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Occurrence, Chemical Characteristics, and Paleontology of the Fossil Resins from New Jersey

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ABSTRACT

The chemical characteristics, geographic and stratigraphic occurrence, and insect inclusions of various fossil resins from New Jersey are presented. Distinctions are made between amber and fossil resin, the latter being the more general term, and each is defined. Most of the fossil resins lie within the Cretaceous band in the Atlantic Coastal Plain, but a unique Tertiary form is probably of *Liquidambar* or other hamamelidaceous origin, as based on Fourier transform infrared diffraction and pyrolysis gas chromatography, which have revealed that the material is composed mostly of polystyrene. The Cretaceous resins (true terpenoid amber) are araucariaceous in origin, as based on chemistry. It has been determined by scanning electron microscope that the carbonized fossil wood found with the amber is coniferous, shows very fine detail, but does not have features diagnostic for the Araucariaceae. Dark red and clear yellow forms of the Cretaceous amber exist, the former of which appears to be an oxidized state of the latter. Despite the rarity of the amber, several interesting new insect inclusions have been found, which have affinities with various living and amber faunas.

INTRODUCTION

Fossils resins from the Atlantic Coastal Plain of the United States have been reported in the literature for more than 150 years, the first account being given by Troost (1821). Since then only three old anecdotal reports have dealt exclusively with the material, and

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several other, but much more recent, reports have dealt in part with chemistry of or inclusions in fossil resins from this region. This report is an attempt to synthesize all that is known on the fossil resins with a great deal of new data. It is the insect inclusions that initially stimulated Grimaldi to collect and study the material, particularly since all the published reports indicated that fossil resins from this region were Cretaceous. This period apparently was a time when many modern insect taxa made their debut. The present analysis seemed pressing as well due to the varied nature of the insect inclusions: compared to modern families, some are undoubtedly plesiomorphic, such as *Sphecomyrma* (Formicidae), others are modern (such as *Trigona prisca* [Apidae: Meliponinae]), and others have Baltic amber and/or Gondwanan affinities. A comprehensive study on the resins is needed to put such fossils into a meaningful paleontological context. Throughout the text we refer to both amber resins and fossil resins, the latter of which is a more general term. In the broadest sense, a fossil resin is any plant exudate of a respectable age, say one million years old or more. Specifically, amber is a polymeric, terpenoid fossil resin, which thus excludes some materials such as the polystyrene type of fossil resin from New Jersey that is treated later in this paper. Most fossil resins are amber; this is because terpenoids are rather resistant to natural decay and readily form extensive polymers that render them virtually chemically inert. Thus, terpenoid resin fossilizes readily.

Troost's (1821) report was stimulated by the finding of what presumably was a large piece of fossil resin found with lignite and pyrite in clay from Cape Sable near the Magothy River, Maryland. This resin contained what he described as perhaps a gall made by "lac coccids." The location of the specimen has not been traced, which apparently would have been in his large, private, mineral collection, now at the Louisville Museum of History and Science, but which is not there. Kunz (1883) likewise was intrigued by a large (20 × 6 × 1 in.) piece of fossil resin, found at "Kirby's Marl Pit" in glauconitic sand at Harrisonville, New Jersey. But this apparently may not have been the largest piece ever found, for there is reference in that report to "the largest specimen of amber . . . ever seen, found on the shore of Raritan Bay [New Jersey], deposited in the museum at Berlin, Germany." This was probably the Humboldt Museum, but no such specimen now resides there. Kunz's specimen was unusual in that it was opaque, cut "like horn," and upon polishing gave "a pearly lustre." Knowlton (1896) also found the fossil resin from Cape Sable to lie among lignite in clay. His observations on the lignite led to the conclusion that, because of a lack of compound medullary rays and large resin tubes, the lignite, and thus the source of the fossil resin, was not from a pine (*Pinus*), but most likely *Sequoia* or *Cupressinoxylon*. An origin of the material at Charleston (formerly Kreischerville), Staten Island, New York, from a species of *Pinus* was the hypothesis proposed by Hollick (1905), even though purported fossils of *Sequoia, Juniperus*, and *Dammara* were also found there. Later, Hollick and Jeffrey (1909) reported that "in all such cases [of finding amber in situ in lignite] . . . the correlated wood was . . . *Pityoxylon statenense*." Cross sections of the lignite revealed large resin canals. These authors placed *Pityoxylon* in the Abietinae, or the pines. Hollick found the resin among lignitic clays, and was the first to report on several forms of the material from this one locality in Staten Island. These forms were mostly drop-shaped, transparent yellow or red, some being opaque or grayish white. Large amounts of the fossil resin were reported as having been found by workers mining clay in the clay brick pits on Staten Island around the turn of the century.

ACKNOWLEDGMENTS

We are very grateful to the following persons who gave advice and help in this project. David Parris, of the New Jersey State Museum in Trenton, loaned amber specimens in that collection and provided information on Cretaceous stratigraphy. Don Baird, of Princeton University, loaned specimens from the university geology department collections (now at the Yale Peabody Museum) and he also gave a great deal of valuable advice regarding the Cretaceous from New Jersey and the manuscript in general. Joe Peters loaned material from the Mineralogy Department at the AMNH. Edward Johnson, Curator of Science at the Staten Island Institute of Arts and Sciences, loaned the amber specimens deposited in that collection by Arthur Hollick. Alan Goldstein, Curator of Science at the Louisville Museum of History and Science, checked through Troost's collection (which is deposited there) for the large piece of amber reported from Ann Arundel County, Maryland. Paul Whalley, British Museum (Natural History), made available his unpublished notes on the Lebanese amber. Penny Dillon and Ralph Johnson were instrumental in showing one source of the amber, and Jim Brown very kindly provided the amber specimens from Marlboro, New Jersey. Frank Carpenter, MCZ, Harvard, loaned specimens of Canadian amber for study. Darlene Judd provided assistance with regard to *Tvetenia.* Jean Langenheim, George Poinar, and Alexander Shedrinsky also provided valuable critiques of the manuscript.

