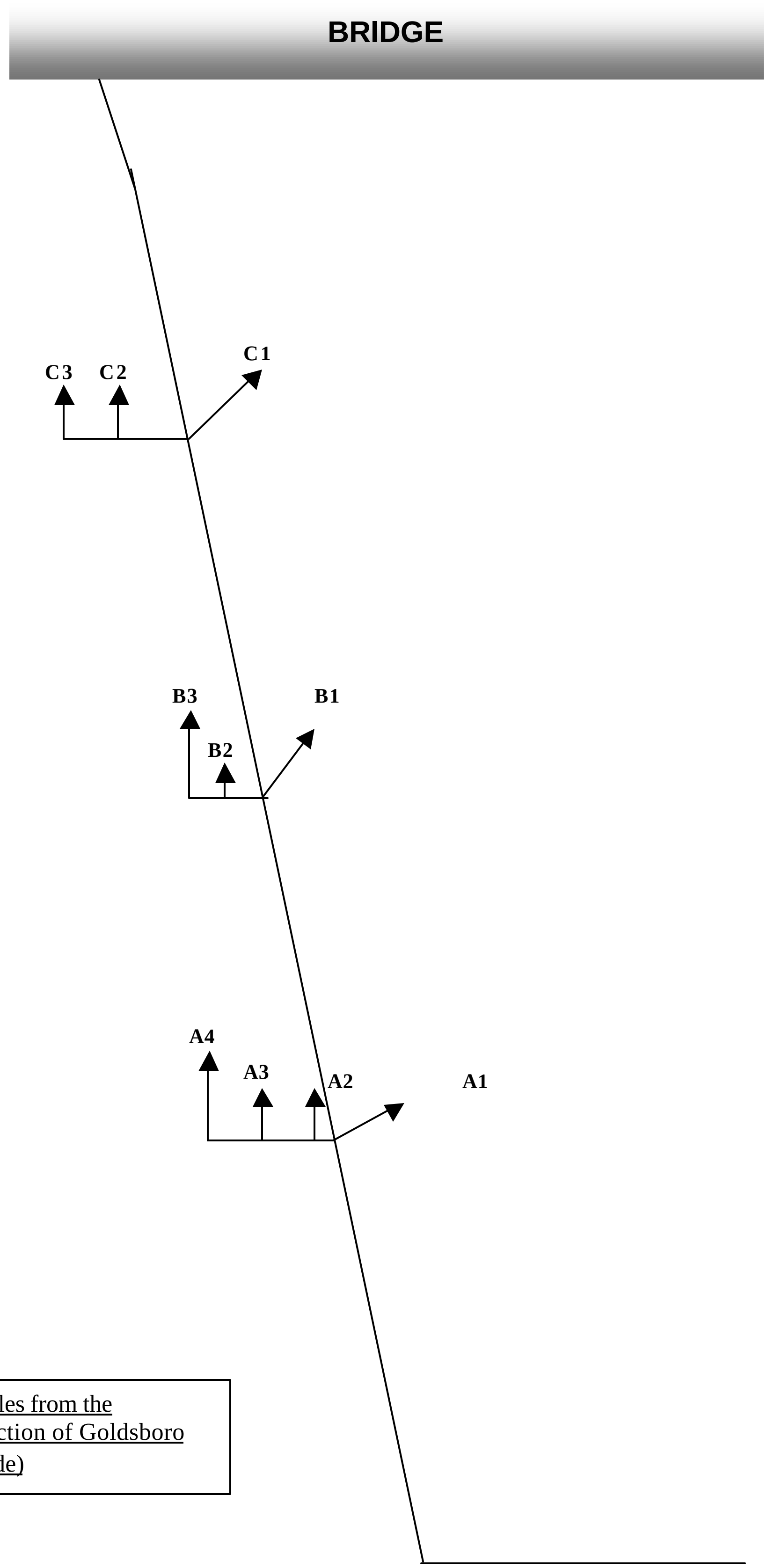


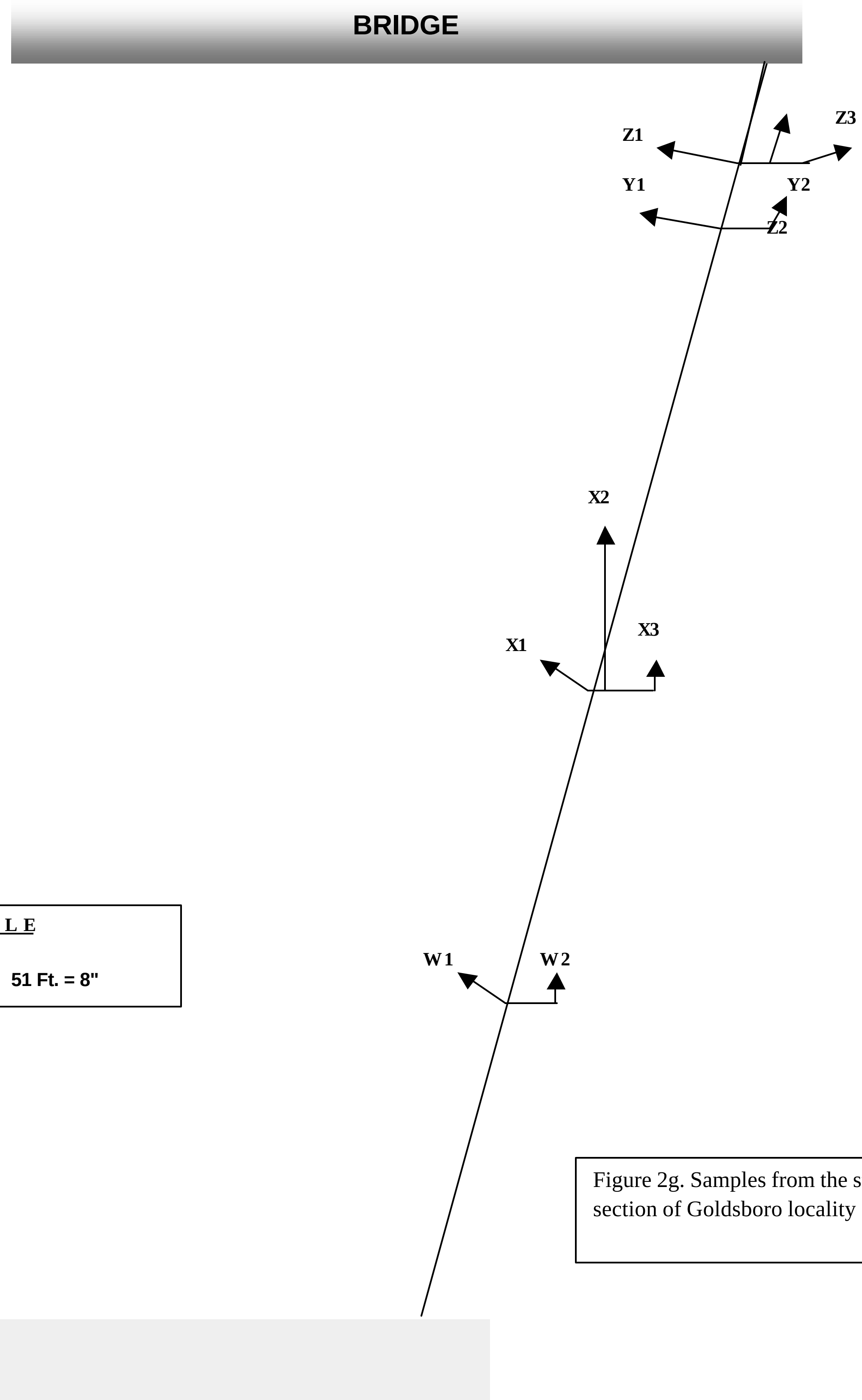
Figure 2e. Samples from the stratigraphic section of Lock Locality.



S C A L E

51 Ft. = 8"

Figure 2f. Samples from the stratigraphic section of Goldsboro locality (Left side)



S C A L E

51 Ft. = 8"

Figure 2g. Samples from the stratigraphic section of Goldsboro locality (right side).

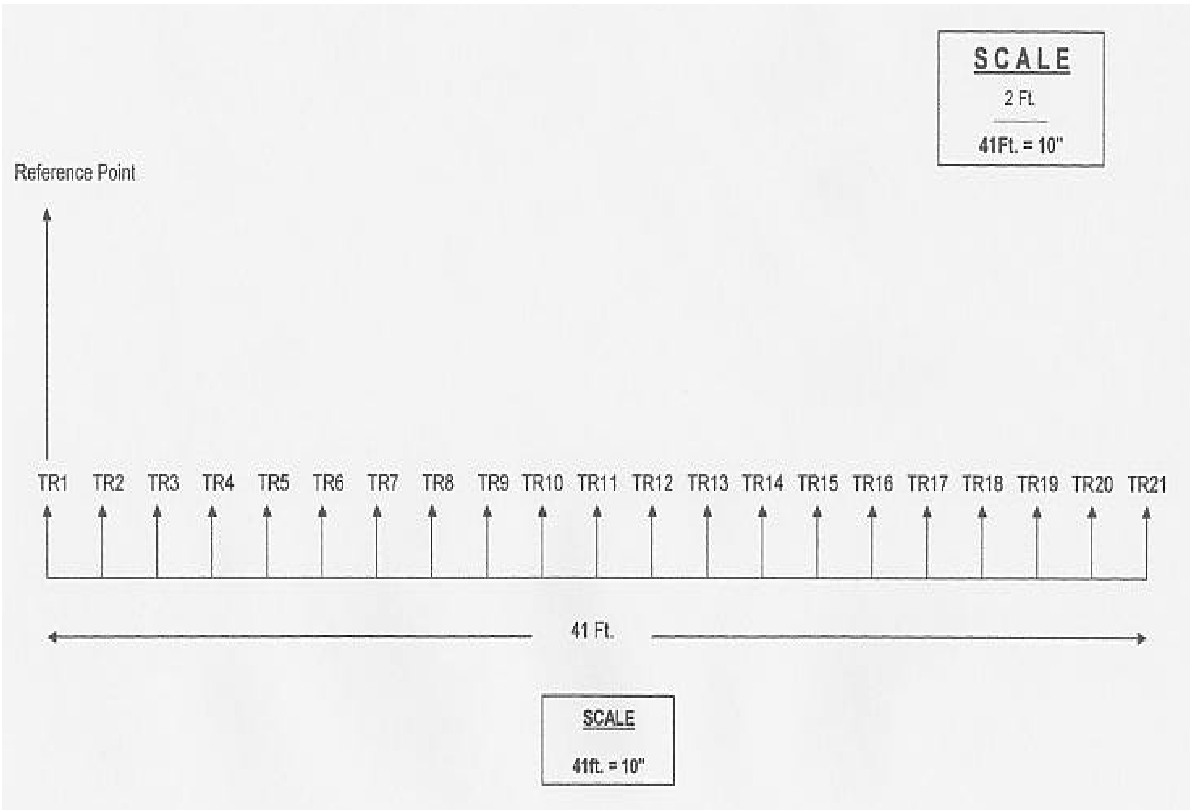


Figure 2h.. Samples from the stratigraphic section of Tar River locality.

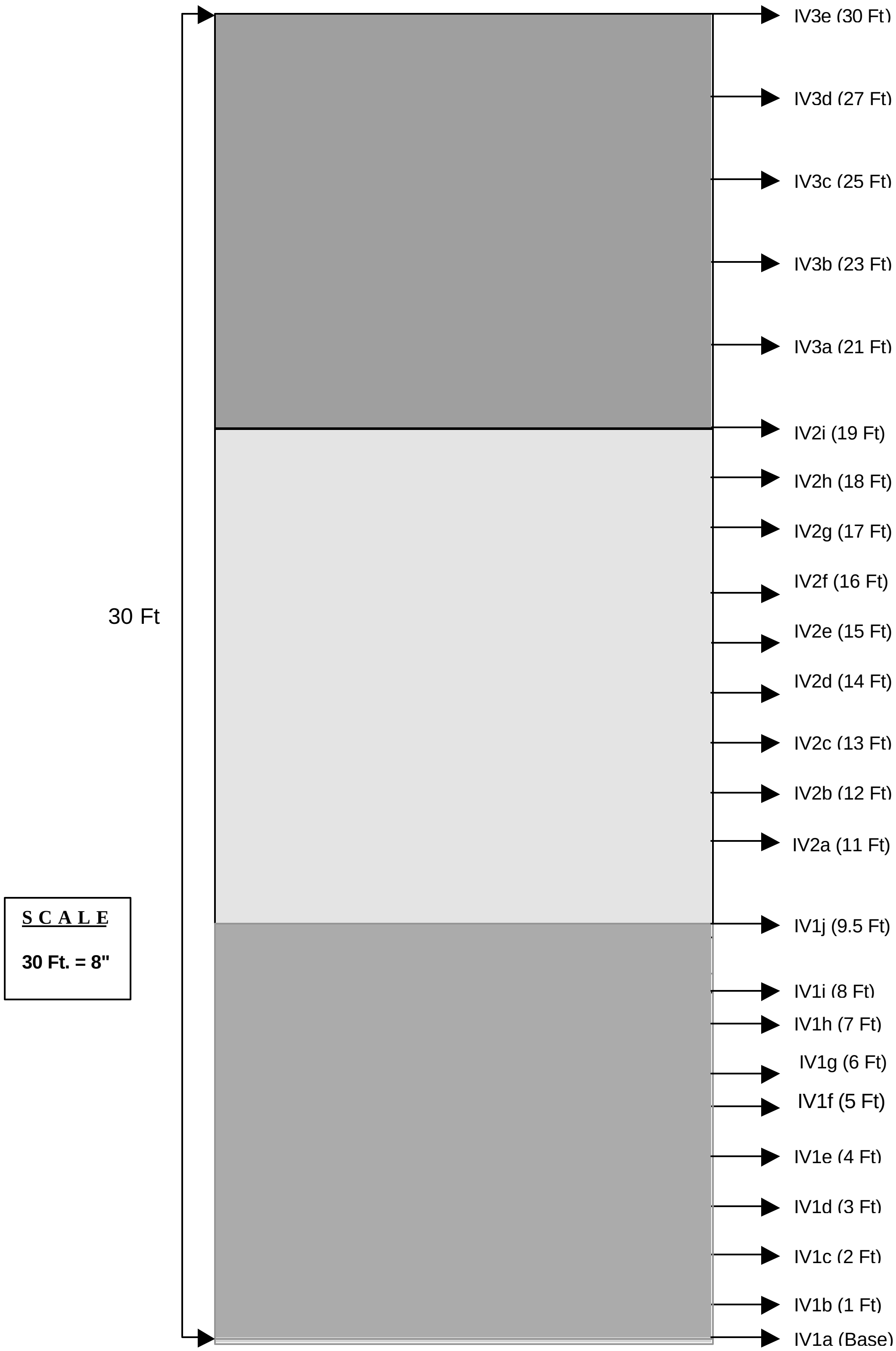


Figure 2i. Samples from the stratigraphic section of Ivanhoe locality.

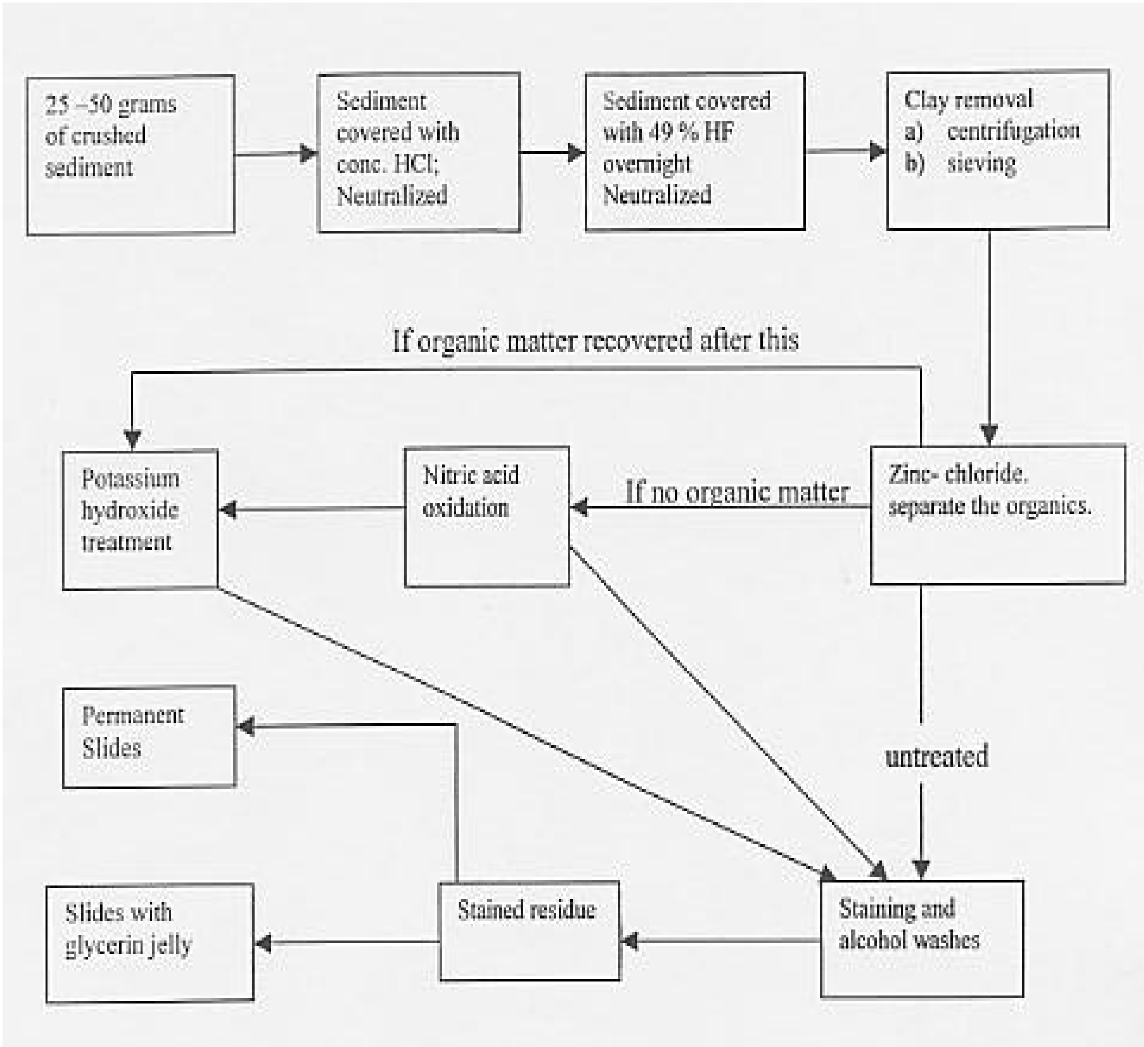


Figure 2j. Outline of the laboratory processing techniques for palynomorphs.

