# DEVELOPMENTAL AND ENVIRONMENTAL HISTORY OF THE DISMAL SWAMP[1]

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ABSTRACT

Pollen analysis of several cores from the Dismal Swamp in southeastern Virginia have indicated that the swamp is a relatively young feature, having begun to develop along drainage lows as recently as the late-glacial. Formation of extensive fresh-water marshes along streams appears to have been brought about by general water-table changes controlled by the post-glacial rise of sea level. As the sea continued to rise, marsh development proceeded inland and fine-grained organic sediments began to accumulate. By 6,000 years B.P. approximately 50% of Dismal Swamp area had been mantled by fine-grained peat deposits. From 6,000 to 3,500 B.P. peat accumulation continued, but at an appreciably lower rate. This corresponds both to the hypsithermal interval and to a distinct slackening in the rate of sea-level rise. By 3,500 B.P. peat had mantled virtually all of the interfluves and "islands" within the swamp.

The pollen diagrams suggest a gradual change from boreal spruce-pine forests during the full-glacial, to somewhat less boreal pine-spruce during the early late-glacial, to hardwood forests containing many species characteristic of the present northern hardwoods forests during the latter portion of the late-glacial, to hardwood-dominated forests containing species now found in southeastern Virginia during the early postglacial. Although precise vegetational and environmental reconstructions are not possible, this general sequence suggests a unidirectional climatic amelioration from conditions comparable to those in northern New England during the full-glacial to a climate comparable to the present by 8,000 years B.P. The climate may have been warmer and drier during the hypsithermal, but the observed changes could just as easily be a result of a slackening in the rate of sea-level rise. The cypress-gum forests that have characterized the Dismal Swamp for the past 3,500 years have been variable both spatially and temporally. These variations doubtless reflect local differences in water table, peat depth, fires, wind throws, and a variety of human disturbances.

The origin of Lake Drummond remains an enigma. It is a young feature of the swamp, apparently originating only 4,000 years ago. It is not the last vestige of an earlier open-water phase of the swamp.

## INTRODUCTION

Extensive forested swamps are common in southeastern United States. Many of these border river systems; others, like the Dismal Swamp in southeastern Virginia and northeastern North Carolina, mantle more general areas of low relief. In most swamps the hydroperiod is long, the soil is a woody peat, and the dominant vegetation is an impressive cypress-gum forest. The uniqueness of the swamp environment has stimulated numerous studies of flora, fauna, and general ecology and has resulted in the preservation of some as natural areas. Unfortunately, most of the swamps have undergone profound changes. Lumbering, fire, and land-reclamation projects have taken a severe toll, so that in many cases the dimensions of the swamps have shrunken markedly and the forests have been modified greatly.

The Dismal Swamp has been affected more profoundly than most. Although it originally encompassed approximately 5,000 km$^2$ (Shaler 1890), by

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the 1930's it embraced no more than 1,800 km² (Lewis and Cocke 1929). Since that time further attrition has taken place. Concomitantly, the forests have undergone dramatic changes. Cypress, once extremely abundant, is now uncommon; white cedar (*Chamaecyparis*) has decreased markedly; and red maple has become the most common tree. In some areas logging and frequent fires have led to replacement of forest by shrub-dominated "light swamp." Tree-farming practices have resulted in the complete elimination of natural vegetation from extensive areas. There is little evidence that any of these trends is likely to be reversed, and hence it appears that as a natural area the northernmost of the great cypress-gum swamps is doomed.

Since many early botanists, zoologists, and geologists ventured into the Dismal Swamp, the literature on its biota, ecology, and geological setting is considerable (e.g., Lesquereux 1853, Chickering 1873, Shaler 1890, Kearney 1901, Hollick 1912, Osbon 1919), and numerous speculations have been forwarded concerning its developmental history. It is evident that the swamp formed on a relatively flat surface bounded on the west by a well-defined Pleistocene shoreline and on the east by a less conspicuous linear feature originally thought to represent a "fossil" dune or barrier complex. Although poor drainage apparently contributed significantly to formation of the swamp, the factor (or factors) responsible for initiation of peat deposition remained obscure. Furthermore, little could be said concerning either the later stages of the swamp's history or the origin of the large shallow lake (Lake Drummond) located in the center of the swamp.

Early palynological studies by Lewis and Cocke (1929) and Cocke, Lewis, and Patrick (1934) provided some information on the history of the northern half of the swamp. Their work suggested that peat deposition did not begin synchronously and uniformly throughout the area, but was initiated in topographic lows. There were indications of brackish conditions initially and of a possible reinvasion of salt water later in the swamp's history. The evidence suggested a vegetational progression from an open fresh-water marsh to a typical swamp forest.

The implications of this work are intriguing. First, it suggests that deposition was initiated in a brackish lagoon, thus implying that sea level was high. Second, the implication is obvious that a second marine transgression may have affected the swamp. Since the most recent transgressions were interglacial or perhaps mid-Wisconsin, considerable antiquity is thus suggested for the swamp. However, the pollen data do not substantiate this, as there is no evidence of the vegetational changes that are usually associated with either early or classical Wisconsin glaciations. Thus numerous questions remain concerning the environmental history of the Dismal Swamp region.

The present study was initiated in part because more information was needed on the vegetational, environmental, and developmental history of the swamp, and in part because detailed geomorphological studies were being carried out in the region by Nicholas Coch, Robert Oaks, John Sanders, and Richard F. Flint. It was felt that the geological investigations would contribute valuable information concerning the surface on which the swamp developed and the factors which may have controlled peat deposition.

## Field and Laboratory Techniques

Field work in the Dismal Swamp was carried out during the summers of 1961 and 1962. The basic objectives were to determine the configuration of the surface that underlies the peat, to locate the deepest sections of organic sediment in several sections of the swamp, to obtain complete cores from the selected deep sections (for pollen analysis and radiocarbon dating), to collect surface samples for analysis, and to obtain data concerning the present vegetation of the swamp. To accomplish these ends it was necessary to obtain numerous borings along

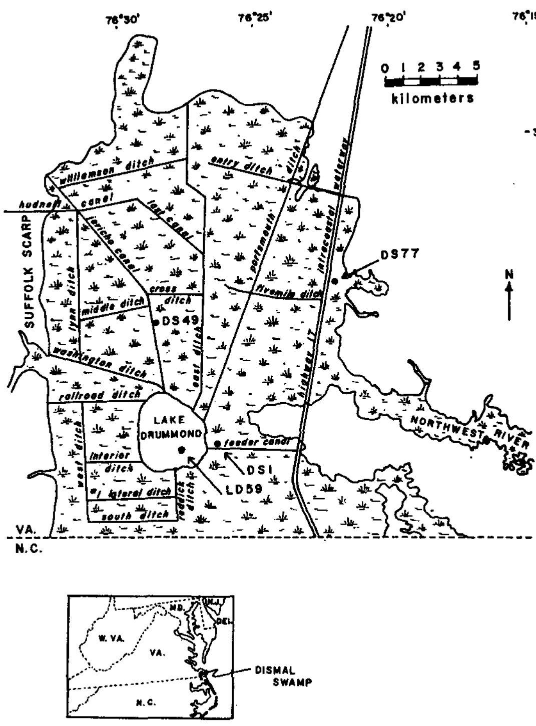


Fig. 1. Index map of the Dismal Swamp and detail map of the Virginia section showing locations of canals, roads, ditches, and coring sites (DS1, DS49, DS77, LD59).

many transects within the Dismal Swamp and Lake Drummond.

Cores were taken along virtually all of the major canals or ditches in the northern half (Virginia section) of the Dismal Swamp. Soundings and cores were taken at 200- to 300-m intervals along the entire length of Jericho Canal (Fig. 1) and at 500- to 600-m intervals along Williamson, Portsmouth, Lynn, Cross, East, Washington, Railroad, Middle, West, Interior, No. 1 Lateral, South, and Reddick ditches and Hudnell, Last, and Feeder Canals. Borings were also taken along Route 17 on the eastern border of the swamp. The location of borings was determined by use of an allidade and stadia rods. For Lake Drummond, three north-south transects and three east-west transects were run. Coring sites were located by triangulation, with fixed reference points on the shores of the lake.

At each of the Dismal Swamp coring stations (approximately 80 in number) a probe was first taken to determine the approximate position of the interface between organic sediment and the underlying sand or clay. The interface was then collected with a Livingstone sampler. The cores were extruded in the field, described, and carefully wrapped in mylar and aluminum foil. The complete borings were taken in a similar manner, except that the upper meter or more was collected with a Hiller sampler, the more compact lower sediments with a Livingstone sampler. From each of the deep sections (DS-1, DS-49, DS-17) several complete borings were taken (spaced 1 m apart) to insure enough material for radiocarbon dating. Borings from Lake Drummond were taken in a similar manner, except that a Livingstone sampler was used for all samples.

In the laboratory, samples were boiled in 10% KOH, demineralized in 10% HCl, boiled in concentrated HF (10 min), acetolyzed for 1 min, and stained with basic fuchsin. Silicone oil was used as a mounting medium. Counts were carried out with a Wild M20 microscope at a magnification of 400 diameters. Critical identifications were made with oil immersion optics, both bright field and phase contrast. The pollen sum includes all tree, shrub, and herb pollen with the exception of grasses and sedges. The latter were excluded from the sum, since their frequencies seemed to parallel those of the abundant aquatic pollen types and they were probably growing locally in semi-aquatic environments. Pteridophytes, aquatics, *Sphagnum,* and algae were also excluded from the pollen sum.

## Geology of the Dismal Swamp Region

The Dismal Swamp is situated on the Coastal Plain in southeastern Virginia and northeastern North Carolina (Fig. 1). The Suffolk Scarp, a sharply delineated Pleistocene (Sangamon) shoreline, defines the western boundary of the swamp. On the east it laps up against the Fentress Rise, a subtle north-south linear high consisting of interglacial marine and barrier sediments (Oaks and Coch 1963). Northward it extends along topographic lows almost to the James River and Chesapeake Bay, and on the south it reaches virtually to Albemarle Sound. One of the most interesting features of the swamp is Lake Drummond, a large shallow body of water located just north of the center of the swamp.

Early workers (e.g., Lewis and Cocke 1929) indicated that the surface of the swamp is convex and that the highest elevations occur in the neighborhood of Lake Drummond. More recent work instead suggests that the surface of the peat slopes gently eastward. The highest elevations lie along the Suffolk Scarp (7.5–8.0 m above mean sea level (MSL)), the lowest occur along the Fentress Rise (3.0–4.4 m above MSL). Peat thickness is quite variable, reflecting the undulating character of the underlying surface. The maximum depths appear to be approximately 3.5 m.

