PHYSICAL PARAMETER DISTRIBUTION PATTERNS IN BOTTOM SEDIMENTS OF THE BUCTOUCHE BAY COMPLEX

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INTRODUCTION

The Buctouche Bay complex offers a unique environment for the study of littoral and estuarine sedimentation. Located 40 km north of Moncton, New Brunswick (Fig. 1), it encompasses within a 33-km^2 area, a drowned river estuary, a coastwise lagoon, and a very well developed complex recurved spit.

Modern sedimentation patterns within the bay represent composite responses to a complex combination of physical, chemical and biological processes that are regulated by the bay's hydraulic regime and geologic framework. In addition, the bay's sedimentary processes are, or have also been influenced by such activities of man as agriculture, channel dredging, oyster culture programs and beach quarrying. The differentiation of natural effects from man-induced effects compounds the problem of understanding estuarine sedimentary processes. Another impeding factor is the variable nature of the estuarine hydraulic regime. It is difficult to predict net sediment responses within a circulatory system that comprises both tidal and fluvial components, each exhibiting short term and long variations in hydrologic characteristics. Still another complicating factor is that several possible contributing sources of sediment may have been operative within the estuarine system at different times. Estuarine sediments can be derived from a combination of external (fluvial, littoral), marginal (coastal erosion) and internal sources (biogenic, substrate erosion) (Guilcher 1967, Rusnak 1967, Meade 1969, Schubel 1971).

The objective of the present study was to delineate the areal variability in bottom sediments within the Buctouche Bay complex in order to determine parametric interrelationships that might provide some insight into the bay's sediment dispersal system.

PREVIOUS WORK

Ganong (1908), in his account of the physcial geography of New Brunswick's northeastern coast was perhaps the first to mention the Buctouche spit in a scientific report. This was followed in 1925 by Johnson's classic study of the New England and Acadian shoreline in which a brief description of the Buctouche "retrograding compound spit" was included.

In 1959, the Geographical Branch of the Department of Energy, Mines and Resources of Canada prepared a report on the physical character of the shoreline along the Northumberland Strait. This report dealt with the effects of tidal changes that could result from the construction of a causeway between New Brunswick and Prince Edward Island (Forward *et al* 1959). Van de Poll (1971) prepared a map showing the dispersal pattern of beach sand along the Northumberland Strait coast.

A resource inventory of Buctouche Bay (England and Daigle 1973) consisted mainly of mapping the shellfish population distribution and checking the consistency of the bottom sediments. This survey, in conjunction with the initiation of an oyster culture program in Kent County, New Brunswick led to a series of annual reports and to a study of some of the physico-biological characteristics of the Buctouche estuary (Andrews 1971, Andrews and Gallant 1972, Gallant 1973, Robichaud and Woo 1974). Billard (1974) gave a brief account of the major hydrodynamic trends of the system in relation to oyster spatfall, and McNally (1976) described some of the foraminifers found in the Buctouche estuary.

GEOLOGICAL FRAMEWORK

The study area is located within the Maritime Plain region of New Brunswick (Bostock 1970). This featureless coastal plain of typically low relief (rarely exceeding 20 m, Owens 1974) consists of gently northeasterly dipping beds of Permo-Carboniferous sedimentary rocks, which form part of the Carboniferous Central Basin (Gussow 1953). The bedrock lithology is very uniform consisting of poorly indurated beds of predominantly greyish buff, arkosic sandstone of the Pennsylvanian, Pictou Group. Siltstone interbeds locally occur within the even-bedded and cross-stratified sandstone, along with occasional thin coal seams and fossilized plant fragments.

These sedimentary rocks are undeformed but in a few exposures along the shore they exhibit closely spaced vertical joint patterns which may be related to a possible extension of the Belleisle-Millstream fault (van de Poll 1970).

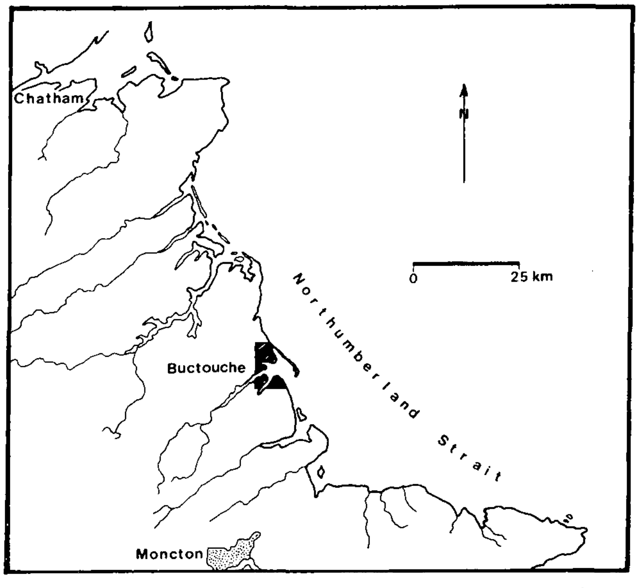

FIG. 1 Location map of the Buctouche Bay complex, New Brunswick.

MARITIME SEDIMENTS Vol. 14, No. 3, December 1978 pp. 95-102.

Prior to glaciation of the Maritime Provinces during the Pleistocene, the Carboniferous terrain was subjected to a long period of fluvial erosion. This, coupled with lithological weaknesses in the Pennsylvanian strata, led to the development of a valley which would later become the Strait of Northumberland. That valley was drained by two river systems which were separated by an isthmus that linked Prince Edward Island with Cape Tourmentine and the mainland (Kranck 1972).

During Pleistocene time, the entire Province of New Brunswick was glaciated (Prest 1970) and variable thicknesses of till and glaciofluvial sediments were deposited.

Waning of the last Wisconsinian glaciers began about 14,000 years B.P. and as the ice retreated from Northumberland Strait, the sea transgressed onto the glacially depressed coastal lowlands (Prest and Grant 1969). By 10,000 years B.P., due to the rapid rate of isostatic rebound, sea-level had fallen approximately 20 m below the present-day level (Thomas *et al* 1973). Since 8,000 years B.P. relative sea-level has risen slowly to its present position. Spits and barrier islands have developed along the gently sloping coastal plain in response to the reworking of glacial sediments by longshore currents.

BAY PHYSIOGRAPHY

The Buctouche Bay complex can be grouped into two geomorphic divisions which together form an approximte T-shaped configuration: (1) the lagoon, oriented parallel to the coastline, representing the arms of the T; and (2) the estuary, oriented perpendicular to the coast, and corresponding to the vertical segment of the T (Fig. 2).

The lagoon (10 km in length and from 0.5 to 3 km wide), was formed by the gradual development of the Buctouche spit across a coastal embayment. This sand spit which forms the seaward margin of the Buctouche Bay complex, is also the southern extremity of a nearly continuous chain of sand barriers and spits that extend for almost 200 km along the eastern coast of New Brunswick. The seaward margin of the spit is smoothly arcuate, in contrast to the highly irregular lagoonal shoreline which consists of a series of washover deltas and distal ends of recurved spits. Ridge-and-swale topography characterizes the southern subaerial portion of the spit with relief varying from sea level to a maximum height of about 7 m along the highest dune crest.

The estuarine bay, with a surface area of about 4 km^2, differs markedly from the coastwise lagoon in terms of origin, environmental characteristics, and sedimentary processes. It consists of an inundated system of river and stream valleys which was submerged during postglacial sea-level rise. Today, three rivers discharge into the estuary: the Buctouche, the Little Buctouche and the Black (Fig. 2). The Buctouche River is the more important of the three and drains a basin of 125 km^2 over which precipitation averages 75 to 130 cm/year (Simpson 1973). Mixing of both fluvial and marine environments characterizes the estuarine bay. The degree of dominance of either environmental system is a function of river discharge, tidal interchange, water depth and distance from the river mouth or tidal inlet. In the case of the Buctouche bay complex, the marine system largely dominates due to low discharge of the three rivers (except perhaps during spring thaw or after heavy rainfalls).

Unrestricted communication between the bay and the open sea is provided through a 2-km tidal inlet. Historic evidence suggests that another tidal inlet may have existed at the point where the spit is now attached to the land.

PRESENT STUDY

During the summer of 1975, a total of 166 bottom samples was obtained from Buctouche Bay. The samples were collected using a 60 lb (27.2 kg) "Clamshell Snapper" with volume capacity of one pint (0.47 l). Physical properties of the sediment (texture, color and odor) and presence or absence of fauna and flora were noted for each sample at time of sampling. The positions of sampling stations were located by sextant (Fig. 2).

Before collecting a bottom sediment sample, the following parameters were noted: (1) time of day, (2) depth of water using a point sonar and (or) a lead line, (3) conductivity, salinity, and temperature of the water using a Beckman induction salinometer, (4) turbidity of the water using a Beckman induction salinometer, (4) turbidity of the water using a Hydroproduct transmissionmeter, (5) direction and relative strength of wind, (6) bay wave direction, amplitude and period.

Laboratory analyses were made of grain size distribution and of the organic carbon content of the samples. Statistical parameters of the grain size distribution were obtained by the moment method utilizing a computer program originally prepared by James (1971). Organic carbon determinations were done following the titration method described by Gaudette *et al* (1974).

HYDROGRAPHY

Salinity

During the period of study, the waters of the lagoon and of the estuarine bay were well mixed and showed no significant salinity gradients. The average recorded value of 28 $^o/oo$ was comparable to observed salinity values in the nearby Northumberland Strait. The salinity value at any position in the bay is primarily a function of the volume of river discharge, and thus pronounced salinity gradients develop only during spring runoff and after heavy rainfalls.

The actual position of the haloclines varies in response to changes in tidal conditions and to variations in the volume of freshwater runoff. Salinity values of up to $20^o/oo$ have been recorded as far as 3 km upstream in the Buctouche River (Gallant 1973), and the author has recorded the presence of salt water 6.5 km upstream.

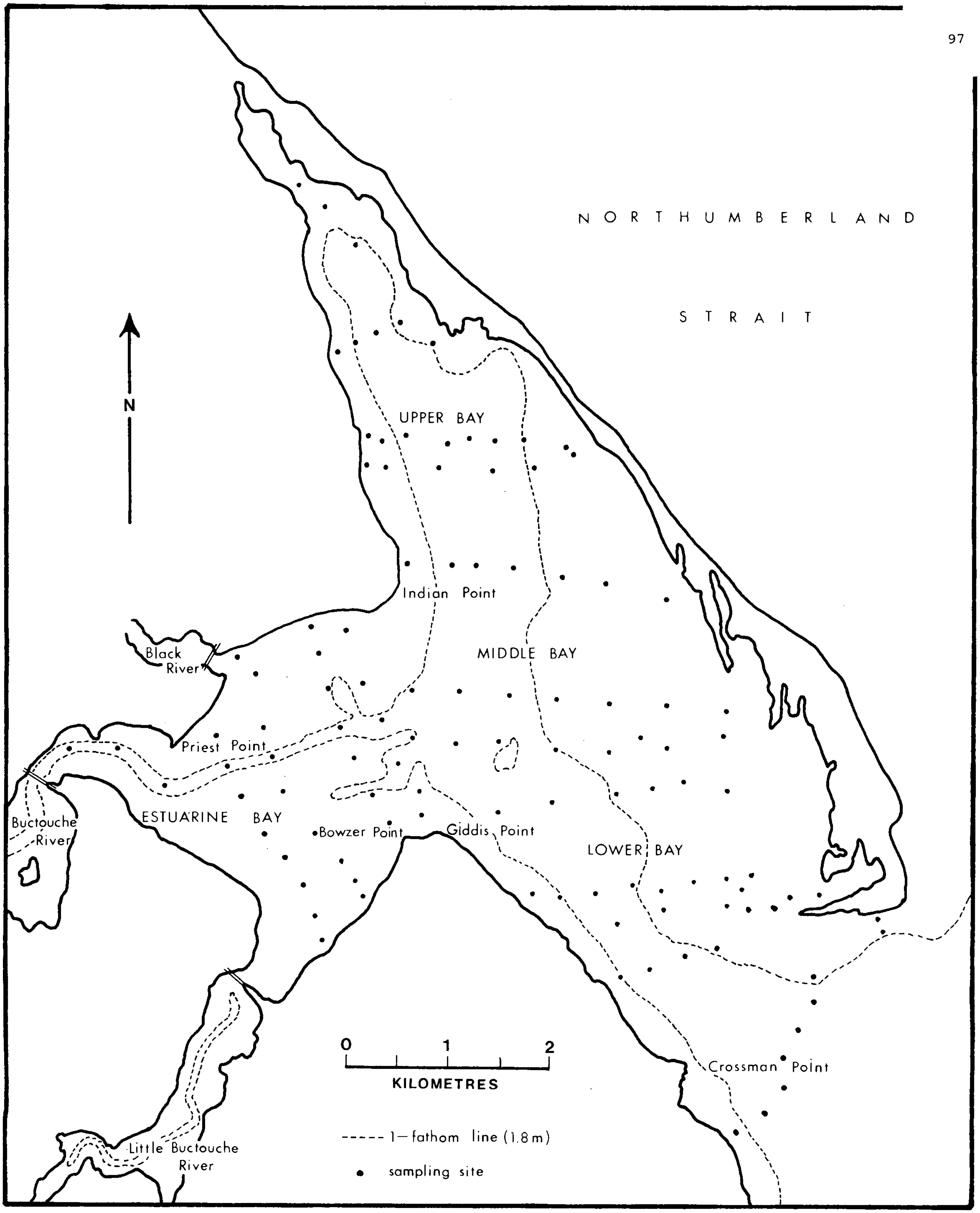

FIG. 2 Physiographic map of the Buctouche Bay complex illustrating sample location sites and bathymetry. Only the 1–fathom isobath is shown (compiled from Canadian Hydrographic Survey Chart 4441 and from field data; data reduced to Lowest normal tide).