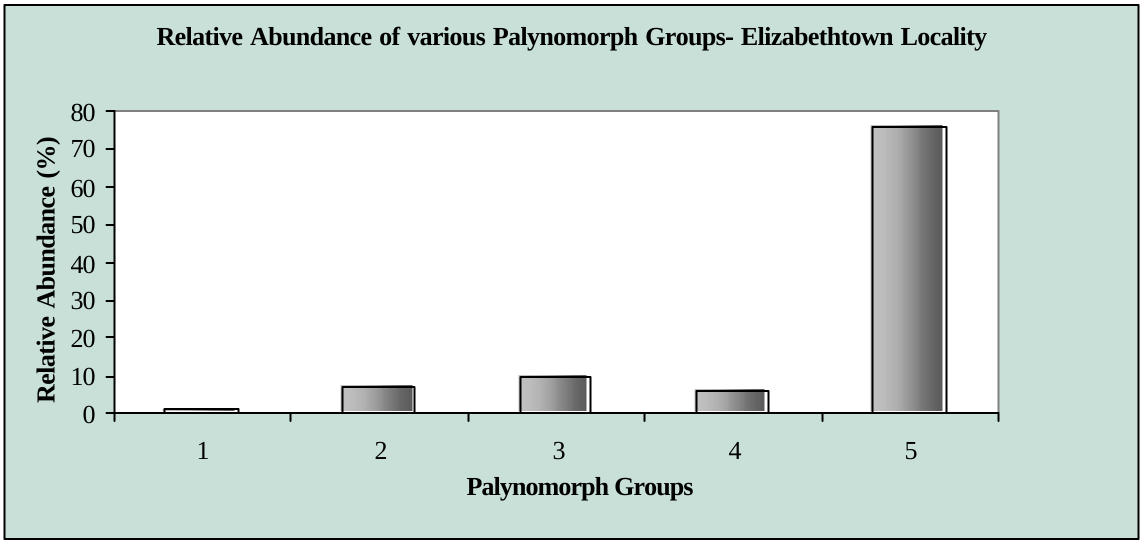


Figure 4a. Relative abundance data of various palynomorph groups from Elizabethtown locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

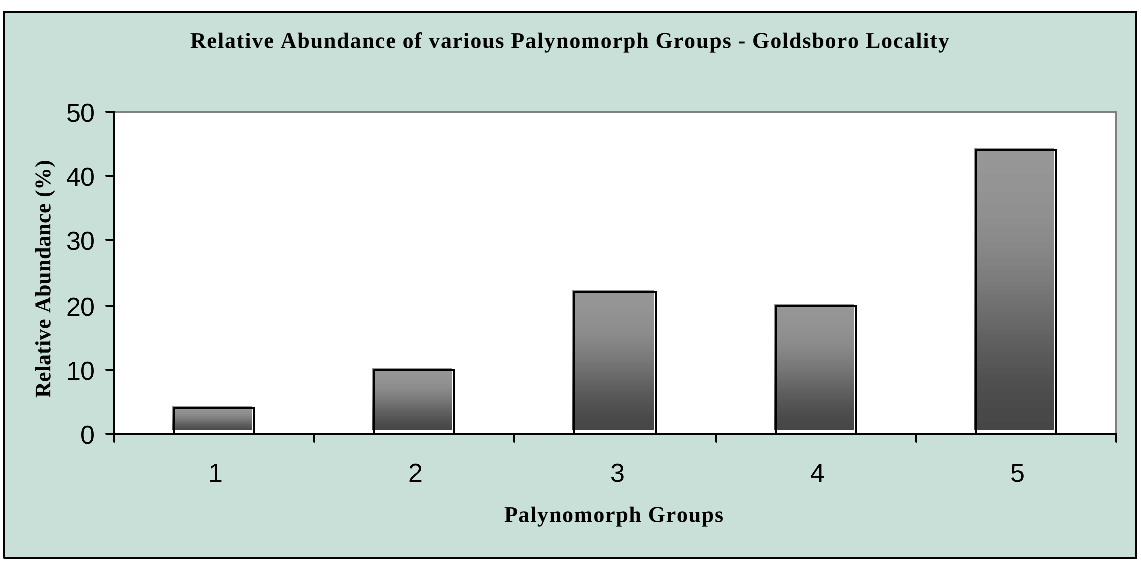


Figure 4b. Relative abundance data of various palynomorph groups from Goldsboro locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

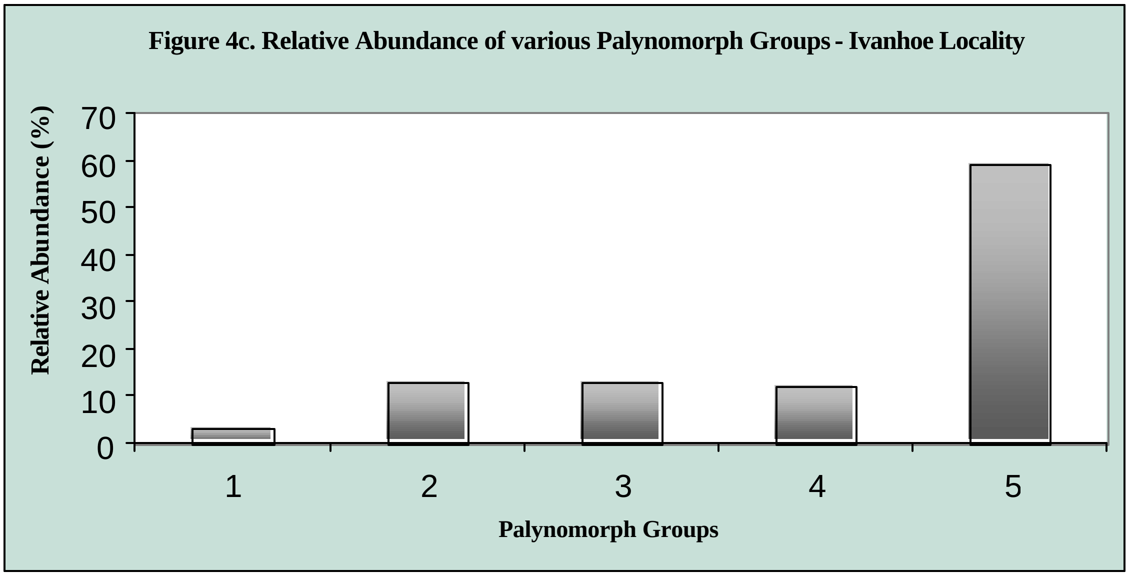


Figure 4c. Relative abundance data of various palynomorph groups from Ivanhoe locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

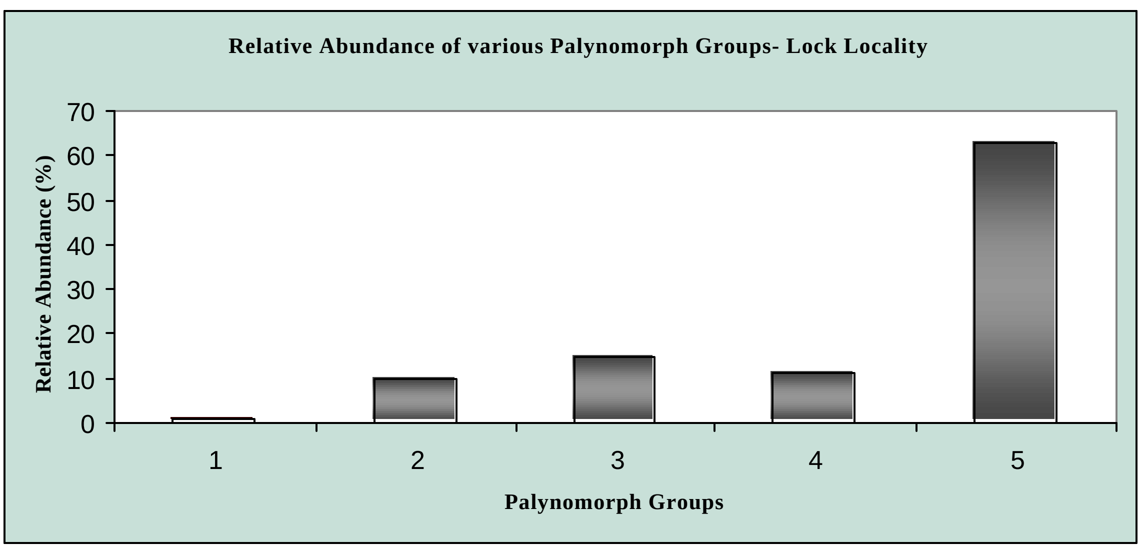


Figure 4d. Relative abundance data of various palynomorph groups from Lock locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

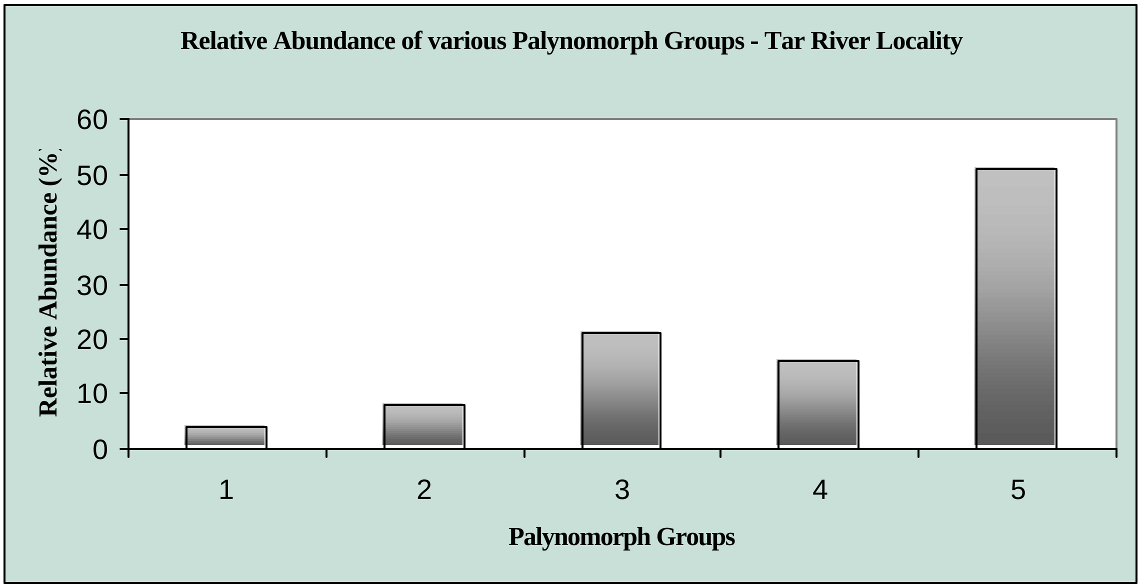


Figure 4e. Relative abundance data of various palynomorphs from Tar River locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

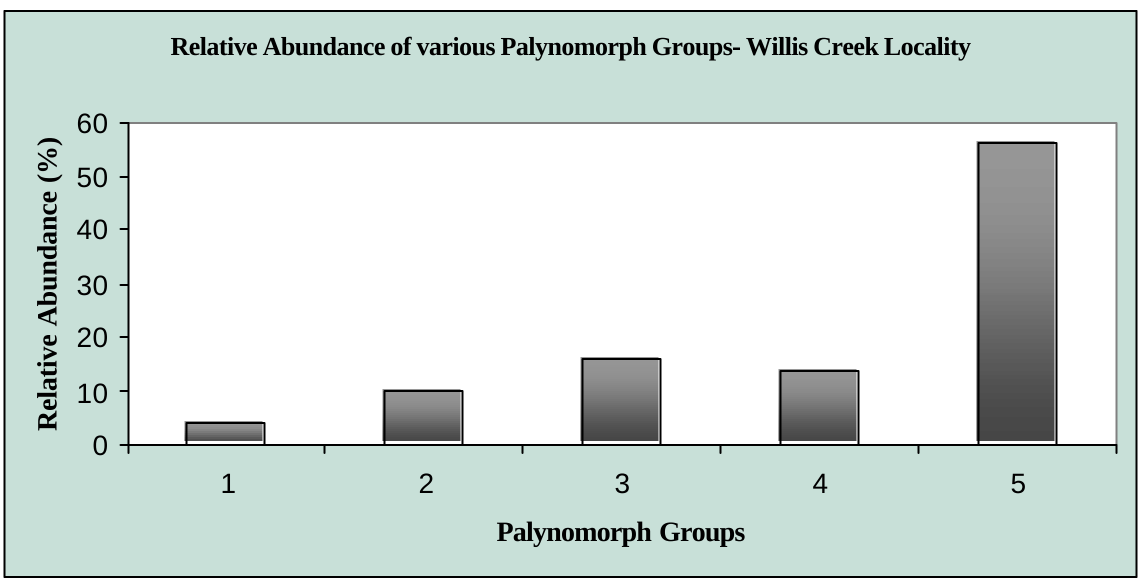


Figure 4f. Relative abundance data of various palynomorphs from Willis Creek locality (1= Freshwater algae and Dinoflagellates, 2 = Fungi, 3 = Pteridophytes, 4 = Gymnosperms, 5 = Angiosperms).

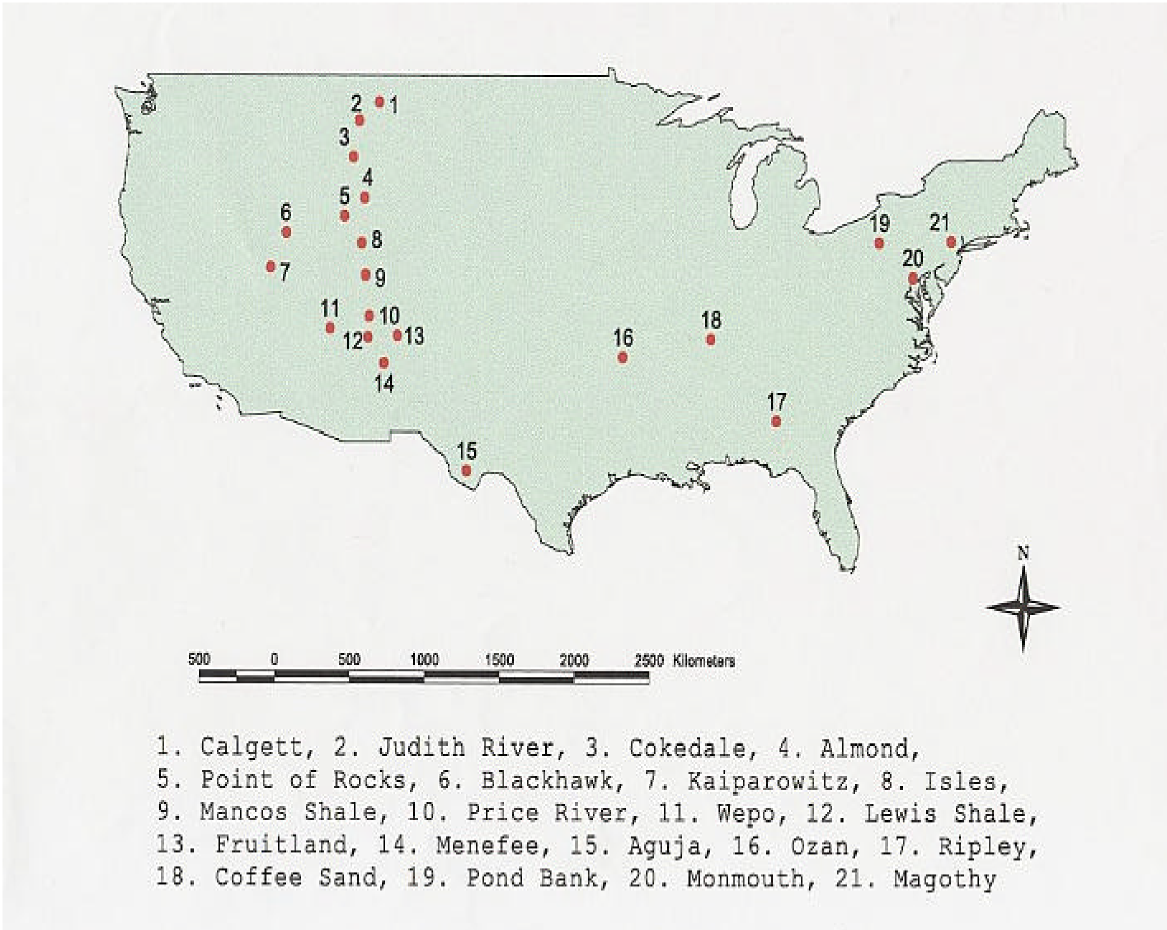


Figure 4g. Geographic locations of previous Campanian palynological studies in the U.S.