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GENERAL CHARACTERISTICS OF THE FOSSIL RESINS

Based on color, hardness, fractal features, and shapes there are basically three types of fossil resins from New Jersey and surrounding areas in the Atlantic Coastal Plain. One is deep red (fig. 1), permeated with needlelike fractures (much like ice). It fractures very easily and concoidally, and the resultant broken form often produces a rounded and polished surface. Some pieces of this type are cylindrical, others are drop-shaped, most are round or amorphous. The other type is a very clear yellow, possessing fewer internal fractures, and it is commonly cylindrical and drop-shaped, occasionally amorphous. The yellow form has few concoidal fractures. The drop shapes are similar to those seen on exuded streams of resin running down the bark of pines and other conifers. When found on an exposed, washed surface of lignitic clay, both color forms occur in about equal proportions in sizes between 1 mm and about 2 cm in diameter, but they may be larger within the clay matrix where weathering would not fragment the pieces. Because the clay is so fine and dense it was virtually impossible to screen for the amber by washing. The third type of fossil resin (fig. 2) can occur in rather large slabs; it is an opaque yellowish-white and has a composition like soft plastic (fig. 2). This no doubt is the type to which Kunz (1883) referred.

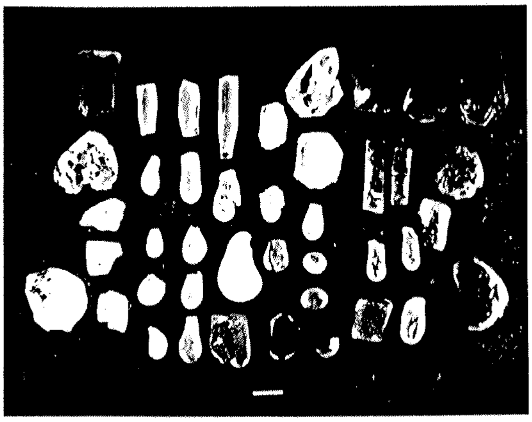
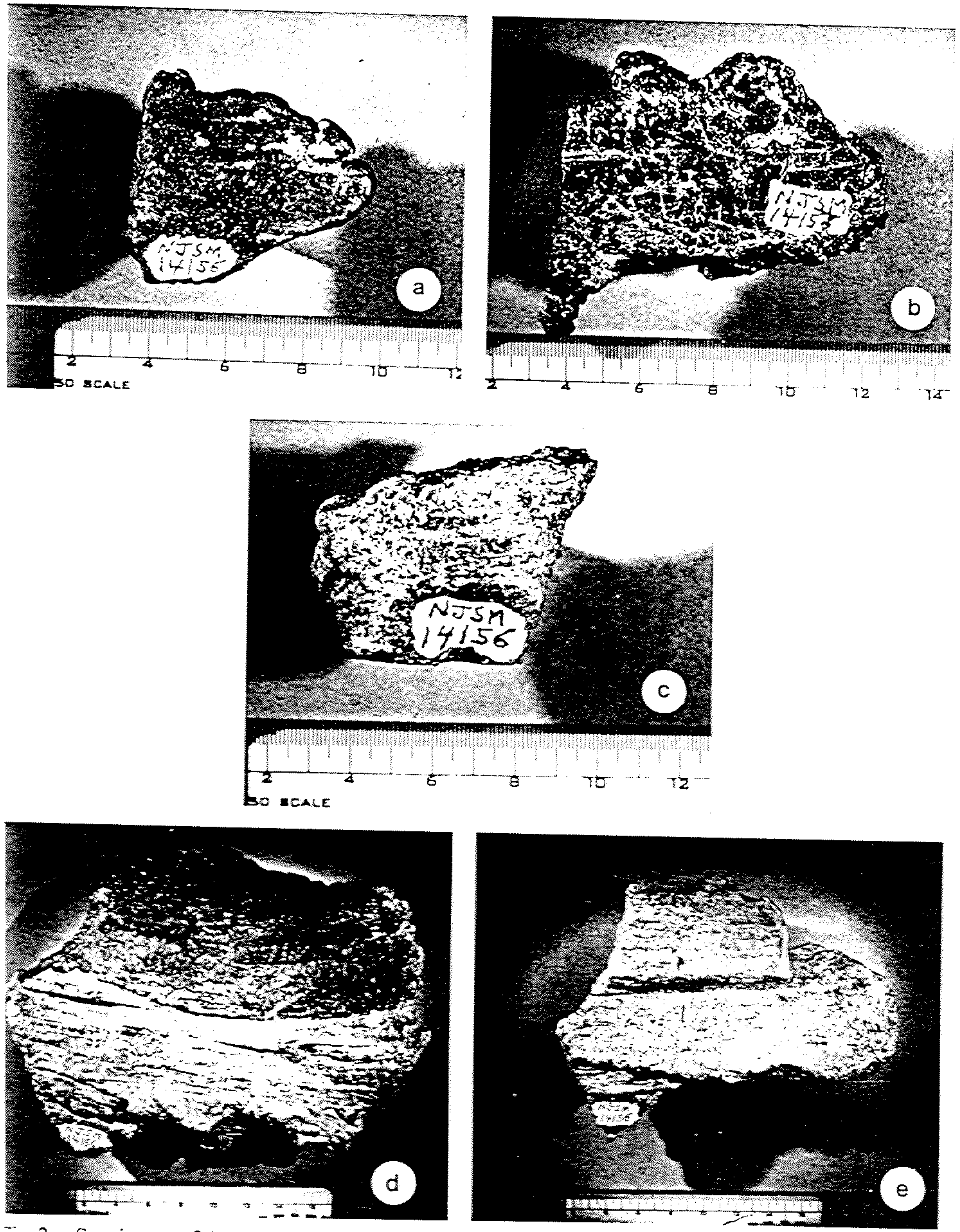


Fig. 1. Examples of the yellow (left half) and red (right half) forms of the amber from New Jersey, with representative shapes. Note the drop-and-stream shapes of some pieces. Taken from the Sayre-Fisher Pits, Sayreville, Middlesex Co. (map site 5, fig. 4). Scale is 1 cm.

One of us (D.G.) has collected fossil resin at the Sayre-Fisher Pits in Sayreville, and at Oschwald's Pits, near Cheesequake State Park, where at least the red and yellow forms of the material were found together in clay permeated with a lignite resembling charcoal, except that it was highly compressed. The material was never found in situ embedded in the lignite. The fossil resin is found sporadically at certain sites in this clay layer, and even then is not abundant.