The surficial sediments of the region are virtually all interglacial in age and marine or lagoonal in origin. The Pleistocene deposits are underlain by the Yorktown formation, a complex of marine sediments of late Miocene age. Formerly the Pleistocene geology of the region was interpreted simply. The Coastal Plain in the vicinity of the Dismal Swamp was thought to be characterized by four gentle seaward-sloping marine terrace plains, separated by three eastward-facing marine shorelines or scarps (e.g., Wentworth 1930, Oaks and Coch 1963). The Suffolk Scarp, which defines the western boundary of the swamp, separates the Wicomico terrace from the Dismal Swamp terrace (the general surface on which the swamp is developed). The next lower scarp, the Princess Anne, occurs to the east of the Dismal Swamp (Wentworth 1930).

Recent studies in the area have indicated that these older interpretations represent oversimplifications (e.g., Oaks and Coch 1963, Oaks 1964). The relatively flat plain east of the Suffolk Scarp cannot be considered a simple terrace plain which developed while the sea was cutting the scarp. The "Dismal Swamp Terrace" and the area further east is underlain by a complex series of marine, barrier, and lagoonal sediments, indicating as many as five transgressions, all possibly occurring during the Sangamon interglacial. The Dismal Swamp peat is immediately underlain by a lagoonal facies of the interglacial Sandbridge formation; this in turn is underlain by a lagoonal facies of the Londonbridge formation; the latter is underlain by some thickness of the Norfolk formation, a near-shore marine sediment. The Norfolk formation was deposited directly on the erosional surface of the Miocene Yorktown formation, although occasional pockets of lagoonal clay of the interglacial Great Bridge formation separate the two. Each of these interglacial formations is related to a separate transgression. In many cases the lagoonal facies grade eastward into barrier and shallow water marine sediments. Thus the pre-Dismal Swamp depositional history of the region is exceedingly complex, and evidence suggests that the interglacial transgressive and regressive cycles fluctuated.

The peat of the Dismal Swamp has been deposited on the clays and sandy clays of the Sandbridge Formation. As implied above, these clays were formed in a lagoonal environment, apparently behind a barrier complex which was located to the east of the present Fentress Rise. Thus one would expect the surface on which the peat developed to be one of extremely low relief. Although this is basically true, it is now apparent that during the period of post-Sandbridge emergence (Wisconsin time), the Sandbridge lagoonal surface was dissected by the streams that flowed across the plain. Numerous borings taken within the Dismal Swamp by the Union Bag-Camp Paper Company, Dr. Robert Q. Oaks, and myself clearly indicate a dendritic drainage pattern developed on the clay beneath the peat (see Fig. 7).

## Vegetation of the Dismal Swamp

The Dismal Swamp is included within the northernmost portion of the Southeastern Evergreen Forest (Braun 1950), a forest region characterized by an abundance of pine and broad-leaved evergreens. This classification of the region is somewhat misleading, since the forests of the swamp proper contain comparatively few evergreen-leaved species, and the vegetation of the surrounding uplands, although dominated by loblolly pine (*Pinus taeda*), contains many deciduous species.

The original forests of the Dismal Swamp were markedly different from those that exist now. Human activities have brought about profound changes. The digging of canals, intensive logging, land clearance, and frequent fires have virtually destroyed the extensive cypress-gum forests that once dominated the area. Earlier, two rather different forest types were common within the borders of the swamp (Kearney 1901). "Dark" or gum swamp was thought to be characteristic of areas that had not been disturbed, whereas "light" or juniper swamp was believed to be developed in areas subject to human interference.

Considerable variability is evident in both of these swamp types. In gum swamp the variation appears to reflect the height of the water table, length of the hydroperiod, and peat depth. In "typical" gum swamp the hydroperiod is long, and occasionally up to a meter of water stands on the surface. As the name implies, the most common tree is black gum (*Nyssa sylvatica*). Red maple (*Acer rubrum*) and cypress (*Taxodium distichum*) are also common, although logging has virtually eliminated the latter. Other common trees include: tupelo gum (*Nyssa aquatica*), white cedar (*Chamaecyparis thyoides*), water ash (*Fraxinus caroliniana*), willow oak (*Quercus phellos*), loblolly pine, pond pine (*Pinus serotina*), holly (*Ilex opaca*), sweet bay (*Magnolia virginiana*), red bay (*Persea palustris*), sweet gum (*Liquidambar styraciflua*), tulip tree (*Liriodendron tulipifera*), willow (*Salix* sp.), cottonwood (*Populus* sp.), beech (*Fagus grandifolia*), elm (*Ulmus* sp.), and many others. A great variety of shrubs, many of them evergreen-leaved, also occur. In areas where the peat is relatively thick and the water table high, gum, cypress, red maple, and cedar are especially common; in areas where the water table is low or the peat thin, the forests are more like those outside the swamp, with an abundance of oak, pine, sweet gum, etc.

The term "light swamp" is applied to two rather different vegetational types, one a cedar-dominated swamp, the other a shrub-dominated type. The former may represent a relatively natural assemblage, whereas the latter is most probably favored and perpetuated by fire. Cedar often grows in pure stands, generally in areas where the hydroperiod is somewhat shorter than typical for gum swamp. Cypress, gum, red maple, holly, loblolly pine, sweet bay, red bay, and tupelo gum are occasionally associated with the cedar.

A remarkably dense shrub-dominated vegetation often grows where cedar swamp or black gum swamp has been destroyed by cutting or by fire. This vegetational type is similar in some respects to that of Pocosins further south on the Coastal Plain (e.g., Whitehead and Tan 1969). Sweet bay is often the most common species, occasionally occurring in virtually pure stands. Various other shrubs, some evergreen-leaved, are also common, e.g., several species of *Ilex* and *Rhus*, and *Itea, Clethra, Rhododendron, Kalmia, Leucothoë, Vaccinium, Lyonia, Viburnum,* and *Myrica*. Laurel-leaved brier, *Smilax laurifolia,* is an extremely conspicuous member of this vegetational type.

The density of the shrub vegetation varies appreciably. In relatively open areas the growth of cane (*Arundinaria*) is dense. In areas that have been burned quite recently an abundant growth of *Myrica* with a ground cover of chain fern (*Woodwardia virginica*) and *Sphagnum* often occurs.

The activities of the past half-century have favored the expansion of light swamp at the expense of gum swamp. Continuous forest inventory plots maintained by the Union Bag-Camp Company (in the northern half of the swamp) indicate that at present red maple is the most frequent tree in the swamp; gum, pine, cedar, sweet bay, cypress, tulip tree, and oak (in

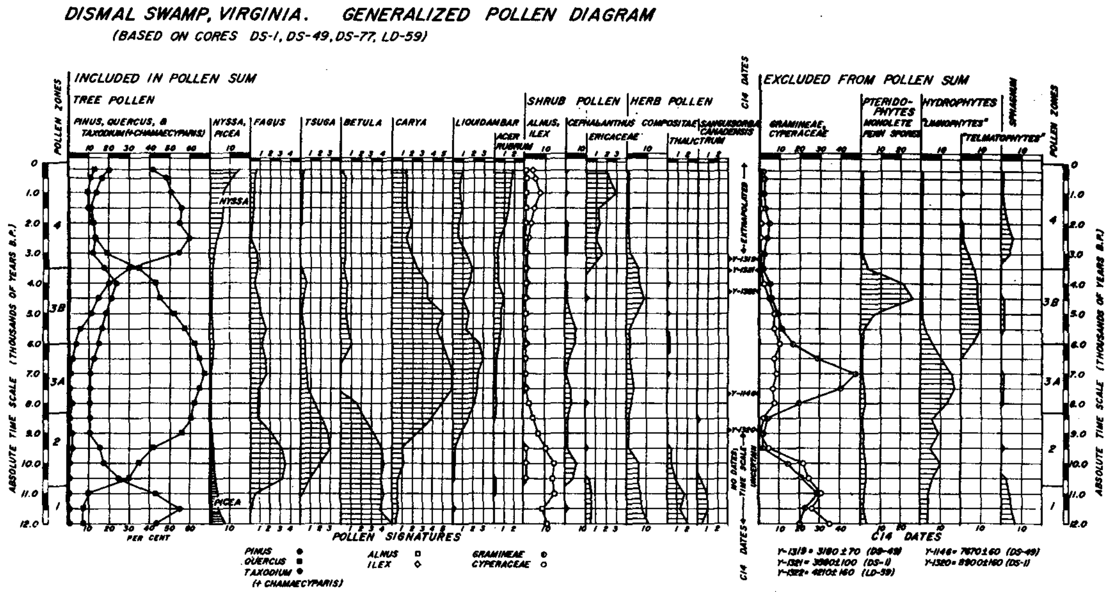


FIG. 6. Generalized pollen diagram, Dismal Swamp (from Whitehead 1965*a*).

decreasing order) are also common (R. M. Osborn, *personal communication*).

The vegetation peripheral to the swamp is quite different. Where the land has been disturbed, pines dominate (loblolly and Virginia pine (*P. virginiana*)). Where there has been less disturbance, many hardwood species occur. Sweet gum is extremely common, along with red maple, several species of oak, black gum, occasional hickories (*Carya* sp.), holly, dogwood (*Cornus florida*), tulip tree, and beech. The considerable variation in these forests reflects in part the nature of the interglacial sediments on which the soils are developed and, in part, the local drainage systems and topography. Many representatives of these "pine and hardwoods" forests occur within the Dismal Swamp, especially near the borders of the swamp and where the peat is very thin.

## ENVIRONMENTAL RECONSTRUCTIONS

### *Pollen assemblage zones*

In pollen diagrams derived from peat profiles pollen assemblage zones are difficult to differentiate (Fig. 2–6). At least three and probably four zones can be delineated, although in some profiles the lower zone or zones may be missing and in at least one case the upper zone is missing (apparently because of loss of peat from the surface either by oxidation or fire).

The four identifiable zones (starting from the base and working upwards) include: (1) pine-spruce; characterized by high percentages of pine, a slight maximum of spruce, maxima of alder and birch, and the occurrence of pollen or spores of several "boreal" elements; (2) beech-hemlock-birch; marked by decreasing percentages of pine, increasing oak, and slight maxima of beech, hemlock, birch, and alder; this zone is not well differentiated and could be considered a subzone of the following; (3) oak-hickory assemblage zone; characterized by high percentages of oak, a maximum of hickory, and relative abundance of pollen of many other deciduous trees; this zone can be differentiated into many subzones; (4) cypress-gum assemblage zone; typified by high percentages of "cupressaceae" pollen (probably mostly cypress), a marked maximum of black gum, and slight maxima of red maple and a variety of swamp shrubs.