Temperature

The bay's water temperature has an annual range of 0°C to about 25°C. During the period of study, observed water temperatures averaged 21°C. Significant thermal stratification was restricted to the deeper parts of the lagoon and to the central part of the estuarine bay. In these areas, differences of 1°C were generally recorded between the upper and the lower layers, and a maximum difference of 3.3°C was recorded in the channel south of Indian Point (Fig. 2). Relatively large and sudden changes in water temperature can occur during the summer months in response to cool northern storm weather or hot dry spells.

Tides

Water depths vary in response to astronomic tides and storm surges. Astronomic tides in the Buctouche Bay area are mixed with the semi-diurnal cycle predominating. The tidal range is from 0.2 to 1.3 m with extreme values occuring when the cycle becomes dirunal (Canadian Hydrographic Service 1975).

Occasionally, high astronomic tides are augmented by strong onshore winds from the northeast. By raising the water level significantly above the normal tidal range, such a condition can have dramatic effects on coastal features. The Buctouche spit has suffered severe breaching in the past as a result of such abnormal high tides.

Waves

Wave fronts in the Buctouche Bay area originate mainly from the northeast or the southwest. During the summer months southwest winds predominate and, blowing over a fetch of about 6 km, produce relatively small bay waves. These waves have short wavelengths with amplitudes that can occasionally reach 0.5 to 1.0 m. Although such waves have minimal turbulent effect on the deeper portions of the bay, they can effectively erode, transport and resuspend sediment along the shore.

Northeast winds blow over a much longer fetch (over 900 km). The resultant wave fronts that originate in the Gulf of Saint-Lawrence are very effective in moving the sand along the seaward side of the spit and are principally responsible for its southerly growth.

Turbidity

During the period of study, the waters of the bay were relatively clear with light transmission values averaging 73%, the clearest waters being found over sandy substrates. Wind-induced wave turbulence will increase the degree of turbidity through resuspension of bottom mud from the intermediate depth zones in the lagoon and in the estuarine bay. Although the degree of turbidity results primarily from inorganic suspended solids, organic suspension may locally and temporarily become important. Actual data on the amount of suspended material are not available but reports of silt covering oyster culture equipment imply some accumulation of fine material (Gallant 1975, personal communication).

Most of the suspended inorganic material is thought to be derived largely from river discharge. Other potential sources include windblown silts and material derived from shoreline erosion.

TEXTURAL PATTERNS IN BOTTOM SEDIMENTS

Distribution of sediment type nt type

Following the example of several recent workers (Stauble and Warnke 1974, Reineck and Singh 1975, Shideler 1975, Reinson 1976) a reconnaissance map was prepared showing the distribution of sediment type within the bay complex. Four facies were differentiated according to their relative weight percentage of mud (material less than 0.063 mm in diameter): sand (less than 20%), muddy sand (20 to 50%), sandy mud (50 to 80%) and mud (greater than 80%).

The mud and sandy mud facies are largely confined to the estuarine bay and to the northern part of the lagoon (the upper bay), whereas the spit platform and the middle and lower bay form a sandy province with relatively little mud (Figs. 2 and 3).

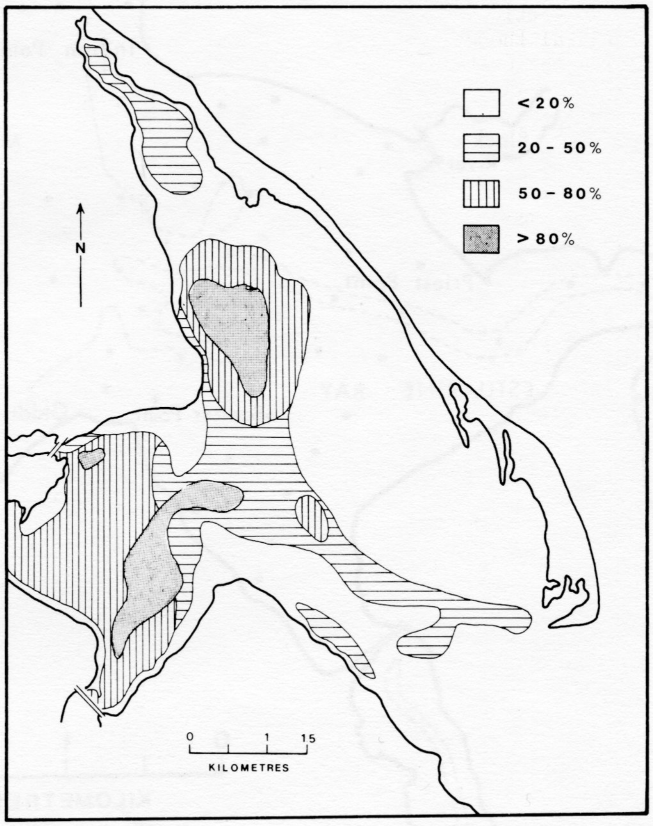

FIG. 3 Isopleth map of total mud content in bottom sediments (weight percentage of the fraction finer than 0.063 mm).

The distribution of mud facies indicates the primary depositional areas for fine-grained material derived from the three rivers, principally the Buctouche River. There is a close relationship between the bathymetry and the mud content of the sediments; this is illustrated by the progressive increase in mud content from the shallower marginal areas towards the estuarine bay and towards the deeper portions of the lagoon (Figs. 2 and 3). The muds and sandy muds are confined to depths greater than 2 m, presumably as the result of lower wave-energy levels relative to the more shallow marginal areas.

Little mud-sized material is found in the sediments of the lower bay area. This is possibly the result of two factors: (1) there is a paucity of muddy effluent contributed by the estuary to this region of the bay complex; (2) high velocity tidal currents in the baymouth region would tend to maintain fine particles in suspension, thus preventing their accumulation as bedload sediments. During the study period, currents within the bay were observed to be of low magnitude and generally restricted to the surface as wind induced currents. However, in the channel at the tidal entrance and in the Buctouche River, current velocities often were extremely high. During ebb tides, Billard (1974) observed a maximum velocity of 1.1 knots in "one particular spot of a narrow channel." In general though, current velocities in the bay, outside the channel, never exceeded 0.2 knot (Billard 1974). The inward curvature of the spit suggests that tidal currents are actively transporting sediments into the bay.

The lack of fine-grained sediments in the southern portion of the lagoon, and their concentration in the estuarine bay, indicate that offshore sources of mud are not significant. The overall mud distribution pattern indicates that the estuarine bay and the upper bay are effective mud traps with the quantity of mud influx apparently exceeding the quantity of mud outflow via the baymouth entrance. In contrast, the middle and lower bays are effective mud-bypass areas, accumulating only winnowed residual and (or) transported sand material.

Sand Texture

Although textural parameters such as mean, standard deviation and skewness have been shown to be environmentally sensitive indicators of geomorphic processes and environments (Friedman 1961, 1967, Folk 1966, Pezzetta 1973, and others), considerable controversy still exists as to the actual geological implications of these statistical parameters and as to the methods used in calculating them.

A major problem connected with the sedimentation methods of analysis of fine-grained materials is the question of whether or not the material should be disaggregated. Whitehouse *et al* (1959) have shown that clay minerals settling out of saline waters do so as aggregates. In the laboratory, where the sample is partly or completely disaggregated, the natural conditions of deposition are not duplicated. This leads to a possible misrepresentation of the original size characteristics of the particles that settled out of suspension. These analytical problems can be countered by restricting the size frequency determinations to the portion of the sample that represents the saltation population, i.e. the fraction coarser than 4 ϕ. Glaister and Nelson (1974) prefer to analyze all sizes down to 5 ϕ but 4 ϕ is generally accepted (Friedman 1961, Pezzetta 1973) as an empirical boundary between the suspension and the saltation populations (Visher 1968). In the case of Buctouche Bay, the textural characteristics of the bottom sediments strongly suggest such a bimodal population. It was thus decided to characterize the sand fraction (greather than 0.063 mm or 4 ϕ) of all bottom sediment samples in terms of their size frequency distribution, using moment statistics and in accordance with Folk's (1965) size terminology (Fig. 4). Obviously, the textural parameters calculated from the coarse data do not reflect a picture of the entire distribution and this factor enters in consideration when interpreting the data. However, Shideler (1975) and Pezzetta (1973) demonstrated that such an approach is sound inasmuch as it can help understand and explain regional variability in textural characteristics of the bottom sediments.

Throughout the Buctouche Bay complex, sand fractions range in texture from very fine-grained to medium-grained; coarse-grained sands are virtually absent (Fig. 4).

Sand textural gradients are parallel or subparallel to the isobaths. The sand fraction generally exhibits a decrease in mean grain size

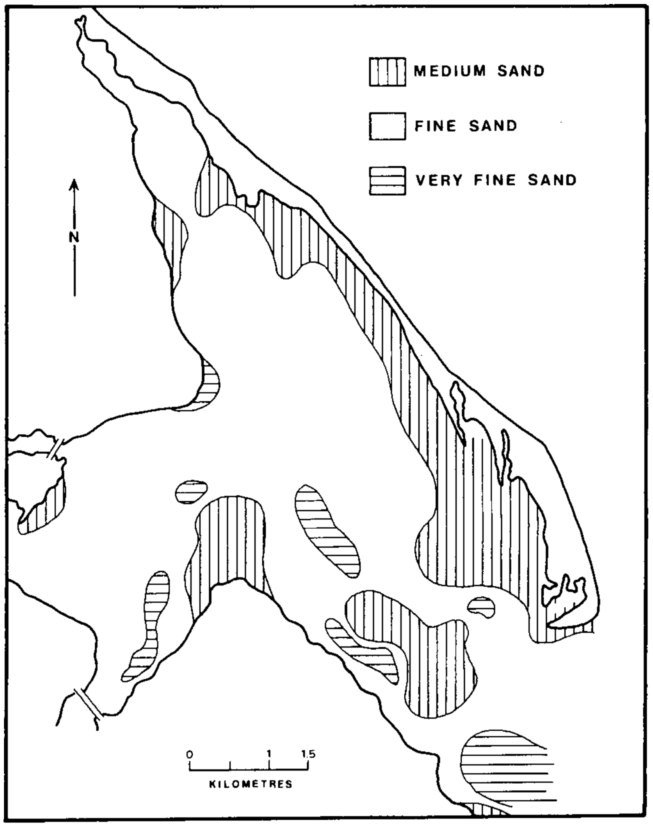

FIG. 4 Isopleth map of mean grain size for sand fractions in bottom sediments.

laterally from the marginal areas toward the central part of the bay. The areas of fine sand coinicde with the major mud areas which further support the contention that the estuary and the upper and central parts of the bay function as fine-sediment traps. Coarser sand is localized along the shallower, higher-energy marginal areas as lag sediment from shoreline erosion, or as a consequence of spit buildup. The extensive patch of medium-grained sand found in the vicinity of Bowzer and Giddis Points is the result of active erosion of a bedrock headland. This headland focuses wave energy and thus undergoes much more rapid erosion. The higher energy is also a factor in winnowing the finer material away from the headland towards the estuary. The headland erosion at Giddis Point is very evident from the bathymetry. Priest Point is also an area of headland erosion and a southward current is accumulating the sand in front of the Buctouche River in the form of a river mouth bar. The patch of medium sand found in the central part of the lower bay is probably related to the stronger currents operating in the tidal channel, and to the proximity of the encroaching spit platform (Fig. 4).