Samples of the carbonized wood collected with resin at three sites were dried and split either in cross section or longitudinally, mounted on SEM stubs, sputter coated with gold, and the fine structure of the vessels ex-



ig. 2. Specimens of the polystyrene (*Liquidambar*) fossil resin type, from Inversand Marl Pit, Sewell, ucester Co., N.J. (D. Parris, coll.) (map site 16, fig. 4).

ined at 10 kV beam current (fig. 3a–l). servation of fine structure in the carbon- d wood varied from excellent (resembling fresh, living wood) to much less so. The presence of bordered pits on the radial walls of the tracheids, and the homogeneously small-

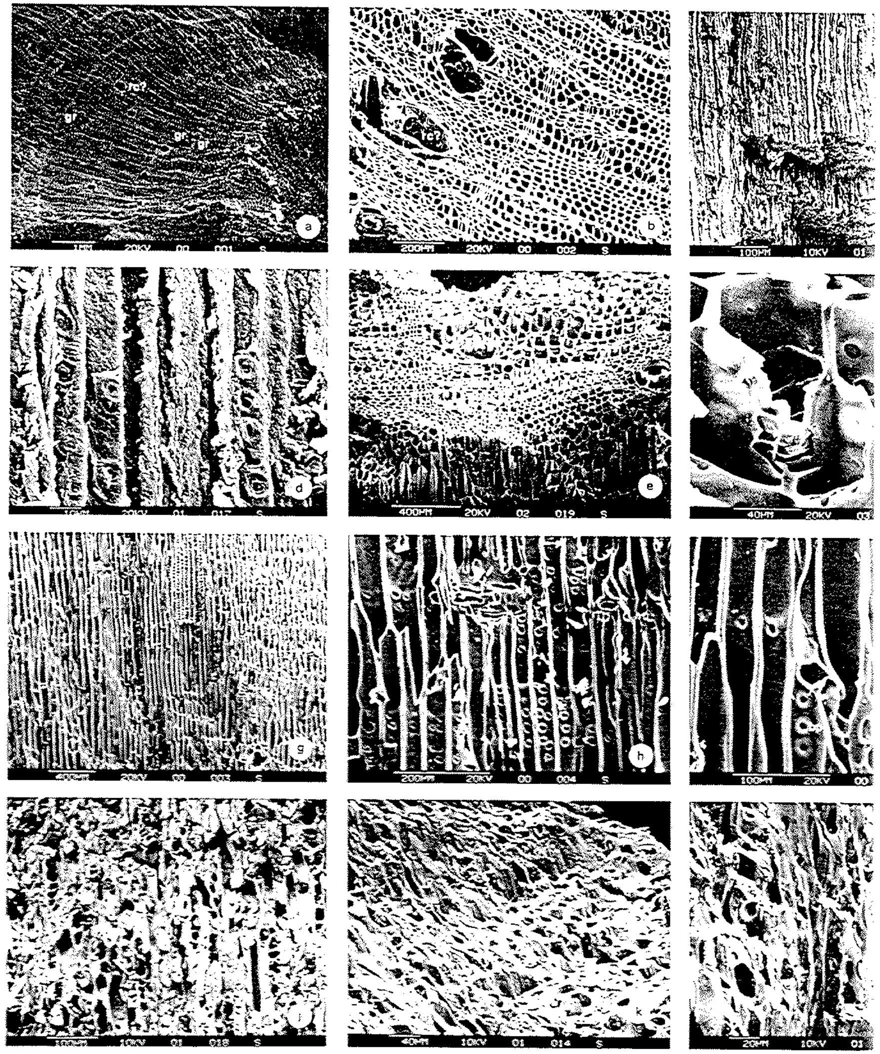


Fig. 3. Scanning electron micrographs of fossil woods collected with Cretaceous amb bonized wood from the Atlantic Coastal Plain, U.S.A.: a–d. Oschwald's Pits (map site transverse section. **b.** detail of section in a. **c.** tangential longitudinal section of different pi b. **d.** detail of section in c. **e–i.** specimens from Sayre Fisher Pits (map site 5, fig. 4). longitudinal section, oblique view. **f.** oblique view of transverse section in detail. **g.** tangentia section. **h, i.** detail of section in g. **j.** tangential longitudinal section of specimen from Outerbr (map site 2, fig. 4). **k, l.** lignite from the Aptian, lower Cretaceous, of Lebanon (specime Mr. Fadi Acra), oblique tranverse (k) and longitudinal sections. Abbreviations: bp, bor growth ring; rc?, resin canal?; t, tracheid.

diameter, linearly arranged longitudinal tracheids, indicate that the fossil wood is coniferous (fig. 3a–j, especially d, h, i), which corroborates Knowlton's (1896) vations. The better preserved sam some growth rings (fig. 3a, b). B

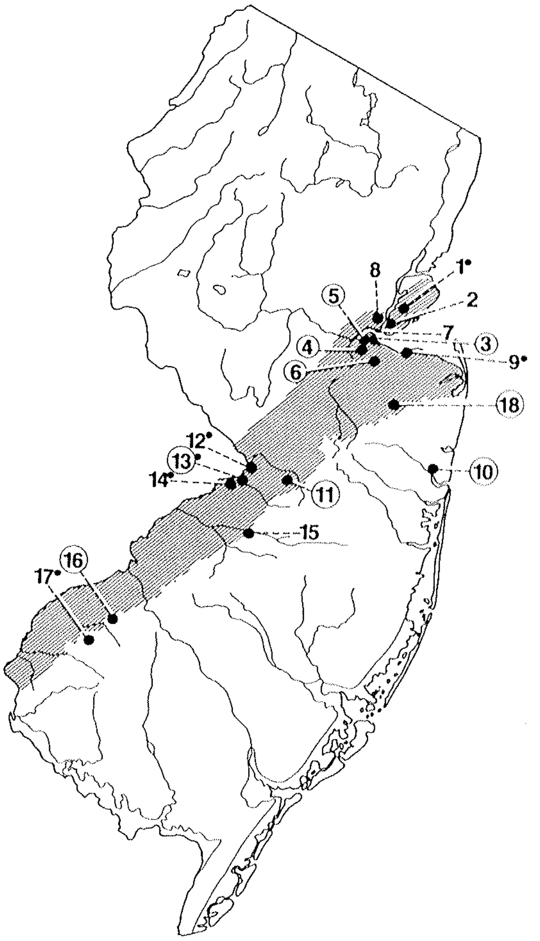


Fig. 4. Distribution of fossil resins in the Atlantic Coastal Plain of New Jersey and Staten Island. Hatched area is Cretaceous, taken from maps by the New Jersey State Geological Survey (1984). Numbers refer to the localities given in text: those that are circled are sites for which samples were analyzed using ir spectroscopy in this study; site numbers followed by a dot were samples analyzed by ir spectroscopy in Langenheim and Beck (1968).

