CLIMATE, TIME AND ORGANISMS IN RELATION TO PODZOL DEVELOPMENT IN MICHIGAN SANDS

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ABSTRACT

CLIMATE, TIME AND ORGANISMS IN RELATION TO PODZOL DEVELOPMENT
IN MICHIGAN SANDS

by Aubrey Steven Messenger

A climatic study was made of the Podzol Region of Michigan and a chronobiosequence study was conducted on eight relatively undisturbed sand soil sites within the region.

The Podzol Region of Michigan is characterized by summer maxima of precipitation or maxima which include the month of September. With minor exceptions, the zone of most strongly developed Podzols is characterized by a mean annual snowfall of greater than 60 inches. Water balance computations indicate that most of the sand soils in this zone would reach field capacity by the end of November in the average year.

A peat bog surrounded by a well-developed, well-drained sand Podzol was sampled for pollen analysis. Pine pollen constituted over 60% of the total tree pollen in the lower three-fourths of the sample column. The upper one-fourth of the column was characterized by increasing amounts of hemlock and birch pollen, a substantially higher percentage of spruce and fir pollen and a somewhat higher percentage of beech and maple pollen.

One very weakly developed Podzol was estimated to have developed within the last 2500 years in calcareous low dune sand under a pine overstory. The extremely acid Oh horizon at that site exhibited a relatively high concentration of extractable aluminum and a relatively low exchangeable Ca/organic matter ratio. These characteristics were

typical of all the Oh horizons in the study. The occurrence of such horizons was associated with the presence of at least 30% (of total basal area) mixed pines and/or hemlock. Foliage samples of these species had relatively low Ca/Al ratios even when collected from trees growing on soils containing free lime.

Direct microscopic counts revealed greater quantities of bacterial cells and fungal hyphae per gram of organic matter in a mull Vh1 horizon as compared to a mor Oh horizon. A much greater quantity of actinomycete filaments was present in the Vh1 horizon than in the Oh horizon.

Crenic acid production was profuse and sustained when Oh horizons were alternately incubated and leached with distilled water. Vh horizons containing more than 3000 # exchangeable Ca/AFS produced no crenic acid. Nitrate production was nil when crenic acid production was profuse. Logarithmic decreases in crenic acid production accompanied logarithmic increases in nitrate formation.

A sustained dominance of white pine and hemlock, in association with a much smaller percentage of northern hardwoods on deep-to-carbonate sites, apparently initiates the evolution of very strongly to extremely acid illuvial horizons which contain as much or more extractable aluminum than extractable iron and may contain ortstein. Continued increases in northern hardwoods coincide with the formation of dark upper illuvial horizons containing a decidedly higher concentration of extractable iron than extractable aluminum.

Forest succession to dominantly northern hardwoods involves an increase in the cycling of Ca and Mg, an increase in the susceptibility of the forest litter to decomposition and a decrease in crenic acid production. The resulting change in the soil organism population is apparently responsible for the formation of a mull humus layer and an

increase in nitrate formation.

The zone of relatively strong Podzol development in Michigan is therefore considered to be a result of: (1) the post-glacial persistence of forests conducive to the formation of mor humus layers; (2) a current climate characterized by relatively mild droughts, relatively great amounts of fall precipitation and the accumulation of a thick and seasonally persistent snow cover which begins to form early enough to retard soil freezing; and (3) a late post-glacial increase in the prevalence of hemlock, maple and beech on some very sandy soils. Zones of less strongly developed Podzols exhibit these characteristics to a lesser degree.

CLIMATE, TIME AND ORGANISMS IN RELATION TO PODZOL DEVELOPMENT IN MICHIGAN SANDS

By

Aubrey Steven Messenger

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INTRODUCTION

Podzols are soils which have the following vertical sequence of horizons beneath the humus layer: (1) a gray or white eluvial horizon which contains mostly resistant minerals and which has lost relatively more sesquioxides than silica and (2) one or more darker-colored illuvial horizons containing sesquioxides and organic matter as the major products of accumulation. Thicknesses of these horizons may differ widely, the relative amounts of sesquioxides and organic matter may exhibit considerable variability and the illuvial horizons may range from loose and friable to hard and irreversibly cemented (Stobbe and Wright, 1959).