Most of the bay portions with depths greater than 1 m are covered with fine sand. The fine sand is brought in from the offshore by overwash fans and from the subaerial part of the spit by winds. The estuarine fine sand may originate from the river and from the erosion of the bedrock along the shoreline.

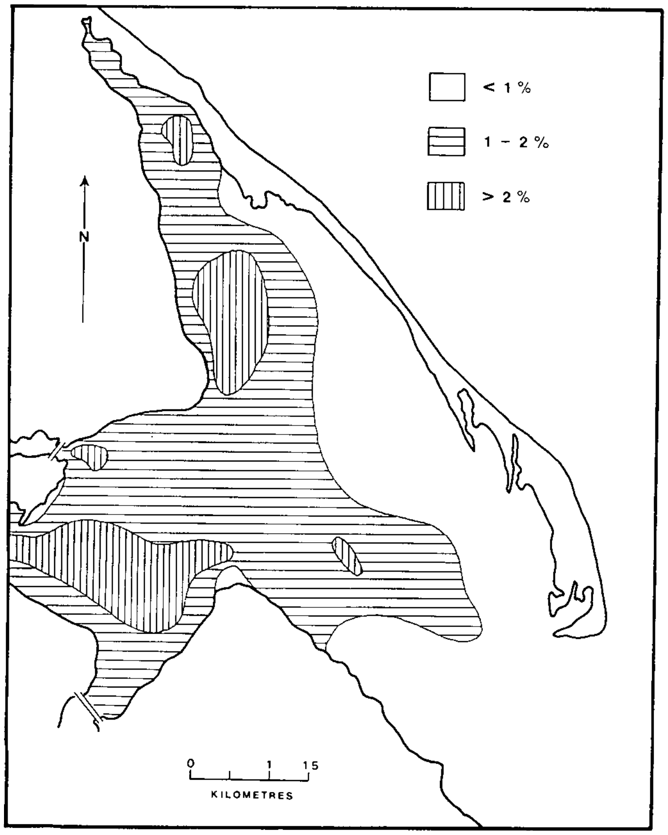

FIG. 5 Isopleth map of organic content (carbonaceous matter) in the bottom sediments (weight percentage).

Organic Carbon Content

Values of organic carbon in the sediments of the Buctouche Bay complex range from 0% to 4.8% by weight, with the majority of the sediment samples containing less than 2%. The most conspicuous feature of the regional distribution is the excellent correlation between the areas of high organic carbon content and the areas of high mud concentration (Fig. 5).

Maximum concentrations of organic carbon occur within the muddy and the very muddy portions of the bay, particularly in the central part of the estuarine bay. Areas of low to no organic carbon correlate with the higher energy zones along the shoreline, over the spit platform and in the tidal entrance.

SUMMARY

Buctouche Bay complex is a composite system consisting of an inner drowned river estuary and an outer elongated lagoon formed as the result of coastwise progradation of Buctouche spit across the baymouth. The physical parameters of the bottom sediments reflect this composite origin. Fine-grained sediments predominate in the deepest parts of the bay complex adjacent to the drowned river mouths, and sandy sediments are dominant near the tidal entrance and adjacent to the spit complex. Such a distribution indicates that the estuary proper and the upper bay are depositional sinks for fine-grained material carried into the system by fluvial discharge. Conversely, the bay complex is being in-filled from the seaward side by sand-sized material derived from the littoral zone. The zone of mixing of marine and fluvial depositional processes is characterized by sediments containing a mixture of both mud and very fine to fine-grained sand.

The enclosed nature of the bay contributes to such a sediment distribution by effecting a relatively low-energy depositional regime throughout the inner and basinal portions of the system. Relatively coarser sediments are confined to the deeper channel areas near the tidal entrance where strong tidal current prevail.

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LATE WISCONSINAN WOOD AND OTHER TREE REMAINS IN THE PRESUMPSCOT FORMATION, PORTLAND, MAINE

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Well preserved tree remains have been discovered in glaciomarine clay of the Late Wisconsinan Presumpscot Formation at Portland, Maine. Logs, branches, cones, and needles occurred just above the contact between the clay and underlying gravel deposit. They were the first tree remains to be found in the Presumpscot Formation. The radiocarbon ages of the logs vary considerably, but their true age is believed to be between 12,000 and 12,500 years. Specimens from the Portland locality are described in detail in the present study. The logs and needles have been identified as spruce, and the associated cones indicate that the species is white spruce, (Picea glauca *(Moench) Voss). The concentration and degree of preservation of the remains suggest a local source - possibly the nearby hills that were above sea level in late-glacial time. The occurrence of the spruce logs in Portland also indicates that trees may have colonized southwestern coastal Maine very soon after the retreat of Late Wisconsinan glacial ice from this area.*

INTRODUCTION

In the summer of 1976, part of a fossil tree trunk was discovered in Portland, Maine. It was exposed by excavation in a gravel pit and found in the course of surficial geologic mapping by W.B. Thompson. The log was embedded in the basal part of the Presumpscot Formation, which is a glaciomarine seafloor deposit of Late Wisconsinan age. It was the first fossil wood to be found in this formation. Subsequent visits to the locality disclosed additional logs and other parts of one or more trees, and also resulted in the discovery of leaf impressions from two species of shrubs. Marine mollusk shells were collected from a pipeline excavation adjacent to the gravel pit.

The fossil wood is also significant because of its bearing on the postglacial vegetational history of Maine. A previous study by Davis and others (1975) indicated that the east-central part of the Maine coast was characterized by tundra vegetation until about 10,000 yr B.P. However, the presence of the logs in the Presumpscot Formation at Portland suggests that trees may have grown in southwestern Maine prior to 12,000 yr B.P. (the minimum age of the Presumpscot Formation according to shell dates (Stuiver and Borns 1975). Thus, the authors undertook an investigation to determine the age, identity, and source of the tree remains. Three of the logs were examined in detail by F. Hyland; and R. Stuckenrath, Jr., determined the radiocarbon ages of both the logs and the shells.

Text Figure 1 shows the location of the study site. The wood occurred in the north end of a gravel pit, the position of which is shown on the United States Geological Survey "Portland West" 7.5-minute quadrangle map. This pit is located 0.2 km from the north bank of the Fore River. The latitude and longitude of the site are 43°38'57"N and 70°16'55"W.

GEOLOGY OF THE SITE

The stratigraphy of the fossil-wood locality is clear. Three to five metres of silty clay overlie cobble gravel. The total thickness of

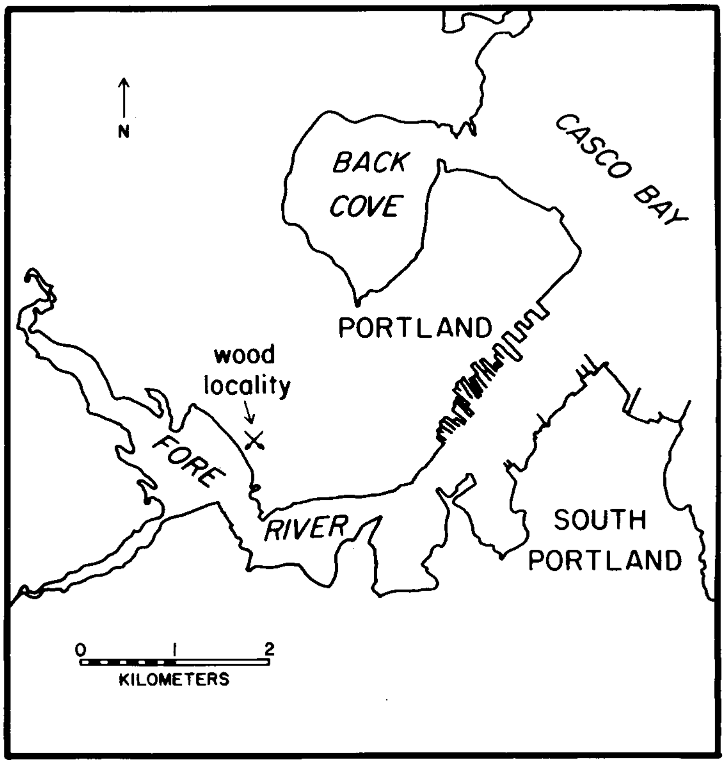

FIG. 1 Map showing the location of the study site.

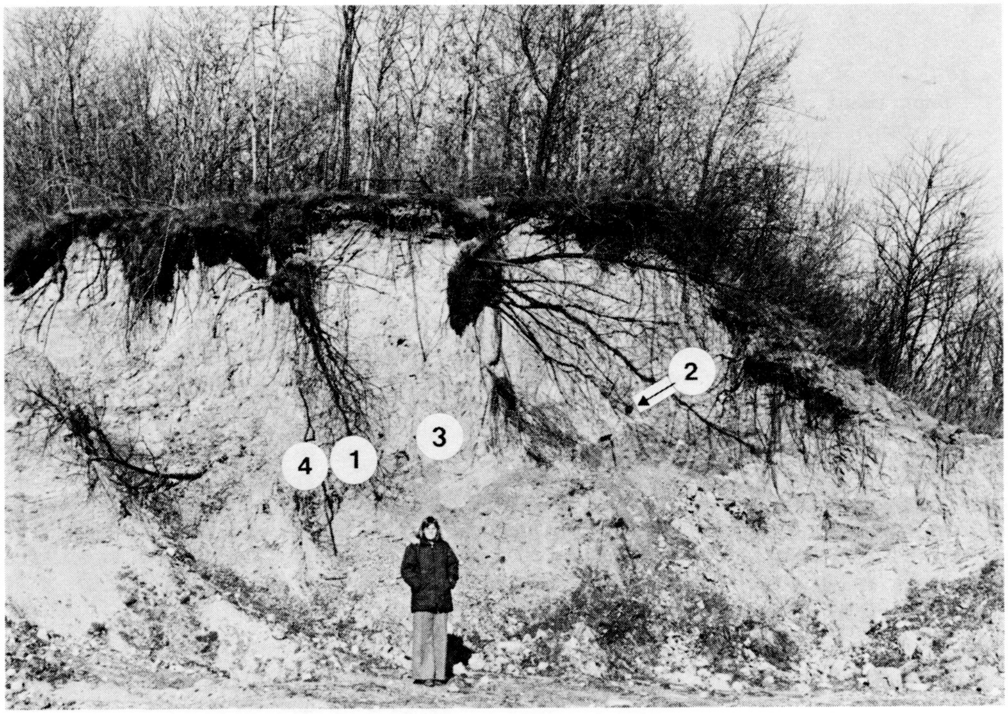

FIG. 2 The pit face where the tree remains were found. The numbers indicate the relative positions of the logs. Specimen No. 2 (at tip of arrow) was the only log exposed when this photo was taken.

the exposed section is about 8 m. The gravel unit is probably a Late Wisconsinan glaciofluvial deposit, although the beds dip to the north-northwest (contrary to the expected flow direction of meltwater from the ice margin). The gravel is poorly sorted, and it is part of a kame that forms the hill to the east of the pit. It presumably was deposited in a submarine environment because the retreat of the last glacier was accompanied by marine submergence of coastal Maine (Schnitker 1974, Stuiver and Borns 1975). The contact between the gravel and the overlying clay is sharp and dips to the northwest. It marks the change that occurred when the meltwater currents slackened and gave way to the seafloor environment in which the clay was deposited. The contact is contorted beneath the thickest part of the clay unit. Here there is a mixed zone of clay, gravel, cobbles, and small boulders. This relationship indicates that a mass of stagnant ice may have been buried in the kame gravel. Melting of the ice during deposition of the overlying clay unit could have produced the observed deformation of the sediments.