were uniseriate and rarely oppositely paired, which contrasts with the characteristic alternate tracheid pitting (in usually two to four rows) seen in the Araucariaceae (e.g., Pool, 1929). Moreover, resin canals were present, which rules out the Araucariaceae, but which corroborates the findings of Hollick and Jeffrey (1909). Penny (1947) described the stem wood of *Araucarioxylon* has having a tracheal pitting "identical with that seen in modern species of *Agathis* and *Araucaria*." Taxodiacean fossils from the Cretaceous of New Jersey are *Geinitzia* and *Sequoia* (Penny, 1947).

Although exact identity of the lignite must await detailed botanical study, the SEM has revealed several things. First, there may have been mixing of amber and lignite of two or more botanical sources in the original deposits, since the spectroscopy indicates an araucariaceous origin. Alternatively, perhaps a primitive conifer produced a resin similar to *Agathis*; in which case, the chemistry described below and the original hypotheses of Hollick and Jeffrey would correspond. These samples were compared to true lignite collected with amber from the Aptian, lower Cretaceous, of Lebanon (courtesy of Mr. Fadi Acra), which is much more mineralized and with substantially less preserved detail than the New Jersey material. Gross structure of the Lebanese amber resembles very closely the transparent yellow form of the amber from the Atlantic Coastal Plain.

OCCURRENCE AND STRATIGRAPHY

Fossil resin specimens for comparison were acquired by collecting at exposed sections in Staten Island and New Jersey, and by borrowing specimens from the New Jersey State Museum, Trenton, the Mineralogy Department at the AMNH, the Staten Island Institute of Arts and Sciences, and from the Mineralogy Collection of Columbia University (now owned by the AMNH). Based on actual museum specimens and on reports in the literature, a total of 18 sites in New Jersey and Staten Island were found to have yielded fossil resins (six additional sites, from Cape Cod to North Carolina were reported, but these were not confirmed in this study with museum specimens).

The following are the fossil resin localities (New Jersey and Staten Island localities are numbered: see map, fig. 4; AMNH = American Museum of Natural History; NJSM = New Jersey State Museum; HBM = Harvard Botanical Museum; USNM = United States National Museum, Smithsonian Institution; USGS = U.S. Geological Survey [the last three depositories as cited by Langenheim and

Beck, 1968]). **New York**: STATEN ISLAND: **1.** Charleston (formerly Kreischerville) (Hollick, 1905; Jeffrey and Chrysler, 1906; Hollick and Jeffrey, 1909); **2.** Outerbridge Crossing (AMNH, no numbers). **New Jersey**: MIDDLESEX CO.: **3.** South Amboy, Isaac Inslee's Pit (NJSM 4641); **4.** Parlin, Crossman's Clay Pits (AMNH 39411); **5.** Sayreville, Sayre-Fisher Pits (AMNH, various pieces); **6.** Cheesequake, Oschwald's Pits (AMNH, various pieces); **7.** "on shore, Raritan Bay" (Kunz, 1883); **8.** Woodbridge, Valentine's Clay Pit (Hollick, 1905). MONMOUTH CO.: **9.** Cliffwood Beach Bluffs (Berry, 1906; Wilson et al., 1967); **10.** Squankum, Marl Pits (AMNH C89828). **11.** Ellisdale (NJSM 14154, 14155). BURLINGTON CO.: **12.** Bordentown (USGS 95367); **13.** Kinkora (AMNH C88712–88720; USNM 5610); **14.** Roebling (USNM R7289); **15.** Pemberton (Langenheim and Beck, 1968, no number). GLOUCESTER CO.: **16.** Sewell, Inversand Marl Pit (NJSM 14156, 14157); **17.** Harrisonville, Kirby's Marl Pit (AMNH, no number; Kunz, 1883; Hollick, 1905; USNM C163); Gloucester Co. (no other locality) (AMNH 39412). Recently added is the following locality: MONMOUTH CO.: **18.** Marlboro, Big Brook (AMNH, no numbers). Other localities in the Atlantic Coastal Plain (but which are not placed on the map in fig. 4) are the following: **Delaware**: St. Georges (USNM 82552). **Maryland**: Cape Sable, Magothy River (Troost, 1821; Berry, 1906; Knowlton, 1896; USNM 72871). **Massachusetts**: Martha's Vineyard, Gay Head (Finch, 1824). **North Carolina**: Charleston (USNM R7317); "Marl beds" (no other locality) (Kunz, 1883). **Washington, D.C.**: (Langenheim and Beck, 1968; no number).

For all except one locality (at Squankum, Monmouth Co., New Jersey), the deposits occurred within the Cretaceous band in New Jersey or on its southern edge. South of the Cretaceous strata are Tertiary and north of it are Jurassic and older exposed strata. Thus, the fossil resins from Staten Island and New Jersey are mostly Cretaceous, and the sources of the unusual plasticlike, polystyrene fossil resin are no older than Tertiary or at the Cretaceous–Tertiary boundary.

Berry (1906: 137) mentioned that "a secondary feature of the Magothy Formation is the occurrence of amber . . ." which suggests the amber from the Atlantic Coastal Plain to be entirely from this geological formation. As discussed below, this is an unreliable assumption. Some of the fossil resin samples in figure 4 have been associated with stratigraphic units based on lithology. Eventually there must be a palynological or foraminiferal study of the lignitic matrices in which the material occurs. The following papers were consulted in assigning stratigraphic positions to the seven fossil resin deposits discussed below that have some sort of vertical sampling data: Christopher, 1977, 1982; Dorf, 1952; Perry et al., 1975; Petters, 1976; Sirkin, 1986; Wolfe, 1976. Work on the Raritan Formation is mostly palynological, as foraminiferans are rare. Richards (1958) provides a history of early studies on the New Jersey Cretaceous.