The oak-hickory assemblage zone is variable and can be differentiated into several subzones (not entirely comparable from profile to profile). The percentage of sweet gum pollen is generally much higher in the lower half of the zone. This, coupled with slightly higher percentages of alder, birch, and hemlock, permits differentiation of one subzone (sweet gum subzone). An apparent succession of herbaceous and aquatic pollen (and spore) types permits subdivision of the upper portion of the oak-hickory zone into two subzones. Initially an abundance of grass and sedge pollen is coupled with a high frequency of pollen from aquatic plants, generally species typical of comparatively deep water (*Myriophyllum, Proserpinaca, Nymphaea, Nuphar, Potamogeton, Utricularia,* etc.). This can be referred to as the grass-"limnophyte" subzone. Above this the frequency of such aquatics (and grass and sedge pollen) decreases, and there are distinct maxima of composites, fern spores, and aquatics typical of shallower water or places where the hydroperiod is much shorter (*Sagittaria, Orontium, Xyris, Eriocaulon*). The frequency of pine pollen is often somewhat higher in this subzone. This can be referred to as the *Orontium*-composite-fern subzone.

The relationship of the various subzones of the oak-hickory assemblage zone is variable. For example, in two profiles (DS-77, DS-49) the maximum of limnophytes and grass appears to coincide with the *Liquidambar* maximum. In addition, the magnitude of the various maxima varies greatly from profile to profile.

### *Pine pollen*

Attempts were made to determine the species of pine present at various times during the swamp's developmental history. Pine grains from two different pollen assemblage zones (pine-spruce and beech-hemlock-birch) from core DS-77 were measured according to procedures outlined previously (Whitehead 1964). In addition, attempts were made to determine the frequency of white pine grains (*Pinus strobus*). Pollen of white pine possesses a verrucate sculpture on the thin exine of the body between the bladders, whereas the other eastern species are either scabrate or psilate (Cushing, *personal communication*). Unfortunately, virtually all pine grains in the two levels studied were ruptured. White pine grains were identified in several other samples from the beech-hemlock-birch assemblage zone.

The size-frequency curves from both assemblage zones are bimodal, yet quite different. The lower spectrum (2.00 m) is dominated by smaller grains (mode = 34 $\mu$), the upper (1.40 m) by larger grains (mode = 45 $\mu$). This suggests the presence of jack or red pine, or both, early in the swamp's history and the occurrence of species with larger grains during deposition of the birch-hemlock-beech assemblage zone. Definite white pine grains were found in some spectra from this assemblage zone; hence *Pinus strobus* may well have been one of the common pines at that time.

### *Radiocarbon dates*

The available radiocarbon dates are indicated on the pollen diagrams. In general, the samples dated are composite, involving stratigraphically equivalent levels from two adjacent borings (usually 1 m apart). The borings were taken with a Livingstone sampler. Once pollen analyses were completed, levels were selected for dating—generally the contact between organic sediment and the underlying clay and certain pollen-zone boundaries.[2]

Although various sources of error could affect the dates, they are believed to be accurate. Great care was taken to avoid contamination in the field and in the laboratory. However, the dates lower in the profiles may be systematically younger because of a downward leaching of organic compounds within the peat profiles. Swain, Blumentals, and Millers (1959) have suggested that in the Dismal Swamp peats (and in peats in general) there is a surface layer in which decomposition takes place, a zone below from which amino acid (and perhaps other organic compounds) are leached by a downward percolation of humic substances, and a lower zone (at a depth of 3–4 ft) where the amino acids accumulate. They suggest that the effect of such a migration would be to decrease the radiocarbon age of the accumulation layer and to increase the age of the leached zone. The former speculation seems reasonable, as the amino acids arriving in the accumulation layer would have a higher $C^{14}$-to-$C^{12}$ ratio than the organic compounds already present in the zone. The latter speculation seems invalid, as it would require a differential leaching of $C^{14}$ containing amino acids. Clearly the $C^{14}$-to-$C^{12}$ ratio of the amino acids removed from the zone would be identical to that of the organic compounds remaining in the zone of leaching. Thus, there would be no net change in $C^{14}$-to-$C^{12}$ ratio and no change in radiocarbon age. The only effect would be a decrease in the organic content of the zone. If the hypothesis of leaching and accumulation can be substantiated, then one can assume that as the peat continues to accumulate, the zone of accumulation would move upwards in the profile. The net result would be a slight decrease in the radiocarbon age of sediments below the present zone of amino acid accumulation, with no change in the radiocarbon age of the sediments above the zone. The magnitude of the age decrease would not be great, however, since the peats are young (hence, relatively rich in $C^{14}$), and the relative enrichment of the accumulation zone would be slight. Thus, even the dates from lower in the peat profiles are probably reasonably accurate.

## Discussion of Zones

The general similarity in stratigraphy and pollen assemblage zones among the four cores (Fig. 2–5) permitted drafting a generalized pollen diagram (Fig. 6). In general, there is a progression from inorganic sediments, mostly clays and sandy clays, to organic clays (gel-mud), clayey peats, and eventually to forest peat. The pine-spruce assemblage zone is invariably associated with the inorganic horizons at the base of the profile, the beech-hemlock-birch with the organic clays, the lower portions of the oak-hickory zone with the finer grained peats, and the upper cypress-gum assemblage zone with the relatively coarse forest peat at the top of each profile.

The clay beneath the organic sequence probably

[2] Dating was carried out by the Geochronometric Laboratory of Yale University, courtesy of Dr. Minze Stuiver. Support was provided by ONR Contract 609(4) to Drs. Richard F. Flint and John E. Sanders.

represents at least two different depositional environments and time intervals. Lower in the section it is undoubtedly part of the interglacial Sandbridge Formation, a lagoonal clay deposited during the Sangamon. The presence of hystrichosphaerids in the basal spectra suggests the marine or brackish origin of at least some of the clay. Admittedly the clay penetrated in several cores may not actually be Sandbridge, as the "hystrix" could be reworked. The upper portion of the clay, containing spectra dominated by pine and spruce, was probably deposited in drainage lows on the Sandbridge surface during either full-glacial or late-glacial time. Clay deposition may have been favored by relatively high precipitation, a more intense frost climate, or the initiation of the late-glacial sea-level rise.

### *Pine-spruce assemblage zone*

Pollen spectra attributable to the pine-spruce assemblage zone occur in the inorganic sediments at the base of two of the Dismal Swamp cores (DS-1 and DS-77). This assemblage zone is far more extensive in core DS-77. Pine is clearly the dominant pollen type; size measurements indicate the presence of jack or red pine, or both (Whitehead 1964). Spruce is also common, plus *Lycopodium lucidulum, L. clavatum, Sanguisorba canadensis,* and fir. The virtual absence of more temperate taxa indicates a vegetation rather different from that presently existing in the region.

A general age for the pine-spruce assemblage zone can be established by using the radiocarbon dates from the overlying organic sediments and by comparison with dated peats from the mouth of Chesapeake Bay (Harrison et al. 1965) and diagrams from the Shenandoah Valley (Craig 1970). The dates on the organic sediments directly overlying the clays suggest that the pine-spruce zone is more than 8,900 years old. Since there is generally a disconformable relationship between the organic clays and inorganic sediments, a hiatus may have occurred. Such a depositional break is also suggested by the abrupt changes in pollen curves between the pine-spruce and beech-hemlock-birch assemblage zones. The comparable pollen spectra from the mouth of Chesapeake Bay range in age from 10,000 to 11,600 years, those from the Shenandoah Valley from 9,500 to 12,700 years. Thus the pine-spruce spectra were apparently formed during late-glacial time. Older spectra from the bay borings and western Virginia are considerably richer in spruce pollen.

Definitive vegetational and environmental reconstructions are difficult to make, since modern analogs for the fossil spectra from this assemblage zone are apparently lacking. Spectra from several areas of boreal forest in Canada are similar in that pine is extremely abundant and spruce subsidiary, but almost invariably birch is also abundant (see Davis 1967). In the Dismal Swamp spectra birch is relatively uncommon. The closest match is with surface samples from an area of jack pine forest on sandy uplands in southeastern Manitoba (Lichti-Federovich and Ritchie 1965). This could be taken to imply that the vegetation and climate existing in southeastern Virginia during the late-glacial was similar to that presently occurring in southeastern Manitoba. However, a more cautious interpretation is necessary, since the Manitoba spectra derive from an extremely localized area in which the dominance of jack pine appears to be conditioned by the occurrence of coarse glacio-fluvial sediments and frequent fires. Thus, one might infer floristic similarity between present-day Manitoba and late-glacial Virginia, but not necessarily climatic similarity. Probably the late-glacial forests in Virginia were under climatic control, since similar spectra are known from the Chesapeake Bay borings and also from full-glacial sediments in the Shenandoah Valley, southeastern North Carolina, and in northwestern Georgia (Frey 1951, 1953, 1955, Whitehead 1964, 1965*a*, 1967, Craig 1970, Watts 1970).

The resemblance of the pine-dominated spectra from the Dismal Swamp to those of full-glacial age from southeastern North Carolina (Whitehead 1964, 1967) and northwestern Georgia (Watts 1970) is interesting. That the vegetation in both areas was boreal in character seems indisputable. The pollen evidence from both areas is convincing, and to this Watts (1970) has added important macrofossil evidence. Needles of jack pine and seeds of many northern aquatics have been identified in the sediments of two ponds in Bartow County, Georgia.

The structure of the vegetation remains open to question. Whitehead (1964) suggests that the structure of pine-dominated full-glacial forests of southeastern North Carolina may have been open, perhaps similar to a boreal savanna. This interpretation is suggested by the presence of pollen of a number of heliophytes and the low pollen accumulation rates. Watts is less convinced of the latter interpretation, feeling that boreal savanna might not be characterized by low pollen productivity. The vegetation in southeastern North Carolina may have been more open structured (as it is today) because of the prevalence of coarse sandy soils. The soils in both Bartow County and the Dismal Swamp region are considerably finer textured.

In the absence of adequate representational information from areas where jack and red pine occur, it is difficult to make an accurate reconstruction of late-glacial forests. The work of Davis and Goodlett (1960) suggests that pine is greatly overrepresented in northern Vermont. However, very different results have been obtained for southeastern North

Carolina (Whitehead and Tan 1969). Therefore, a cautious interpretation must be made. The forests of the region were doubtless dominated by pine and spruce, but in what proportions and with what structure one cannot say. The climate may have been significantly cooler than the present, but again, the magnitude of the difference is obscure. There is evidence that the late-glacial clays were deposited in lows on the Sandbridge surface and that the water table was high enough to permit the growth of many aquatics and to maintain "bog" conditions in some areas. Pollen or spores of many aquatics are represented in the spectra, and algal remains are common. The bog conditions are suggested by the occurrence of alder, Ericaceae, *Viburnum, Myrica, Thalictrum, Sanguisorba canadensis, Potentilla* cf. *palustris, Lycopodium inundatum-alopecuroides,* and abundant grass and sedge in core DS-77.