The clay is part of the Presumpscot Formation. It can be traced continuously to the deposits along the Presumpscot River that were described and named by Bloom (1960). These deposits consist of rock flour that washed out of the glacier and accumulated on the ocean floor. They are now exposed as a result of postglacial uplift of the coast. The gently sloping surface of the formation has an elevation of about 12 m at the wood locality. In many places the Presumpscot Formation contains more silt than clay (Caldwell 1959), but the cohesiveness of the sediment at the study site suggests that it is composed mostly of clay-size particles. It is dark gray (Munsell color of N 4/ when moist), massive, and uniform. The only structures are vertical desiccation cracks that cause the clay to break apart in large columnar fragments.

GENERAL DESCRIPTION OF THE TREE REMAINS

Four large sections of tree trunks have been found in the Presumpscot Formation at the study site. Mass wasting of the pit face exposed them one at a time during the period 1976-1978. Text Figure 2 shows the positions in the pit face where the logs were unearthed. All or part of each log was collected, and henceforth they are designated as Specimens No. 1 through No. 4. All of the specimens lay within 25 cm of the clay-gravel contact. They did not have a preferred orientation, but their long axes were roughly parallel to the contact. One of the logs (Specimen No. 1) was crumbly and appeared to be poorly preserved. It was located on the surface of the gravel and subject to intermittent ground-water circulation. Numerous fine rootlets of more recent plants penetrated this log.

The other specimens (No. 2, 3, and 4) were completely enclosed in the relatively impermeable clay. They were 3.5 to 4.5 m below the surface of the Presumpscot Formation and were, for the most part, very well preserved. Due to the difficulty

FIG. 3 Wood Specimen No. 3, embedded in glaciomarine clay. Exposed part of log is 1 m long. Photo also shows the clay-gravel contact (marked by shovel blade) and desiccation cracks in both the clay and the log.

of excavating the clay, the total lengths of some of the logs are not known. All of the trunk sections had diameters of at least 10 cm. The two largest specimens (No. 3, shown in text Figure 3, and No. 4) were about 20 cm in diameter and 1 m long. A minimum of 180 growth rings were counted in Specimen No. 4. Two parts of Specimen No. 2 were collected (at different times), and the aggregate length of these pieces was at least 1 m. Slender branches and twigs with conifer needles still attached were clustered around the logs (text Figure 4).

A thin layer of peaty material occurred at the base of the clay in the vicinity of the tree trunks. This layer was as much as 1 cm thick. It was composed of conifer needles, cones (text Figure 5), twigs, and bark fragments that probably came from the associated trees. In most cases the peaty layer was separated from the underlying kame gravel by up to 2 cm of dark-brown very fine sand, the color of which was due to the presence of fine organic sediment.

Scattered twigs, branches, and larger pieces of wood were found in the clay near the logs described above. Like the logs, they all occurred in the lower part of the clay. The pieces of wood included two specimens (each about 5 cm across) that were poorly preserved and may have been either trunk or limb sections. Clay had permeated both specimens, and modern rootlets had penetrated one of them. Another crumbly specimen that was found appeared to be part of a tree stump. Numerous twigs were present in the clay, and some of them retained their needles. Text Figure 6 shows an unusually

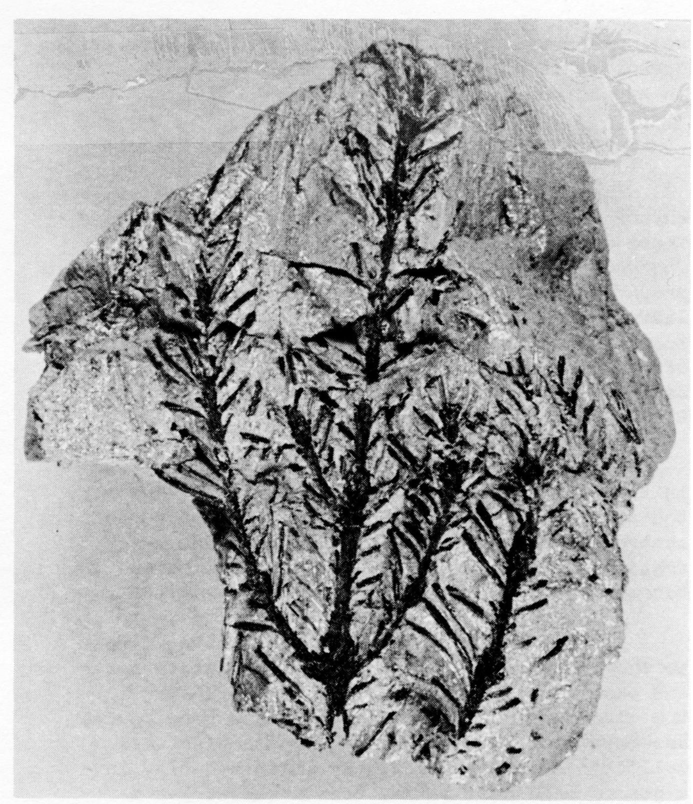

FIG. 4 Tip of conifer branch, embedded in clay. Height of specimen is 7 cm.

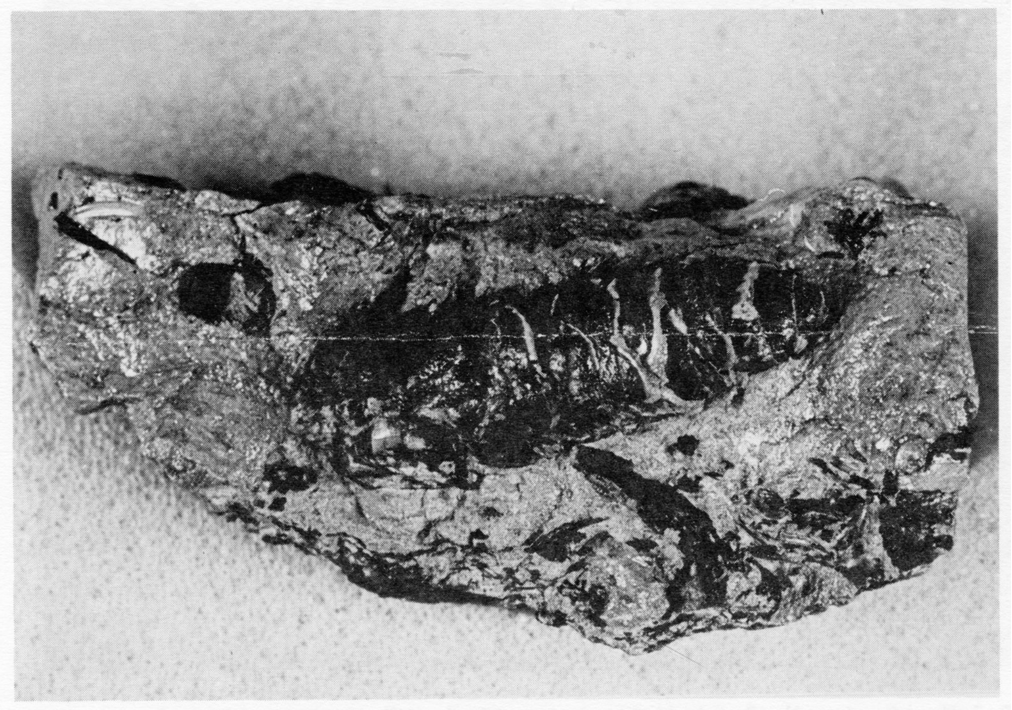

FIG. 5 Conifer cone on surface of peat layer. Cone is 3 cm long and surrounded mostly by clay. White areas are reflections from protective varnish coating.

well preserved twig on which the needles were still green. This specimen is described in detail in Appendices A and B.

OTHER FOSSILS ASSOCIATED WITH THE TREE REMAINS

Impressions of leaves from two species of shrubs were collected from the clay near the logs. These species were tentatively identified as *Chamaedaphne calyculata* (Leatherleaf) and *Gaultheria procumbens* (Aromatic Wintergreen). Only a few leaves from the former and one from the latter were found. Both types were located in the lowest part of the clay, in or just above the peaty layer. The best leaf impressions are shown in text Figures 7 and 8, and described in Appendix A.

A few impressions of shells were also found in the clay at the fossil wood locality. However, the actual shell material had been dissolved and removed by ground water. The impressions were tentatively identified as *Hiatella arctica* and *Macoma balthica*.

In 1978 a pipeline trench was excavated next to the railroad track that lies immediately north and east of the study site. This trench was in the glaciomarine clay and disclosed a very sparse assemblage of actual shells. Two samples were collected - one from slightly disturbed clay in a graded bank next to the trench (about 2-3 m below the surface of the Presumpscot Formation), and the other from spoil that was cast up from the trench. The location from which the former sample (No. 1) was taken appeared to be stratigraphically higher than the fossil logs, while the relative position of Sample No. 2 was uncertain. Correlation between sites was not possible because of the absence of bedding in the clay and the lack of continuous exposure. The shells were identified (Table 1) by comparison with photographs of specimens found elsewhere in the Presumpscot Formation and its equivalent in the St. Lawrence River Valley (Richards 1962, Prest and Hode-Keyser 1977). So few shells were found that it was necessary to

TABLE 1

Identification of Shells

Sample No. 1
Astarte (species uncertain)
Cerastoderma pinnulatum (Conrad)
Hiatella arctica
Macoma calcarea
Mytilus edulis
Portlandia arctica
Serripes groenlandicus
Sample No. 2
Macoma balthica (?)
Mya arenaria

TABLE 2

Radiocarbon Ages of Wood and Shells

Material	Laboratory Sample No.	C^{14} Age (years before present)
Wood Specimen No. 1	SI-2923	10,885 ± 95 yr B.P.
	SI-2923A	11,830 ± 115 yr B.P.
	SI-2923B	11,570 ± 90 yr B.P.
Wood Specimen No. 2	SI-3091	12,510 ± 100 yr B.P.
	SI-3091A	11,280 ± 85 yr B.P.
Wood Specimen No. 3	SI-3524	11,375 ± 95 yr B.P.
	SI-3524A	10,875 ± 80 yr B.P.
	SI-3524B	11,035 ± 95 yr B.P.
Shells	SI-3926	12,040 ± 105 yr B.P.

All determinations by R. Stuckenrath, Jr., Radiation Biology Laboratory, Smithsonian Institution.

use all of both samples to obtain the single radiocarbon age given in the following section.

RADIOCARBON AGES OF THE LOGS AND SHELLS

Three logs were dated by the radiocarbon method, and their C^{14} ages are given in Table 2. C^{14} dates on numerous shell samples from other localities indicate that the Maine coast was uplifted above sea level by about 12,000 yr B.P. (Stuiver and Borns 1975). However, all but one of the dates on the wood specimens from the marine clay are younger than 12,000 yr B.P. The discrepancy is over 1,000 years in some cases, and cannot be explained by the small error factors of the individual dates. Even more perplexing is the great difference between the two dates on Specimen No. 2, which was a very well preserved log with negligible penetration by rootlets of more recent plants.

The authors believe that the anomalously young wood dates are the result of *in situ* contamination, though the cause is unknown. Specimen No. 1 may have been contaminated by rootlets, and large variations in the C^{14} content of the atmosphere in

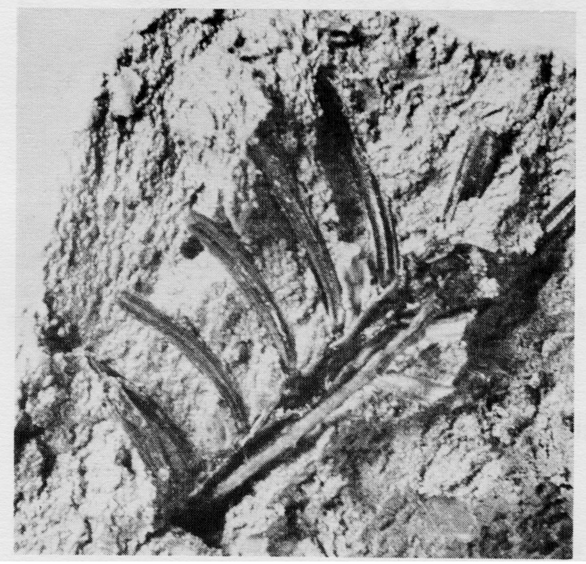

FIG. 6 Twig with well preserved needles. Length of longest needle (top) is 16 mm.