The geologically oldest known fossil resin deposits in New Jersey are at Woodbridge (site 8) and Sayreville (site 5). These belong to the Woodbridge Clay Member in the lower Raritan Formation (or palynological zone IV of Christopher [1982] and Sirkin [1986]), which is considered by these and other authors as being middle Cenomanian, an age of about 95 m.y.b.p. Perry et al. (1975) assigned this clay member to the upper Cenomanian. The amber-bearing lignitic clay at the Sayre-Fisher Pit lies just below the South Amboy Fire Clay an Old Bridge Sand Members of the Magothy Formation (Metz, 1978, 1985; sensu Wolfe and Pakiser, 1971). The next oldest sites appear to be the sites at Cliffwood (site 9) (Cliffwood beds of the upper Magothy Formation) and at Oschwald's Pits (site 6) (Merchantville Formation—see fig. 5), both generally considered to be Santonian, but the latter considered to be late Campanian by Wolfe (1976) and Perry et al. (1975). According to the late Cretaceous dates provided by Wolfe (1976), which are based on radiometric and stratigraphic methods and cited hereafter, these sites would be about 80 m.y. old. As discussed by Michener and Grimaldi (1988a), the site from Kinkora (no. 13) is possibly from the upper Magothy, and thus may be of a similar age.

The youngest known fossil resin deposits in the New Jersey Cretaceous are at Ellisdale (site 11), Marlboro (site 18), and Sewell (site

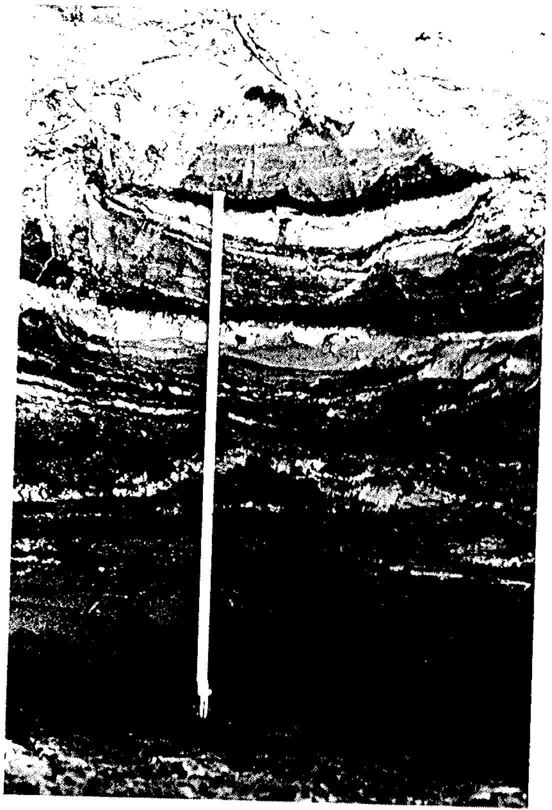


Fig. 5. Section through alternating layers of carbonized fossil wood (black) and fine sand, lying just above one of the clay layers (on floor of section) of the Merchantville Formation, taken at Oschwald's Pits, near Cheesequake State Park, Middlesex Co. (map site 6, fig. 4). Ruler is extended to 3 ft.

16). The Ellisdale fossil resin is in the Marshalltown Formation (late Campanian), and the Marlboro fossil resin is in the Wenonah-Mt. Laurel Sands Formation (late Maestrichtian [Koch and Olson, 1977; Petters, 1976] or late Campanian [Perry et al., 1975; Wolfe, 1976]), both being about 70 m.y. old. The Sewell specimens come from the "Main Fossiliferous Layer" of the Hornerstown Formation, which is the latest Maestrichtian and possibly extending into the Paleocene (Koch and Olson, 1977; Olson and Parris, 1987; Parris, 1986), abut 65 m.y. old.

CHEMICAL FEATURES AND RESIN ORIGINS

Gies' (1907) study on the elemental composition of fossil resin from Charleston, Staten Island, New York, yielded results that fall within the range of that published for the Baltic amber, and as such it is uninformative in describing characteristics of the New Jersey amber. He did, however, report on the possible presence of succinic acid, which was formed after distillation (see also a copy of the letter sent to Hollick by Gies, pp. 11–12 in Hollick and Jeffrey [1909]). Distillation of amber yields several crystalline products, one of which can be succinic acid derivatives, so it is possible that Gies had always identified such solids as "succinic acid." In fact, as described below, there is no indication at all that succinic acid occurs in the fossil resins from New Jersey. Clearly, the methods of choice in chemically analyzing fossil resins are now x-ray diffraction (Frondel, 1967), nuclear magnetic resonance spectroscopy (Lambert and Frye, 1982; Lambert et al., 1985), pyrolysis mass spectrometry (Poinar and Haverkamp, 1985), pyrolysis gas chromatography (e.g., Stout et al., 1988), and infrared (ir) spectroscopy (summary in Beck, 1986).