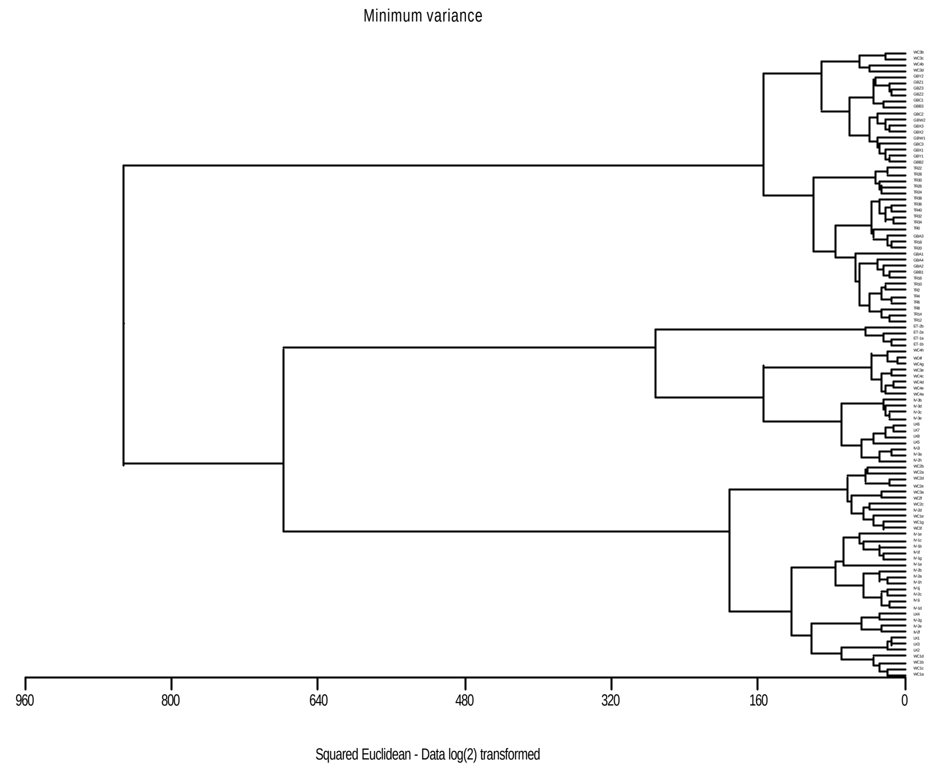


Figure 6a. Dendrogram showing clustering of 103 sample-units from the Tar Heel Formation using minimum variance clustering method using log (2) transformation.

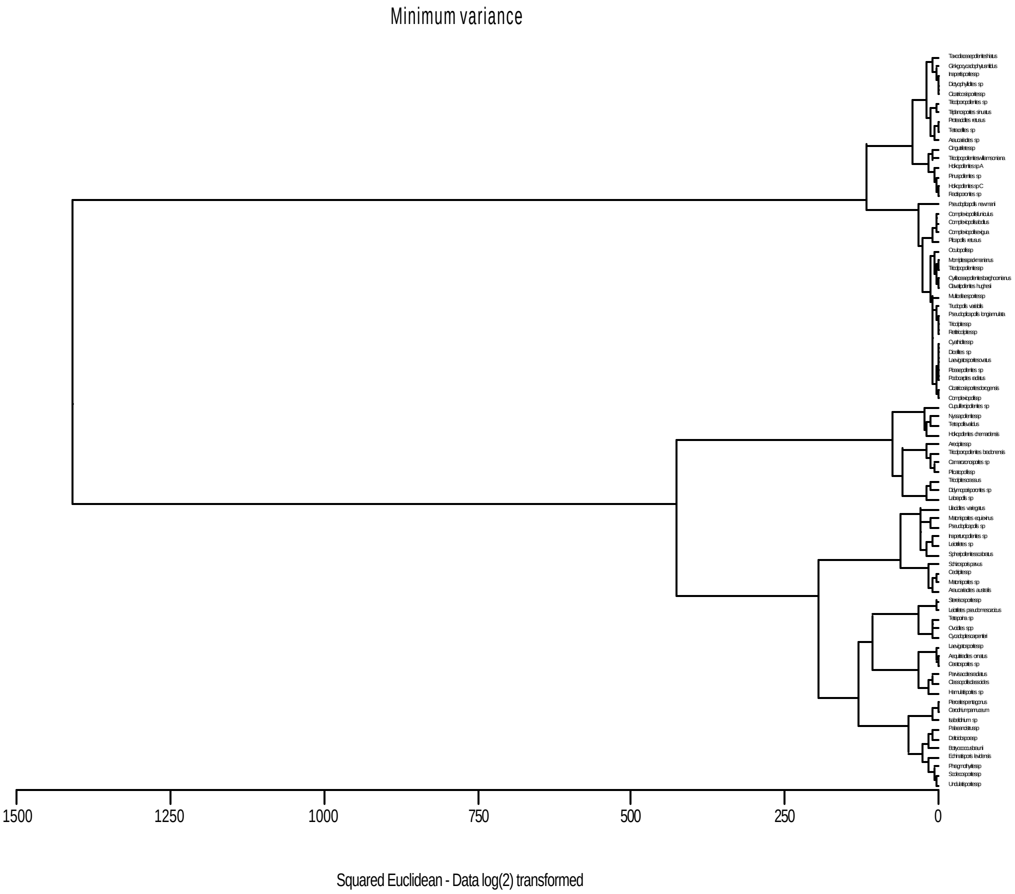


Figure 6b. Dendrogram showing clustering of 80 taxa using minimum variance clustering method with log(2) transformation.

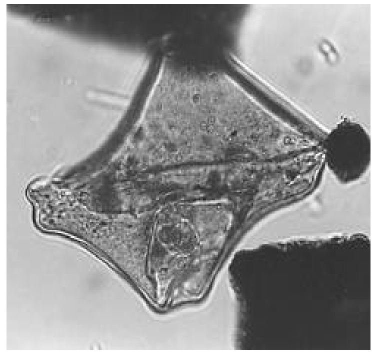
Plate I

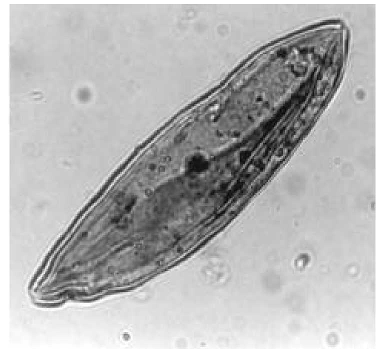
All figures are at 750X maginification and are from the samples of Tar Heel Formation unless specified otherwise.

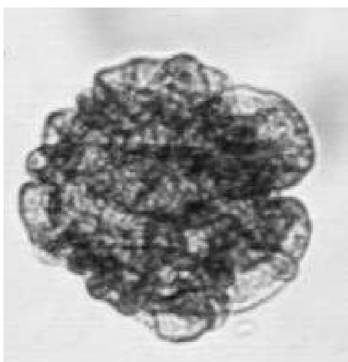
Figures:

1. Ovoidites sp.: 48 µm x 28 µm, GBA4.
2. Tetraporina sp.: 56 µm x 54 µm, GBB1.
3. Schizosporis parvus: 74 µm x 21 µm, GBY2.
4. Botryococcus braunii: 50 µm in diameter, TR 38.
5. Cerodinium pannuceum: 76 µm x 47 µm; GBW1.
6. Isabelidinium sp.: 60 µm x 51 µm, WC3b.
7. Pierceites pentagonus : 56 µm in diameter, WC4a.

PLATE I







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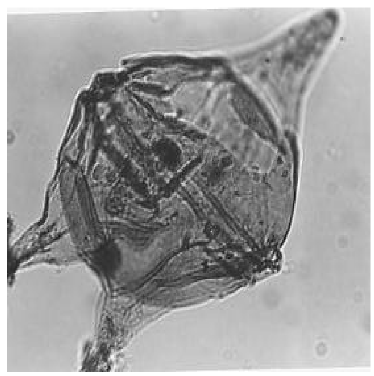

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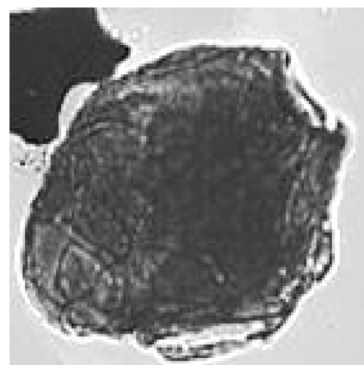

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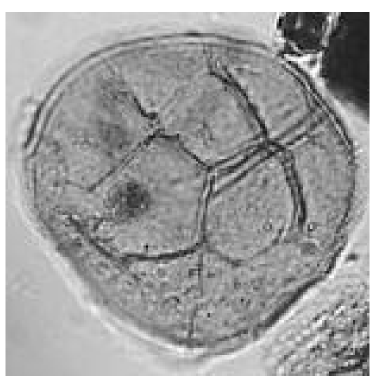

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PLATE II

All figures are at 1000X maginification and are from the samples of Tar Heel Formation, unless otherwise specified.

Figures:

1. Dicellites sp.: 32 μm x 15 μm, GBA1.
2. Multicellaesporites sp.: 40 μm x 13 μm; WC3a.
3. Fractisporonites sp.: 37 μm x 12 μm; IV1a.
4. Tetracellites sp.: 31 μm x 18 μm, IV1e.
5. Didymoporisporonites sp.: 32 μm x16 μm larger cell; 6 μm x 2 μm smaller cell, GBB2.
6. Phragmothyrites sp.: 51 μm in diameter, WC2d. 600X
7. Palaeancistrus sp.: 25 μm x 3 μm, IV1e.
8. Inapertisporites sp.: 14-16 μm (each cell) in diameter, GBC1.
9. Scolecosporites sp.: 35 μm x 4 μm, WC1b.

PLATE - II

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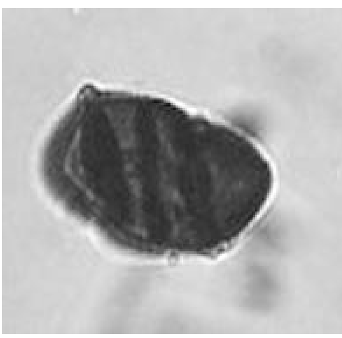

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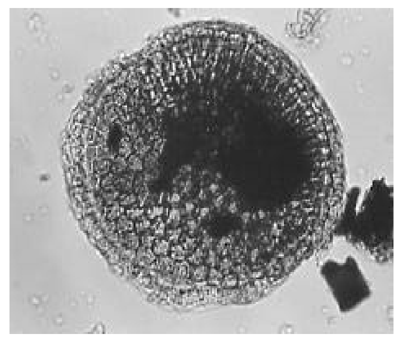

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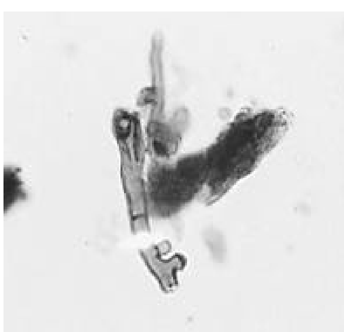

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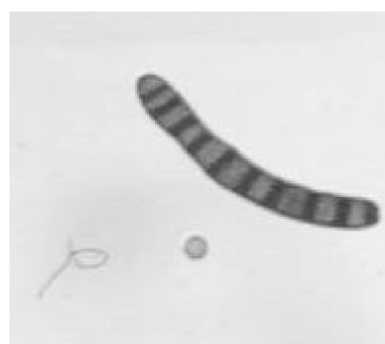

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PLATE III

All figures are at 750X maginification and are from the samples of Tar Heel Formation unless specified otherwise.

Figures:

1. Laevigatosporites ovatus: 55 µm x 39 µm, GBA4.
2. Laevigatoporites sp.: 44 µm x 36 µm; WC2d.
3. Dictyophylliditestes sp.: 51 µm in diameter; WC2c.
4. Matonisporites equiexinus : 47 µm in diameter, IV1c.
5. Aequitriradites ovatus: 38 µm in diameter, TR18.
6. Matonisporites sp.: 44 µm in diameter, WC2e.
7. Camarozonosporites sp.: 50 µm in diameter, TR4.
8. Ceratosporites sp.: 16 µm in diameter, GBB3.
9. Stereisosporites sp.: 52 µm in diameter, TR24.
10. Deltoidospora sp.: 57 µm in diameter, TR34.

PLATE – III

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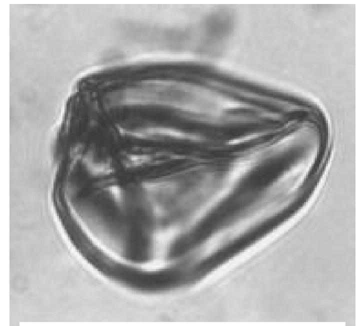

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PLATE IV

All figures are at 750X maginification and are from the samples of Tar Heel Formation unless specified otherwise.

Figures:

1. Leiotriletes sp.: 51 µm in diameter, WC3b.

2. Echinatisporis levidensis : 37 µm in diameter, WC2d.

3. Hamulatisporites sp.: 53 µm in diameter; TR4.

4. Cyathidites sp.: 51 µm in diameter, TR36.

5. Cicatricosisporites sp.: 51 µm in diameter, WC1a.

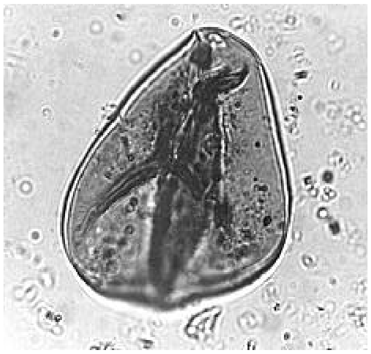
6. Undulatisporites sp. : 40 µm in diameter, WC1f.

7. Cicatricosisporites dorogensis : 56 µm in diameter, GBX3.

8. Leiotriletes pseudomesozoicus: 43 µm in diameter, TR24.

9. Cingutriletes sp.: 52 µm in diameter, WC3c.

PLATE - IV



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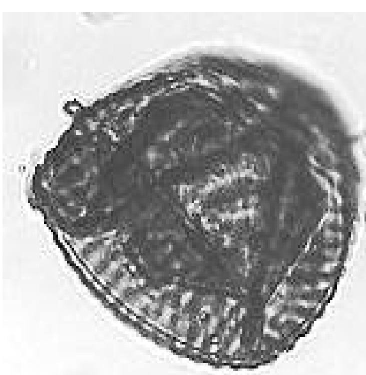

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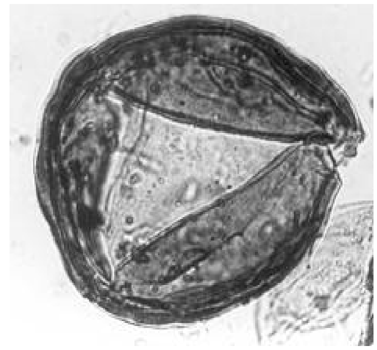
PLATE V

All figures are at 750X maginification and are from the samples of Tar Heel Formation unless specified otherwise.

Figures:

1. Parvisaccites radiatus: 53 µm x 46 µm, LK2.
2. Cycadopites carpentieri: 43 µm x 13 µm, GBB1.
3. Araucariacites australis: 73 µm in diameter; 600x, IV1a.
4. Piceaepollenites sp: 58 µm x 38 µm, IV3a.
5. Araucariacites sp: 62 µm in diameter, 600x, ET1a.
6. Podocarpites radiatus: 51 µm x 47 µm, IV1g.
7. Inaperturopollenites sp.: 67 µm in diameter, ET2b.
8. Pinuspollenites sp.: 66 µm x 40 µm, IV1d.
9. Ginkgocycadophytus nitidus: 63 µm x 43 µm, GBW1.
10. Classopollis classoides: 47 µm indiameter, GBA1.
11. Cedripites sp.: 60 µm x 49 µm, GBA2.
12. Taxodiaceaepollenites hiatus: 35 µm in diameter, IV1a.

PLATE V



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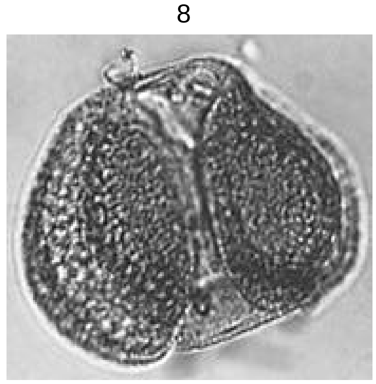

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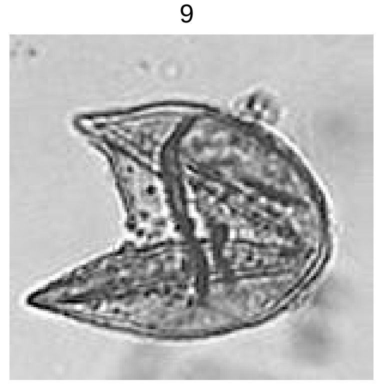

12

PLATE VI

All figures are at 1000X maginification and are from the samples of Tar Heel Formation, unless otherwise specified.

Figures:

1. Pseudoplicapollis sp.: 35 µm, GBA1.
2. Labrapollis sp.: 34 µm; GBB2.
3. Triplanosporites sinuatus: 40 µm x 33 µm; GBZ2.
4. Liliacidites variegatus: 42 µm x 27 µm; IV1c.
5. Tricolpites sp.: 40 µm x 37 µm; WC4h.
6. Plicatopollis sp.: 34 µm x 30 µm; WC4a.
7. Tricolpopollenites sp.: 17 µm x 10 µm; 1600X; TR6.
8. Retitricolpites sp.: 39 µm x 31 µm; WC4a
9. Tricolpites crassus: 36 µm; WC4g.