Most definitions of Podzols also indicate that the natural type of Podzol humus layer is a mor (Buckman and Brady, 1963; Russell, 1961; Stobbe and Wright, 1959 and Wilde, 1958), a layer which always contains a horizon of well-decomposed, dark, amorphous organic matter which is essentially unmixed with the mineral portion of the soil (Hoover and Lunt, 1952).

The mechanisms by which a Podzol forms have been the subject of numerous investigations. However, the roles of the various soil-forming factors and their interactions are still somewhat obscure. The first purpose of this thesis is to determine what relationships exist between certain climatic parameters, past and present types of natural vegetation and Podzol zones in Michigan. The second purpose is to examine sand soil ecosystems in the field and in the laboratory in order to establish relationships between tree species, time, soil properties and soil processes.

Part I. LITERATURE REVIEW

CHAPTER 1. PODZOL REGIONS AND ZONES

The non-montane Podzol regions of the world occur poleward of 42° latitude and are known as such only in the northern hemisphere (Robinson, 1949 and Orvedal, 1960).

The North American Region

The North American region extends farthest south in the state of Michigan (to 42°20'N) although some non-montane Podzols can be found south of this latitude under specific circumstances (vide Gysel, 1941; Kellogg, 1941; Tavernier and Smith, 1957; NCR-3 Technical Committee on Soil Survey, 1960 and Tedrow, 1962). Near the Atlantic Ocean in New England, the Podzol Region gives way on the east to the Brown Podzolic Soil Region (Kellogg, 1941) where Podzols are restricted to elevations above 1000 to 1400 feet above sea level or to strictly local situations (Lunt, 1948). The Podzol Region west of 96°W is confined to Canada and tapers northwestward to where the Grey-Wooded Soil Region joins the Sub-Arctic Soil Region just south of Great Slave Lake in the District of Mackenzie (Stobbe, 1960).

The Eurasian Region

The Eurasian Podzol Region extends from the British Isles northeastward to the juncture of the Siberian tundra and the Kolyma Mountain Range (Orvedal, 1960). As in North America, the Eurasian Podzol Region trends northward in mid-continent where it yields on its east boundary to the grassland soils of the USSR. However, since Russian soil scientists identify Podzols by the presence of an Em (A2) horizon and the lack of an appreciable Vh (A1) horizon (vide Ciric, 1962), soils which are classified as Grey-Wooded in the United States and Canada would be

classified as Podzols by the Russians. Thus, much of the Siberian Podzol Region may be dominated by soils which do not meet the North American specifications for Podzols.

Podzol Zones in Michigan

Within the Podzol Region of Michigan (see Figure 1), zones occur which differ from one another in the degree to which orterde (non-indurated illuvial horizons) development has taken place on well-drained land surfaces (*vide* Veatch, 1938). Figure 2 illustrates this zonation and, for convenience, these zones are designated as Podzol Zones I, II and III in order of increasing orterde development. The boundary between Zones I and II has been adjusted slightly to take the Midland County data (Johnsgard, 1950) into account.