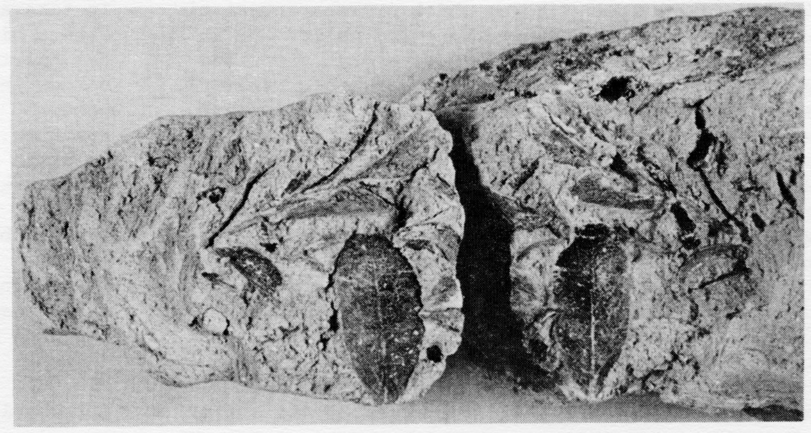

FIG. 7 Matching impressions of *Chamaedaphne calyculata* leaves. An intact group of several leaves is faintly visible above the large, darker impression.

late-glacial to early postglacial time may have contributed to the problem (Meyer Rubin, personal communication). Some of the variation within individual logs probably was due to the dated samples having been taken at different distances from the centre of the log. The latter factor could have caused discrepancies of no more than 200 years, judging from growth-ring counts. It is likely that the age of Sample No. SI-3091 (12,510 ± 100 yr B.P.) is most nearly correct because this is the only wood date that lies within the 13,000 to 12,000 yr B.P. age range of the Presumpscot Formation as determined from shell dates. The shells from the pipeline excavation likewise were found to be greater than 12,000 years old (Table 2). However, the date on Sample No. SI-3926 is a composite age for all the shells that could be found, and cannot accurately be compared with the wood dates.

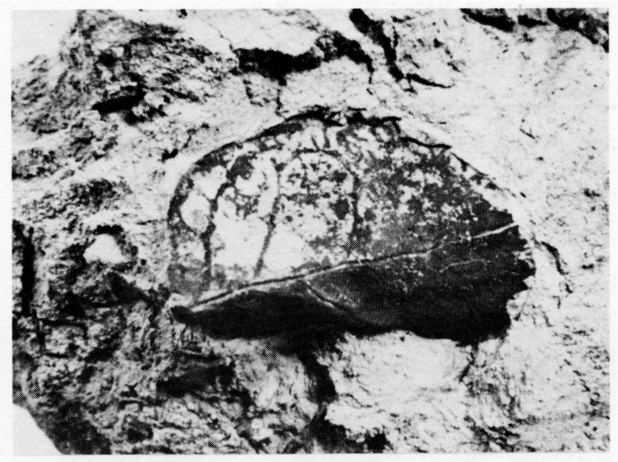

FIG. 8 Impression of *Gaultheria procumbens* leaf. Leaf is 20 mm long.

STRUCTURE AND IDENTIFICATION OF THE TREE SAMPLES

Wood

WOOD SPECIMEN NO. 1 (Plate I). This specimen was poorly preserved but was sufficiently firm to be readily sectioned, without embedding, on the sliding microtome. Enough structural detail remained to prove it to be a conifer (softwood). Vessel elements and fibers, which are characteristic of hardwoods, were absent. The wood cells (tracheids and ray parenchyma) were much flattened and distorted (Plate I, Fig. 1). However, resin ducts (canals) were present and quite well preserved (Plate I, Fig. 2). Thick-walled epithelial cells were clearly discernible. As an identifying character this feature ruled out the pines as a possible consideration. Pines possess thin-walled epithelial cells surrounding the resin ducts. The only genera of trees in the northeastern United States having resin ducts with thick-walled epithelial cells are spruce *(Picea)* and tamarack *(Larix)*. Although the living trees of these genera are easily distinguished, their woods are strikingly similar. However, the presence of several spruce cones (described later and identified by the senior author as white spruce *(Picea glauca* (Moench) Voss) in the mat of peaty material below the wood lends credence to the probability that the wood specimen is spruce, and not tamarck. No tamarack or cones other than those of spruce were found in the peaty material examined. Little or no bark was present on this log or Specimens No. 2, 3, or 4 (discussed below).

WOOD SPECIMEN NO. 2 (Plates II, III, and IV). This specimen had been completely covered by clay and was preserved in exceptionally good condition. In structural detail, microtome sections rivaled those of present day wood. Most of the cells were little, if at all, crushed or distorted. The specimen was well enough preserved to be readily identified as either spruce or tamarack. The ray pitting was eroded, so the aperture angle could not be measured with the degree of accuracy required to identify the genus with certainty. Also, the presence of compression wood (rothholz, redwood, reaction wood) in the specimen complicated the use of the earlywood-latewood transition zone in the microscopic differentiation of spruce and tamarack. The tree was exceptionally slow-growing as indicated by an average ring count of two rings per millimeter. Since the trunk measured about 12 cm in diameter, the tree had attained an age of at least 100 years. The average number of wood cells (tracheids) added in a radial file each year was determined from microscopic cross sections to be about 25. This is only a small fraction of that considered good growth and indicates an unfavorable environment. It is suggestive of conditions presently encountered under alpine or subarctic environments. An average count of 1.5 axial resin ducts per square millimeter was obtained from random microscopic cross sections (Plate II, Fig. 1). This is within the range (0-5) for normal spruce wood (Brown and others, 1949, p. 157). Several rings (two or more consecutive rings in some cases) were entirely without resin ducts (Plate II, Fig. 2), but this is not unusual for spruce. A study of horizontal resin ducts of the fusiform rays in tangential sections of the wood revealed the resin cavities to be lined with 7 to 9 epithelial cells (Plate III, Fig. 1). This diagnostic feature substantiates the identification as spruce because tamarack has a count of up to 12 or more (Brown and others, p. 160). In a recent article, Bartholin (1979) states that spruce and tamarack may be further distinguished by the structure of the bordered pits in their ray tracheids. In tamarack "The bordered pit is relatively large with a big aperture, the margin of the border to the aperture is rounded or slightly pointed. The border is often thin." In spruce (Type 1), "The bordered pit is relatively small with a small aperture. The margin of the border to the aperture is often edged with 1 or 2 angles and the aperture looks like a little channel. The border is often thick." Type 2 "... has the same appearance as Type 1, but the border is dentate."

Upon comparing our material (microscopic sections) with those figured by Bartholin, a close resemblance was seen between the pits figured in his spruce (Type 1) and those of our specimens (Plate VIII, Fig. 1). The pits of tamarack, by comparison, were noticeably different from those of spruce. This feature further substantiates our identification of the material as spruce.

An interesting feature of compression wood tracheids (illustrating the exceptional preservation of detail) is shown in the photomicrograph (Plate III, Fig. 2). The secondary walls of these tracheids are 2-layered, as contrasted with the 3-layered structure of normal tracheids not under compression in the living tree. The inner wall layer, which is much thickened, shows radial checks extending in a spiral fashion from the lumen (central cavity of the tracheid) to the outer secondary wall. These checks can be shown branching as they approach the outer secondary wall. This type of wall thickening is characteristic of conifer tracheids which are under compression in the living tree and probably indicates a leaning tree. These tracheids are round in cross section (Plate IV, Fig. 1) as opposed to the squarish ones of normal wood (Plate IV, Fig. 2) which are not under compression in the tree. The thick inner wall is composed of helical plates, which are visible in the photomicrograph. It is interesting that this structural detail was so well preserved. For striking similarities, compare our Plate III, Fig. 2 with that of Côté, 1964, p. 405.

Microscopic sections of Specimen No. 2 revealed strands of fungi in some of the tracheids, especially in the pit margins as revealed by the enlarged pit mouths with jagged margins (Plate VII, Fig. 2). However, extensive decay or fungus erosion of wall substance was not in evidence. It appears that most cell collapse in the logs was due to physical or chemical, not biological, action. Most of the collapsed areas occurred in apparently fungus-free wood.

WOOD SPECIMEN NO. 3 (Text Figure 3). This log was discovered near the others and was well embedded in the clay. It was one of the larger trunk sections, measuring 20 cm in diameter. It closely resembled Specimen No. 2 in all essentials of morphology and anatomy. Much of the exterior of the log was black and showed completely collapsed cells, but the interior portion appeared fairly sound. Unweathered pieces of wood split from the interior of the log were light brown in color, in contrast to the dark brown or gray outer portion.

Because of the similarity of this log to Specimen No. 2, it will not be further described. It was examined in an attempt to ascertain whether the four logs were parts of a single tree. It might have been possible to compare signatures in the growth rings if the outer rings of all four wood specimens had been present and well preserved; but since the outer rings of all specimens were distorted and the cells collapsed, it was impossible to establish that the logs were once part of the same tree. However, positive identification of needles and cones (described below) indicated that we are dealing with a single species, i.e. white spruce.

WOOD SPECIMEN NO. 4 Specimen No. 4 was associated with the other trunk sections, and had the same appearance. It is assumed to be white spruce. A growth-ring count indicated an age of at least 180 years. It was noted that the width of the growth rings in Specimen No. 4 was not uniform, but varied between less than 1 mm and a maximum of 6 mm. This variation may have resulted from local short-term fluctuations in climate.

Twigs

Numerous twigs, many with a full complement of needles, were found in the clay near the logs. The twigs ranged in size from fine (0.5 mm in diameter) to coarse branchlets several mm in diameter. They retained little or no bark. Xylem (wood) was well preserved on the lower (rothholz) side of the twig, but badly collapsed on the upper side (Plate V, Fig. 1). Axial (vertical) resin ducts were absent, but this is not unusual in the wood of spruce twigs. Pith commonly was absent, but when present usually contained an abundance of conspicuous, well preserved sclerotic cells (Plate V, Fig. 2). (Most pith cells are thin-walled and decompose readily, but sclerotic cells are often well preserved because of their exceptionally thick walls.)

Cross sections of twigs were examined in an attempt to determine the time of year that growth ceased. Only those sections that still retained a remnant of bark were considered. This precaution was necessary as an assurance that all the wood formed during the last season of growth was present. Based on the fact that the transition from earlywood to latewood in spruce is gradual, beginning with a rather wide zone of large, thin-walled tracheids and ending the season with a narrower zone of thick-walled, tangentially flattened cells, it was possible to determine whether a complete ring had formed in the twigs. A study of several twigs revealed that typical latewood cells, which normally terminate the season's growth and form the bulk of the latewood, were absent. This indicated that growth had been interrupted sometime in middle or late season. Apparently the tree was somehow dislodged at this time and thus was unable to complete the normal growth increment. (The photomicrograph, Plate V, Fig. 1, does not show this feature as clearly as several others examined.)

Needles

A full complement of needles was still present on many of the twigs that were recovered from the clay (text Figures 4 and 6). This is interpreted to mean that the twigs could not have been transported a great distance, which certainly would have caused the needles to be detached due to the buffeting action they would have received. Also, the presence of needles on the twigs indicated that the tree was living at the time of dislodgement, and had not been allowed to dry before burial in the clay. (Spruce twigs lose their needles when dry). Leafy twigs that were exposed by breaking away the surrounding clay matrix revealed rather sharp-pointed needles diverging in all directions, characteristic of spruce. Externally the needles appeared identical to those of present-day specimens in size and other characteristics except that most of them were visibly shrunken, somewhat twisted, and grotesquely lobed (Plate VI, Fig. 1). However, a few retained their squarish cross-sectional shape (Plate VI, Fig. 2). Several of the needles still retained some of their chlorophyll as indicated by their grayish green color. (See Appendix B for analysis and discussion).

Microscopic sections revealed that the internal structure of most needles was greatly modified. The chlorenchyma (chlorophyll-bearing cells) and, to a great extent, the phloem (food-conducting tissue) were completely disintegrated, leaving a shrunken cavity that was once occupied by living cells. Only the xylem was preserved in a slightly unaltered structural condition. However, the internal structure of a few needles was fairly well preserved, as shown in Plate VI, Fig. 2. Regarding the exterior of the needles, the cross-sectional area appeared much shrunken and conspicuously lobed as contrasted with the expected squarish outline characteristic of spruce needles. Due to the tough epidermis around the fibrous subepidermal layer (Plate VII, Fig. 1), the needles were protected from complete disintegration. Another noteworthy feature was the good preservation of the stomates that could be seen on all four faces of the needles. One closed stomate is shown in Plate VII, Fig. 1.