### *Beech-hemlock-birch assemblage zone*

This pollen assemblage zone can be recognized in the three Dismal Swamp profiles. It occurs at the base of DS-49, within a narrow zone just above the pine-spruce zone in profile DS-1, and it extends through 0.5 m above the pine-spruce assemblage in core DS-77. In general, spectra attributable to this zone are associated with extremely fine-grained organic sediments that are transitional between the inorganic clays at the base of each section and the forest peat above. The sediments are here referred to as organic clays or gel-muds. Radiocarbon dates from the Dismal Swamp profiles and from the Chesapeake Bay peats (in which a similar pollen zone can be recognized) suggest that this assemblage zone was deposited between 10,600 and 8,200 years ago. It can be thought of as transitional between the distinct pine-spruce zone at the base of the profiles and the easily distinguished oak-hickory zone in the lower half of the peat.

A precise vegetational and environmental reconstruction is difficult, because the fossil spectra are not similar to any presently available modern spectra. There are no close matches among the many modern spectra collated by Davis (1967) from Canada and northern United States. Spectra have been described in which the dominant pollen types of the assemblage occur concurrently, but generally birch is far more abundant than in the fossil samples. Because of the simultaneous occurrence of many members of the present "northern hardwoods" forest (Braun 1950) (white pine, hemlock, beech, birch, sugar maple) it is tempting to suggest that the forests which produced the beech-hemlock-birch spectra were like those presently growing in some areas of the northeast; but again, no modern spectra match. Clearly, the vegetation was markedly different from that presently existing in southeastern Virginia, and probably the climate was somewhat cooler (and moister) than at present. In this context the occurrence of two aquatics is of interest as it emphasizes the interpretational problems. Grains of *Cabomba caroliniana* and *Polygonum amphibium* occur in this assemblage zone. At the present time *Cabomba* does not grow naturally north of Virginia, and *Polygonum amphibium* extends only as far south as New Jersey.

Although no modern spectra provide a close match at the moment, fossil spectra from other areas correspond quite favorably. Spectra from the Chesapeake Bay borings (Harrison et al. 1965) and the Shenandoah Valley (Craig 1970) are very similar. The late-glacial portions of the Bay Lakes profiles from southeastern North Carolina are also similar. Vegetation producing beech-hemlock-birch spectra was widespread in the Southeast during the early postglacial, although it appears to have occurred earlier in southeastern North Carolina than in the Dismal Swamp region (Whitehead 1965*a*).

The abundance of aquatics (and grasses and sedges) in most of the beech-hemlock-birch spectra suggests the presence of standing water, at least in the drainage lows. The hydroperiod appears to have been comparatively long in such sites. Precipitation (and lower temperatures) might have contributed, but equally possible would be a ponding in drainage lows controlled by the postglacial rise of sea level. This will be discussed in greater detail subsequently.

### *Oak-hickory assemblage zone*

The oak-hickory zone is well developed and extensive in all three of the Dismal Swamp profiles and at the base of the Lake Drummond core. Oak-hickory type spectra are generally associated with relatively fine-grained fibrous peat, less commonly with gel-mud near the base of the zone, and with forest peat near the top. The available radiocarbon dates suggest that the zone ranges from 8,200 to 3,500 years in age. As indicated in the description of pollen zones, there are distinctive changes in the frequency of certain shrub, herb, and aquatic pollen (and spore) types. These permit delimitation of two and possibly three subzones. The subzones may reflect localized edaphic changes (controlled by water level) within the swamp rather than regional climatic changes.

Environmental reconstructions will suffer from the same indefiniteness alluded to previously, since no modern equivalents are known for the fossil spectra. This does not necessarily mean that the vegetation was not similar to that of any present forest region. It may reflect instead the absence of data from the appropriate region. As yet very little work has been done on modern pollen rain in the area south of the drift border.

Probably the vegetation producing the oak-hickory assemblage zone was rather similar to that presently existing on the uplands surrounding the Dismal Swamp. All of the pollen types represented are those that would be expected in the region today (oak, hickory, gum, cypress, sweet gum, ash, elm, red maple, walnuts, etc.). Neither more "boreal" nor more "austral" taxa are represented. Thus one might suggest that the climate during this time span (8,200–3,500) was comparable to the present.

The trends in tree pollen types, especially the decrease in oak hickory and the increase in cypress, gum, and red maple, might indicate a general climatic amelioration resulting in the replacement of hardwood forest by an essentially austral cypress-gum swamp. However, it is just as likely that the changes in vegetation were a function of the continued development of peat controlled by the postglacial rise of sea level. As mentioned previously, the surface on which the swamp developed possesses a subtle dendritic drainage pattern with normally developed, albeit shallow, branching stream valleys and corresponding interfluves or "highs." The peat began to develop first in the drainage lows, and as the depth increased, began to spread inland and laterally, mantling the interfluves. Thus, progressive change took place from a regional "mineral soil" (developed on the Sandbridge Formation) to a peat soil (Fig. 7–9). One can assume that the forests growing on the inorganic soil were basically hardwood forests, similar in species composition to those presently occurring on the uplands within and outside the Dismal Swamp. These hardwood forests were apparently replaced by types better adapted to an acid, peaty soil. Cypress, gum, cedar, red maple, and various swamp shrubs began to increase at the expense of oak, hickory, and sweet gum.

The slight pine maximum is difficult to interpret.

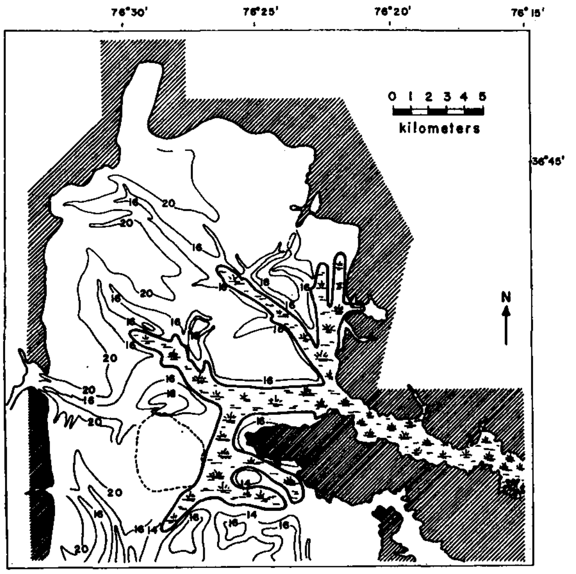


FIG. 7. Topography of Dismal Swamp, ca. 8,300 B.P.

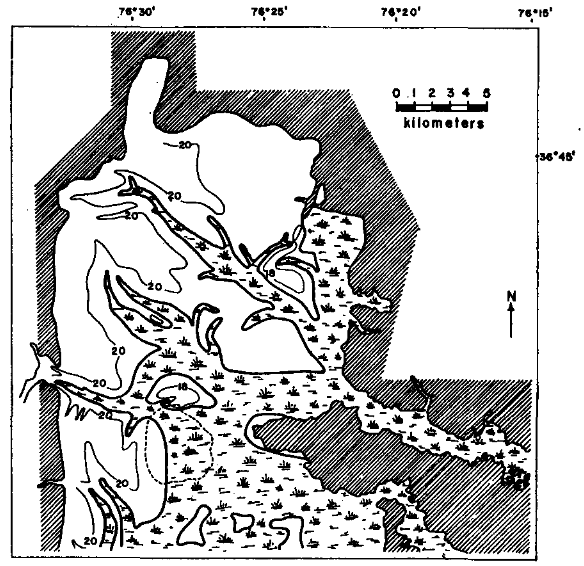


FIG. 8. Topography of Dismal Swamp, ca. 6,000 B.P.

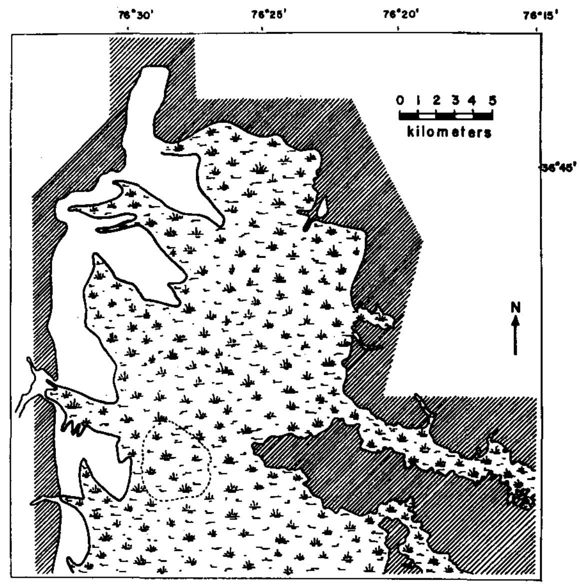


FIG. 9. Topography of Dismal Swamp, ca. 3,500 B.P.

It might indicate expansion of pond pine (*Pinus serotina*) within the swamp. It might reflect drier conditions and a consequent expansion of *Pinus taeda*. It might be nothing more than a statistical artifact, reflecting a sharp decrease in oak (a prolific pollinator) within the vegetation, rather than an actual increase in the frequency of pine. Unfortunately, absolute pollen counts (e.g., Davis 1965*a*) were not taken, so that this question cannot be answered. The significance of the pine maximum will be discussed below.

*Sweet gum subzone.*—In general, the oak-hickory zone can only be differentiated into two subzones:

(1) a grass-limnophyte subzone and (2) an *Orontium*-composite-fern spore subzone. In core DS-1, however, another transitional subzone seems to occur at the base. In spectra from 2.2 to 1.7 m sweet gum pollen is fairly frequent, but, in contrast to the other two Dismal Swamp cores, higher aquatics are not abundant. Algae (*Botryococcus, Pediastrum,* and *Peridinium*) occur in the zone, and *Botryococcus* is quite frequent. Lastly, hemlock and beech pollen continues to be well represented.

The significance of this indefinite subzone is by no means clear. In some respects it appears to be strictly transitional between the beech-hemlock-birch and overlying oak-hickory zones. It can be interpreted as representing the upper portion of the former zone (because of the continued presence of beech, hemlock, and birch). In this case the abundance of oak, hickory, and sweet gum would simply represent a local variation within the swamp. It can be thought of as the lower portion of the sweet gum-limnophyte subzone, since, even though it lacks abundant pollen of aquatics, the presence of algae (and gel-mud sediment) might be taken to indicate standing water. However, the algae involved, all planktonic species, can also grow in temporary pools (Prescott 1962, Starr, *personal communication*). Lastly, it could represent a distinct zone, indicating at least a local difference in the swamp's developmental history, with a "low water phase" (or relatively short hydroperiod) prior to the deposition of the relatively distinct overlying sweet gum-limnophyte zone.