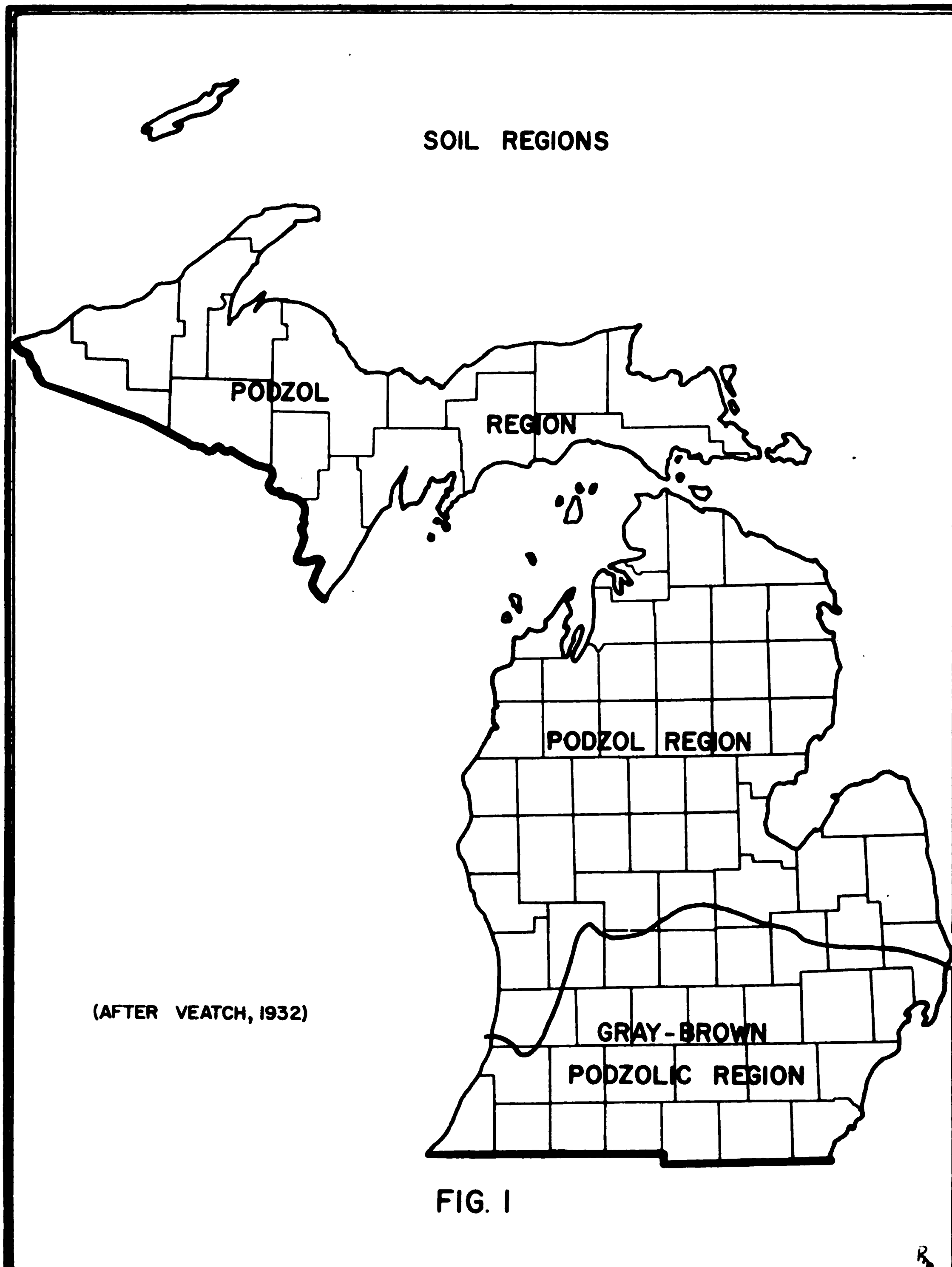
SOIL REGIONS
PODZOL
REGION
PODZOL REGION
GRAY-BROWN
PODZOLIC REGION
(AFTER VEATCH, 1932)