PLATE VI


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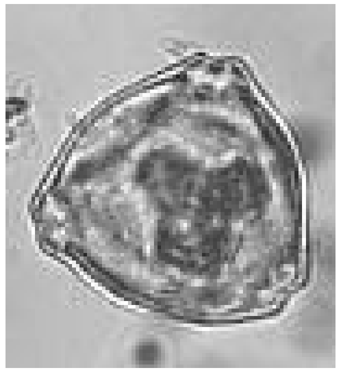
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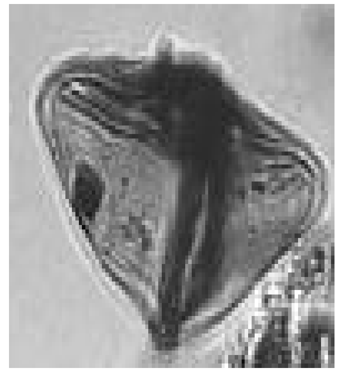
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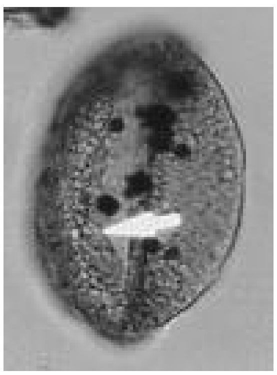
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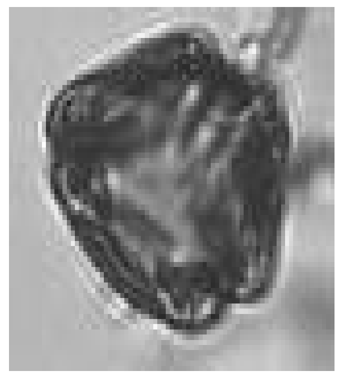
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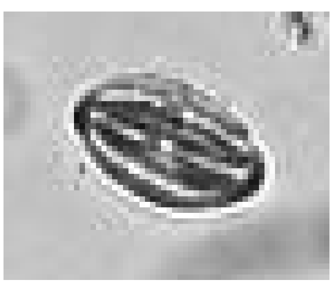
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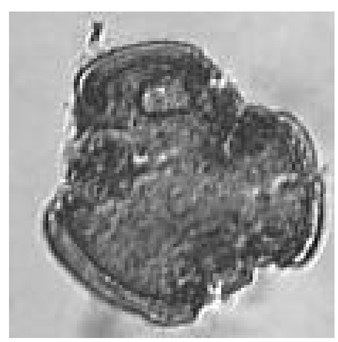
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PLATE VII

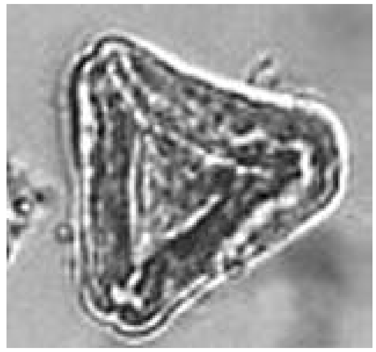
All figures are at 1000X maginification and are from the samples of Tar Heel Formation, unless otherwise specified.

Figures:

1. Clavatipollenites hughesii: 37 µm, ET1a.
2. Complexiopollis abditus: 30 µm x 35 µm; ET1b.
3. Complexiopollis exigua: 35µm; ET2b.
4. Complexiopollis funiculus: 36 µm x 34 µm; ET2b.
5. Complexiopollis sp.: 37 µm x 35 µm; IV1a.
6. Plicapollis retusus: 15 µm x 17 µm; WC4e.
7. Pseudoplicapollis newmanii: 34 µm; WC4c.
8. Pseudoplicapollis longiannulata: 34 µm; WC4g.
9. Tetrapollis validus: 36 µm x 40 µm; WC4a.
10. Cupuliferoipollenites sp.: 18 µm x 13 µm; 1600X; WC3c.
11. Tricolpopollenites williamsoniana : 44 µm x 27 µm; WC4c.
12. Tricolporopollenites sp.: 35 µm x 25 µm; LK6.

<u>**PLATE - VII**</u>

1



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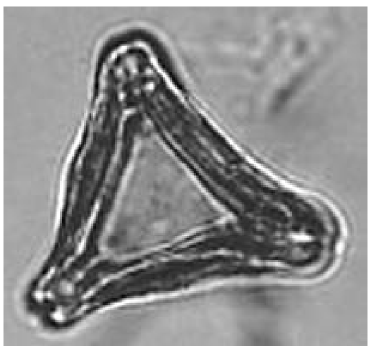

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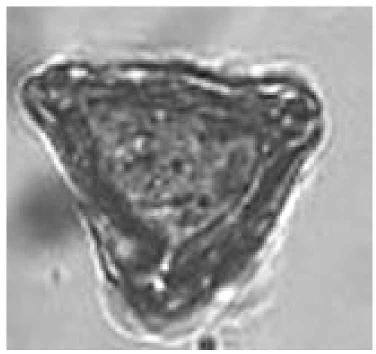

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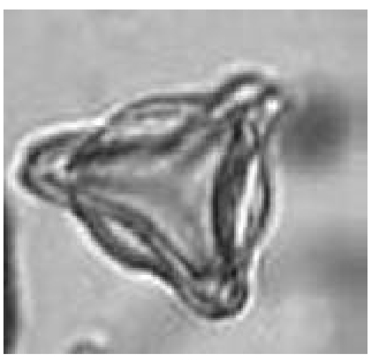

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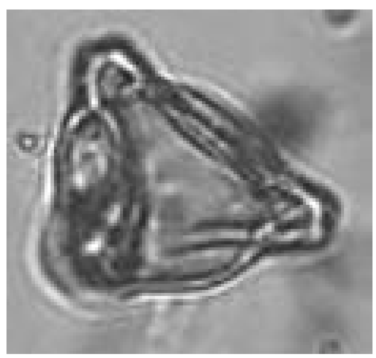

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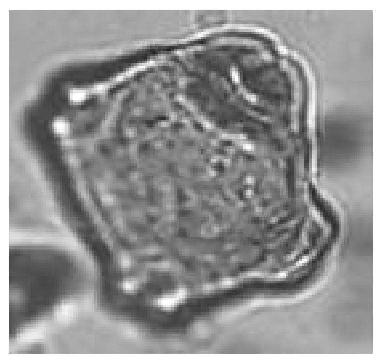

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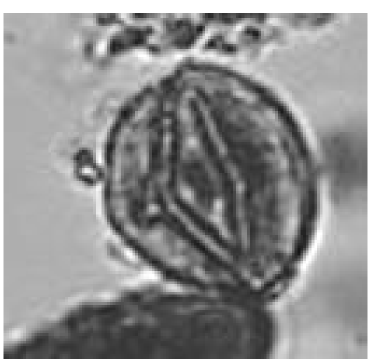

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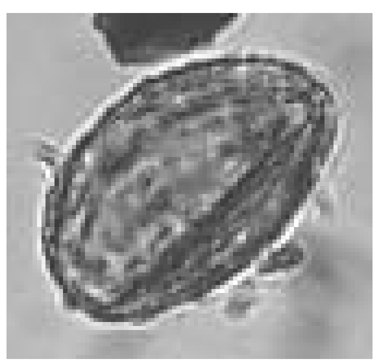

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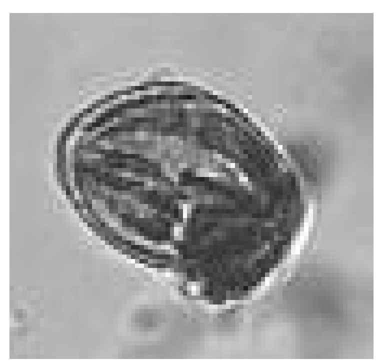

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PLATE VIII

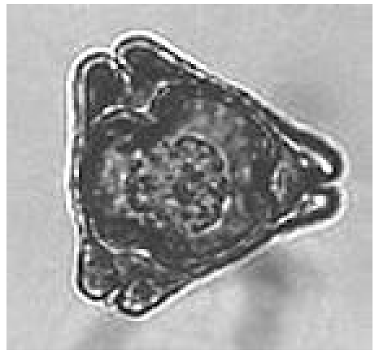
All figures are at 1000X maginification and are from the samples of Tar Heel Formation, unless otherwise specified.

Figures:

1. Oculopollis sp.: 25 µm x 34 µm, WC4a.
2. Trudopollis variabilis: 30 µm x 32 µm; TR18.
3. Cyrillaceaepollenites barghoornianus: 30µm; IV2c.
4. Holkopollenites chemardensis: 37 µm x 35 µm; TR34.
5. Holkopollenites sp.A: 36 µm x 34 µm; IV2a.
6. Holkopollenites sp.C: 40 µm; WC4e.
7. Nyssapollenites sp.: 38 µm; IV3d.
8. Proteacidites retusus: 30 µm x 33 µm; WC4c.
9. Spheripollenitis perinatus: 19 µm; 1600X; WC3g.
10. Momipites spackmanianus: 30 µm; IV1e.
11. Tricolporopollenites bradonensis: 30 µm; WC3e.
12. Arecipites sp.: 35 µm x 31 µm; GBW1.

PLATE - VIII


1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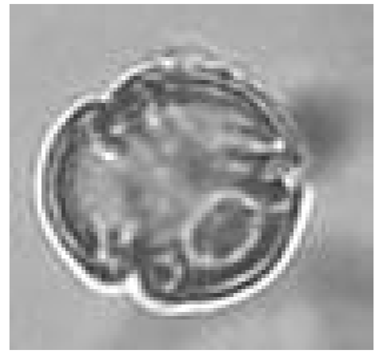
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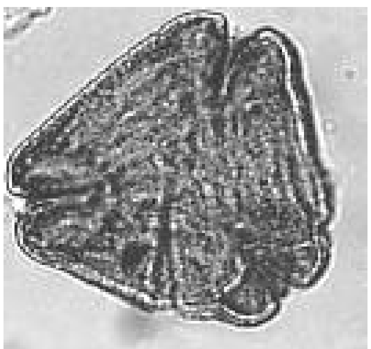
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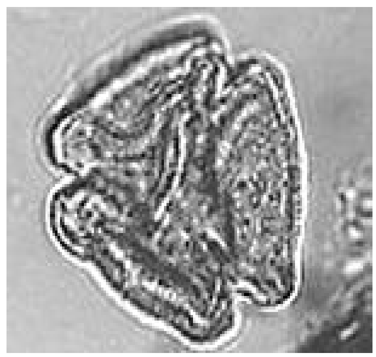
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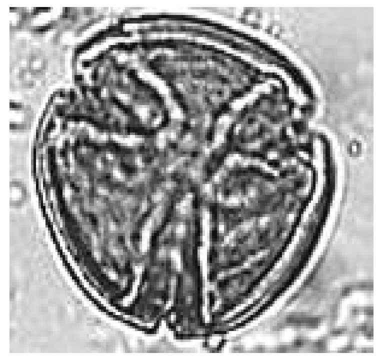
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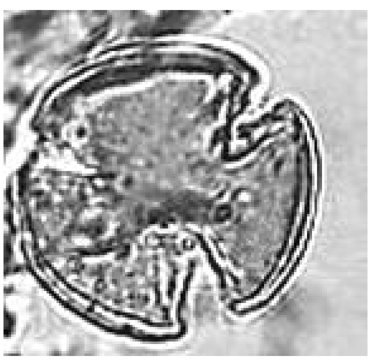
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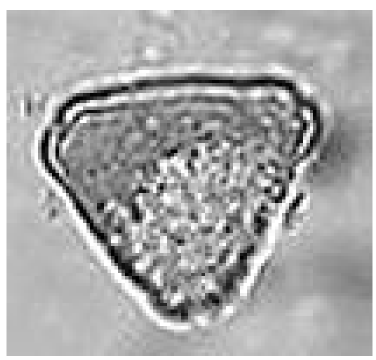
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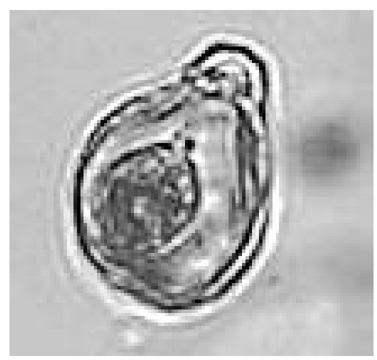
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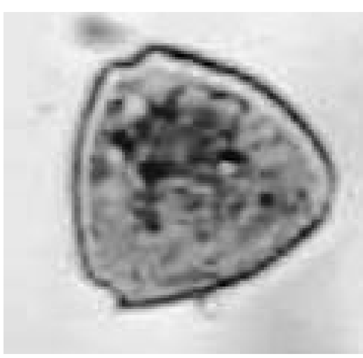
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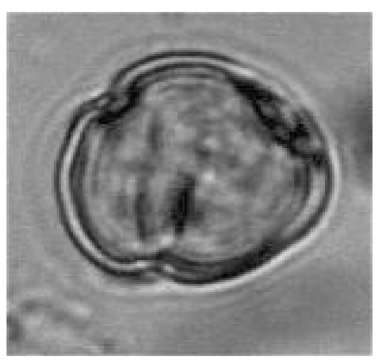
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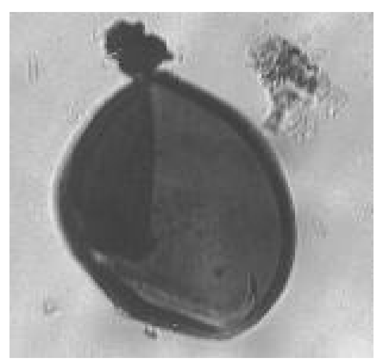
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PLATE IX

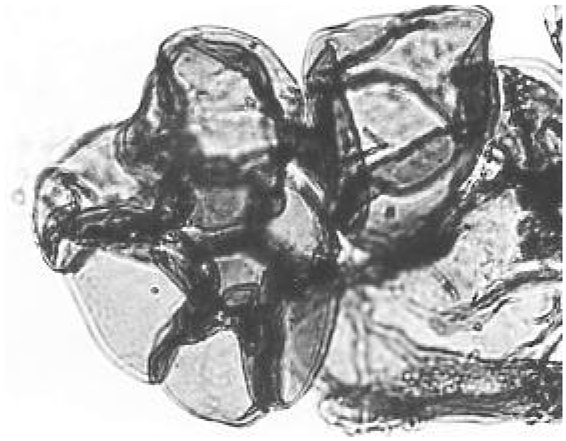
All figures are at 600X maginification and are from the samples of Tar Heel Formation, unless otherwise specified.

Figures:

1. Microforaminiferal lining, Trochospiral type; WC3a.

2. Microforaminiferal lining, Planispiral type; WC3d.

PLATE IX



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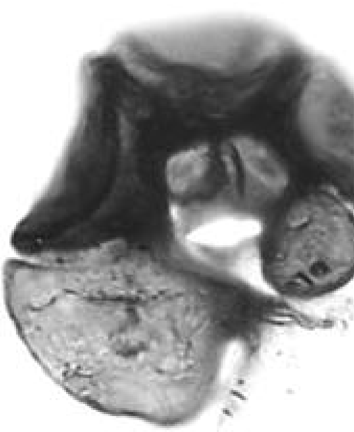

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Appendix 1a: Counts of palynomorph samples from designated stratigraphic intervals of Elizabethtown locality of the Tar Heel Formation.

Taxonomic Identification	ET-1a	ET-1b	ET-2a	ET-2b
Botryococcus braunii	0	0	0	0
Ovoidites spp	0	0	0	0
Schizosporis parvus	0	0	0	0
Tetraporina spp	0	0	0	0
Cerodinium pannuceum	0	0	0	0
Isabelidinium spp	3	2	0	1
Pierceites pentagonus	0	0	0	0
Dicellites spp	5	2	6	5
Didymoporisporonites spp	0	0	0	0
Fractisporonites spp	0	0	0	0
Inapertisporites spp	4	2	4	4
Multicellaesporites spp	3	1	6	5
Palaencistrus spp	0	0	0	0
Phragmothyrites spp	0	0	0	0
Scolecosporites spp	0	0	0	0
Tetracellites spp	3	2	5	0
Aequitriradites ornatus	0	0	0	0
Camarozonosporites spp	0	0	0	0
Ceratosporites spp	0	0	0	0
Cicatricosisporites dorogensis	2	2	4	6
Cicatricosisporites spp	3	1	3	5
Cingutriletes spp	0	0	0	0
Cyathidites spp	2	2	3	4
Dictyophyllidites spp	2	1	3	4
Echinatisporis levidensis	0	0	0	0

Taxonomic Identification	ET-1a	ET-1b	ET-2a	ET-2b
Hamulatisporites spp	0	0	0	0
Laevigatosporites ovatus	3	3	5	6
Laevigatosporites spp	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0
Leiotriletes sp	0	0	4	6
Matonisporites equiexinus	3	3	2	0
Matonisporites spp	0	0	0	0
Stereisosporites spp	0	0	0	0
Undulatisporites spp	0	0	0	0
Deltoidospora spp	0	0	0	0
Araucariacites australis	0	0	0	0
Araucariacites spp	3	2	0	0
Cedripites spp	0	0	0	0
Classopollis classoides	0	0	0	0
Cycadopites carpentieri	0	0	0	0
Ginkgocycadophytus nitidus	2	3	2	4
Inaperturopollenites spp	2	3	0	4
Parvisaccites radiatus	0	0	0	0
Pinuspollenites spp	0	0	0	0
Piceaepollenites spp	3	4	3	4
Podocarpites radiatus	3	4	3	6
Taxodiaceaepollenites hiatus	1	2	1	3
Arecipites spp	0	0	0	0
Clavatipollenites hughesii	6	4	3	4
Complexiopollis abditus	5	10	12	12
Complexiopollis exigua	8	7	10	9

Taxonomic Identification	ET-1a	ET-1b	ET-2a	ET-2b
Complexiopollis funiculus	7	5	5	8
Complexiopollis spp	5	5	6	5
Cupuliferoipollenites spp	2	1	3	3
Cyrillaceaepollenites barghoornianus	8	5	4	3
Holkopollenites chemardensis	6	7	8	0
Holkopollenites sp A	0	0	0	0
Holkopollenites sp C	0	0	0	0
Labrapollis spp	0	0	0	0
Momipites spackmanianus	5	4	5	7
Tricolpopollenites spp	12	8	8	6
Nyssapollenites spp	15	12	8	10
Oculopollis spp	20	10	14	12
Plicapollis retusus	15	12	10	0
Liliacidites variegatus	12	8	14	12
Pseudoplicapollis spp	7	6	0	0
Proteacidites retusus	4	6	4	0
Pseudoplicapollis newmanii	3	4	4	5
Pseudoplicapollis longiannulata	2	8	4	7
Plicatopollis spp	0	0	0	0
Spheripollenites scabratus	0	0	0	0
Tricolpites crassus	0	0	0	0
Tetrapollis validus	3	6	5	5
Retitricolpites spp	2	4	5	4
Tricolpites spp	2	10	4	4
Tricolpopollenites williamsoniana	0	0	0	0
Tricolporopollenites bradonensis	0	0	0	0

Taxonomic Identification	ET-1a	ET-1b	ET-2a	ET-2b
Tricolporopollenites spp	1	5	0	1
Triplanosporites sinuatus	0	8	1	2
Trudopollis variabilis	3	6	3	2

Appendix 1bi: Counts of palynomorph samples from designated stratigraphic intervals of Goldsboro locality of the Tar Heel Formation.