The radiocarbon date from the base of DS-1 illustrates the problem of interpretation. The date is 8,900 ± 160, which compares with a date of 7,670 ± 60 from a similar position in core DS-49. Given the older DS-1 date, perhaps it is surprising that beech, hemlock, and birch persist into the base of the oak-hickory subzone. In any case, one should not be surprised at local differences within a vast, peat-forming swamp. Significant vegetational differences exist at present, and the underlying Sandbridge surface is not flat, suggesting that prominent "islands" occurred within the swamp in the earlier phases of its development. The presence of such highs would further accentuate vegetational differences.

*Grass-limnophyte subzone.*—This subzone is distinctive and is well represented in all three Dismal Swamp profiles. In general, it is characterized by a significant maximum of grass and sedge pollen and maxima for many aquatics (e.g., *Myriophyllum, Nymphaea, Nuphar, Polygonum* sect. Persicaria, *Isoëtes, Typha* spp., *Proserpinaca, Potamogeton,* etc.). The correlation of grass and sedge pollen with aquatics suggests that the former probably represent species growing in aquatic or semiaquatic habitats. The subzone, which appears to have been deposited between 8,200 and 6,000 years before present, is named primarily for the aquatics which appear so commonly within it. Since different taxa occur in the three profiles, the term "limnophyte" is used rather than the names of several different pollen types. In this case limnophyte contrasts the constellation of aquatic pollen types with those that occur abundantly in the overlying subzone, where "telmatophytes" abound (such as *Orontium.*) Neither term should be construed in a strict sense. Rather they are meant to imply general differences in the ecology of the aquatic types represented in the two subzones.

The grass-limnophyte subzone probably indicates the presence of fresh-water marsh formations (Kearney 1901) along the streams that flowed over the Sandbridge surface. The bordering interfluves appear to have been forested by a hardwood-dominated vegetation, whereas the stream courses appear to have supported extensive marshes perhaps similar to the reed marshes described by Kearney (1901). Sedges (e.g., *Scirpus* sp.) and grasses (*Zizania* sp.) are at present abundant along the larger streams above influence of salt water. Cattails and numerous other aquatics appear to have been abundant as well. It is suggested that this represents one of the earliest phases in the development of the Dismal Swamp and indicates a general ponding that probably was evident in virtually all topographic lows on the Sandbridge surface. The cause of the paludification is conjectural, but most likely it was controlled by the rapid rise of sea level (e.g., Emery and Garrison 1967, Redfield 1967) rather than by precipitation.

Apparently development of a limnophyte-dominated zone was metachronous within the swamp. In core DS-77 limnophyte pollen is quite common in the pine-spruce and beech-hemlock-birch assemblage zones, chronologically earlier than in cores DS-49 and DS-1. Thus, the development of the aquatic-dominated subzones is somewhat independent of the major assemblage zones.

Orontium*-composite-fern subzone.*—This subzone is also distinctive and is well developed in the three Dismal Swamp profiles. It occurs in the upper portion of the fine-grained fibrous peat and the lower portion of the forest peat. It ranges in age from 6,000 to 3,500 years before present. As mentioned previously, aquatics are also common in this zone, but in general they are species that grow on muddy shores or where the hydroperiod is comparatively short. Furthermore, the presence of composites, fern spores (possibly indicating *Woodwardia,* which is common in the swamp today), *Cephalanthus,* and *Diodia* indicates that the substratum had become significantly more peaty and probably dried out during at least one portion of the year. The transition to a forest peat and the presence of a distinct stump layer at this level also suggest this. Furthermore, the deterioration of pollen preservation within this subzone indicates periodic drying of the peat surface and accelerated oxidation.

Thus, as the swamp continued to develop, conditions along the main water courses became significantly less moist. Several factors may have contributed to this: (1) the continued accumulation of organic sediment over the surface, (2) changes in the rate of water-table rise, and (3) decrease in precipitation. The gradual accumulation of peat could contribute appreciably to this condition even if the water table continued a slow rise, but most likely the subzone reflects an interaction of the two phenomena. It is probably significant that there is good evidence for a distinct slackening of the rate of sea-level rise between 6,000 and 4,000 years before the present (Newman and Rusnak 1965, Emery and Garrison 1967, Redfield 1967).

### *Cypress-gum assemblage zone*

This zone is well developed in the Lake Drummond profile and the upper portion of cores DS-1 and DS-49 from the Dismal Swamp, but is missing from the top of DS-77, although there is an indication that it was once present. The zone is characteristically developed in forest peat (gel-mud for Lake Drummond) and appears to span the time from 3,500 years ago to the present.

The spectra are virtually identical to those from the surface of the peat in the swamp. In addition, the taxa represented are those that characteristically grow in cypress-gum swamps. Thus the zone mirrors the culmination of peat development over the entire swamp surface and the consequent expansion of swamp forest (contrast Fig. 8 and 9). The obvious differences among the profiles indicate that forest development has been slightly different in various portions of the swamp. Sharp changes also occur in some curves within the zone, changes which are not concordant from profile to profile. The types most usually demonstrating such fluctuations are "cupressaceae," black gum, and various swamp shrubs. The differences between profiles indicate that, as at present, a spatial vegetational mosaic probably existed within the swamp at any point in time. The changes doubtless reflect a number of influences such as fluctuations in water table (under either climatic or sea-level control), blow-downs within localized areas (due to storms), and forest fires. It is significant that the sharp fluctuations within the zone occur only in the peat profiles, not in the Lake Drummond section.

That early man may have been instrumental in precipitating changes within the Dismal Swamp, even during the deposition of the cypress-gum assemblage zone, is suggested by the occurrence of maize pollen at the 0.49-m level of core DS-1. As indicated previously (Whitehead 1965*b*), apparently maize was grown in localized clearings within the swamp approximately 2,000 years ago. The maxima of grass, *Myrica,* and *Corylus* at roughly the same level suggest the presence of an open area. The origin of the clearing is conjectural, but a fortuitous fire may have been the primary agent. The presence of charcoal within the forest peat horizons at a number of points in the swamp suggests the probability of similar disturbances in other portions of the swamp during the last two thousand years.

The absence of this assemblage zone from the top of core DS-77 might be taken to indicate that the eastern portion of the swamp never developed an extensive cypress-gum forest. However, the absence more likely reflects the loss of peat from the surface through oxidation (the pollen at the top of the profile is badly preserved) or fires. This profile is located just east of the Intracoastal Waterway, and Shaler (1890) has indicated that the construction of the waterway had a profound influence on the water table. The spoil dredged up served as a levee that blocked the normal eastward flow of water, thus leading to a rise of water table west of the canal. In contrast, the water table of the area east of the canal was lowered, since it was deprived of the normal inflow from the west. Thus the suggested oxidation of peat may have been initiated by the construction of the waterway.

During deposition of the cypress-gum zone the climate has been quite comparable to the present. Development of swamp forest may have been controlled by a gradual amelioration of climate, but, as indicated previously, the writer feels that the expansion was controlled instead by the continued accumulation and expansion of peat. By the time deposition of this zone was initiated, virtually the entire Sandbridge surface had become mantled by peat. Thus, the habitats favoring growth of hardwood forests were eliminated and swamp forest became dominant. The rate of peat development was controlled by the water table, with sea level exercising at least an indirect influence.

## Post-Wisconsin Environmental Changes in Southeastern Virginia

Comparatively little work has been done in southeastern Virginia, but the present investigation and the studies of Lewis and Cocke (1929), Cocke, Lewis, and Patrick (1934), Vick (1961), and Terasmae (Harrison et al. 1965) permit some speculations concerning the late-Pleistocene history of this area. The evidence available is derived from the early investigations of Lewis and Cocke in the northern half of the Dismal Swamp, more recent work by Vick in the southern border of the swamp, and Terasmae's analysis of radiocarbon-dated peat horizons situated well below present sea level in the mouth of Chesapeake Bay. Of these studies, Terasmae's appears the most meaningful, since it covers an earlier period of time (approximately 16,000–7,000 B.P.), and the techniques employed are far more modern. Nevertheless, the early analyses of Dismal Swamp sediments provide interesting correlative information on the most recent phase of the swamp's development.

The several profiles analyzed by Lewis and Cocke (Lewis and Cocke 1929, Cocke, Lewis, and Patrick 1934) seem to depict a gradual change from an open fresh-water marsh to a cypress- and gum-dominated swamp forest. The possibility of at least one interruption of the seemingly unidirectional progression is indicated by maxima of grass pollen (and some aquatics) midway in two profiles. Furthermore, Patrick's study of diatoms in one profile suggests that the "retrogression" may have been caused by an influx of salt water.

The profiles studied by Lewis, Cocke, and Patrick appear to be both incomplete and markedly different from those studied by the present writer. There is no indication of pine-spruce, beech-hemlock-birch, or oak-hickory assemblage zones, oak pollen is uncommon throughout the profiles, and willow, rarely found in the present study, appears to have been strongly represented. These differences are hard to reconcile. The apparent abundance of willow pollen in the earlier study might represent a misidentification (*Cephalanthus,* which also possesses a reticulate sculpture, is a likely possibility). The general lack of comparability might be a function of the sites at which cores were taken. Only the uppermost pollen zone is represented in the earlier cores, suggesting that the base of the profiles might be only 3,500 years old. If one assumes that the deposition of organic sediment began along the stream courses and other topographic lows on the Sandbridge surface and gradually spread laterally to mantle the interfluves, then it is comparatively easy to explain the difference between the two studies. The earlier cores were not taken in topographic lows, but rather from the present peat surface above Sandbridge slopes or interfluves where deposition of organic sediment did not commence until rather late in the swamp's history.

The changes within the cypress-gum assemblage zones further the idea that the vegetation of the forested swamp has undergone many fluctuations. The prominent maxima of grass (and other herbs and aquatics) found by Lewis and Cocke are similar to those found in the present study (although they occur in association with different pollen zones). I do not think that they represent "retrogressions," as Lewis and Cocke imply, but rather local changes in the aquatic and semiaquatic plant communities, probably controlled by water table. In contrast to Patrick's suggestion, I find no indication of any salt-water phase during the latter phase of the swamp's development. Furthermore, there is no indication that sea level was ever high enough during the past 10,000 years to permit any influx of salt water (Newman and Rusnak 1965, Emery and Garrison 1967, Redfield 1967).

The work of Vick (1961) is perplexing. In general, there are few similarities to either the earlier studies or the work here reported. *Quercus* is barely represented, and the maxima for willow (up to 40%) are extraordinary. Additional work will be necessary in the southern portion of the Dismal Swamp to determine the nature of the environmental changes.