FIG. 1

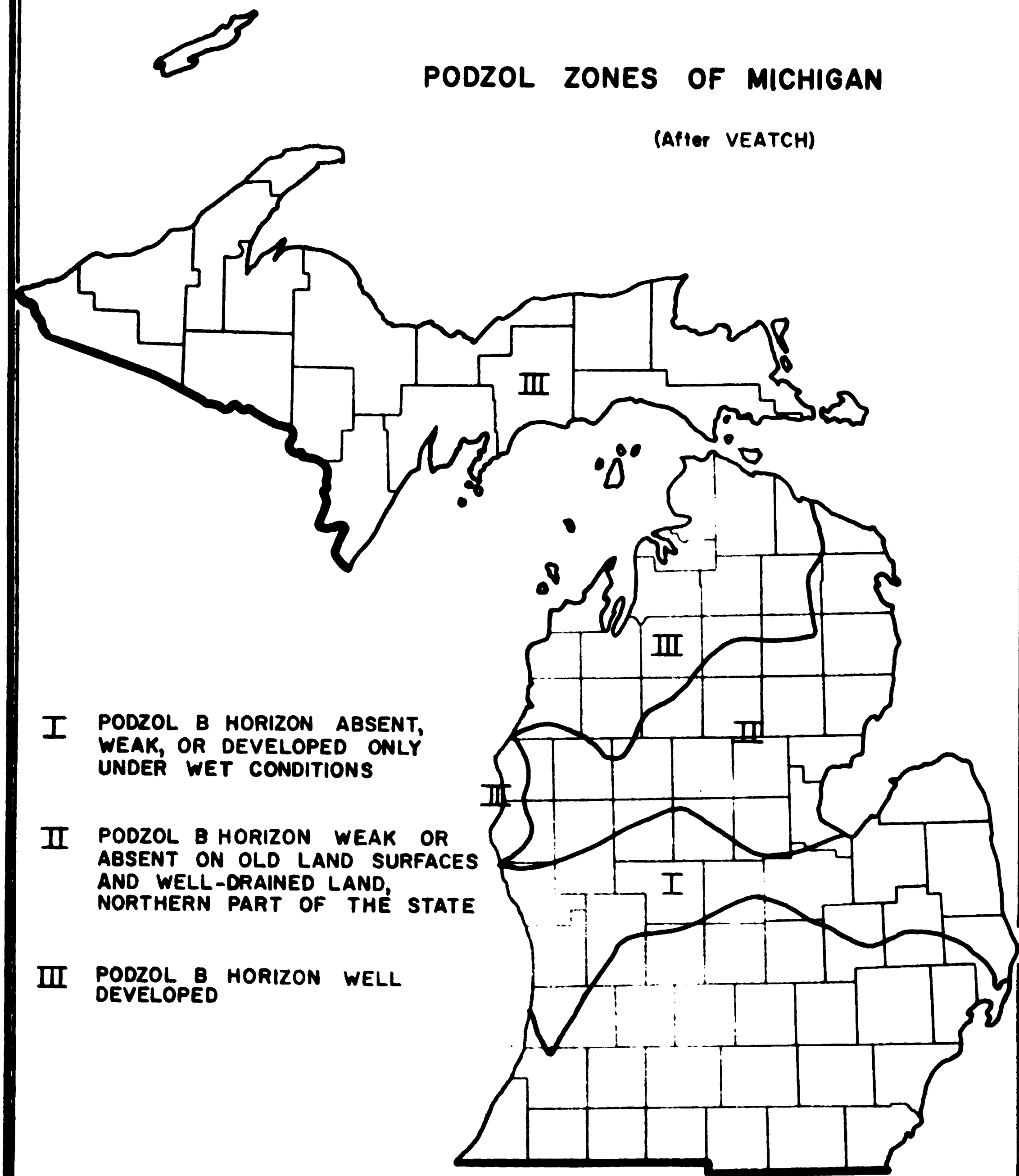
PODZOL ZONES OF MICHIGAN
(After VEATCH)
I PODZOL B HORIZON ABSENT, WEAK, OR DEVELOPED ONLY UNDER WET CONDITIONS
II PODZOL B HORIZON WEAK OR ABSENT ON OLD LAND SURFACES AND WELL-DRAINED LAND, NORTHERN PART OF THE STATE
III PODZOL B HORIZON WELL DEVELOPED
III
III
III
III
I

FIG. 2

CHAPTER 2. CLIMATIC RELATIONSHIPS

Climate functions as an independent factor in the development of the weathering complex and of soil profiles at the great soil group level. Climate also indirectly influences the soil by determining: (1) the mass and form of plant production, (2) the soil water balance over long periods, (3) the soil temperature and (4) the rate of decay of organic matter (Bunting, 1965).

Climates of the North American and Eurasian Podzol Regions

According to Glinka (1914), the climatic conditions of the Podzol zone in Russia are a yearly rainfall between 500 and 570 mm, with an average mean annual temperature of 3.6°C. Within this zone any temperature rise is accompanied by a rise in the annual precipitation, and similarly any drop in temperature is accompanied by a lowering in the annual precipitation. In North America, Joffe (1949) states that Podzols are found in sections where the rainfall runs up to 1100 mm annually with a mean annual temperature as high as 10°C.

In comparing European soils to similar ones in the United States, Jenny (1949) found that Podzol soil regions in Europe had annual NS Quotients* of 400 to 1000 compared to 380-750 for those in the U. S.

Volubuyev's studies (1959) indicate that Podzol zones are characterized by summer or fall maxima of precipitation and by positive precipitation/evaporation ratios in spring and fall. He states that these climatic conditions instigate: (1) a spring leaching phase, (2) a summer

*Obtained by dividing the rainfall in inches or centimeters by the deficit from the saturation value of the atmospheric water vapor pressure, measured also in inches or centimeters of mercury.

phase with relatively low soil moisture and (3) a fall leaching phase.