Taxonomic Identification	GBA1	GBA2	GBA3	GBA4	GBB1	GBB2	GBB3	GBC1	GBC2	GBC3
Botryococcus braunii	2	1	1	2	2	1	1	2	0	0
Ovoidites spp	3	2	1	1	2	1	2	1	0	1
Schizosporis parvus	5	4	2	3	4	2	3	2	3	1
Tetraporina spp	2	1	2	1	2	1	3	1	1	1
Cerodinium pannuceum	1	0	0	0	0	0	0	0	2	0
Isabelidinium spp	2	2	0	0	0	0	0	2	2	2
Pierceites pentagonus	2	0	0	0	0	0	0	1	1	0
Dicellites spp	4	5	2	4	2	5	4	3	1	4
Didymoporisporonites spp	1	2	1	2	1	2	0	1	2	3
Fractisporonites spp	2	3	1	4	2	2	2	4	3	2
Inapertisporites spp	3	4	2	0	2	2	3	2	2	3
Multicellaesporites spp	4	5	3	4	3	4	4	2	3	1
Palaencistrus spp	2	2	1	2	1	2	2	0	1	2
Phragmothyrites spp	2	1	1	2	3	1	0	0	2	1
Scolecosporites spp	2	2	0	2	1	2	0	1	0	1
Tetracellites spp	5	6	3	4	5	4	0	3	5	2
Aequitriradites ornatus	1	3	2	2	3	1	3	1	3	1
Camarozonosporites spp	0	0	2	1	0	1	3	0	0	0
Ceratosporites spp	2	4	2	3	1	2	4	3	2	0
Cicatricosisporites dorogensis	0	3	1	2	3	4	4	2	4	2
Cicatricosisporites spp	0	4	3	2	4	3	2	3	2	2
Cingutriletes spp	1	5	2	4	2	3	5	2	4	3
Cyathidites spp	1	3	4	5	2	4	3	4	4	2
Dictyophyllidites spp	1	4	3	4	4	2	1	3	2	3

Taxonomic Identification	GBA1	GBA2	GBA3	GBA4	GBB1	GBB2	GBB3	GBC1	GBC2	GBC3
Echinatisporis levidensis	0	0	1	2	0	1	0	2	1	0
Hamulatisporites spp	2	4	3	2	2	3	2	0	2	0
Laevigatosporites ovatus	2	5	3	4	3	4	2	3	3	3
Laevigatosporites spp	0	3	2	2	3	3	2	1	2	4
Leiotriletes pseudomesozoicus	3	3	1	1	2	1	2	0	0	2
Leiotriletes sp	2	4	2	3	2	2	4	3	3	4
Matonisporites equiexinus	4	4	2	2	3	3	0	0	0	2
Matonisporites spp	3	4	2	1	2	4	3	4	0	4
Stereisoporites spp	4	2	2	4	3	3	2	3	4	3
Undulatisporites spp	1	0	1	2	1	2	1	1	0	2
Deltoidospora spp	1	0	1	2	1	2	3	2	0	2
Araucariacites australis	4	3	2	4	3	5	4	3	5	4
Araucariacites spp	4	4	3	4	4	6	3	4	6	5
Cedripites spp	3	5	4	3	4	5	4	3	4	5
Classopollis classoides	5	3	3	4	3	4	3	3	5	6
Cycadopites carpentieri	4	3	2	3	4	0	2	0	0	3
Ginkgocycadophytus nitidus	5	2	0	0	5	4	2	4	3	4
Inaperturopollenites spp	4	4	3	0	3	3	4	4	3	3
Parvisaccites radiatus	3	4	3	2	4	3	2	3	4	3
Pinuspollenites spp	4	5	4	3	5	4	3	5	4	4
Piceaepollenites spp	3	6	5	4	4	5	3	3	4	3
Podocarpites radiatus	4	3	4	3	3	4	4	3	5	5
Taxodiaceaepollenites hiatus	3	2	3	3	2	3	2	3	4	3
Arecipites spp	0	0	0	0	0	0	0	0	0	2
Clavatipollenites hughesii	4	3	4	3	4	5	4	4	5	4
Complexiopollis abditus	5	6	7	4	5	4	5	6	4	4

Taxonomic Identification	GBA1	GBA2	GBA3	GBA4	GBB1	GBB2	GBB3	GBC1	GBC2	GBC3
Complexiopollis exigua	4	5	6	5	4	5	4	5	6	6
Complexiopollis funiculus	4	4	5	6	3	4	6	5	4	5
Complexiopollis spp	0	3	0	2	3	3	3	2	3	2
Cupuliferoipollenites spp	2	0	3	0	0	2	0	0	2	3
Cyrillaceaepollenites barghoornianus	3	5	4	3	4	4	2	4	4	5
Holkopollenites chemardensis	0	0	0	2	3	2	0	2	3	2
Holkopollenites sp A	0	4	2	3	4	5	3	4	2	4
Holkopollenites sp C	0	2	1	2	3	3	2	4	1	5
Labrapollis spp	3	4	3	4	5	4	3	4	3	4
Momipites spackmanianus	3	3	4	3	3	4	2	3	3	4
Tricolpopollenites spp	1	2	3	4	3	3	2	3	4	3
Nyssapollenites spp	2	4	3	4	3	2	3	4	5	6
Oculopollis spp	4	1	4	3	2	3	2	3	2	3
Plicapollis retusus	6	2	5	3	3	4	3	5	3	2
Liliacidites variegates	3	0	0	4	0	2	4	2	4	0
Pseudoplicapollis spp	4	0	3	4	3	3	4	3	4	2
Proteacidites retusus	3	1	4	3	4	1	3	2	4	1
Pseudoplicapollis newmanii	5	0	2	0	0	0	0	0	2	0
Pseudoplicapollis longiannulata	4	2	3	2	4	3	4	3	3	2
Plicatopollis spp	3	1	4	2	3	1	2	3	0	3
Spheripollenites scabratus	4	2	3	0	2	2	4	2	3	1
Tricolpites crassus	0	0	0	0	0	0	3	3	2	2
Tetrapollis validus	0	2	3	0	4	2	3	2	2	1
Retitricolpites spp	3	2	4	3	4	1	4	3	3	2
Tricolpites spp	2	0	5	2	3	2	4	2	2	3
Tricolpopollenites williamsoniana	2	1	2	2	2	1	3	2	1	1

Taxonomic Identification	GBA1	GBA2	GBA3	GBA4	GBB1	GBB2	GBB3	GBC1	GBC2	GBC3
Tricolporopollenites bradonensis	3	0	1	1	2	0	3	4	1	2
Tricolporopollenites spp	2	1	5	2	4	2	5	4	2	1
Triplanosporites sinuatus	3	1	3	2	3	0	3	2	0	1
Trudopollis variabilis	3	1	5	4	5	2	5	4	3	2

Appendix 1bii Counts of palynomorph samples from designated stratigraphic intervals of Goldsboro locality of the Tar Heel Formation.

Taxonomic Identification	GBW1	GBW2	GBX1	GBX2	GBX3	GBY1	GBY2	GBZ1	GBZ2	GBZ3
Botryococcus braunii	0	0	2	1	2	1	2	1	0	0
Ovoidites spp	0	0	3	1	2	3	2	3	2	0
Schizosporis parvus	0	0	2	2	1	3	4	1	3	0
Tetraporina spp	0	0	2	1	2	2	1	1	2	0
Cerodinium pannuceum	3	2	2	1	2	0	0	0	0	0
Isabelidinium spp	3	4	0	2	2	0	0	0	0	0
Pierceites pentagonus	2	2	0	1	1	0	0	0	0	0
Dicellites spp	5	3	4	3	3	4	3	4	4	2
Didymoporisporonites spp	1	1	0	2	1	1	2	1	1	1
Fractisporonites spp	3	2	2	4	3	2	4	3	3	2
Inapertisporites spp	2	2	1	3	1	2	4	5	3	1
Multicellaesporites spp	4	3	4	2	2	3	2	4	2	1
Palaencistrus spp	3	1	2	0	1	1	2	0	1	0
Phragmothyrites spp	2	1	3	3	1	1	2	0	1	0
Scolecosporites spp	3	2	1	1	2	2	1	0	3	2
Tetracellites spp	4	3	4	2	4	3	1	4	3	1
Aequitriradites ornatus	3	1	2	4	2	4	3	3	2	4
Camarozonosporites spp	4	2	0	0	0	2	2	1	3	1
Ceratosporites spp	2	3	4	2	3	2	2	1	2	2
Cicatricosisporites dorogensis	4	3	4	2	4	2	3	3	4	4
Cicatricosisporites spp	4	2	2	2	3	2	4	2	3	2
Cingutriletes spp	3	3	2	3	4	2	5	2	4	3
Cyathidites spp	2	3	4	2	3	4	3	4	5	4
Dictyophyllidites spp	1	1	2	1	4	5	3	2	3	2

Taxonomic Identification	GBW1	GBW2	GBX1	GBX2	GBX3	GBY1	GBY2	GBZ1	GBZ2	GBZ3
Echinatisporis levidensis	1	0	1	0	1	0	0	1	2	1
Hamulatisporites spp	4	2	4	2	3	2	1	0	0	0
Laevigatosporites ovatus	7	4	3	4	2	2	4	3	2	3
Laevigatosporites spp	3	2	4	3	4	3	1	2	2	2
Leiotriletes pseudomesozoicus	3	0	2	0	0	2	2	2	1	2
Leiotriletes sp	3	2	4	2	3	2	4	3	3	2
Matonisporites equiexinus	4	3	2	3	2	3	4	2	2	3
Matonisporites spp	3	2	3	4	3	4	2	3	4	4
Stereisosporites spp	4	3	2	1	2	3	4	2	3	3
Undulatisporites spp	1	1	2	2	1	0	2	0	0	0
Deltoidospora spp	1	1	1	2	1	1	0	0	0	0
Araucariacites australis	3	5	5	4	6	4	5	6	5	4
Araucariacites spp	4	3	3	4	5	4	3	4	3	5
Cedripites spp	4	4	3	4	4	3	4	2	4	5
Classopollis classoides	5	4	5	6	4	5	3	3	4	3
Cycadopites carpentieri	0	2	3	2	3	2	2	4	0	0
Ginkgocycadophytus nitidus	4	3	2	3	3	4	3	2	2	3
Inaperturopollenites spp	3	2	3	4	3	4	2	3	2	4
Parvisaccites radiatus	2	3	4	4	2	3	2	2	3	2
Pinuspollenites spp	5	4	5	3	6	5	3	4	5	4
Piceaepollenites spp	4	3	2	2	4	3	4	3	4	5
Podocarpites radiatus	3	2	4	3	2	4	3	2	3	2
Taxodiaceaepollenites hiatus	2	1	2	2	1	3	0	1	0	0
Arecipites spp	3	0	3	2	3	4	5	4	5	3
Clavatipollenites hughesii	5	6	4	4	5	5	2	3	5	4
Complexiopollis abditus	3	4	5	5	6	4	6	3	4	6

Taxonomic Identification	GBW1	GBW2	GBX1	GBX2	GBX3	GBY1	GBY2	GBZ1	GBZ2	GBZ3
Complexiopollis exigua	3	4	5	5	6	4	6	3	4	6
Complexiopollis funiculus	3	2	5	4	3	4	3	5	4	6
Complexiopollis spp	2	3	4	2	3	3	2	3	2	4
Cupuliferoipollenites spp	1	0	3	2	0	0	1	1	2	1
Cyrillaceaepollenites barghoornianus	3	2	4	3	0	3	3	4	1	3
Holkopollenites chemardensis	0	0	0	2	3	2	3	1	4	2
Holkopollenites sp A	2	3	4	3	4	3	2	2	5	4
Holkopollenites sp C	2	2	3	4	3	4	1	3	3	3
Labrapollis spp	3	4	4	3	4	2	0	3	4	5
Momipites spackmanianus	5	3	3	2	3	2	0	4	3	4
Tricolpopollenites spp	4	2	4	3	1	3	0	2	2	5
Nyssapollenites spp	3	4	5	4	2	4	2	3	4	6
Oculopollis spp	2	3	4	3	1	2	2	3	4	4
Plicapollis retusus	4	5	5	4	2	4	4	5	5	6
Liliacdites variegatus	1	3	4	3	1	3	2	3	2	4
Pseudoplicapollis spp	3	4	3	4	2	3	2	4	2	5
Proteacidites retusus	2	3	2	2	3	4	3	2	3	4
Pseudoplicapollis newmanii	0	4	1	3	2	1	0	0	0	0
Pseudoplicapollis longiannulata	2	3	2	2	2	3	2	3	3	5
Plicatopollis spp	1	2	0	2	3	2	3	2	2	3
Spheripollenites scabratus	1	3	0	3	2	3	2	4	2	4
Tricolpites crassus	3	2	0	2	3	2	2	4	5	3
Tetrapollis validus	1	3	2	3	2	3	4	4	2	2
Retitricolpites spp	2	4	0	2	2	2	4	3	2	2
Tricolpites spp	1	5	1	3	2	1	5	4	1	1

Taxonomic Identification	GBW1	GBW2	GBX1	GBX2	GBX3	GBY1	GBY2	GBZ1	GBZ2	GBZ3
Tricolpopollenites williamsoniana	0	3	0	2	1	0	4	3	1	2
Tricolporopollenites bradonensis	0	3	0	1	0	1	3	2	2	1
Tricolporopollenites spp	2	4	2	1	2	2	5	4	3	3
Triplanosporites sinuatus	0	3	0	1	1	0	2	4	2	2
Trudopollis variabilis	2	4	2	2	3	1	5	4	2	4

Appendix 1ci: Counts of palynomorph samples from designated stratigraphic intervals (Zone 1) of Ivanhoe locality of the Tar Heel Formation.

Taxonomic Identification	IV1a	IV1b	IV1c	IV1d	IV1e	IV1f	IV1g	IV1h	IV1i	IV1j
Botryococcus braunii	2	0	0	0	0	0	3	0	0	0
Ovoidites spp	2	4	0	3	4	2	4	3	3	3
Schizosporis parvus	0	4	5	4	3	3	4	5	4	3
Tetraporina spp	0	3	2	0	0	2	3	0	0	0
Cerodinium pannuceum	0	2	3	0	3	1	3	1	2	3
Isabelidinium spp	0	2	4	0	3	3	4	0	0	0
Pierceites pentagonus	0	3	0	3	4	2	3	2	2	3
Dicellites spp	0	1	5	5	4	4	3	4	4	3
Didymoporisporonites spp	0	0	1	0	0	0	0	0	0	0
Fractisporonites spp	4	3	3	4	3	5	3	4	3	4
Inapertisporites spp	2	2	3	3	5	2	2	3	3	2
Multicellaesporites spp	3	3	4	4	3	5	5	6	5	6
Palaencistrus spp	4	2	3	3	4	3	3	3	2	2
Phragmothyrites spp	2	1	2	1	2	0	2	2	2	1
Scolecosporites spp	2	1	2	1	3	2	3	4	3	2
Tetracellites spp	4	3	3	3	2	6	3	4	4	3
Aequitriradites ornatus	0	0	0	0	0	0	0	0	0	0
Camarozonosporites spp	0	0	0	0	0	0	0	0	0	0
Ceratosporites spp	0	1	0	0	0	0	0	0	0	0
Cicatricosisporites dorogensis	5	3	2	4	3	2	4	3	4	5
Cicatricosisporites spp	7	2	0	2	4	1	3	3	4	2
Cingutriletes spp	4	3	3	3	0	4	4	0	0	3
Cyathidites spp	2	4	4	3	2	3	4	5	4	5
Dictyophyllidites spp	0	3	2	4	4	3	4	3	4	4

Taxonomic Identification	IV1a	IV1b	IV1c	IV1d	IV1e	IV1f	IV1g	IV1h	IV1i	IV1j
Echinatisporis levidensis	0	1	0	0	2	2	0	3	0	2
Hamulatisporites spp	0	0	0	0	0	0	0	0	0	0
Laevigatosporites ovatus	2	3	3	4	5	4	5	3	5	5
Laevigatosporites spp	0	0	0	0	0	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0	0	0	0	0
Leiotriletes sp	0	4	0	0	0	4	0	0	0	0
Matonisporites equiexinus	4	4	6	3	4	0	2	0	0	2
Matonisporites spp	2	2	0	3	3	0	0	0	4	2
Stereisoporites spp	0	0	0	0	0	0	0	0	0	0
Undulatisporites spp	1	0	5	5	3	0	3	1	2	2
Deltoidospora spp	0	0	3	0	0	0	0	0	0	2
Araucariacites australis	3	4	4	5	4	5	3	4	5	5
Araucariacites spp	2	2	3	4	0	3	2	3	4	3
Cedripites spp	3	2	4	0	4	2	0	0	0	0
Classopollis classoides	0	0	3	0	0	0	0	0	0	0
Cycadopites carpentieri	0	0	0	0	4	0	2	0	0	3
Ginkgocycadophytus nitidus	2	0	0	0	3	5	3	0	3	4
Inaperturopollenites spp	3	0	3	0	4	0	2	0	0	3
Parvisaccites radiatus	0	0	3	0	0	0	0	0	0	0
Pinuspollenites spp	4	4	3	5	3	4	4	5	4	4
Piceaepollenites spp	3	3	2	3	4	4	3	4	5	3
Podocarpites radiatus	3	3	2	2	3	5	2	4	5	2
Taxodiaceaepollenites hiatus	3	0	2	3	2	3	1	3	4	2
Arecipites spp	0	0	0	0	0	0	0	0	0	0
Clavatipollenites hughesii	6	5	6	5	3	4	5	3	4	5
Complexiopollis abditus	11	8	7	6	7	10	6	8	7	9