The most comprehensive prior treatment of the New Jersey and other Costal Plain fossil resins was in the large study by Langenheim and Beck (1968). Specimens analyzed in that study with ir spectroscopy were from one locality in State Island and six in New Jersey (Kreischerville, now named Charleston, erroneously placed in that study on Long Island) (see map, fig. 4). Infrared spectroscopy allows the classification of fossil and recent resins by the measurement of differential absorption of ir spectra by various functional radicals. Langenheim and Beck made two major conclusions on the New Jersey fossil resins. One, most, but not all, New Jersey amber was similar to that from other areas of the Atlantic Coastal Plain (e.g., Maryland and Delaware) and to the Cretaceous amber from Manitoba, Canada (the Kreischerville fossil resin was most similar to the Cretaceous amber from the Arctic Coastal Plain of northern Alaska). Second, a distinctive "amber" from Harrisonville and Pemberton, New Jersey had a "composition similar to that of the European fossil resin siegburgite which has been related to *Liquidambar* by chemical studies in which cinnamic acid and styrene were isolated . . . " (p. 86). The similarity was due specifically to the presence of monosubstituted benzenoid hycarbon composition of the Tertiary fossil polystyrene, the term *amber* in this study, again, should be reserved solely for the Cretaceous, terpenoid, coniferous fossil resins. The pyrolysis of ambers such as AMNH 39411 and AMNH C88720 leads to complex mixtures of terpenoid compounds with no apparent regularity. The pyrolysis products can be classified as terpenoid hydrocarbons on the basis of their mass spectra, but the compounds are difficult to identify without the appropriate standards. A worldwide survey of fossil resins by Tom et al. (1988) with the same technique has shown that each sample has a unique PYGC fingerprint, but that samples of the same botanical origin and from the same deposit share the most similarity in their traces. Conclusions conflict to some extent with earlier data of Poinar and Haverkamp (1985) based on Curie point PY-EI-MS data, a technique that tends to underestimate the importance of terpenoid stereoisomers. On the basis of the PYGC data, one can say that the two amber samples analyzed from New Jersey either have a different botanical origin, they differ in depositional history or conditions, or both. There is presently not enough comparative PYGC data available, however, to postulate a botanical source of this amber. Comparison of the PYGC fingerprints of these resins with the Baltic sample (fig. 10b) shows that they are not at all related in botanical origin because of their entirely different terpenoid profiles. The Baltic ambers (succinites) release succinic acid, which is present as succinic acid anhydride in the PYGC. This compound is not present in the New Jersey ambers analyzed.

BOTANICAL CONCLUSIONS

The presence of polystyrene and its derivatives, as seen in the FTIR and PYGC and PYMS results, shows this material to be fossil storax (= styrax = sweet gum), a product of the genus *Liquidambar* (family Hamamelidaceae). *Liquidambar orientalis* is native to the Near East and yields Levant storax, while *L. styraciflua* is the source of American storax, also called copalm balm. Modern storax contains less than 1 percent free styrene, but its major constituents, cinnamic acid and its esters, are readily decarboxylated to styrenes that then polymerize, the polymer of which apparently resists biodegradation for up to 65 or 70 million years. Styrene was originally shown to occur in the fossil resin material, siegburgite, by Klinger and Pitschki (1884), and our data indicate a similar type of fossil resin from a different location. The purity of the fossil sample on the basis of all our chemical results is truly remarkable for a resin of geochemical origin. The fact that no mixed condensate was formed points to a very pure precursor substance or excretion product, which may have reacted catalytically to this kind of polymer immediately after its release. Future research will compare the exudates from living *Liquidambar* with the fossil material.

The ancient Egyptians used Levant storax for impregnating burial gauze so as to better preserve the corpse, and other uses were as an incense and a treatment for venereal disease. The chief center of production of American storax is Honduras, and the tree species yielding it is native to the Atlantic Coast from Connecticut to Central America. According to Peattie (1950), American storax, when first exuded, is "semitransparent and yellowish brown, but on exposure to air it hardens into a rosin-like and darker solid. From pioneer times it was used in the South [U.S.] for the treatment of sores and skin troubles, for chewing gum, for catarhh, and in the treatment of dysentery . . . " (p. 310). The center of production in the United States was Clarke County, Alabama. The pollens of *Liquidambar* and *Altingia* (almost structurally inseparable) are known from the Paleocene of Europe and the Rocky Mountains, U.S.A., and by numerous Eocene records in Japan and Europe, but no Cretaceous records exist (Muller, 1981). There is no megafossil evidence of *Liquidambar* in the deposits of the Atlantic Coastal Plain, but, as the spectra show, the range of the genus during the Tertiary included this area as well.

The exocyclic double bonds seen in the FTIR are typical features of acid resins with a labdane skeleton, which in turn are characteristic of fossil and recent copals derived from *Agathis* (Araucariaceae). The acid resin nature of the Cretaceous amber from New Jersey is corroborated with the PYGC. The acid resins of New Jersey can therefore be assigned to a botanical source within that family. The Araucariaceae are presently distributed from southern South America to northern Australia, New Zealand, and the Indo-Pacific to the Malaysian peninsula (Whitmore, 1980). Fossil species of *Agathis* are known from the Oligocene and Miocene of New Zealand and Australia, and the Tertiary of Antarctica. Apparently, more primitive fossil genera of Araucariaceae were quite extensively distributed around the world. They are known from the Jurassic of several localities in the Northern hemisphere and from numerous records from the Cretaceous (Seward and Ford, 1906; Townrow, 1969; Stockey, 1982). Penny (1947) described a wood of *Araucarioxylon* as being common in the Magothy Formation of New Jersey, as well as having found cones of *Protodammara speciosa* Hollick and Jeffrey (which he believed to be an *Agathis*).

INCLUSIONS

Inclusions in the amber from New Jersey are curious in that despite their rarity, at least two of the most important insect fossils have been found here, both of them social insects. Nearly 300 red and yellow pieces of amber from the Sayre-Fisher Pits and Oschwald's Pits, Middlesex County have been examined, along with about 50 pieces collected by Hollick on Staten Island, New York, but only one yielded a partial fungus gnat (Diptera: Sciaroidae; AMNH SF-1; fig. 11). The oldest known amber sciarids are undescribed from the Aptian of Lebanon (P. Whalley, personal commun.).