Romell and Hesselmann (Handley, 1954) mention that the cold temperatures of Podzol regions may cause the development of a mor humus by depressing the rate of decomposition of vegetable debris and the rate of nitrogen mobilization. However, reports of mor humus Podzols in tropical lowlands (Russell, 1961) indicate that in some places, factors other than cool temperature are operative.

Climate of the Podzol Region of Michigan

The transition zone between the Gray-Brown Podzolic Soil Region and Podzol Zone II in Michigan closely approximates the so-called "vegetation tension zone" (Potzger, 1948) which separates the pine-northern hardwood forests on the north from the oak-hickory-northern hardwood forests to the south (see Figure 3).

Potzger (1948) mentions the following sharp climatic gradients which occur within this 60-mile zone: (1) the average date of the beginning of warm weather (daily normals above 50°F.) is April 1 near the southern boundary and May 1 near the northern boundary; (2) the number of days with temperatures constantly below 32°F. (per normal year) in the shade are 60 at the northern zone limit and 30 southward; (3) the zone separates the region of long winters, where (bare) soil freezes to depths of 3 to 6 feet, and the more southerly regions of milder winters where bare soil freezes to depths of only 18 to 36 inches. Other less drastic changes occurring within this zone are also mentioned; however, they all relate to temperature or temperature-controlled phenomena.

Climatic studies by Brunnschweiler (1962) indicate that precipitation regime boundaries coincide very closely with the boundary between the Podzol Region and the Gray-Brown Podzolic Soil Region. The Gray-

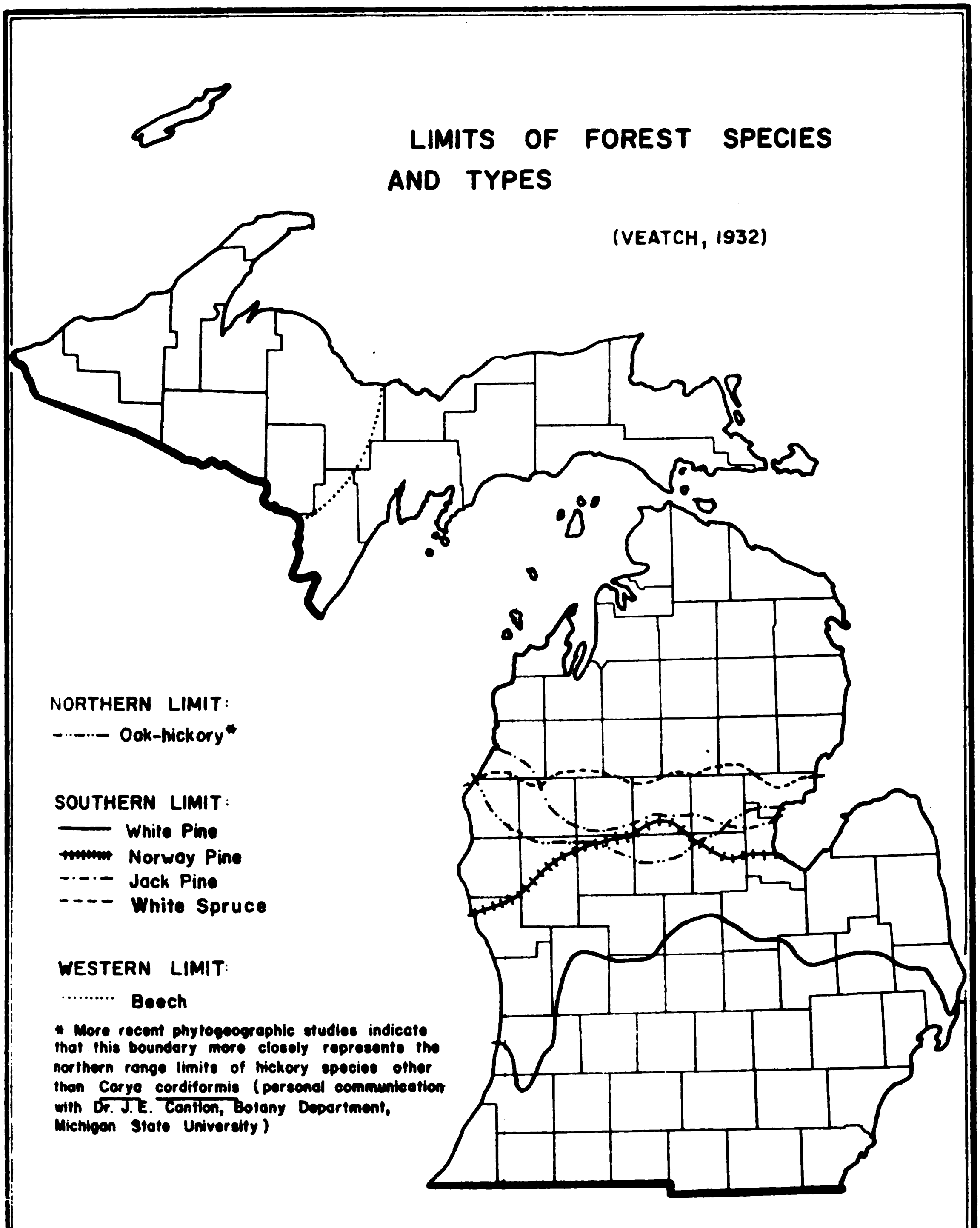
LIMITS OF FOREST SPECIES AND TYPES
(VEATCH, 1932)
NORTHERN LIMIT:
Oak-hickory*
SOUTHERN LIMIT:
White Pine
Norway Pine
Jack Pine
White Spruce
WESTERN LIMIT:
Beech
* More recent phytogeographic studies indicate that this boundary more closely represents the northern range limits of hickory species other than Carya cordiformis (personal communication with Dr. J. E. Cantlon, Botany Department, Michigan State University)