The diagrams from Chesapeake Bay parallel the Dismal Swamp diagrams in virtually all details. The samples were derived from two borings which penetrated a series of sand, peat, and clay horizons deposited in the vicinity of the present mouth of Chesapeake Bay between 7,000 and 16,000 years ago. The horizons occur 17–29 m below present mean sea level. Some spectra correspond well to those of the two Chesapeake Bay borings, although spruce is significantly more abundant. Higher in each section a beech-hemlock-birch zone is indicated, and above this the spectra are similar to those from the lower portion of the oak-hickory zone. The spectra most similar to those of the pine-spruce zone have provided radiocarbon dates of $10,340 \pm 130$ and $11,590 \pm 150$ B.P. These peat horizons are located approximately 25 m below mean sea level. A spectrum from one boring containing considerably more spruce and positioned approximately 27 m below mean sea level has been dated at $15,280 \pm 200$ B.P. The basal spectrum in the other boring contains even more spruce (45%) and hence may be older than 15,000 B.P. The uppermost spectra (similar to the oak-hickory zone) have not been dated, but a comparison with the dated profiles from the Dismal Swamp suggested that they were deposited about 7,000 years ago.

As mentioned previously, the close parallel between the Chesapeake and Shenandoah Valley profiles and the lower half of the Dismal Swamp diagrams suggests that the succession of assemblage zones (pine-spruce, beech-hemlock-birch, oak-hickory) has regional significance and indicates the nature of full-glacial, late-glacial, and early postglacial environmental changes in southeastern Virginia. The recent work of Craig (1970) in western Virginia lends support to these contentions, as the sequence of pollen zones from the full-glacial to the present is quite similar.

The vegetational changes suggested above indicate a unidirectional climatic amelioration from relatively boreal conditions during full-glacial time to conditions roughly comparable to the present by about 8,200 years ago. Within the Dismal Swamp this corresponds to the boundary between the beech-hemlock-birch and oak-hickory assemblage zones, and it probably correlates with the beginning of the hypsithermal interval (Deevey and Flint 1957). However, there is no unequivocal evidence to indicate that conditions may have been warmer or drier (or both) during this interval. Admittedly, one might cite the evidence for "shoaling" (the *Orontium*-composite-fern subzone, stump layer, poor pollen preservation, lower rate of peat accumulation) as indicative of higher temperatures or lower precipitation, but as mentioned previously, these changes correspond in time to a slackening in the rate of sea-level rise (e.g., Redfield 1967). It is just as likely that this was the controlling factor. Similarly, there is no convincing indication of a climatic deterioration late in the postglacial (see discussion in Davis 1965*b*), although it might be tempting to interpret the cypress-gum assemblage zone as indicative of increased precipitation. The gradual shift from hardwood forest to swamp forest was probably conditioned not by climate but instead by edaphic changes within the Dismal Swamp, specifically, the progressive inundation of hardwood-dominated interfluves by peat.

## Developmental History of the Dismal Swamp

Much has been written by earlier workers concerning the history of the Dismal Swamp and the origin of Lake Drummond. It has been likened to the European raised bogs (Lesquereux 1853); its development has been considered as analogous to that of bogs in glaciated regions (Shaler 1890); it is thought by some to have developed discontinuously, initially in topographic lows on the pre-Dismal Swamp surface (Cocke, Lewis, and Patrick 1934). In most speculations, the low relief of the subsurface is thought to have exercised a strong control on the origin and subsequent development of the swamp. Lake Drummond has been variously interpreted. Some consider it to have originated as a result of a deep peat burn at a time when the water table was low, others consider it to be similar to bog lakes in the north, in which vegetation and peat develop centripetally, with the central lake representing the last vestige of the original open-water phase (Shaler 1890). The possibility of meteoritic origin has been suggested, a theory once widely considered to explain the origin of the Carolina Bays (e.g., Prouty 1952).

The present study and recent geomorphological investigations in southeastern Virginia have provided new insight concerning the development of the Dismal Swamp. The following sequence of events can be suggested: (1) deposition of Sandbridge lagoonal clays during a high stand of the sea in the Sangamon interglacial; (2) development of a dendritic drainage pattern on the Sandbridge surface during the lower sea level phases of the Wisconsin; (3) deposition of inorganic clays in topographic lows (along water courses) between 12,000 and 10,000 years ago; fresh-water marsh vegetation along streams, boreal pine-spruce vegetation on interfluves; (4) sedimentation of gel-mud in shallow water along the water courses (between 10,000 and 8,200 years ago); fresh-water marsh conditions along streams, gradually extending inland and laterally to encroach upon interfluves; on interfluves a gradual shift to a vegetation containing many species now found in the white pine-hemlock-northern hardwoods forests in the Northeast (Fig. 7); (5) 8,200–6,000 years B.P.; continued extension of fresh-water marsh inland along streams and laterally onto interfluves; sediments more fibrous; vegetation of interfluves basically a hardwood forest with taxa that are presently common in southeastern Virginia (Fig. 8); (6) 6,000–3,500 B.P., continued extension of swamp inland; gradual inundation of interfluves by peat; sediments far more fibrous; rate of peat deposition slows; water table lower within swamp; hydroperiod considerably shorter; gradual replacement of hardwood forest by cypress-gum forest (Fig. 9); (7) 3,500-present; peat development throughout swamp; cypress-gum forest dominant; many local variations.

The origin of the Sandbridge formation and subsequent dissection of the surface are suggested by recent geomorphological work (Oaks and Coch 1963, Oaks 1964) and by the many borings taken in the swamp by Oaks, by the Union Bag-Camp Paper Company, and by me. A comparison of pollen profiles from the topographic lows and those derived from above slopes or Sandbridge interfluves suggests that post-Sandbridge sedimentation did not begin uniformly over the entire surface, but rather was initiated between 12,000 and 11,000 years ago along the stream courses. Evidence concerning the postglacial rise of sea level suggests that by this time the sea level must have risen from a postulated full-glacial low of −120 m to between −50 and −80 m (Curray 1965, Emery and Garrison 1967), a rise probably sufficient to influence water tables inland along the stream courses on the Sandbridge surface. It is suggested that the primary factor controlling the beginning of swamp development was ponding due to the rise of sea level.

The latter phases of the swamp's development were probably also controlled by an interaction between topography of the Sandbridge surface and the rise of sea level. The postglacial climatic amelioration appears to have controlled the character of the vegetation growing on the interfluves within the swamp, but ultimately edaphic factors related to sea level seem to have superseded. Peat development appears to have been initiated along the streams and to have spread inland toward the Suffolk Scarp and as the peat accumulated, laterally onto the interfluves. The gradual mantling of "mineral soil" highs and interfluves by peat resulted in the replacement of hardwood forest by swamp forest. Various lines of evidence seem to indicate a change in the relationship of the water table to the surface of the peat approximately 6,000 years ago. It may be significant that this correlates with a distinct slackening in the rate of sea-level rise. The slow rise of sea level in the last 4,000 years (and increased precipitation?) permitted a continued accumulation of peat. Pollen profiles from several points indicate that spatial and temporal variability in the swamp forests was considerable. Apparently changes in water table, fortuitous fires, and human activities have been the primary controlling factors.

The origin of Lake Drummond remains enigmatic. However, the radiocarbon date from the base of the gel-mud indicates that it is a relatively young feature. This is inconsistent with Shaler's (1890) hypothesis suggesting that vegetational development was essentially centripetal, and the lake was the last vestige of an open-water phase. If this were true, the sediments would be considerably older. The supposedly mythical idea of origin through a deep peat burn cannot be eliminated. In fact, conditions may have been ideal for such a burn between 6,000 and 3,500 years ago. The general water table may have been lower during this period of time and, since the peat mantle over the present position of Lake Drummond would have been relatively thin, the burn would not have to be as deep as Shaler seems to imply. In addition, it would not have to cover an area as large as that of the present lake, as evidence obtained in southeastern North Carolina indicates that peat-ringed lakes may increase their area through erosion of the marginal peat (Wells and Boyce 1953, Frey 1954). However, the evidence for a fire is certainly inconclusive, and the question of origin must be left open.

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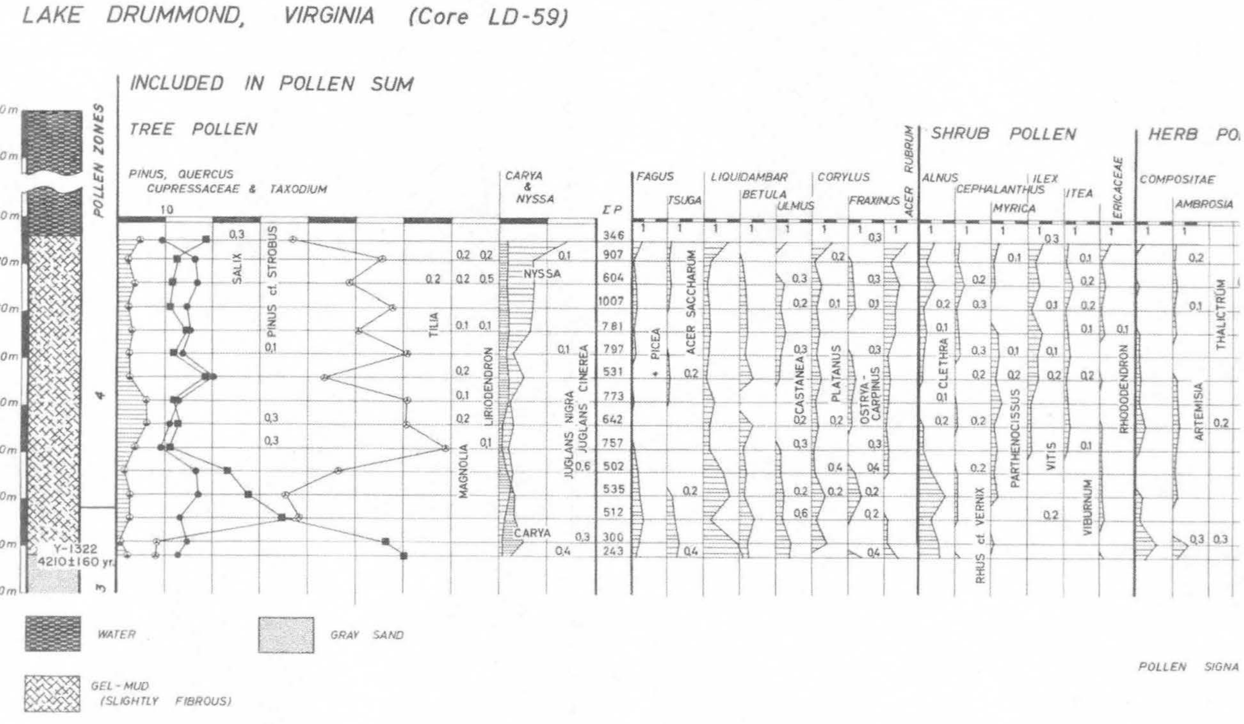