Considering all the morphological and anatomical features discussed above, there is little doubt that the needles are those of spruce, although the species could not be determined due to the poor state of preservation.

Cones

Several cones from the peaty material beneath the tree trunks were identified as white spurce (*Picea glauca* (Moench) Voss). The cones were cylindric-oblong with rather flexible scales, and showed evidence of having entire scale margins characteristic of white spruce. The closed cones measured 1.0 to 1.2 cm in diameter and 2.0 to 3.0 cm in length. This is only about one-half the length of mature white spruce cones. They were evidently immature, as shown by the dissection of several cones that revealed tiny seeds in an early stage of development. No depressions in the cone scales (which would be present if mature seeds had been formed) were observed. When the cones were exposed to alternate drying and wetting conditions in the laboratory, the scales opened and closed much as they would in fresh specimens, indicating a still-functional seed-release mechanism. Comparison of these cones with those from a local living tree indicated a stage of development probable in late June or July. This means that the tree must have been uprooted or broken off at that approximate time, thus preventing further cone development. Burial in the sediments must have taken place soon, as indicated by the good state of preservation of the cones.

SUMMARY AND CONCLUSIONS

It is not known whether the logs and other tree remains represent a single fragmented tree or were derived from two or more trees. In either case their concentration in a very small part of the former sea floor suggests that they came from within several kilometres of Portland. Furthermore, the cones and delicate twigs (with attached needles) probably could not have undergone transport over a great distance without being detached from the tree(s) in route. The tree(s) must have grown above the marine limit, which is now at an elevation of 75 to 80 m at the study site (judging from the elevations of glaciomarine deltas in coastal Maine).

On the basis of the factual information and inferences presented in this article, the authors postulate the following history for the tree remains at the Portland site. In late-glacial time at least a sparse population of spruce trees grew in the vicinity of Portland, Maine. They had become established in the area between about 13,300 and 12,500 yr. B.P. (the interval between deglaciation and the growth of the dated trees). Much of coastal Maine was submerged by the sea during this period, but many hills at short distances to the north and west of Portland were islands during the submergence. The largest spruce trees that lived there were at least 20 cm in diameter and 200 years old. The rather narrow growth rings over a period of more than 100 years suggests an unfavorable environment that may have been subarctic in nature. Climatic factors probably were more important then edaphic ones in producing this result. A marine environment might also have caused the narrow growth rings. The trunks of some of the trees were leaning, and much compression wood had been built up on their lower sides as is characteristic of conifer trees growing in this position.

One year, in late June or July, one or more trees somehow were broken off from their roots and washed into the ocean nearby. They floated a short distance before sinking to the sea floor, where they came to rest on or just above a deposit of glacial gravel as it was being covered by marine clay. Branches, leafy twigs, and cones became detached and were buried in the clay with the trunks. Burial of the tree remains took place rapidly, excluding the oxygen that is necessary for degradation by decay-causing microorganisms. Most of the wood was sound (practically free from fungi) at the time it was buried in the sediments, and remained so.

During postglacial time the cells in some portions of the logs completely collapsed, but in others they remained essentially unaltered in shape and other characteristics. There was little infiltration by mineral matter and no apparent replacement of carbonaceous substance of the cell walls. The wood cells gave a strong positive lignin reaction when treated with phloroglucinol. Thus, lignin and cellulose were preserved throughout the long time between burial and discovery.

The needles, being less woody and more fragile than the trunk sections, were much more altered. The external morphological characters were well enough preserved to allow positive identification of the genus, but the internal anatomy of the needles was so disrupted that the tissues were of little use as diagnostic features.

The cones were in sufficiently good condition to be identified as white spruce. Since the cones were immature, they established the date of dislodgement of the tree as June or July. This date was substantiated by a study of twig cross sections, which revealed that the last-formed growth ring was incomplete and had likewise been interrupted in early summer.

Other than the remains of spruce trees, little identifiable plant material of late-glacial age was discovered at the Portland locality. Two morphologically well preserved leaves of broad-leaved shrubs were found in the glaciomarine clay near the logs. One was tentatively identified as Aromatic Wintergreen and the other as Leatherleaf. Both species may be found presently growing in the area.

The data presented in this study forms a logical basis for the above speculation regarding the history of the fossil spruce trees under consideration. Additional studies of fossil tree remains discovered in other places in the Presumpscot Formation may shed further light on the late-glacial to early postglacial vegetational history of Maine. At present several pieces of the "jigsaw puzzle" are missing, and, without them, the fitting together of the existing pieces to form a complete picture is impossible.

ACKNOWLEDGEMENTS

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APPENDIX A

DESCRIPTIONS OF LEAF SPECIMENS

Description of Leatherleaf *(Chamaedaphne calyculata)* leaf shown in text Fig. 7.

length	15 mm
width	6 mm
shape	elliptic - oblong
margins	free from teeth or only obscurely toothed, slightly revolute
veins	midvein distinct, lateral veins indistinct, slightly curved
tip	acute or slightly obtuse
base	broad - cuneate
surface	appearing somewhat scurfy

Description of Aromatic Wintergreen *(Gaultheria procumbens)* leaf shown in text Fig. 8 (tentative identification).

length	20 mm - petiole absent
width	18 mm
shape	broadly obovate or nearly orbicular
margins	obscured, but apparently without teeth
veins	netted, distinct, curving and anastomosing near the margin
tip	broad - acute or rounded
base	broad - rounded
surface	appearing rather smooth

Description of White Spruce *(Picea glauca)* leaves shown in text Fig. 6.

length	8-16 mm
width	mostly less than 1 mm in diameter
shape	short acicular, 4-angled but often compressed or distorted at one corner, slightly curved
tip	acute
base	acute, narrowed to a peg-like base
surface	shiny, firm, appearing grayish green in color

APPENDIX B

ANALYSIS OF NEEDLE PIGMENTS FROM THE SPECIMENS SHOWN IN FIG. 6

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Methods

Pigments were extracted following the method of Arnon (1949). The fossil needles were homogenized in a ten broeck glass homogenizer with 1 ml of 80% Acetone to which a small amount of $MgCO_3$ was added. The brei was centrifuged at 10,000xg for 10 minutes to remove insoluble debris. An absorption spectrum was recorded from 750 to 350 nm in a Cary model-15 recording spectrophotometer. Owing to the small amount of pigment present, the absorption spectrum was done using micro currettes masked to avoid edge effects and with the spectrophotometer on the most sensitive (0-0.1A) scale.

The extract was transferred from 80% Acetone diethyl ether and spotted on No. 1 Whatman paper for chromotography. Ascending chromotography was carried out using petroleum ether (30 - 60° fraction) plus 1% n-propanol. Spots were eluted with diethyl ether and their absorption spectra recorded in the recording spectrophotometer.

Results

The absorption maximum of the 80% Acetone extract was 661 nm with a smaller peak at 610. In the blue region there was a maximum in absorbance at 417 nm with distinct shoulders at 446 and 475 nm. Using the extinction coefficients of Arnon (1949), the total chlorophyll present was 0.28 μgm and the ratio of chlorophyll *a* to chlorophyll *b* was calculated to be 1.5.

Calculation of the total chlorophyll from the absorbance of the extract at the isobestic point (652 nm) of chlorophyll *a* and chlorophyll *b* (Holden 1965) indicated 0.30 μgm of chlorophyll was present.

Following chromotography using 1% n-propanol in petroleum ether there was a yellow spot of Rf = 5.6 (the same Rf as authentic chlorophyll and lutein from spinach chromatographed at the same time on the same sheet of paper). Elution in diethyl ether and absorption spectroscopy revealed no chlorophyll but a carotenoid with maximum absorbance at 430 nm and shoulders at 400 nm and 470 nm. A yellow spot (Rf = .97) was eluted in diethyl ether and absorption spectroscopy indicated the three-banded maxima typical of carotenoids (Davies, 1965). The absorption maximum was around 440 nm with shoulders around 440 nm and 470 nm.

Discussion

The absorption spectrum of the 80% acetone extract of fossil needles suggests the presence of chlorophyll *a* and *b*. The close agreement of two computations of the total amount of chlorophyll present in these extracts using different wavelengths lends further support to that suggestion. If there were any other red absorbing substances present, as is often found in marine sediments (Sanger and Gorham, 1972), the two computations of chlorophyll concentration would be expected to be more divergent.

It should be noted that the chlorophyll *a*:*b* ratio was lower in this extract than in extracts of fresh material (Black, 1973). It is possible that this indicates a more rapid degradation of chlorophyll *a* than chlorophyll *b* in these samples.

Chromatographic confirmation was unsuccessful with regard to chlorophyll pigments owing to the small amount of pigment recovered. However, the presence of carotenoids was definitely shown. In the solvent system used, the yellow pigments(s) of Rf 5.6 chromatographing with chlorophyll *a* would likely be carotenoids (lutein in fresh tissue) (Strain and Svec, 1966). The yellow pigment(s) having Rf = 0.97 are carotenes in extract of fresh tissue.

PLATE I

Fig. 1. Wood Specimen No. 1.
Low power view of collapsed wood. (50X)

a. Resin duct.
b. Collapsed wood cells.
c. Wood ray.

Fig. 2. Wood Specimen NO. 1.
Cross section of wood in collapsed area, enlarged (210X)

a. Totally collapsed cells.
b. Thick-walled epithelial cells surrounding a resin duct.

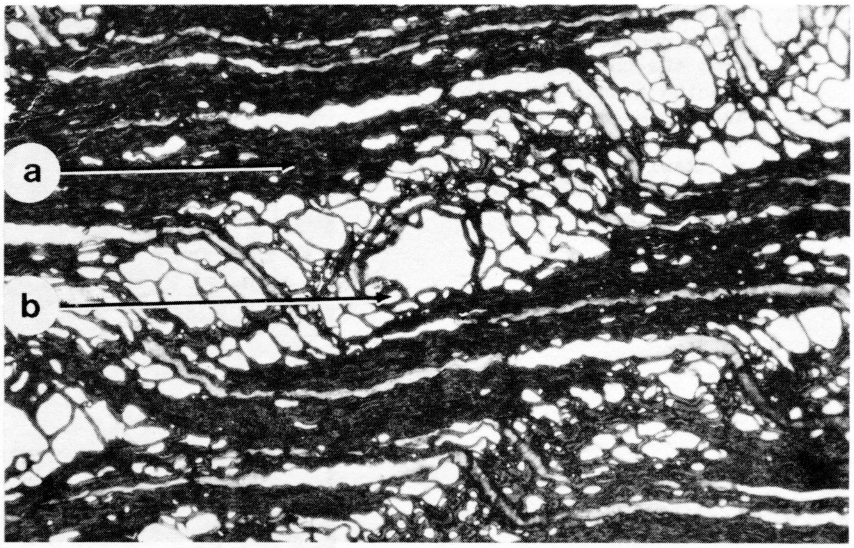

PLATE II

Fig. 1. Wood Specimen No. 2. Cross section of wood from the lower side of a leaning trunk; resin ducts present. (50X)

a. Rounded thick-walled rothholz tracheids of the latewood.
b. Resin duct in the latewood.
c. Earlywood tracheids.