FIG. 3

Brown Podzolic Soil Region is characterized by a spring maximum of precipitation while the Podzol Region has summer maxima or maxima which include the month of September (see Figure 4). In addition, the soil transition zone is characterized by PE* values of 625 to 650 millimeters and no values below 625 occur in the Gray-Brown Podzolic Soil Region (Messenger, 1962; see Figure 5).

Within the Podzol Region of the Lower Peninsula, the zone of strongest developed Podzols (Zone III) closely coincides with the area having a mean fall precipitation of 9 inches or more and a mean annual snowfall of greater than 60 inches (vide Brunnschweiler, 1962: see Figures 6 and 7). The zone of weak to no orterde horizons (Zone I) has generally higher periodic water deficits** and PE values than either of the other two zones (see Figures 4, 8 and 9).

The relationship between white pine and the precipitation regime of the Podzol Region may be one of improved soil moisture conditions in the middle or latter part of the growing season of that species. For instance, a considerable number of investigations have been made on the terminal growth of white pine as related to day length, temperature and soil moisture. These studies indicate that a season's terminal growth usually starts around May 1, but dates of cessation of growth vary with locality and season, extending to September in some instances (Husch, 1959). Husch's study of white pine in southeastern New Hampshire indicated that the cessation of growth in late summer was controlled by an interaction of photoperiod and soil moisture, consequently leader

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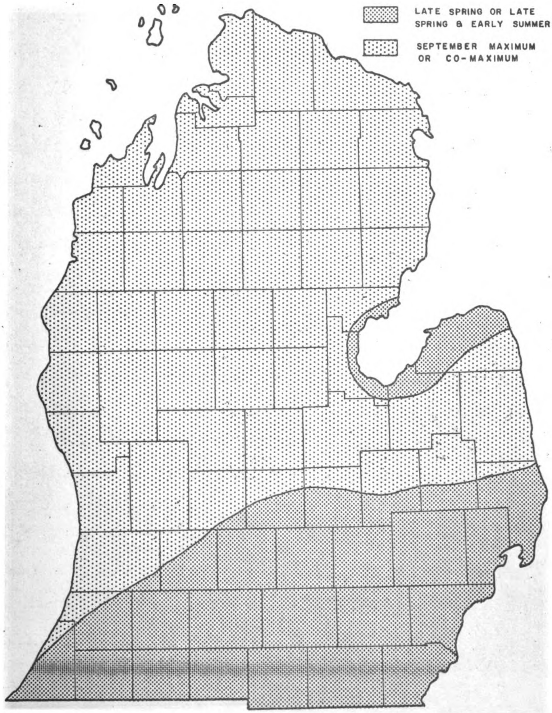
*PE = potential evapotranspiration as defined by Thornthwaite and Mather (1955).