Taxonomic Identification	IV1a	IV1b	IV1c	IV1d	IV1e	IV1f	IV1g	IV1h	IV1i	IV1j
Complexiopollis exigua	12	0	10	7	6	8	8	7	6	6
Complexiopollis funiculus	8	7	8	6	5	12	8	7	8	8
Complexiopollis spp	9	6	7	4	4	7	7	3	5	3
Cupuliferoipollenites spp	2	1	2	2	2	1	0	0	0	0
Cyrillaceaepollenites barghoornianus	4	3	0	4	3	3	2	4	5	4
Holkopollenites chemardensis	0	0	0	0	0	0	0	0	0	0
Holkopollenites sp A	7	6	6	10	8	7	6	7	8	7
Holkopollenites sp C	5	4	5	6	4	3	5	3	6	5
Labrapollis spp	0	0	0	0	0	0	0	0	0	0
Momipites spackmanianus	6	4	3	3	5	2	2	1	3	3
Tricolpopollenites spp	8	3	4	4	0	3	3	1	3	2
Nyssapollenites spp	0	0	0	0	0	0	0	0	0	0
Oculopollis spp	0	4	4	8	8	5	4	7	4	6
Plicapollis retusus	8	10	8	11	7	8	5	6	7	6
Liliacidites variegatus	0	5	7	5	5	5	4	0	4	0
Pseudoplicapollis spp	0	0	0	0	6	2	0	0	0	0
Proteacidites retusus	5	0	0	6	6	0	0	3	4	4
Pseudoplicapollis newmanii	6	8	8	9	4	5	6	5	7	5
Pseudoplicapollis longiannulata	4	7	6	8	5	6	7	7	0	6
Plicatopollis spp	0	0	0	0	0	0	0	0	0	0
Spheripollenites scabratus	0	8	6	4	5	5	3	6	4	4
Tricolpites crassus	0	0	0	0	0	0	0	0	0	0
Tetrapollis validus	0	0	0	0	00	0	0	0	0	0
Retitricolpites spp	0	5	2	2	0	3	4	0	3	3
Tricolpites spp	0	3	3	3	3	4	4	6	4	4

Taxonomic Identification	IV1a	IV1b	IV1c	IV1d	IV1e	IV1f	IV1g	IV1h	IV1i	IV1j
Tricolpopollenites williamsoniana	0	0	0	0	0	0	0	4	0	0
Tricolporopollenites bradonensis	0	0	0	0	0	0	0	0	0	0
Tricolporopollenites spp	0	6	0	2	0	1	2	6	3	3
Triplanosporites sinuatus	1	3	0	0	0	1	0	5	1	4
Trudopollis variabilis	0	6	0	3	2	4	7	6	3	7

Appendix 1cii: Counts of palynomorph samples from designated stratigraphic intervals (Zone II) of Ivanhoe locality of the Tar Heel Formation.

Taxonomic Identification	IV2a	IV2b	IV2c	IV2d	IV2e	IV2f	IV2g	IV2h	IVi
Botryococcus braunii	0	0	0	0	0	0	0	0	0
Ovoidites spp	4	0	3	4	3	0	0	0	0
Schizosporis parvus	5	4	4	2	0	0	0	0	0
Tetraporina spp	0	0	0	0	0	0	0	0	0
Cerodinium pannuceum	0	0	0	0	0	0	0	0	0
Isabelidinium spp	0	0	0	0	0	0	0	0	0
Pierceites pentagonus	2	0	0	0	0	0	0	0	0
Dicellites spp	5	3	2	5	3	0	4	3	5
Didymoporisporonites spp	0	0	0	0	0	2	0	2	1
Fractisporonites spp	3	2	4	4	1	2	4	2	2
Inapertisporites spp	2	3	4	4	5	3	5	3	4
Multicellaesporites spp	5	6	7	7	9	10	10	12	10
Palaencistrus spp	2	1	2	1	0	1	0	2	0
Phragmothyrites spp	1	0	2	0	1	1	2	0	0
Scolecosporites spp	1	2	2	1	2	1	2	0	2
Tetracellites spp	4	3	4	3	2	3	4	1	3
Aequitriradites ornatus	0	0	0	0	0	0	0	0	0
Camarozonosporites spp	0	0	0	0	0	0	1	2	3
Ceratosporites spp	0	0	0	0	0	0	0	0	0
Cicatricosisporites dorogensis	2	4	3	4	3	3	4	3	4
Cicatricosisporites spp	3	2	4	3	2	2	6	2	3
Cingutriletes spp	0	3	4	1	3	0	5	0	0
Cyathidites spp	4	4	5	4	5	4	3	4	5
Dictyophyllidites spp	3	2	2	3	2	2	3	3	2

Taxonomic Identification	IV2a	IV2b	IV2c	IV2d	IV2e	IV2f	IV2g	IV2h	IVi
Echinatisporis levidensis	1	1	0	0	1	0	1	0	0
Hamulatisporites spp	0	0	0	0	0	0	0	0	0
Laevigatosporites ovatus	2	4	4	5	4	4	4	0	4
Laevigatosporites spp	0	0	0	0	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0	0	0	0
Leiotriletes sp	3	0	3	2	0	0	0	0	0
Matonisporites equiexinus	0	0	4	4	0	0	0	0	0
Matonisporites spp	0	0	3	4	3	0	0	0	0
Streisosporites spp	0	0	0	0	0	0	0	0	0
Undulatisporites spp	0	0	1	2	1	2	0	0	1
Deltoidospora spp	2	0	1	2	1	1	0	0	0
Araucariacites australis	4	3	4	3	2	1	0	0	0
Araucariacites spp	5	4	4	4	3	4	3	0	4
Cedripites spp	0	3	0	0	2	0	0	0	0
Classopollis classoides	0	0	0	0	0	0	0	0	0
Cycadopites carpentieri	2	0	0	0	0	0	2	0	0
Ginkgocycadophytus nitidus	2	0	3	2	3	5	3	4	4
Inaperturopollenites spp	0	0	0	0	0	4	0	4	0
Parvisaccites radiatus	0	0	0	4	0	0	0	3	0
Pinuspollenites spp	3	4	4	3	4	6	3	4	2
Piceaepollenites spp	3	2	3	1	3	0	2	3	4
Podocarpites radiatus	2	3	3	3	3	0	3	1	3
Taxodiaceaepollenites hiatus	1	2	2	3	2	3	3	0	3
Arecipites spp	0	0	0	0	0	0	0	0	0
Clavatipollenites hughesii	6	5	6	6	4	5	3	3	3
Complexiopollis abditus	8	7	8	0	7	8	9	10	12

Taxonomic Identification	IV2a	IV2b	IV2c	IV2d	IV2e	IV2f	IV2g	IV2h	IVi
Complexiopollis exigua	7	8	7	5	5	3	5	3	4
Complexiopollis funiculus	6	9	6	7	9	7	5	8	10
Complexiopollis spp	6	5	6	4	4	5	4	3	2
Cupuliferoipollenites spp	0	1	0	0	0	0	0	3	4
Cyrillaceaepollenites barghoornianus	5	4	6	3	4	6	0	2	3
Holkopollenites chemardensis	0	0	0	0	0	0	0	0	0
Holkopollenites sp A	7	8	7	5	8	7	7	10	12
Holkopollenites sp C	4	5	4	2	5	4	6	6	5
Labrapollis spp	0	0	0	0	0	0	4	3	7
Momipites spackmanianus	2	3	2	3	4	3	0	2	5
Tricolpopollenites spp	3	4	3	2	3	4	3	3	3
Nyssapollenites spp	0	0	0	0	0	0	1	2	5
Oculopollis spp	4	6	4	0	5	5	4	7	6
Plicapollis retusus	5	7	7	6	8	9	8	8	7
Liliacidites variegatus	4	0	0	4	0	0	0	0	0
Pseudoplicapollis spp	0	4	5	4	0	0	0	0	0
Proteacidites retusus	5	0	4	3	7	5	5	3	2
Pseudoplicapollis newmanii	7	5	4	5	8	6	5	12	5
Pseudoplicapollis longiannulata	5	7	6	4	7	10	6	9	3
Plicatopollis spp	0	0	0	0	0	0	3	4	3
Spheripollenites scabratus	7	6	2	5	3	2	0	0	0
Tricolpites crassus	0	0	0	5	6	5	4	0	0
Tetrapollis validus	0	0	0	0	0	0	4	3	5
Retitricolpites spp	5	5	4	3	6	6	5	5	2
Tricolpites spp	7	8	3	6	7	5	6	7	3

Taxonomic Identification	IV2a	IV2b	IV2c	IV2d	IV2e	IV2f	IV2g	IV2h	IVi
Tricolpopollenites williamsoniana	3	6	0	4	3	4	4	3	3
Tricolporopollenites bradonensis	0	0	0	0	0	0	3	0	0
Tricolporopollenites spp	5	7	2	3	3	6	5	5	7
Triplanosporites sinuatus	6	7	1	4	5	5	4	4	5
Trudopollis variabilis	6	8	5	6	6	0	10	11	5

Appendix 1ciii: Counts of palynomorph samples from designated stratigraphic intervals (Zone III) of Ivanhoe locality of the Tar Heel Formation.

Taxonomic Identification	IV3a	IV3b	IV3c	IV3d	IV3e
Botryococcus braunii	0	0	0	0	0
Ovoidites spp	0	0	0	0	0
Schizosporis parvus	0	0	0	0	0
Tetraporina spp	0	0	0	0	0
Cerodinium pannuceum	0	0	0	0	0
Isabelidinium spp	0	0	0	0	0
Pierceites pentagonus	0	0	0	0	0
Dicellites spp	6	4	5	4	6
Didymoporisporonites spp	2	5	3	5	4
Fractisporonites spp	1	2	3	3	4
Inapertisporites spp	4	0	3	0	3
Multicellaesporites spp	11	12	12	12	14
Palaencistrus spp	0	0	0	0	0
Phragmothyrites spp	0	0	1	1	0
Scolecosporites spp	0	2	3	4	0
Tetracellites spp	6	2	4	6	3
Aequitriradites ornatus	0	0	0	0	0
Camarozonosporites spp	4	0	2	4	5
Ceratosporites spp	0	0	0	0	0
Cicatricosisporites dorogensis	2	0	3	5	3
Cicatricosisporites spp	3	2	0	0	1
Cingutriletes spp	0	3	2	3	0
Cyathidites spp	4	4	6	4	2
Dictyophyllidites spp	2	2	3	3	4

Taxonomic Identification	IV3a	IV3b	IV3c	IV3d	IV3e
Echinatisporis levidensis	0	0	2	0	0
Hamulatisporites spp	0	0	0	0	0
Laevigatosporites ovatus	5	4	5	2	3
Laevigatosporites spp	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0
Leiotriletes sp	0	0	0	0	0
Matonisporites equiexinus	0	0	0	0	0
Matonisporites spp	0	0	0	0	0
Stereisosporites spp	0	0	0	0	0
Undulatisporites spp	1	0	0	2	0
Deltoidospora spp	1	0	0	3	0
Araucariacites australis	0	0	0	0	0
Araucariacites spp	3	0	0	4	3
Cedripites spp	0	0	0	0	0
Classopollis classoides	0	0	0	0	0
Cycadopites carpentieri	0	0	0	0	0
Ginkgocycadophytus nitidus	4	3	0	2	0
Inaperturopollenites spp	0	0	0	0	0
Parvisaccites radiatus	0	0	0	0	0
Pinuspollenites spp	4	4	6	3	5
Piceaepollenites spp	4	4	4	5	3
Podocarpites radiatus	3	5	5	6	5
Taxodiaceaepollenites hiatus	1	3	4	3	2
Arecipites spp	4	0	5	4	5
Clavatipollenites hughesii	2	2	3	4	2
Complexiopollis abditus	11	10	10	12	7

Taxonomic Identification	IV3a	IV3b	IV3c	IV3d	IV3e
Complexiopollis exigua	2	2	3	5	4
Complexiopollis funiculus	5	8	9	8	5
Complexiopollis spp	3	4	4	2	3
Cupuliferoipollenites spp	2	5	4	4	4
Cyrillaceaepollenites barghoornianus	3	1	0	2	0
Holkopollenites chemardensis	0	8	6	7	8
Holkopollenites sp A	7	4	6	5	5
Holkopollenites sp C	5	0	5	0	0
Labrapollis spp	6	8	8	8	7
Momipites spackmanianus	3	3	4	3	2
Tricolpopollenites spp	3	2	3	2	2
Nyssapollenites spp	2	4	5	3	6
Oculopollis spp	3	5	3	4	5
Plicapollis retusus	6	6	4	4	6
Liliacidites variegatus	0	0	0	0	0
Pseudoplicapollis spp	0	0	0	0	0
Proteacidites retusus	4	4	4	3	5
Pseudoplicapollis newmanii	5	7	4	6	7
Pseudoplicapollis longiannulata	6	6	5	4	5
Plicatopollis spp	4	5	7	3	4
Spheripollenites scabratus	0	0	0	0	0
Tricolpites crassus	4	5	7	3	4
Tetrapollis validus	5	7	3	3	4
Retitricolpites spp	6	4	3	4	4
Tricolpites spp	2	5	2	2	5

Taxonomic Identification	IV3a	IV3b	IV3c	IV3d	IV3e
Tricolpopollenites williamsoniana	4	3	2	1	3
Tricolporopollenites bradonensis	0	2	1	3	4
Tricolporopollenites spp	6	7	3	1	5
Triplanosporites sinuatus	7	4	2	1	4
Trudopollis variabilis	8	7	4	4	6

Appendix 1d: Counts of palynomorph samples from designated stratigraphic intervals of Lock locality of the Tar Heel Formation.

Taxonomic Identification	LK1	LK2	LK3	LK4	LK5	LK6	LK7	LK8
Botryococcus braunii	0	2	0	0	0	0	0	0
Ovoidites spp	0	0	0	0	0	0	0	0
Schizosporis parvus	4	4	3	0	0	0	0	0
Tetraporina spp	0	0	0	0	0	0	0	0
Cerodinium pannuceum	0	0	0	0	0	0	0	0
Isabelidinium spp	3	2	0	0	0	0	0	0
Pierceites pentagonus	0	0	0	0	0	0	0	0
Dicellites spp	5	4	2	6	7	5	4	5
Didymoporisporonites spp	0	0	0	0	2	3	5	3
Fractisporonites spp	4	5	3	4	1	1	2	2
Inapertisporites spp	3	4	2	5	4	3	1	2
Multicellaesporites spp	2	3	2	4	3	1	0	3
Palaencistrus spp	0	0	0	0	0	0	0	0
Phragmothyrites spp	0	2	1	2	0	0	0	1
Scolecosporites spp	0	0	0	0	0	0	0	0
Tetracellites spp	5	4	5	4	3	3	2	4
Aequitriradites ornatus	0	0	0	0	0	0	0	0
Camarozonosporites spp	0	0	0	0	4	3	3	4
Ceratosporites spp	0	0	0	0	0	0	0	0
Cicatricosisporites dorogensis	3	4	2	4	5	4	6	5.
Cicatricosisporites spp	4	3	1	3	4	3	5	3
Cingutriletes spp	6	5	4	2	3	0	0	0
Cyathidites spp	4	6	5	4	6	5	3	4
Dictyophyllidites spp	3	3	6	2	5	4	4	3
Echinatisporis levidensis	0	2	1	0	3	10	1	2

Taxonomic Identification	LK1	LK2	LK3	LK4	LK5	LK6	LK7	LK8
Hamulatisporites spp	0	0	0	0	0	0	0	0
Laevigatosporites ovatus	3	4	4	3	6	4	3	3
Laevigatosporites spp	0	0	0	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0	0	0
Leiotriletes sp	4	3	0	0	2	0	0	0
Matonisporites equiexinus	5	5	5	5	4	0	0	0
Matonisporites spp	3	4	4	0	0	0	0	0
Stereisosporites spp	0	0	0	0	0	0	0	0
Undulatisporites spp	0	0	0	0	0	0	0	0
Deltoidospora spp	0	0	0	0	0	0	0	0
Araucariacites australis	3	2	5	2	1	1	1	0
Araucariacites spp	0	4	3	2	3	4	4	0
Cedripites spp	4	6	4	3	0	0	0	0
Classopollis classoides	0	0	0	0	0	0	0	0
Cycadopites carpentieri	0	0	0	0	0	0	0	0
Ginkgocycadophytus nitidus	0	3	2	1	4	1	3	3
Inaperturopollenites spp	0	4	0	0	0	0	0	0
Parvisaccites radiatus	0	3	0	2	0	0	0	0
Pinuspollenites spp	3	4	1	2	5	2	4	4
Piceaepollenites spp	4	3	2	3	6	3	3	5
Podocarpites radiatus	3	2	3	3	4	4	5	3
Taxodiaceaepollenites hiatus	1	4	3	1	2	2	3	4
Arecipites spp	0	0	0	0	0	0	4	5
Clavatipollenites hughesii	6	6	5	2	3	2	3	4
Complexiopollis abditus	10	8	9	9	7	10	5	8
Complexiopollis exigua	7	7	5	8	6	4	3	3

Taxonomic Identification	LK1	LK2	LK3	LK4	LK5	LK6	LK7	LK8
Complexiopollis funiculus	7	4	6	5	5	8	8	9
Complexiopollis spp	5	5	4	4	4	4	6	4
Cupuliferoipollenites spp	0	0	0	0	5	3	5	4
Cyrillaceaepollenites barghoornianus	4	5	6	3	2	3	4	2
Holkopollenites chemardensis	0	0	0	0	3	5	6	3
Holkopollenites sp A	10	7	8	9	8	6	7	7
Holkopollenites sp C	5	3	4	6	3	3	4	4
Labrapollis spp	0	0	0	2	5	4	3	2
Momipites spackmanianus	4	4	5	2	4	4	4	3
Tricolpopollenites spp	3	5	4	1	3	1	3	4
Nyssapollenites spp	0	0	0	0	4	4	5	7
Oculopollis spp	4	4	2	3	3	2	3	4
Plicapollis retusus	4	7	8	3	6	6	7	3
Liliacidites variegatus	0	0	0	0	4	0	0	2
Pseudoplicapollis spp	0	0	0	4	5	3	0	0
Proteacidites retusus	3	2	4	3	4	5	6	0
Pseudoplicapollis newmanii	4	4	5	8	5	8	7	6
Pseudoplicapollis longiannulata	5	3	5	7	6	5	6	8
Plicatopollis spp	0	0	0	0	0	3	3	5
Spheripollenites scabratus	0	0	0	0	0	0	0	0
Tricolpites crassus	0	0	0	6	2	4	6	4
Tetrapollis validus	0	0	0	3	1	2	5	7
Retitricolpites spp	6	4	5	6	3	5	5	6
Tricolpites spp	7	5	6	8	1	6	4	4
Tricolpopollenites williamsoniana	5	3	4	5	0	5	4	3

Taxonomic Identification	LK1	LK2	LK3	LK4	LK5	LK6	LK7	LK8
Tricolporopollenites bradonensis	0	0	0	0	0	0	0	0
Tricolporopollenites spp	7	4	8	8	3	6	5	4
Triplanosporites sinuatus	6	1	5	7	4	8	1	3
Trudopollis variabilis	9	5	12	9	4	13	5	4

Appendix 1e i: Counts of palynomorph samples from designated stratigraphic intervals of Tar River locality of the Tar Heel Formation.