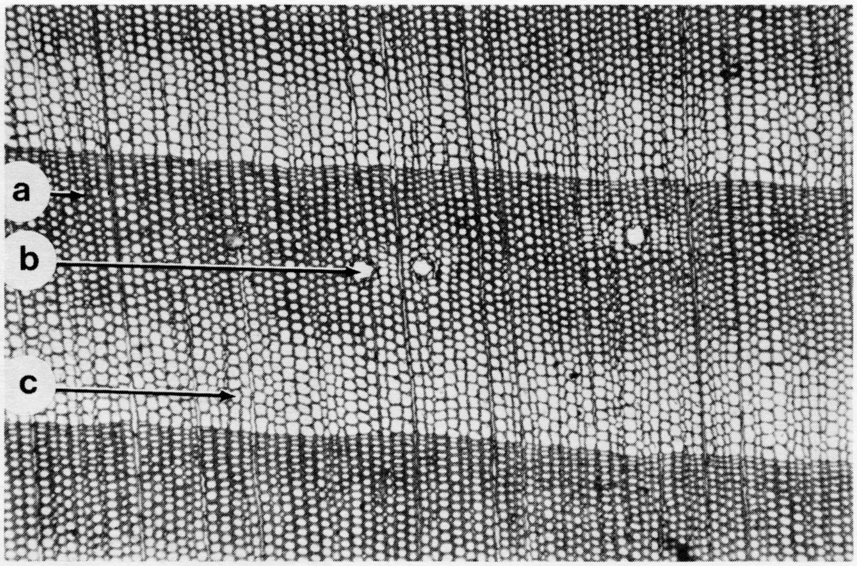

Fig. 2. Wood Specimen No. 2. Cross section of wood from the underside of a leaning trunk; no resin ducts present. (130X)

a. Earlywood tracheids.
b. Latewood tracheids.
c. Wood ray.

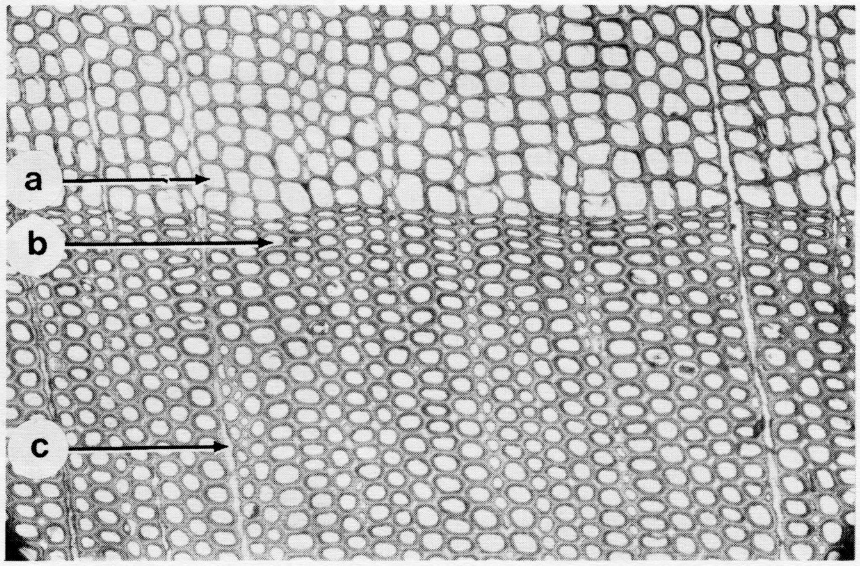

PLATE III

Fig. 1. Wood Specimen No. 2. Tangential section of wood showing horizontal resin ducts and partially collapsed tracheids, some with fungus strands. (320X)

a. Fungus strand in tracheid wall.
b. Central cavity of a horizontal resin duct lined with thick-walled epithelial cells.

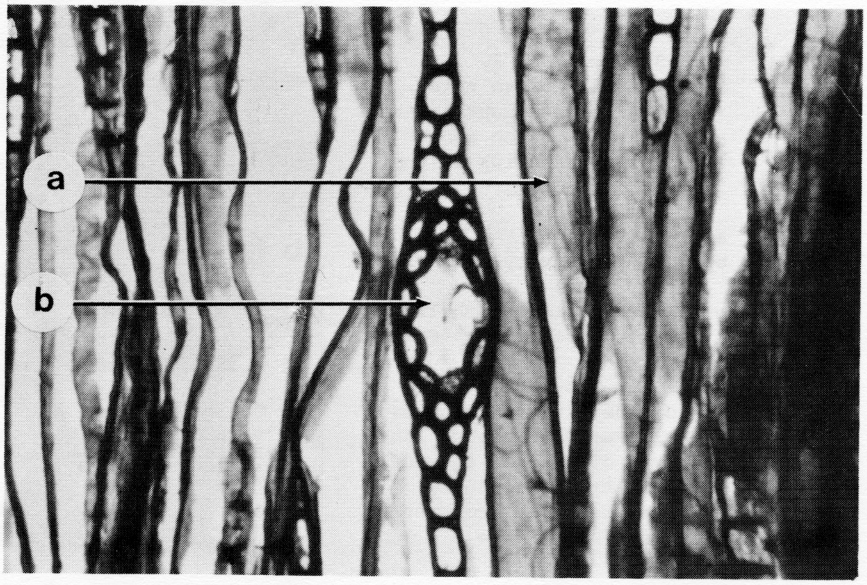

Fig. 2. Wood Specimen No. 2. Cross section of a rothholz tracheid, greatly enlarged, showing details of structure. (4040X)

a. Lumen (central cavity).
b. Radial checks in the thick secondary wall are seen branching as they approach the periphery of the wall.

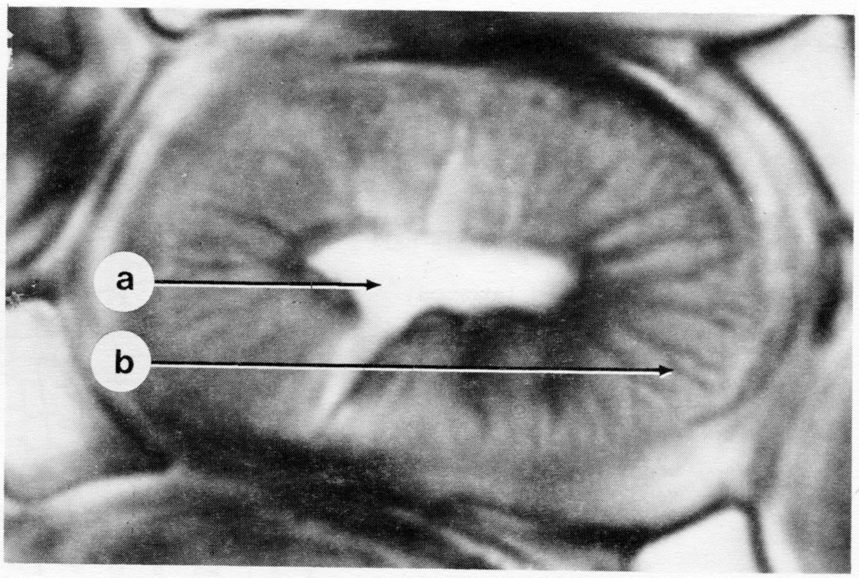

PLATE IV

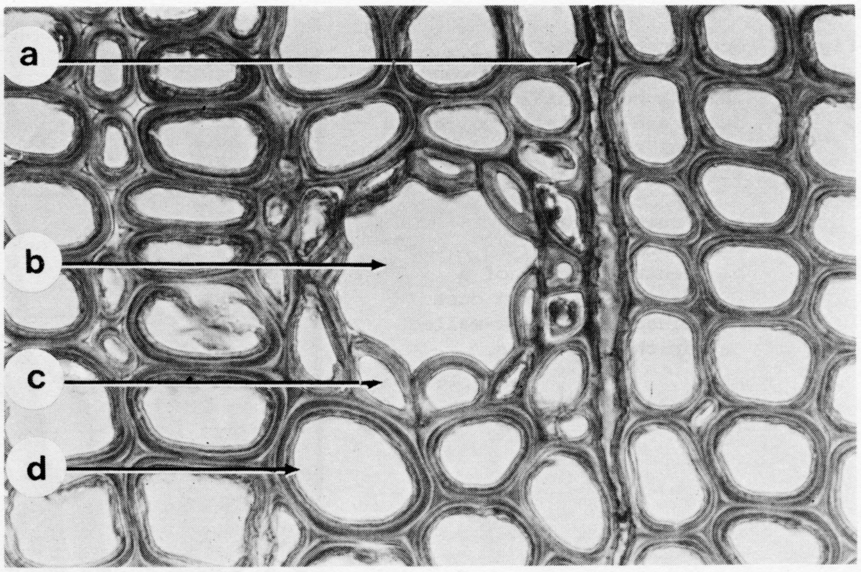

Fig. 1. Wood Specimen No. 2.
Cross section of an axial (vertical) resin duct in an area of compression wood (rothholz) tracheids of the latewood. (520X)

- a. Wood ray.
- b. Central cavity of resin duct.
- c. Thick-walled epithelial cell bordering the resin duct.
- d. Thick two-layered wall of the circular compression-wood tracheid. This type of cell is characteristic of tracheids that are under compression in the tree.

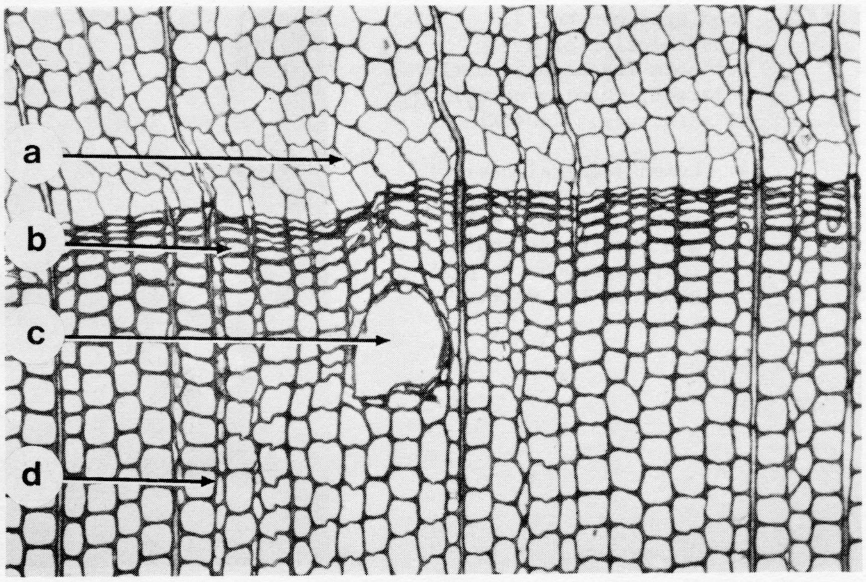

Fig. 2. Wood Specimen No. 2.
Cross section of an axial (vertical) resin duct surrounded by normal latewood tracheids. (130X)

- a. Earlywood tracheid. Note the thin walls and rectangular shape of most of the cells in this part of section.
- b. Thick-walled latewood tracheid. Note the squarish or tangentially flattened cells in this area.
- c. Central cavity of a resin duct in the latewood.
- d. Wood ray.

PLATE V

Fig. 1. Cross section of one of the twigs recovered from the clay. (40X)

a. Upper side of twig, composed of collapsed normal tracheids.
b. Area of torn, thin-walled pith cells.
c. Area of thick-walled sclerotic pith cells.
d. Lower side of twig, composed of thick-walled compression-wood tracheids.

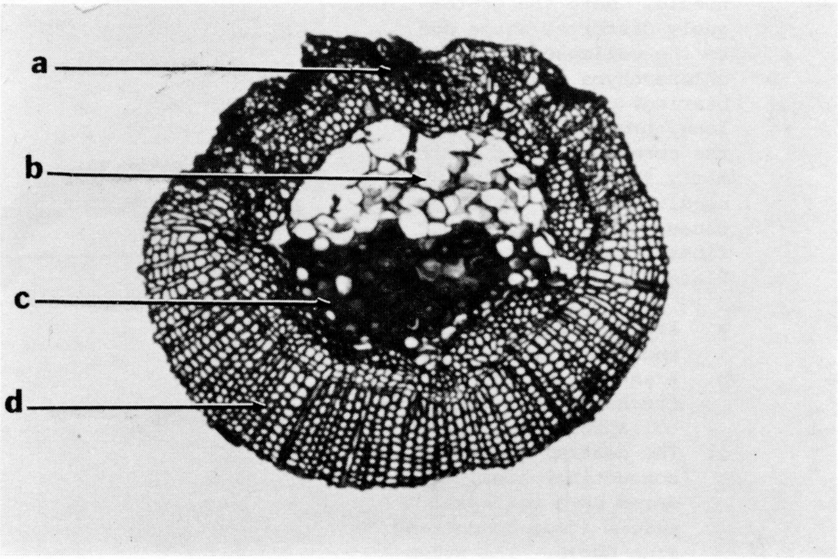

Fig. 2. Enlargement of pith area of the twig shown in Fig. 1. (320X)

a. Thin-walled pith cells.
b. Thick-walled sclerotic pith cells.
c. Xylem (wood) tracheids bordering the pith.