**Water deficit = the difference between potential evapotranspiration and the estimated actual evapotranspiration.

FIG. 4

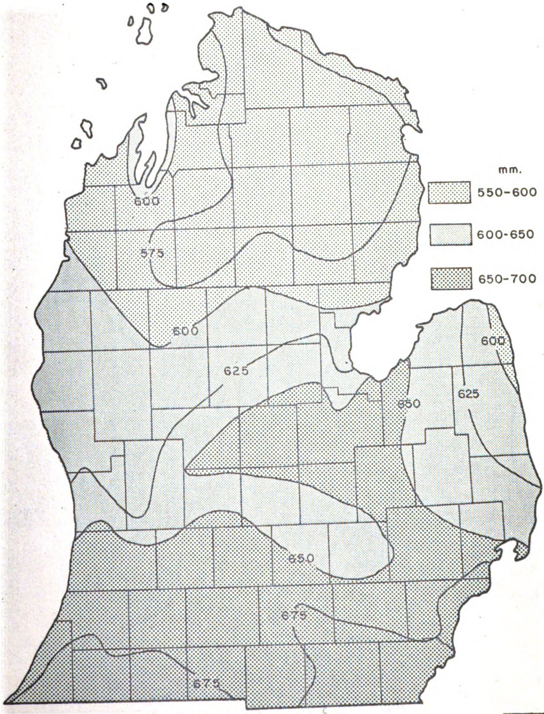
SEASON OF MAXIMUM PRECIPITATION



(AFTER BRUNNSCHWEILER, 1962)

FIG. 5

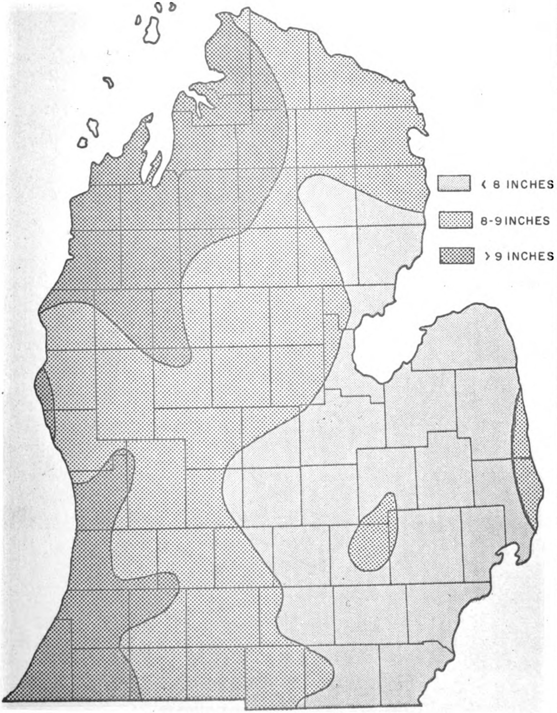
MEAN ANNUAL PE



(AFTER MESSENGER, 1962)

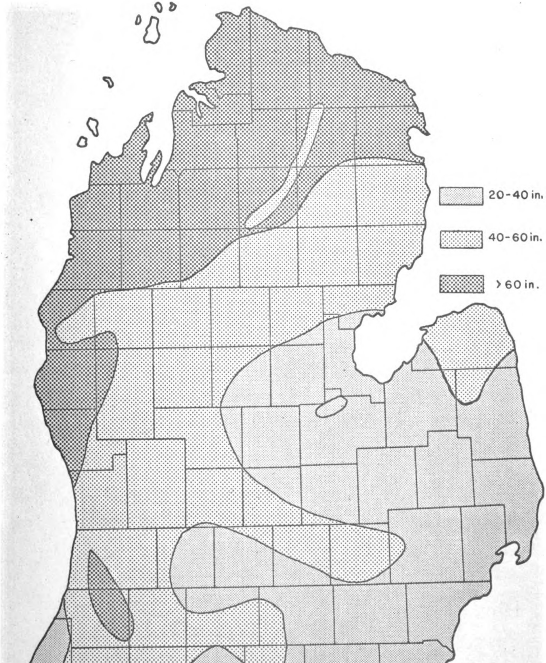
FIG. 6

MEAN FALL PRECIPITATION



(AFTER BRUNNSCHWEILER, 1962)