FIG. 2. Pollen diagram from boring LD-59, Lake Drummond.
agrams): 1, pine-spruce zone; 2, beech-hemlock-birch zone; 3, c
zone designations: 3A, grass-limnophyte subzone; 3B, *Orontiun*
has two subdivisions of subzone 3A: $3A_1$, sweet gum subzone; 3

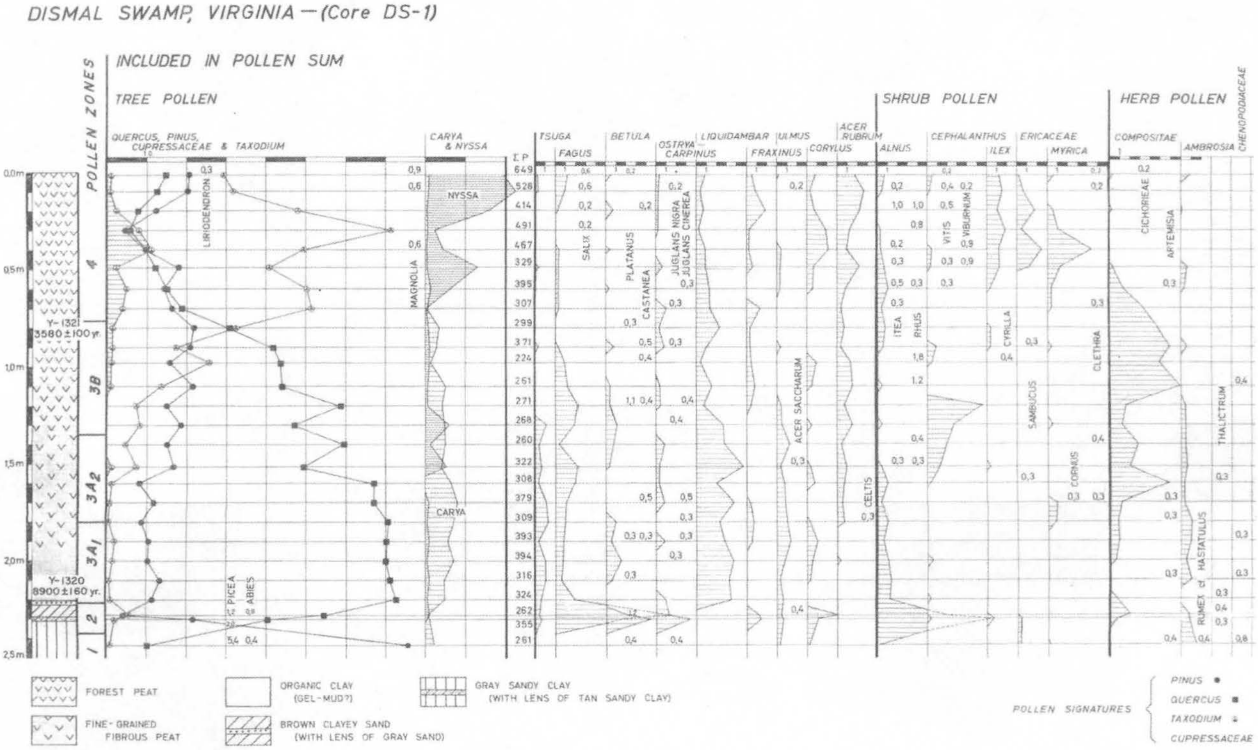
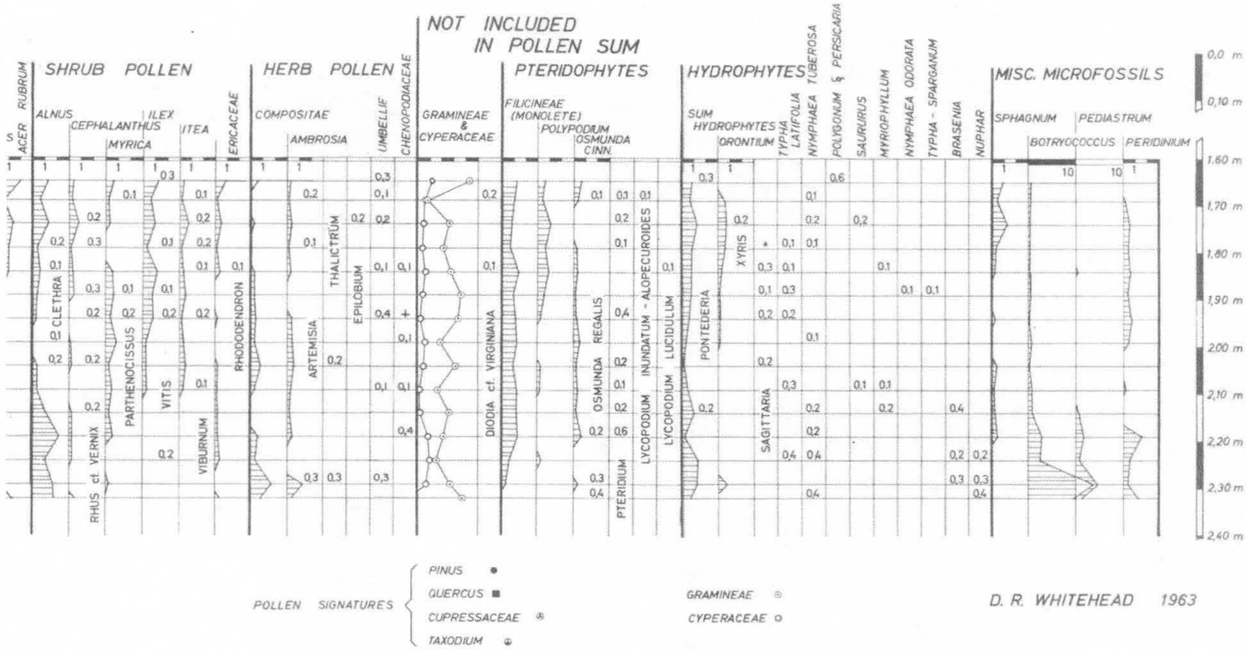



FIG. 3. Pollen diagram from boring l




from boring LD-59, Lake Drummond. Assemblage zone notations (same on all di-
one; 2, beech-hemlock-birch zone; 3, oak-hickory zone; 4, cypress-gum zone. Sub-
:ass-limnophyte subzone; 3B, *Orontium*-composite-fern subzone. One profile (DS-1)
bzone 3A: $3A_1$, sweet gum subzone; $3A_2$, grass-limnophyte subzone.

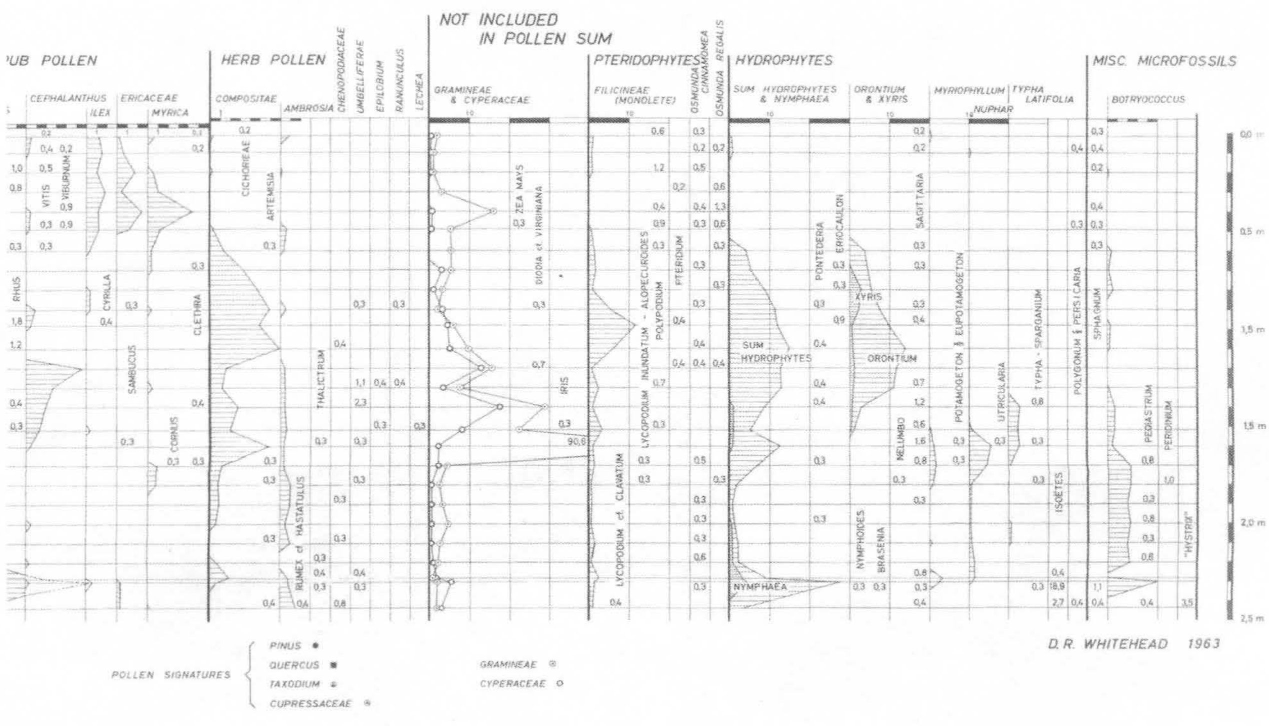



FIG. 3. Pollen diagram from boring DS-1, Dismal Swamp.