Specimen AMNH SF-1 is most similar to *Sciara defectuosa* Meunier, in Baltic amber, as based on comparison to Meunier's (1904) illustrations. The venation of both species is distinctive, in particular an incomplete first medial (M) vein and a loss of the second medial. The venation of these two species shares the complete loss of vein M_2 and loss of the proximal portion of M_1 with another fossil sciaroid, an undescribed species from the Upper Cretaceous amber of Cedar Lake, Manitoba, Canada (MCZ specimen no. 6927). Specimen MCZ 6927, however, is even more modified in venation: R_{4+5} is incomplete proximally and runs very close (almost touching) to R_1; R_s is lost, and the point where the fork of CuA_1 and CuA_2 lies is considerably distal to that in the other amber species, in fact lying at the level of the apex of R_1. MCZ 6927 has the dorsal eye bridge of sciarids, and the well-developed apical tibial spurs seen in the Mycetophilidae. The only other sciaroids with a similar venation are the manotine Mycetophilidae, in which veins M_1 and M_2 are always present, albeit also incomplete. Other important venational features of the New Jersey amber specimen are the presence of vein R_s (common to most sciarids and mycetophilids), the fork of CuA_1 and CuA_2 near the level of vein R_s, and microtrichia that occur only on the radial veins and not on the medial or anterior cubitals. Unfortunately, the distal portions of the legs are not preserved in AMNH SF-1, for the spination of these parts of the legs are taxonomically very important. Relationships of these enigmatic sciaroids to living genera is still uncertain, but a chronological similarity of

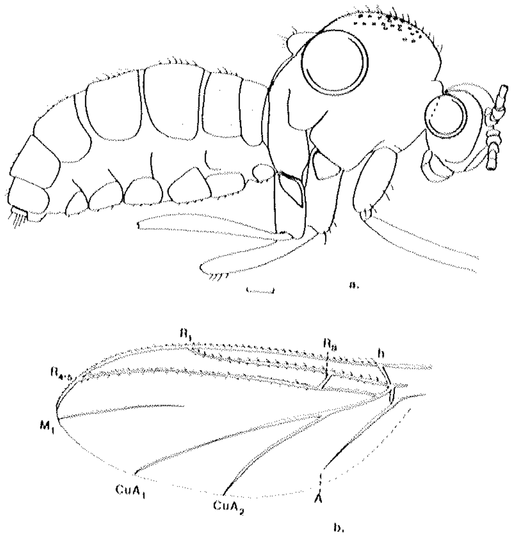


Fig. 11. Sciaroidae (Diptera) inclusion in amber from the Sayre-Fisher Pits, Sayreville (AMNH SF-1). **a.** Lateral view of body showing all portions intact in the fossil. The piece was found fractured along one side of the specimen, so this view of the specimen is actually along the inner surface of the bodywall. **b.** Reconstructed wing of fossil, taken from portions of both wings. Veins: A, anal; CuA, anterior cubitals; h, humeral; M_1, first medial; R, radials; R_s, radial sector. Scale is 0.10 mm.

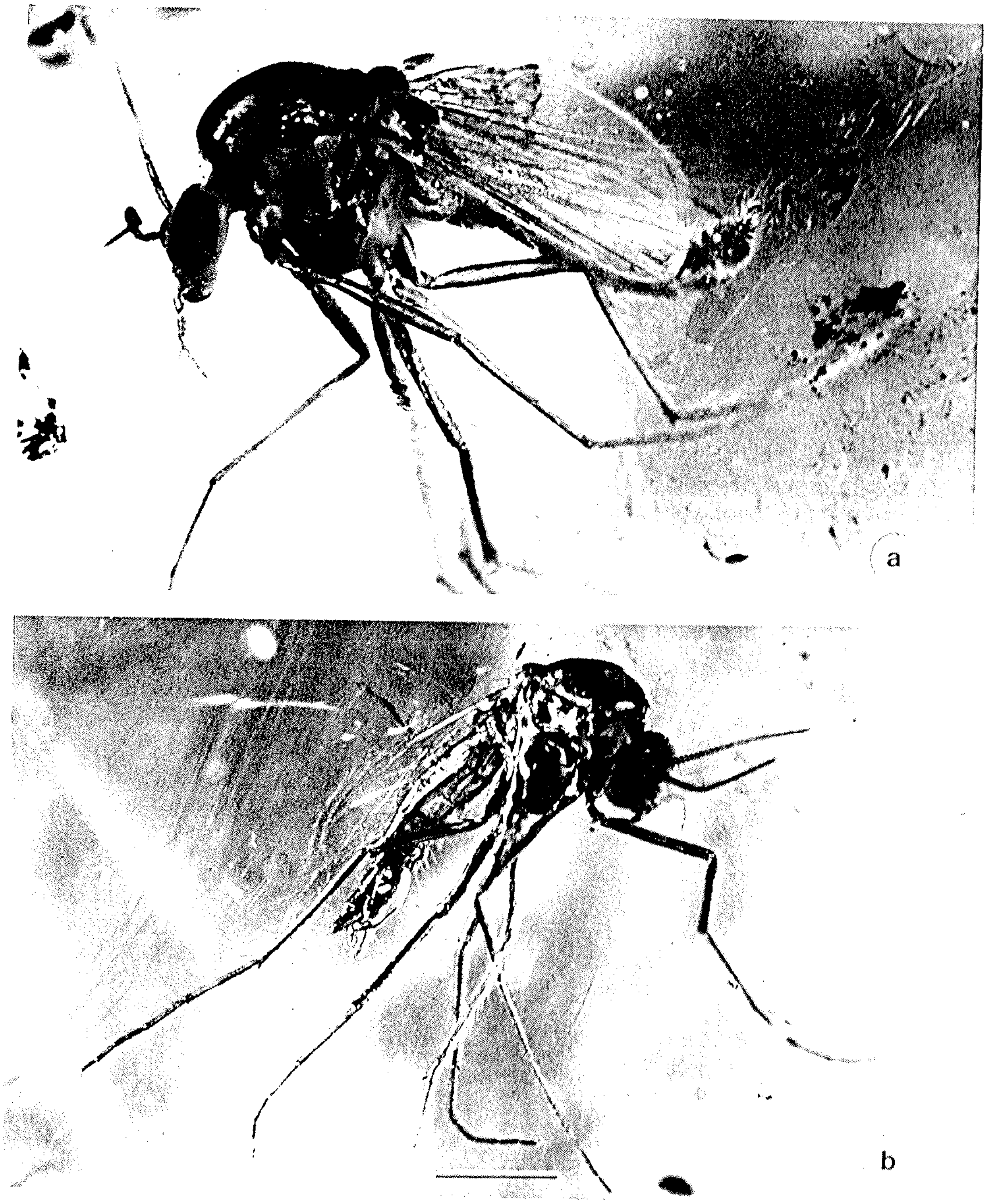


Fig. 12. Two males of a species of orthocladiine Chironomidae (Diptera) in amber from the Sayre-Fisher Pits, Sayreville (PU 88892a, b). Scale is 1.0 mm.