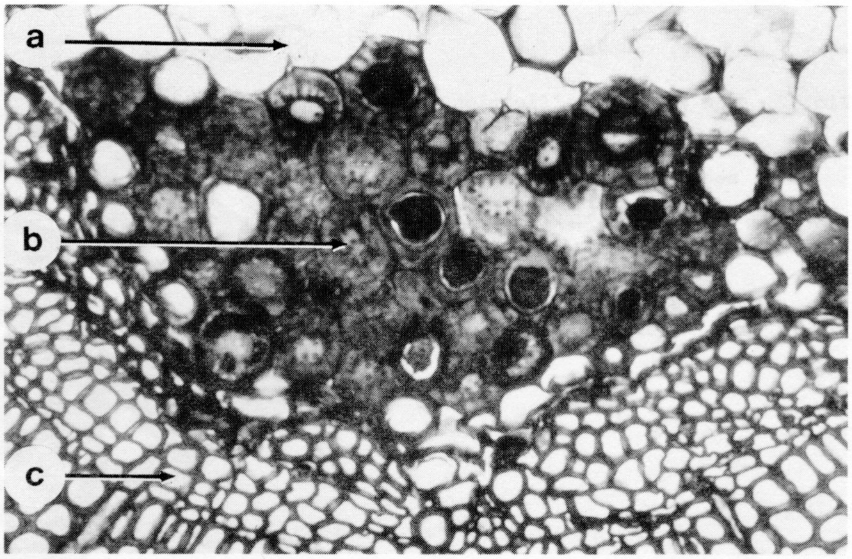

PLATE IV

Fig. 1. Low power magnification of a cross section of a spruce needle. Note the grotesquely distorted shape due to the collapse of the chlorenchyma (chlorophyll-bearing) cells within. The long, projecting arms are the corner areas of the formerly squarish needle. The needle was kept intact because of the subepidermal fibers (shown in detail in Plate VII, Fig. 1). (200X)

- a. Area of collapsed chlorenchyma.
- b. Area of vascular tracheids that resisted collapse.
- c. The central xylem (water-conducting) area, bordered by a collapsed phloem (food-conducting area above. The xylem resisted collapse by virtue of its thick-walled cells.

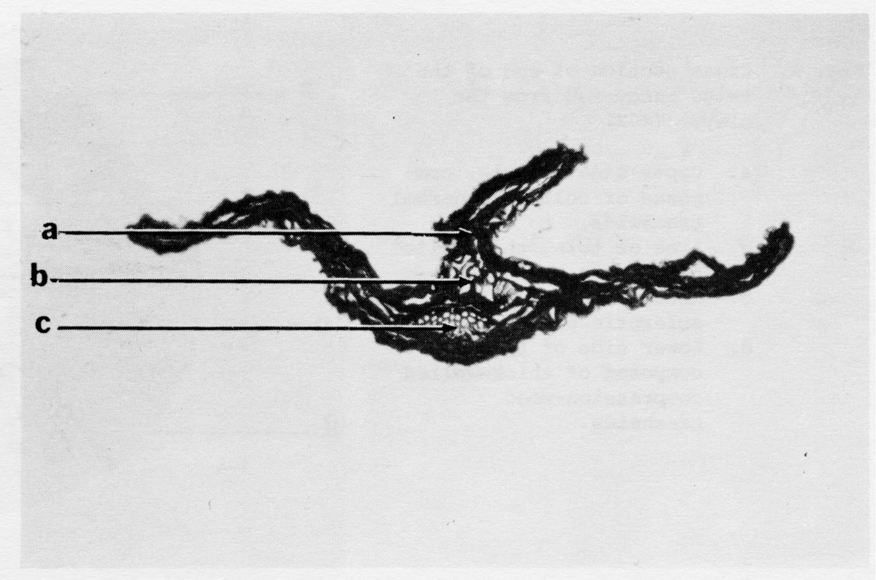

Fig. 2. Low power magnification of a cross section of a well preserved spruce needle. (200X)

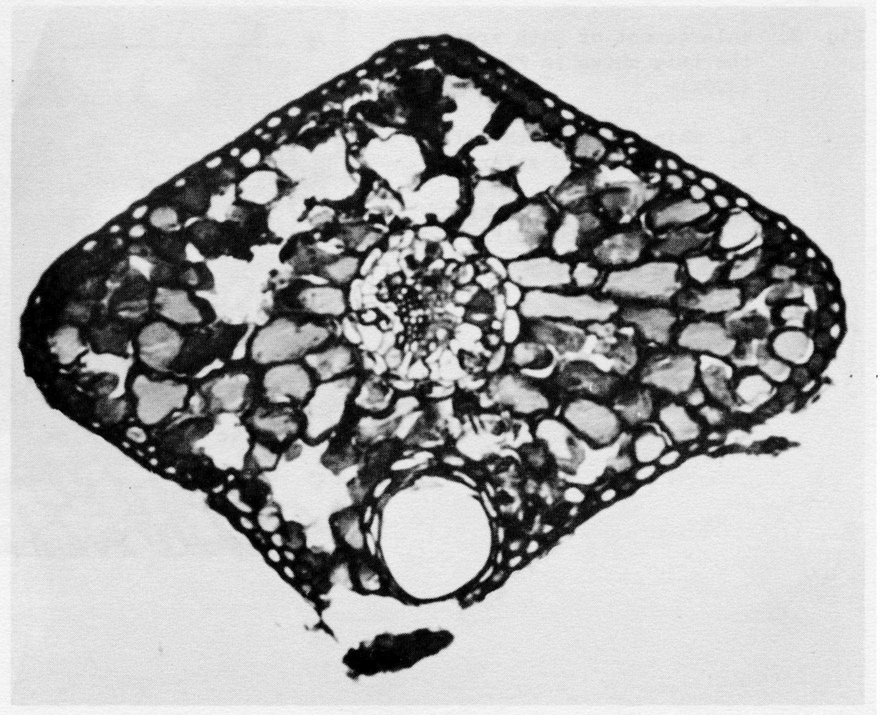

PLATE VII

Fig. 1. Enlargement of a portion of a spruce needle with practically all cells collapsed, except the guard cells of the closed stomate. (520X)

a. Narrow layer of thick-walled sub-epidermal fibers that kept the needle intact.
b. One of the guard cells of a closed stomate (pore for exchanging gases). In other sections (not shown here) many stomates were noted on all four faces of the needles.

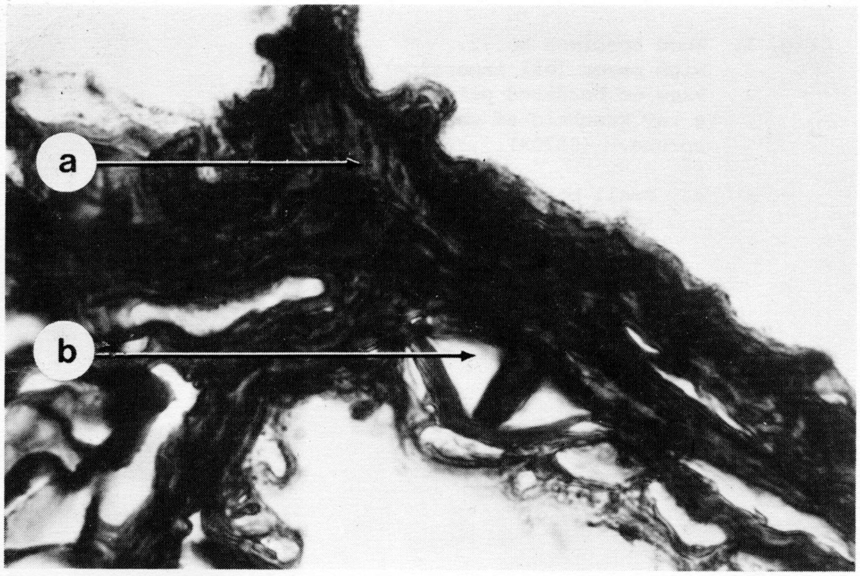

Fig. 2. Wood Specimen No. 2. Radial (longitudinal) section of a piece of wood containing fungus strands. (520X)

a. Large pit mouths on the radial sides of the wood tracheids. The pit margins commonly are jagged and irregular due to fungus erosion. This specimen was in an advanced stage of decay as evidenced by the thin and eroded tracheid walls.
b. A strand of fungus ramifying through the wood cells.

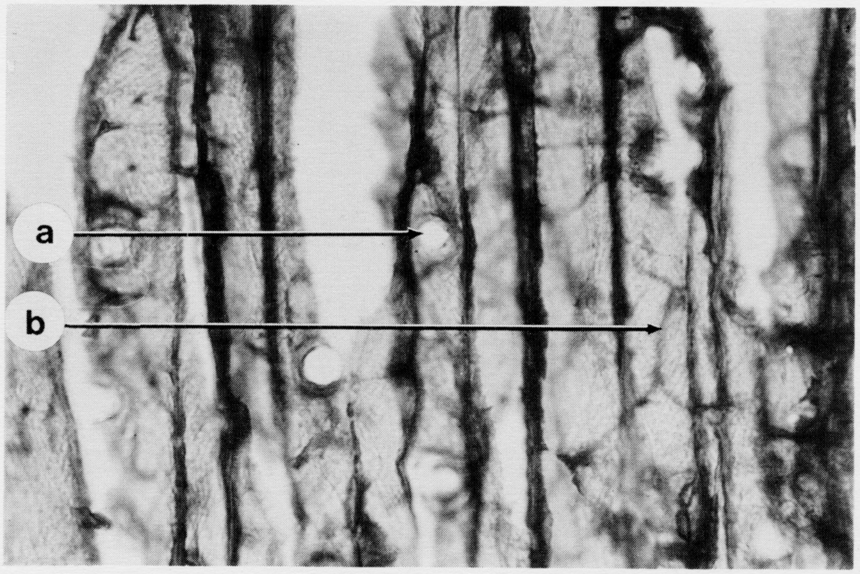

PLATE VIII

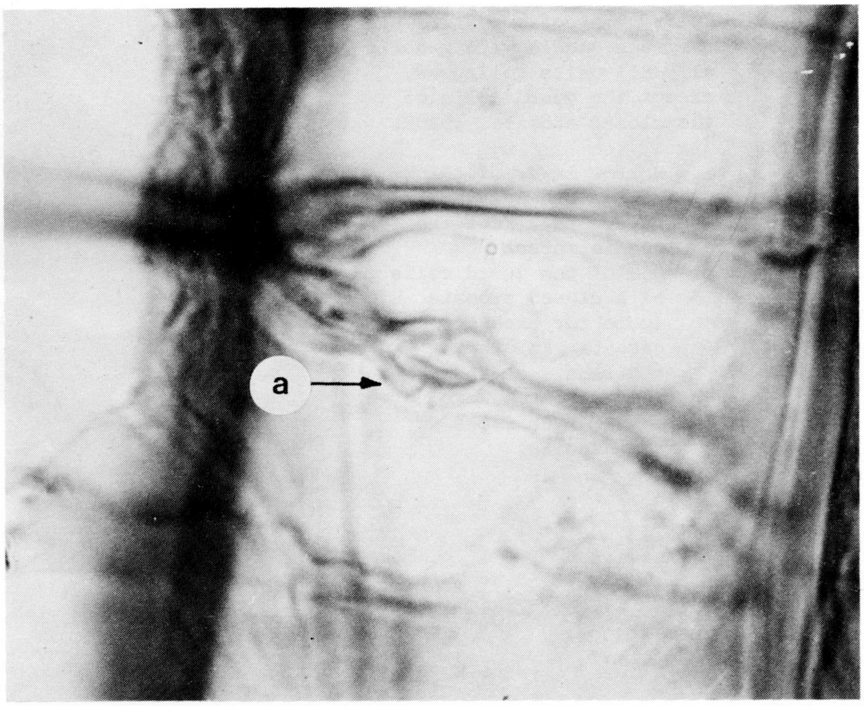

Fig. 1. Wood Specimen No. 2. High power (oil immersion) view of bordered pits in a ray tracheid of white spruce. (2520X)

a. Small bordered pit with tiny aperture characteristic of spruce. Margin of the border to the aperture is thick and somewhat angled.