Taxonomic Identification	TR0	TR2	TR4	TR6	TR8	TR10	TR12	TR14	TR16	TR18
Botryococcus braunii	4	3	2	1	3	2	3	2	3	2
Ovoidites spp	3	2	3	3	2	3	4	3	2	1
Schizosporis parvus	2	5	2	2	4	3	2	2	4	3
Tetraporina spp	2	3	2	1	3	2	3	4	2	2
Cerodinium pannuceum	0	0	0	0	0	0	0	0	0	0
Isabelidinium spp	0	3	2	0	2	2	2	0	0	0
Pierceites pentagonus	0	0	0	0	0	0	0	0	0	0
Dicellites spp	0	2	1	3	4	1	4	3	1	3
Didymoporisporonites spp	2	2	0	0	1	0	2	1	0	2
Fractisporonites spp	4	3	1	3	2	3	2	2	3	3
Inapertisporites spp	0	2	3	2	3	2	3	2	2	4
Multicellaesporites spp	1	1	2	4	1	1	2	3	3	2
Palaencistrus spp	1	0	1	2	1	0	1	0	1	1
Phragmothyrites spp	1	0	0	2	2	0	1	0	1	1
Scolecosporites spp	0	0	1	2	1	1	1	2	0	0
Tetracellites spp	3	4	3	4	3	3	2	4	4	3
Aequitriradites ornatus	0	0	0	0	0	0	2	2	3	4
Camarozonosporites spp	3	2	3	3	0	2	1	2	1	1
Ceratosporites spp	2	1	2	1	2	1	2	1	2	2
Cicatricosisporites dorogensis	2	3	3	3	1	4	2	4	3	3
Cicatricosisporites spp	1	4	2	2	3	2	3	1	2	3
Cingutriletes spp	2	5	2	3	4	3	4	4	2	4
Cyathidites spp	2	3	3	4	3	5	3	3	2	4
Dictyophyllidites spp	3	4	2	3	3	9	3	2	3	2

Taxonomic Identification	TR0	TR2	TR4	TR6	TR8	TR10	TR12	TR14	TR16	TR18
Echinatisporis levidensis	0	1	3	1	0	0	2	1	0	0
Hamulatisporites spp	2	2	2	3	2	2	4	4	3	3
Laevigatosporites ovatus	3	5	2	4	3	4	3	3	4	2
Laevigatosporites spp	1	2	3	3	4	3	2	1	3	1
Leiotriletes pseudomesozoicus	2	4	2	3	2	2	2	3	2	1
Leiotriletes sp	3	4	4	2	4	3	3	4	2	0
Matonisporites equiexinus	3	2	3	2	2	4	0	0	3	0
Matonisporites spp	2	3	4	4	3	2	2	3	4	3
Stereisosporites spp	4	3	3	3	2	3	4	3	4	2
Undulatisporites spp	0	2	1	2	1	2	2	3	1	0
Deltoidospora spp	0	2	1	1	1	1	1	0	0	0
Araucariacites australis	2	1	2	2	0	1	2	0	2	1
Araucariacites spp	4	5	3	4	2	4	3	4	3	2
Cedripites spp	3	4	4	2	3	5	3	4	4	3
Classopollis classoides	3	4	5	3	4	3	4	3	3	2
Cycadopites carpentieri	0	3	4	3	0	2	1	0	4	3
Ginkgocycadophytus nitidus	2	4	3	4	2	3	3	4	3	2
Inaperturopollenites spp	0	4	4	2	3	2	3	4	3	2
Parvisaccites radiatus	0	0	0	0	2	3	2	3	2	3
Pinuspollenites spp	3	4	4	3	3	5	3	4	5	4
Piceaepollenites spp	0	3	3	2	2	6	4	3	3	4
Podocarpites radiatus	3	3	4	3	4	2	3	2	4	2
Taxodiaceaepollenites hiatus	2	0	3	2	3	2	0	1	2	2
Arecipites spp	0	0	0	0	0	0	0	0	0	0
Clavatipollenites hughesii	3	4	4	2	4	4	2	4	4	3
Complexiopollis abditus	5	7	6	7	8	6	7	8	7	8

Taxonomic Identification	TR0	TR2	TR4	TR6	TR8	TR10	TR12	TR14	TR16	TR18
Complexiopollis exigua	6	5	5	4	5	4	5	4	5	5
Complexiopollis funiculus	4	6	7	6	5	6	6	5	6	3
Complexiopollis spp	3	4	3	4	3	4	3	5	2	2
Cupuliferoipollenites spp	0	0	2	3	1	2	0	0	0	2
Cyrillaceaepollenites barghoornianus	4	3	4	4	2	3	2	3	4	4
Holkopollenites chemardensis	0	0	0	0	3	2	4	4	2	2
Holkopollenites sp A	5	2	3	4	2	4	5	6	5	4
Holkopollenites sp C	4	1	2	3	2	5	2	4	4	3
Labrapollis spp	5	4	5	4	0	5	3	4	5	4
Momipites spackmanianus	3	4	3	3	3	3	2	3	3	4
Tricolpopollenites spp	4	3	2	4	2	4	3	2	4	2
Nyssapollenites spp	5	3	5	4	5	4	4	4	5	4
Oculopollis spp	4	1	2	3	2	3	2	3	2	3
Plicapollis retusus	5	3	3	5	3	5	3	5	4	4
Liliacidites variegatus	4	1	2	4	4	3	2	0	0	3
Pseudoplicapollis spp	5	3	4	2	3	1	2	0	0	4
Proteacidites retusus	6	4	3	3	2	2	3	2	3	3
Pseudoplicapollis newmanii	7	3	4	5	5	2	4	3	4	5
Pseudoplicapollis longiannulata	4	0	0	3	4	1	2	2	5	4
Plicatopollis spp	5	0	3	4	3	0	3	4	0	4
Spheripollenites scabratus	4	2	2	3	4	0	1	3	2	5
Tricolpites crassus	0	0	0	0	0	0	0	0	0	0
Tetrapollis validus	4	2	3	0	5	0	2	0	0	3
Retitricolpites spp	4	3	4	2	2	2	3	4	3	4
Tricolpites spp	5	4	2	1	4	3	4	3	2	3

Taxonomic Identification	TR0	TR2	TR4	TR6	TR8	TR10	TR12	TR14	TR16	TR18
Tricolpopollenites williamsoniana	4	3	2	2	3	2	3	2	3	2
Tricolporopollenites bradonensis	0	0	0	0	0	0	0	0	0	0
Tricolporopollenites spp	5	4	4	3	4	3	4	3	4	5
Triplanosporites sinuatus	3	1	3	3	2	0	3	1	3	3
Trudopollis variabilis	2	3	3	2	5	4	4	5	5	3

Appendix 1e ii: Counts of palynomorph samples from designated stratigraphic intervals of Tar River locality of the Tar Heel Formation.

Taxonomic Identification	TR 20	TR 22	TR 24	TR 26	TR 28	TR 30	TR 32	TR 34	TR 36	TR 38	TR 40
Botryococcus braunii	3	2	0	0	0	0	2	3	2	2	3
Ovoidites spp	0	0	0	0	0	0	1	2	1	3	4
Schizosporis parvus	2	2	0	0	0	0	2	3	4	3	4
Tetraporina spp	3	1	1	2	0	0	2	1	2	1	3
Cerodinium pannuceum	0	0	0	0	0	0	0	0	0	0	0
Isabelidinium spp	1	2	2	1	0	0	0	0	0	0	0
Pierceites pentagonus	0	0	0	0	0	0	0	0	0	0	0
Dicellites spp	2	1	4	3	1	3	4	5	1	4	2
Didymoporisporonites spp	1	0	1	0	1	1	0	1	0	0	1
Fractisporonites spp	4	3	3	2	2	3	2	1	2	3	1
Inapertisporites spp	1	4	4	8	2	1	3	3	1	2	3
Multicellaesporites spp	4	2	3	3	4	3	1	2	2	4	2
Palaencistrus spp	1	0	0	2	0	1	1	0	2	0	0
Phragmothyrites spp	0	0	1	0	0	1	1	0	1	0	0
Scolecosporites spp	0	0	2	1	0	0	0	1	0	0	1
Tetracellites spp	2	3	4	3	2	3	2	4	3	4	2
Aequitriradites ornatus	3	2	3	0	3	0	2	3	0	2	1
Camarozonosporites spp	3	3	4	0	2	0	4	4	3	4	3
Ceratosporites spp	3	1	2	2	1	0	1	2	1	1	2
Cicatricosisporites dorogensis	4	4	2	4	4	2	4	4	2	3	2
Cicatricosisporites spp	2	3	4	3	3	2	4	3	4	3	4
Cingutriletes spp	2	4	3	4	5	4	3	2	3	4	5
Cyathidites spp	3	5	3	4	3	5	4	3	5	3	3
Dictyophyllidites spp	3	4	3	2	4	4	2	4	4	2	4

Taxonomic Identification	TR 20	TR 22	TR 24	TR 26	TR 28	TR 30	TR 32	TR 34	TR 36	TR 38	TR 40
Echinatisporis levidensis	1	0	2	2	0	1	0	0	0	2	0
Hamulatisporites spp	3	5	4	3	3	2	4	3	2	3	2
Laevigatosporites ovatus	5	4	2	2	4	3	4	2	4	5	3
Laevigatosporites spp	3	2	2	4	2	2	3	1	2	3	4
Leiotriletes pseudomesozoicus	2	4	3	2	2	1	0	0	0	0	0
Leiotriletes sp	0	0	0	0	0	0	0	0	0	0	0
Matonisporites equiexinus	2	0	0	4	0	0	3	2	3	0	3
Matonisporites spp	2	3	3	5	3	4	2	1	4	3	2
Stereisosporites spp	3	2	4	3	4	3	3	2	2	4	3
Undulatisporites spp	2	0	1	0	0	1	0	2	0	1	0
Deltoidospora spp	0	0	0	0	0	0	0	1	0	0	0
Araucariacites australis	0	1	2	0	1	0	2	3	2	3	1
Araucariacites spp	3	4	3	4	3	2	3	4	3	5	3
Cedripites spp	1	3	0	0	2	2	4	3	4	4	3
Classopollis classoides	3	4	4	6	3	3	2	4	3	3	4
Cycadopites carpentieri	2	3	0	3	4	2	0	0	2	0	0
Ginkgocycadophytus nitidus	3	4	4	4	4	3	2	0	3	0	2
Inaperturopollenites spp	2	5	3	3	3	4	3	3	4	0	3
Parvisaccites radiatus	2	0	2	0	0	0	2	2	1	3	2
Pinuspollenites spp	3	4	4	3	4	5	3	4	3	4	5
Piceaepollenites spp	4	5	3	4	3	2	2	3	4	5	4
Podocarpites radiatus	3	4	2	3	4	3	3	2	3	4	3
Taxodiaceaepollenites hiatus	2	3	3	2	3	0	0	0	2	0	1
Arecipites spp	0	0	0	0	0	0	0	0	0	0	0
Clavatipollenites hughesii	4	4	2	5	4	4	3	4	3	5	4
Complexiopollis abditus	6	5	7	9	7	8	4	6	7	8	7

Taxonomic Identification	TR 20	TR 22	TR 24	TR 26	TR 28	TR 30	TR 32	TR 34	TR 36	TR 38	TR 40
Complexiopollis exigua	4	6	4	7	8	5	5	3	6	6	4
Complexiopollis funiculus	5	7	8	7	6	4	6	4	5	7	5
Complexiopollis spp	2	5	3	5	5	5	4	3	6	3	4
Cupuliferoipollenites spp	0	0	0	0	3	0	0	0	2	0	1
Cyrillaceaepollenites barghoornianus	3	6	3	5	4	3	3	4	3	4	5
Holkopollenites chemardensis	0	0	0	0	3	4	4	3	4	3	3
Holkopollenites sp A	5	5	4	7	6	5	3	5	5	4	3
Holkopollenites sp C	3	4	2	5	5	3	1	3	4	2	1
Labrapollis spp	4	6	4	5	3	4	5	4	5	3	4
Momipites spackmanianus	5	5	5	6	3	5	3	2	4	2	5
Tricolpopollenites spp	3	4	3	4	4	6	4	3	3	2	3
Nyssapollenites spp	4	5	6	5	5	6	3	4	5	3	5
Oculopollis spp	2	4	3	4	3	3	2	3	2	3	4
Plicapollis retusus	3	5	4	6	6	4	6	5	5	6	5
Liliacidites variegatus	2	3	5	3	5	6	4	3	4	0	4
Pseudoplicapollis spp	3	2	4	3	4	4	3	4	3	3	4
Proteacidites retusus	4	0	3	4	5	4	5	3	2	2	1
Pseudoplicapollis newmanii	3	3	4	5	6	7	6	5	4	3	4
Pseudoplicapollis longiannulata	2	0	3	2	0	4	4	3	0	3	2
Plicatopollis spp	3	0	4	3	3	5	6	4	2	0	0
Spheripollenites scabratus	4	2	3	0	2	4	5	4	4	3	2
Tricolpites crassus	0	0	0	0	0	0	0	0	0	0	0
Tetrapollis validus	4	2	2	2	2	3	3	5	3	4	3
Retitricolpites spp	3	3	3	2	3	4	4	3	2	5	4
Tricolpites spp	4	1	4	1	1	3	2	2	3	4	3
Tricolpopollenites williamsoniana	3	0	0	2	0	3	4	2	4	0	2

Taxonomic Identification	TR 20	TR 22	TR 24	TR 26	TR 28	TR 30	TR 32	TR 34	TR 36	TR 38	TR 40
Tricolporopollenites bradonensis	0	0	0	0	0	0	0	0	0	0	0
Tricolporopollenites spp	5	4	2	0	2	3	3	5	4	3	4
Triplanosporites sinuatus	4	0	1	0	0	1	3	3	2	4	3
Trudopollis variabilis	5	2	3	2	2	3	3	5	2	5	2

Appendix 1f i: Counts of palynomorph samples from designated stratigraphic intervals (Zone 1) of Willis Creek locality of the Tar Heel Formation.

Taxonomic Identification	WC1a	WC1b	WC1c	WC1d	WC1e	WC1f	WC1g
Botryococcus braunii	4	2	3	0	3	2	2
Ovoidites spp	4	2	3	0	3	2	2
Schizosporis parvus	3	0	4	0	0	4	3
Tetraporina spp	0	0	0	0	0	0	0
Cerodinium pannuceum	3	3	5	7	0	0	0
Isabelidinium spp	2	0	2	5	0	3	0
Pierceites pentagonus	3	4	4	6	0	0	0
Dicellites spp	2	4	3	5	5	3	1
Didymoporisporonites spp	0	0	0	0	2	2	2
Fractisporonites spp	4	2	2	5	2	1	3
Inapertisporites spp	3	4	2	3	1	3	2
Multicellaesporites spp	1	1	0	3	3	4	3
Palaencistrus spp	4	2	1	4	3	2	2
Phragmothyrites spp	1	0	0	2	1	0	1
Scolecosporites spp	0	2	0	0	2	1	2
Tetracellites spp	2	4	4	2	4	4	2
Aequitriradites ornatus	0	0	0	0	0	0	0
Camarozonosporites spp	0	0	0	0	0	0	0
Ceratosporites spp	0	0	0	0	0	0	0
Cicatricosisporites dorogensis	3	1	5	1	2	5	3
Cicatricosisporites spp	4	2	2	2	3	3	2
Cingutriletes spp	5	4	3	2	3	4	2
Cyathidites spp	3	5	6	3	4	4	3
Dictyophyllidites spp	3	0	2	4	4	3	2

Taxonomic Identification	WC1a	WC1b	WC1c	WC1d	WC1e	WC1f	WC1g
Echinatisporis levidensis	0	0	2	2	0	2	1
Hamulatisporites spp	0	0	0	0	3	4	3
Laevigatosporites ovatus	3	6	3	4	4	3	4
Laevigatosporites spp	0	0	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0	0
Leiotriletes sp	0	4	0	0	1	2	3
Matonisporites equiexinus	0	4	4	5	4	3	3
Matonisporites spp	0	5	3	0	0	2	0
Stereisosporites spp	0	0	0	0	0	0	0
Undulatisporites spp	0	2	1	0	2	3	0
Deltoidospora spp	0	0	0	0	3	1	0
Araucariacites australis	4	4	4	6	5	5	4
Araucariacites spp	3	3	6	4	6	3	4
Cedripites spp	5	2	4	0	4	0	0
Classopollis classoides	5	4	3	0	6	4	0
Cycadopites carpentieri	0	0	0	0	0	0	0
Ginkgocycadophytus nitidus	3	0	5	0	4	2	2
Inaperturopollenites spp	4	4	5	0	0	0	3
Parvisaccites radiatus	0	0	0	0	5	2	3
Pinuspollenites spp	3	4	4	5	4	4	2
Piceaepollenites spp	3	5	3	4	5	2	4
Podocarpites radiatus	4	4	3	3	6	3	5
Taxodiaceaepollenites hiatus	2	2	1	2	0	0	0
Arecipites spp	0	0	0	0	0	0	0
Clavatipollenites hughesii	3	6	7	7	6	4	4
Complexiopollis abditus	8	7	8	8	9	7	6

Taxonomic Identification	WC1a	WC1b	WC1c	WC1d	WC1e	WC1f	WC1g
Complexiopollis exigua	7	8	4	8	7	5	6
Complexiopollis funiculus	6	6	7	7	4	6	5
Complexiopollis spp	4	4	5	2	3	4	3
Cupuliferoipollenites spp	0	0	0	0	0	0	0
Cyrillaceaepollenites barghoornianus	5	3	3	4	4	0	3
Holkopollenites chemardensis	0	0	0	0	0	0	0
Holkopollenites sp A	7	6	4	7	5	7	5
Holkopollenites sp C	5	4	3	5	3	3	3
Labrapollis spp	0	0	0	0	0	0	0
Momipites spackmanianus	6	2	2	4	5	5	2
Tricolpopollenites spp	5	3	3	3	3	4	3
Nyssapollenites spp	0	0	0	0	0	0	0
Oculopollis spp	6	5	2	3	5	6	5
Plicapollis retusus	8	6	4	7	8	7	8
Liliacidites variegatus	0	0	0	0	3	0	5
Pseudoplicapollis spp	0	0	0	0	0	5	6
Proteacidites retusus	5	3	4	4	5	4	4
Pseudoplicapollis newmanii	8	7	8	6	8	6	7
Pseudoplicapollis longiannulata	6	5	7	5	4	6	4
Plicatopollis spp	0	0	0	0	0	0	0
Spheripollenites scabratus	5	5	7	7	5	5	6
Tricolpites crassus	2	0	0	0	3	4	5
Tetrapollis validus	0	0	0	0	0	0	0
Retitricolpites spp	2	5	3	5	2	3	5
Tricolpites spp	2	6	4	4	1	3	4

Taxonomic Identification	WC1a	WC1b	WC1c	WC1d	WC1e	WC1f	WC1g
Tricolpopollenites williamsoniana	0	3	3	3	0	2	4
Tricolporopollenites bradonensis	0	0	0	0	0	0	0
Tricolporopollenites spp	3	5	5	3	2	4	6
Triplanosporites sinuatus	2	0	2	2	0	5	6
Trudopollis variabilis	6	8	6	7	5	4	8

Appendix 1f ii: Counts of palynomorph samples from designated stratigraphic intervals (Zone II) of Willis Creek locality of the Tar Heel Formation.