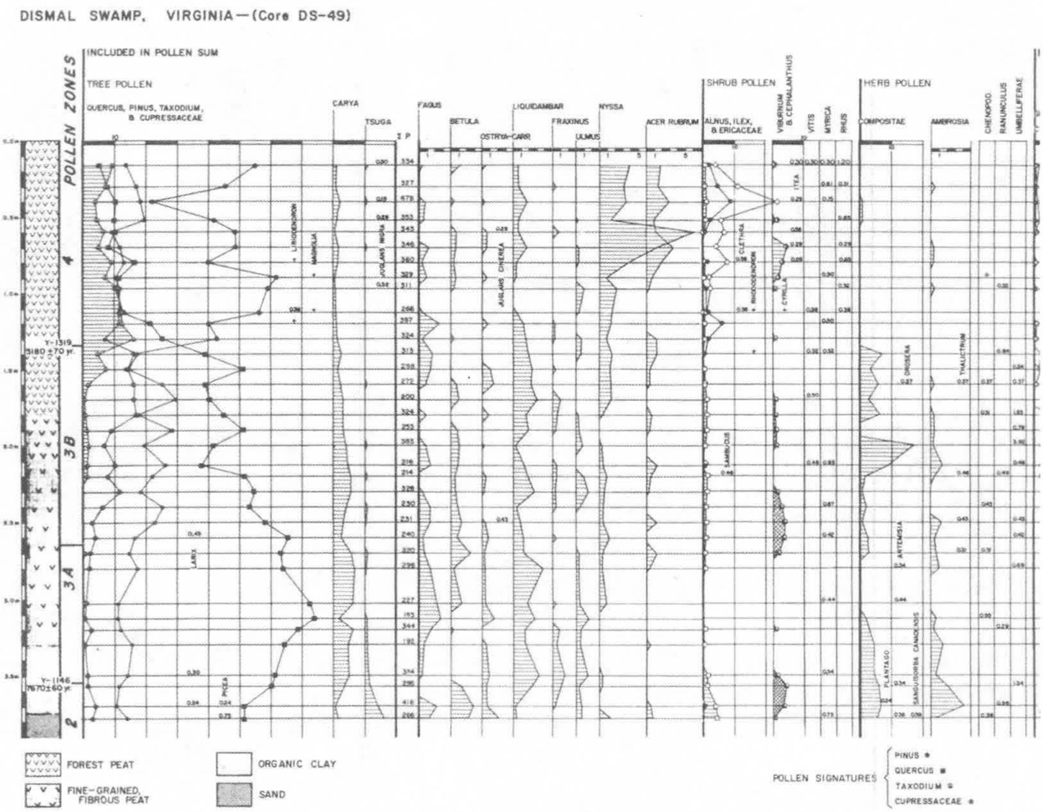



FIG. 4. Pollen diagram from boring DS-49, Dismal

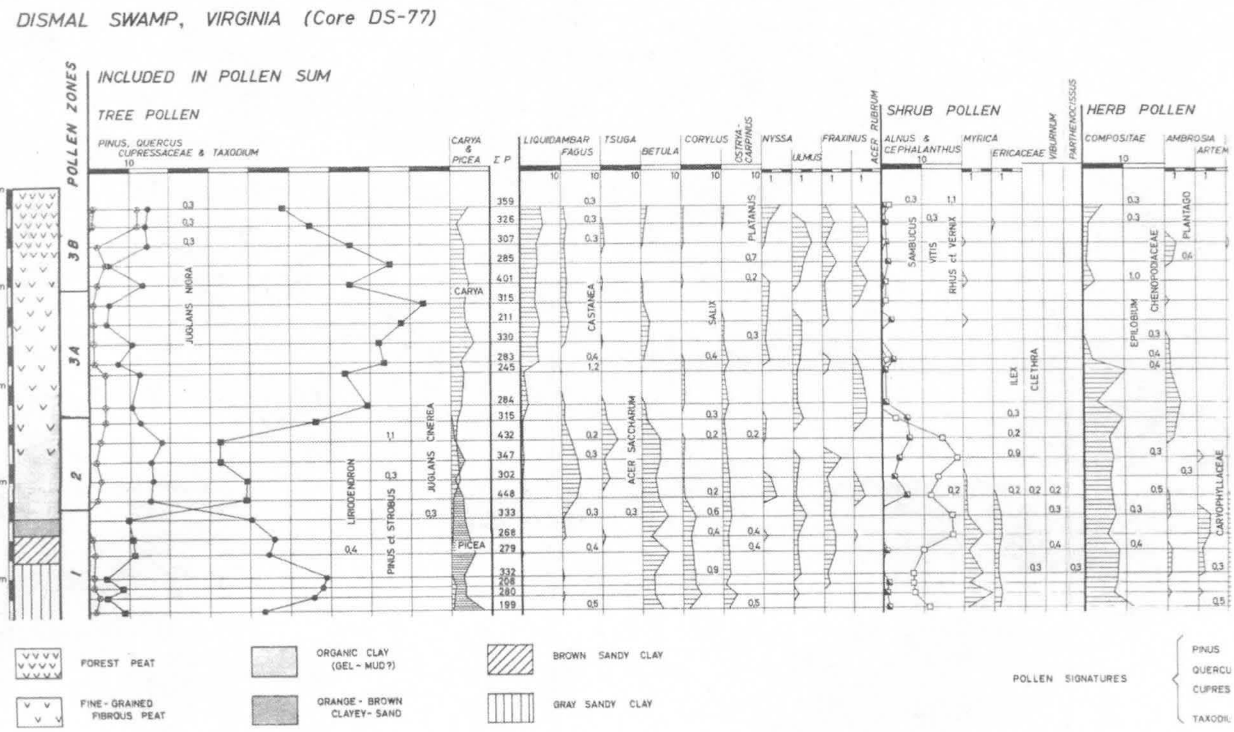



FIG. 5. Pollen diagram from boring DS-77, Dism

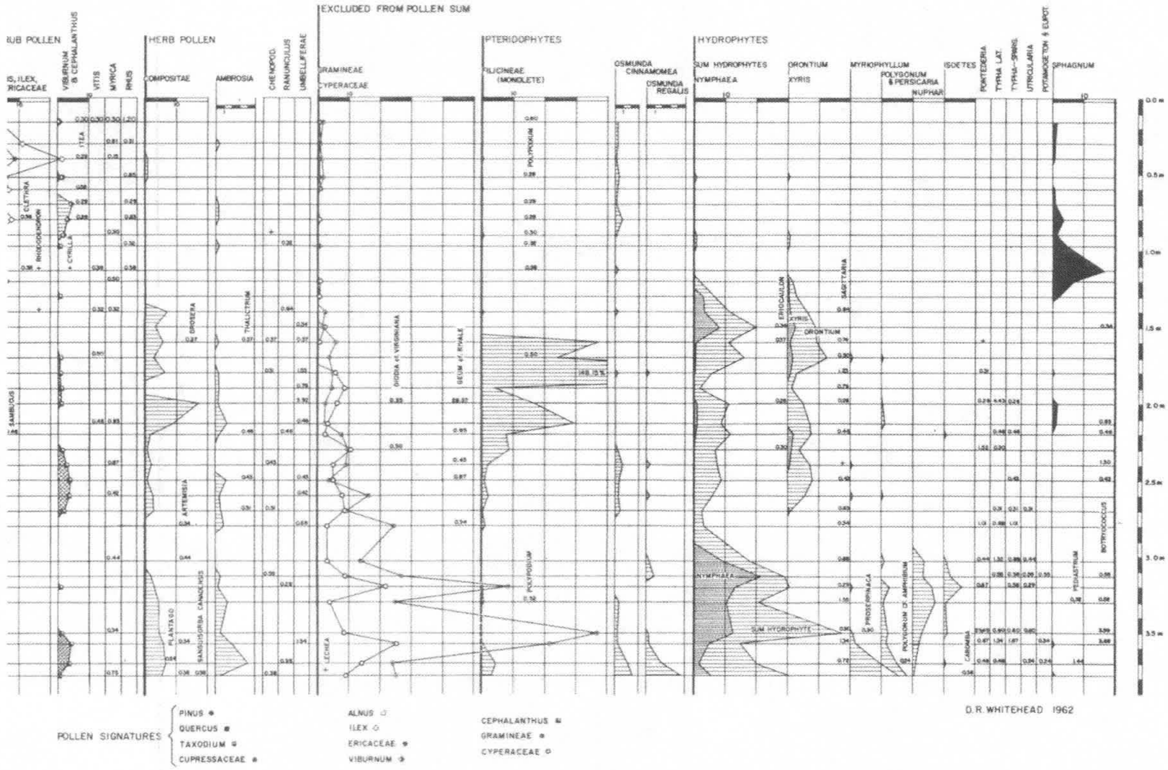



diagram from boring DS-49, Dismal Swamp.

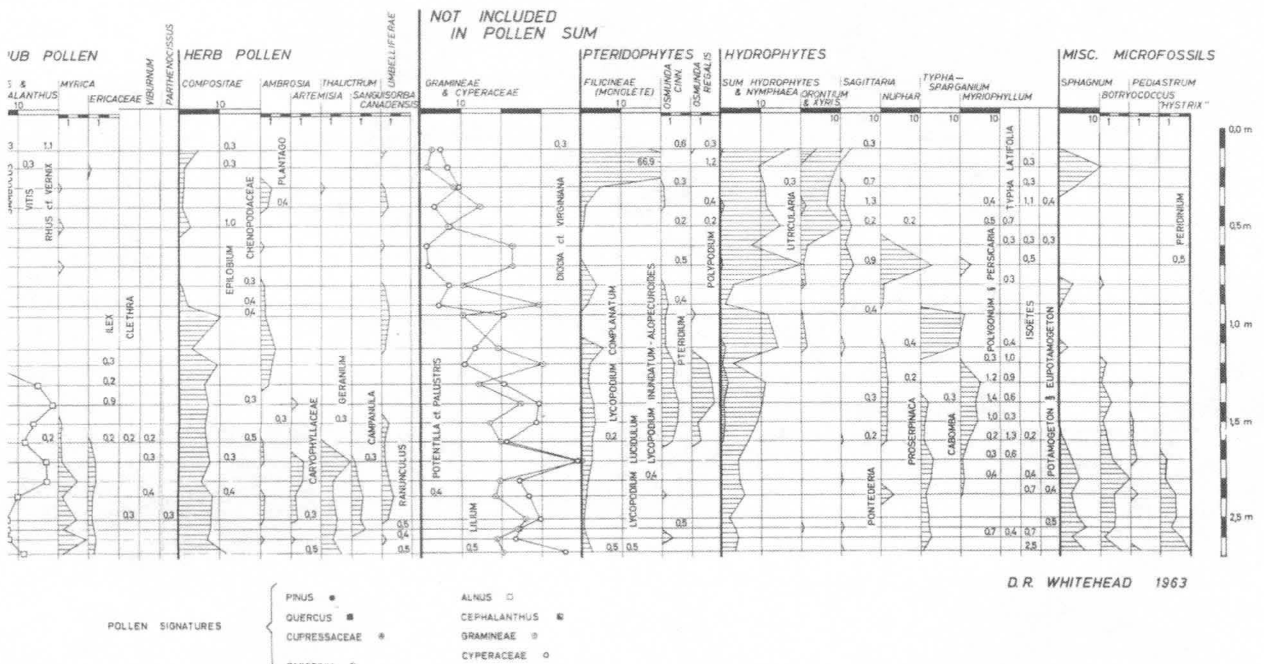



diagram from boring DS-77, Dismal Swamp.