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Fig. 13. Some inclusions from piece no. AMNH C88720 from Kinkora, N.J. **a.** entire piece; large insect near center is meliponine bee, *Trigona prisca*. **b.** Isoptera (termite) wing. **c.** Coleoptera (Curculionidae) and Acarina (mite, at upper left of weevil, see arrow). **d.** Muscomorphan fly, arrow points to acute bend in proboscis, which indicates that the fossil may be a milichiid. **e.** Lateral view of nymphal

emesine Reduviidae (Heteroptera), arrow points to raptorial forelegs. **f.** Two species of Phoridae (Diptera), at left is badly preserved specimen (undetermined), at right is *Metopina*. **g.** Lateral view of *Dohrniphora*? (Phoridae), the genus of which is partially characterized by the peculiar, long rostrum. **h.** A tiny parasitoid wasp, Scelionidae (Hymenoptera). Scale in each is 1.0 mm, except for h, which is 0.10 mm.

the Baltic, Canadian, and New Jersey ambers is suggested by their presence in these ambers.

In a piece (Princeton University 88892) collected by Mr. Gerard Case also at the Sayre-Fisher Pits (map site 5, fig. 4) were three small nematocerous Diptera, which have been separated. In one section is a male Ceratopogonidae, probably a species of *Culicoides* (PU 88892a) (identified by W. L. Grogan, personal commun. 1987). In two other pieces (PU 88892b, c) are two males of a species of orthocladiine Chironomidae in *Tvetenia* or a very closely related genus, such as *Eukiefferiella* or *Paratrissocladius* (fig. 12). *Tvetenia* is mostly a holarctic genus of approximately 15 species, but its limits and that of *Eukiefferiella* (sensu Saether and Halvorsen, 1981) need to be sorted out. Chironomidae (and especially Ceratopogonidae, because of their minute size) are well represented in ambers around the world, probably the most exciting described thus far being *Libanoclites,* a podonomine from the Aptian amber of Lebanon (Brundin, 1976). Biogeographic patterns and generic affinities of the Cretaceous chironomids are reviewed by Ashe et al. (1987), who indicate that a Triassic origin of the family is reasonable. This age seems unjustified in the light of any discernible patterns based on vicariance and drift of continents during this time.

Until 1975, the oldest and morphologically most primitive known ant was *Sphecomyrma freyi,* found in amber for Cliffwood Beach bluffs, N.J. (Wilson et al., 1967) (map site 9, fig. 4) (but see Dlussky, *in* Rasnitsyn [1975], and Dlussky [1983]). The Russian evidence is from Coniacian-Santonian amber of the Magadan region in eastern Siberia and the Taymyr Peninsula, and compression fossils from the Turonian of southern Kazakhstan. In compression fossils it is virtually impossible to confirm the presence of several important ant synapomorphies, such as the metapleural gland. Most of the names for the taxa in the Russian deposits have been synonymized with the genus *Sphecomyrma* (Wilson, 1987). Most recently, Dlussky (1987) has completed the study of the fossil formicoids in the collection at the Paleontological Institute, USSR, including the description of a primitive new genus of ant. Thus, he includes 4 genera, 3 of them from the Taymyr amber (the other, *Sphecomyrma,* from New Jersey and Canadian Cretaceous amber), placed in the family Sphecomyrmidae (Dlussky's ranking), the sister-group to the true ants, the Formicidae. He stated that in all of them the metapleural gland is well developed. To Dlussky, the true ants did not appear until the Paleocene. Wilson (1987) provided evidence that within the Cretaceous diversity of these primitive ants there are three recognizable castes, so Dlussky's genera may actually just represent polymorphism. Despite the fact that the Sphecomyrminae were social, their primitive morphological features indicate that the Cretaceous was a very important period in the evolution and appearance of Formicidae.

The oldest known bee, the meliponine *Trigona prisca* (in piece no. AMNH C88720), is from Kinkora, New Jersey (Michener and Grimaldi, 1988a) (fig. 13a). It is very closely related to the living species *Trigona cilipes,* which occurs from Brazil to Panama. Geological ages of the bees have important implications for the ages of advanced angiosperms (Michener and Grimaldi, 1988b). Prior to this the oldest known bees were from the Baltic amber. The large piece (12 × 17 × 12 mm) in which it occurs contains 14 inclusions, representing 10 arthropod families. Besides the bee, the inclusions are three Phoridae (Diptera: one being *Metopina,* another is perhaps *Dohrniphora,* fig. 13f, g), one weevil (Coleoptera: Curclionidae, fig. 13c), one Scelionidae (Hymenoptera, fig. 13h; very similar to *Idris* from Baltic amber [Szábo and Oehlke, 1986]), one nymphal emesine Reduviidae (Heteroptera, fig. 13e), two gall midges (Diptera: Cecidomyiidae), one spiderling (Araneae), two mites (Acarina), one termite wing (Isoptera, fig. 13b), and a small muscomorphan fly which, because of the geniculate proboscis (other features are not obvious) is probably in the Milichiidae or a close relative thereof. The milichiid is only the second instance of the Muscomorpha Diptera in the Mesozoic. This is also the oldest record for the Emesinae, which is a dominantly tropical group. *Metopina* contains approximately 33 described and undescribed species, most of which are Neotropical, Palearctic, with a few Old World tropical species (only two are

Nearctic). *Metopina* has also been found in the Oligomiocene ambers of the Dominican Republic and Chiapas, Mexico (Grimaldi, 1989).

All the insect inclusions thus far have been found in the clear yellow amber. It is doubtful that any will be found in the polystyrene fossil resin because it is so opaque, and the dense fractures inside the red amber also obscure the interior of each piece. The emesine, the meliponine bee, and to a lesser extent *Metopina,* demonstrate some geographical extinction of tropical elements from the New Jersey Cretaceous, which corroborates the paleobotanical evidence. The sciaroids have affinities with species in the Baltic (Oligocene to Eocene) and Canadian (upper Cretaceous) amber. D. Grimaldi is at present collecting and examining additional New Jersey amber for insect inclusions.

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