Taxonomic Identification	WC2a	WC2b	WC2c	WC2d	WC2e	WC2f
Botryococcus braunii	0	0	0	0	0	0
Ovoidites spp	0	0	0	0	0	0
Schizosporis parvus	0	0	0	0	0	0
Tetraporina spp	0	0	0	0	0	0
Cerodinium pannuceum	3	0	0	3	3	0
Isabelidinium spp	4	2	0	2	0	0
Pierceites pentagonus	3	3	0	3	2	0
Dicellites spp	4	2	0	4	2	4
Didymoporisporonites spp	0	0	0	2	2	3
Fractisporonites spp	3	3	2	3	3	2
Inapertisporites spp	2	2	1	2	0	3
Multicellaesporites spp	4	3	4	4	3	3
Palaencistrus spp	2	3	1	1	0	1
Phragmothyrites spp	2	0	0	1	0	2
Scolecosporites spp	0	2	1	2	2	3
Tetracellites spp	0	3	2	3	3	4
Aequitriradites ornatus	3	0	0	4	4	3
Camarozonosporites spp	0	0	0	0	0	0
Ceratosporites spp	0	3	0	2	3	2
Cicatricosisporites dorogensis	4	3	4	2	4	3
Cicatricosisporites spp	2	2	3	1	2	2
Cingutriletes spp	4	3	0	0	0	0
Cyathidites spp	2	3	4	4	4	5
Dictyophyllidites spp	1	0	3	3	2	3

Taxonomic Identification	WC2a	WC2b	WC2c	WC2d	WC2e	WC2f
Echinatisporis levidensis	0	0	2	2	1	1
Hamulatisporites spp	0	0	0	4	3	4
Laevigatosporites ovatus	1	5	3	2	4	3
Laevigatosporites spp	0	0	0	3	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0
Leiotriletes sp	3	4	3	3	4	2
Matonisporites equiexinus	4	3	4	4	4	0
Matonisporites spp	0	2	3	3	3	0
Stereisosporites spp	0	0	0	0	0	0
Undulatisporites spp	2	0	2	3	2	0
Deltoidospora spp	0	3	2	3	2	0
Araucariacites australis	4	5	4	3	3	4
Araucariacites spp	3	2	3	2	3	3
Cedripites spp	0	4	0	0	0	2
Classopollis classoides	4	3	4	4	5	4
Cycadopites carpentieri	0	0	0	0	0	0
Ginkgocycadophytus nitidus	3	1	4	2	4	3
Inaperturopollenites spp	0	4	3	0	0	3
Parvisaccites radiatus	3	2	4	0	4	0
Pinuspollenites spp	2	3	5	4	3	4
Piceaepollenites spp	3	1	3	3	2	3
Podocarpites radiatus	4	2	5	3	2	4
Taxodiaceaepollenites hiatus	0	0	4	0	0	2
Arecipites spp	0	0	0	0	0	0
Clavatipollenites hughesii	5	3	6	5	4	3
Complexiopollis abditus	8	7	8	7	6	7

Taxonomic Identification	WC2a	WC2b	WC2c	WC2d	WC2e	WC2f
Complexiopollis exigua	5	6	7	8	5	5
Complexiopollis funiculus	5	8	9	8	7	7
Complexiopollis spp	3	2	5	4	3	3
Cupuliferoipollenites spp	0	0	0	2	0	2
Cyrillaceaepollenites barghoornianus	2	5	6	4	4	2
Holkopollenites chemardensis	0	0	0	0	0	0
Holkopollenites sp A	4	4	7	5	6	7
Holkopollenites sp C	3	4	5	4	5	6
Labrapollis spp	0	3	5	6	6	7
Momipites spackmanianus	4	0	4	5	2	3
Tricolpopollenites spp	2	0	3	3	3	2
Nyssapollenites spp	0	0	0	0	0	0
Oculopollis spp	6	6	5	3	4	3
Plicapollis retusus	8	7	8	5	6	4
Liliacidites variegatus	6	0	6	3	0	3
Pseudoplicapollis spp	5	6	5	4	9	4
Proteacidites retusus	0	3	3	1	4	3
Pseudoplicapollis newmanii	7	6	5	3	4	5
Pseudoplicapollis longiannulata	6	4	4	2	3	5
Plicatopollis spp	0	0	0	0	0	0
Spheripollenites scabratus	6	3	3	3	4	3
Tricolpites crassus	5	4	0	3	5	4
Tetrapollis validus	0	2	1	1	2	2
Retitricolpites spp	4	4	2	2	3	3
Tricolpites spp	5	5	3	3	4	4

Taxonomic Identification	WC2a	WC2b	WC2c	WC2d	WC2e	WC2f
Tricolpopollenites williamsoniana	4	3	0	3	3	4
Tricolporopollenites bradonensis	0	0	0	0	0	0
Tricolporopollenites spp	7	5	1	3	4	5
Triplanosporites sinuatus	5	7	2	5	4	4
Trudopollis variabilis	6	12	4	5	5	5

Appendix 1f iii: Counts of palynomorph samples from designated stratigraphic intervals (Buff colored Sandstone Bed) of Willis Creek locality of the Tar Heel Formation.

Taxonomic Identification	WC3a	WC3b	WC3c	WC3d	WC3e
Botryococcus braunii	4	2	3	2	0
Ovoidites spp	3	4	3	4	0
Schizosporis parvus	4	2	4	2	0
Tetraporina spp	2	3	3	2	0
Cerodinium pannuceum	0	0	0	3	4
Isabelidinium spp	0	3	0	2	3
Pierceites pentagonus	0	0	0	3	2
Dicellites spp	4	1	4	2	3
Didymoporisporonites spp	2	3	3	3	3
Fractisporonites spp	2	3	1	3	2
Inapertisporites spp	3	2	2	2	3
Multicellaesporites spp	4	4	2	5	4
Palaencistrus spp	1	2	1	2	1
Phragmothyrites spp	1	2	1	0	2
Scolecosporites spp	2	3	3	0	1
Tetracellites spp	3	3	2	2	2
Aequitriradites ornatus	3	4	3	2	0
Camarozonosporites spp	2	2	0	3	2
Ceratosporites spp	1	2	1	2	3
Cicatricosisporites dorogensis	2	4	2	3	2
Cicatricosisporites spp	2	3	2	2	3
Cingutriletes spp	0	4	3	3	2
Cyathidites spp	4	3	1	4	3
Dictyophyllidites spp	3	2	3	1	3

Taxonomic Identification	WC3a	WC3b	WC3c	WC3d	WC3e
Echinatisporis levidensis	0	2	1	0	0
Hamulatisporites spp	3	2	3	2	4
Laevigatosporites ovatus	4	3	4	3	3
Laevigatosporites spp	0	4	2	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0
Leiotriletes sp	0	5	3	3	4
Matonisporites equiexinus	0	4	2	4	0
Matonisporites spp	0	3	3	2	0
Stereisosporites spp	0	0	0	0	0
Undulatisporites spp	0	2	3	2	3
Deltoidospora spp	0	3	3	2	2
Araucariacites australis	3	2	4	1	0
Araucariacites spp	4	3	2	3	2
Cedripites spp	0	0	0	2	0
Classopollis classoides	3	4	4	2	4
Cycadopites carpentieri	0	0	0	0	0
Ginkgocycadophytus nitidus	2	3	3	2	2
Inaperturopollenites spp	0	0	4	0	0
Parvisaccites radiatus	3	4	3	3	3
Pinuspollenites spp	4	3	4	2	4
Piceaepollenites spp	4	3	3	2	2
Podocarpites radiatus	5	2	4	3	1
Taxodiaceaepollenites hiatus	3	3	0	1	2
Arecipites spp	0	0	2	2	3
Clavatipollenites hughesii	4	3	2	1	2
Complexiopollis abditus	9	6	6	5	7

Taxonomic Identification	WC3a	WC3b	WC3c	WC3d	WC3e
Complexiopollis exigua	3	6	4	1	4
Complexiopollis funiculus	6	4	5	4	6
Complexiopollis spp	5	3	4	2	4
Cupuliferoipollenites spp	0	1	3	2	3
Cyrillaceaepollenites barghoornianus	3	3	4	2	5
Holkopollenites chemardensis	0	2	3	2	2
Holkopollenites sp A	5	7	4	3	5
Holkopollenites sp C	4	3	4	1	3
Labrapollis spp	6	4	5	3	6
Momipites spackmanianus	3	3	3	2	3
Tricolpopollenites spp	2	2	4	3	2
Nyssapollenites spp	0	0	1	3	5
Oculopollis spp	3	3	3	2	4
Plicapollis retusus	5	7	5	4	6
Liliacidites variegatus	4	0	0	0	0
Pseudoplicapollis spp	0	4	4	5	0
Proteacidites retusus	3	3	3	2	4
Pseudoplicapollis newmanii	6	4	6	5	5
Pseudoplicapollis longiannulata	2	3	3	3	4
Plicatopollis spp	0	2	1	2	3
Spheripollenites scabratus	5	1	1	2	4
Tricolpites crassus	4	0	0	3	5
Tetrapollis validus	3	2	1	4	5
Retitricolpites spp	4	2	3	4	4
Tricolpites spp	5	3	2	5	3

Taxonomic Identification	WC3a	WC3b	WC3c	WC3d	WC3e
Tricolpopollenites williamsoniana	4	0	3	4	2
Tricolporopollenites bradonensis	0	0	0	3	2
Tricolporopollenites spp	5	3	4	5	3
Triplanosporites sinuatus	5	2	1	6	1
Trudopollis variabilis	2	2	4	8	3

Appendix 1f iv. Counts of palynomorph samples from designated stratigraphic intervals (Zone IV) of Willis Creek locality of the Tar Heel Formation.

Taxonomic Identification	WC4a	WC4b	WC4c	WC4d	WC4e	WC4f	WC4g	WC4h
Botryococcus braunii	0	0	0	0	0	0	0	0
Ovoidites spp	0	0	0	0	0	0	0	0
Schizosporis parvus	0	0	0	0	0	0	0	0
Tetraporina spp	0	0	0	0	0	0	0	0
Cerodinium pannuceum	2	3	2	2	3	3	2	0
Isabelidinium spp	2	1	3	1	2	0	0	0
Pierceites pentagonus	3	2	2	3	2	3	2	0
Dicellites spp	1	4	3	4	3	1	2	1
Didymoporisporonites spp	3	3	2	2	2	2	1	2
Fractisporonites spp	1	4	2	4	4	3	5	4
Inapertisporites spp	2	2	1	2	2	2	1	2
Multicellaesporites spp	4	5	6	7	7	6	9	11
Palaencistrus spp	0	0	0	0	0	0	0	0
Phragmothyrites spp	2	2	1	0	1	1	0	1
Scolecosporites spp	2	3	1	1	2	2	1	3
Tetracellites spp	1	3	2	2	3	4	2	1
Aequitriradites ornatus	2	3	2	1	0	0	0	0
Camarozonosporites spp	3	4	2	3	2	3	4	3
Ceratosporites spp	2	1	2	1	0	2	0	0
Cicatricosisporites dorogensis	4	4	3	3	1	4	3	4
Cicatricosisporites spp	2	2	1	2	2	3	4	2
Cingutriletes spp	4	0	3	2	0	0	0	0
Cyathidites spp	3	4	3	4	3	4	5	4
Dictyophyllidites spp	2	0	2	2	3	3	4	2

Taxonomic Identification	WC4a	WC4b	WC4c	WC4d	WC4e	WC4f	WC4g	WC4h
Echinatisporis levidensis	1	0	0	1	1	0	0	0
Hamulatisporites spp	3	0	3	2	2	3	2	0
Laevigatosporites ovatus	4	4	4	3	4	2	3	4
Laevigatosporites spp	0	3	0	0	0	0	0	0
Leiotriletes pseudomesozoicus	0	0	0	0	0	0	0	0
Leiotriletes sp	2	0	3	2	3	1	0	0
Matonisporites equiexinus	2	6	0	0	0	0	0	0
Matonisporites spp	3	1	0	0	0	0	0	0
Stereisosporites spp	0	0	0	0	0	0	0	0
Undulatisporites spp	1	2	0	2	1	0	2	1
Deltoidospora spp	0	0	0	0	0	0	0	0
Araucariacites australis	0	0	0	0	0	0	0	0
Araucariacites spp	2	4	4	3	4	3	4	4
Cedripites spp	2	0	0	0	0	0	0	0
Classopollis classoides	3	5	3	4	3	3	2	4
Cycadopites carpentieri	0	0	0	0	0	0	0	0
Ginkgocycadophytus nitidus	2	3	2	3	4	2	2	3
Inaperturopollenites spp	0	2	0	2	0	0	0	2
Parvisaccites radiatus	4	3	3	4	3	4	4	2
Pinuspollenites spp	3	4	5	4	4	5	6	5
Piceaepollenites spp	2	3	4	3	3	3	2	4
Podocarpites radiatus	3	2	3	4	3	4	2	5
Taxodiaceaepollenites hiatus	4	1	2	3	3	2	3	4
Arecipites spp	4	4	3	4	2	4	4	5
Clavatipollenites hughesii	2	2	3	4	4	3	2	2
Complexiopollis abditus	5	8	7	6	8	9	10	9

Taxonomic Identification	WC4a	WC4b	WC4c	WC4d	WC4e	WC4f	WC4g	WC4h
Complexiopollis exigua	2	2	4	4	3	2	2	3
Complexiopollis funiculus	4	4	6	5	3	6	5	5
Complexiopollis spp	3	3	4	3	5	6	4	3
Cupuliferoipollenites spp	4	4	3	5	6	4	5	3
Cyrillaceaepollenites barghoornianus	3	3	3	4	5	4	3	4
Holkopollenites chemardensis	4	5	2	5	4	4	5	6
Holkopollenites sp A	3	3	4	6	5	3	6	7
Holkopollenites sp C	2	2	2	2	5	4	3	4
Labrapollis spp	7	6	7	8	6	8	7	5
Momipites spackmanianus	3	4	5	3	4	3	4	4
Tricolpopollenites spp	2	3	4	4	3	2	3	2
Nyssapollenites spp	4	4	3	5	6	5	4	6
Oculopollis spp	4	3	4	3	4	4	5	5
Plicapollis retusus	6	6	7	4	5	7	6	6
Liliacidites variegatus	0	4	0	3	0	0	0	4
Pseudoplicapollis spp	6	5	0	4	5	0	0	0
Proteacidites retusus	4	3	4	3	3	4	4	3
Pseudoplicapollis newmanii	7	4	5	4	6	5	7	5
Pseudoplicapollis longiannulata	4	2	4	3	2	3	2	3
Plicatopollis spp	2	2	3	4	3	5	4	2
Spheripollenites scabratus	3	1	4	3	4	2	1	2
Tricolpites crassus	4	0	0	3	3	4	5	3
Tetrapollis validus	5	0	3	2	4	5	3	2
Retitriclpites spp	4	2	3	2	2	3	2	4
Tricolpites spp	2	3	4	3	3	4	3	2

Taxonomic Identification	WC4a	WC4b	WC4c	WC4d	WC4e	WC4f	WC4g	WC4h
Tricolpopollenites williamsoniana	0	2	3	1	0	2	3	3
Tricolporopollenites bradonensis	2	3	3	1	2	3	2	3
Tricolporopollenites spp	3	2	5	2	3	4	2	4
Triplanosporites sinuatus	2	4	4	0	0	2	1	1
Trudopollis variabilis	4	5	5	2	2	3	2	2