FIG. 7
MEAN ANNUAL SNOWFALL

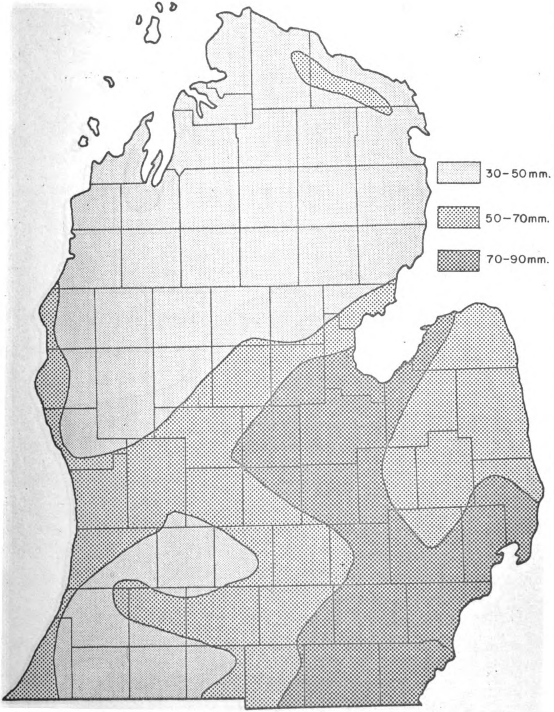


(AFTER BRUNNSCHWEILER, 1962)

FIG. 8

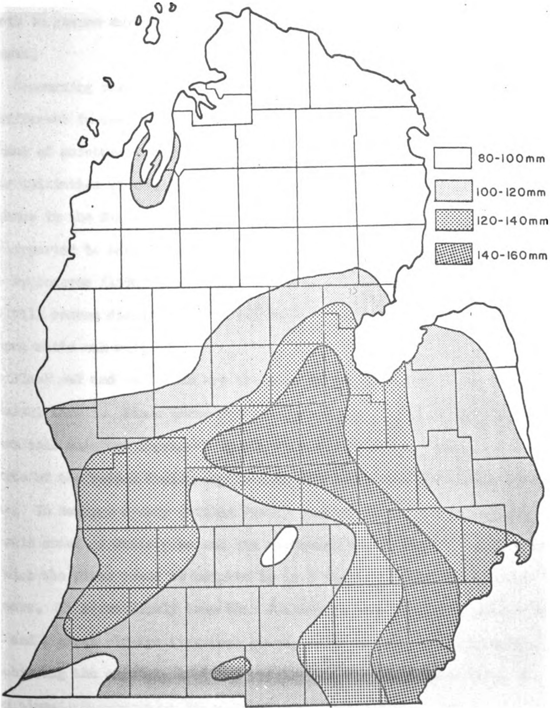
MEAN DEFICIT

Dry 50% of Years



(AFTER MESSENGER, 1962)

FIG. 9
MEAN DEFICIT
Driest 2 Consecutive Years



(AFTER MESSENGER, 1962)

elongation continued longer in years of ample soil moisture.

According to Zahner (1963), when severe soil moisture deficits do not occur, conifers usually continue moderately rapid cambial growth throughout the entire season; in forested northern latitudes, it can be through September. He also states that it is common for rapid cambial growth to resume during late growing season rainy periods following a drought.

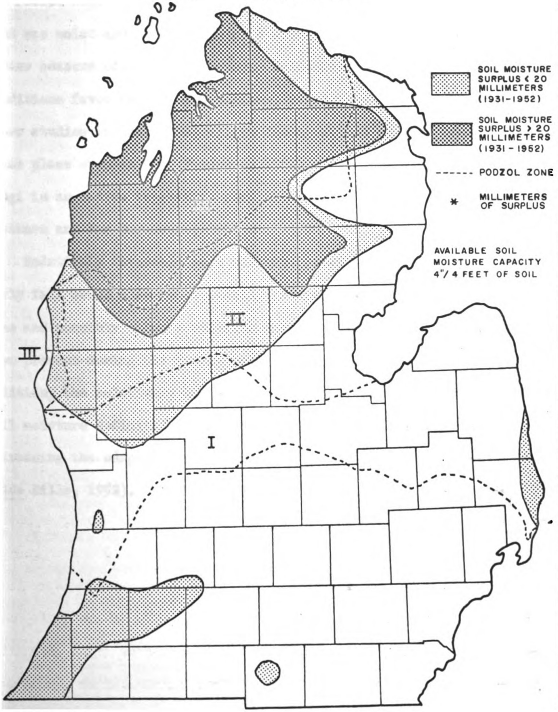
Concerning oaks, however, the patterns of terminal growth seem to be different in that cessation of shoot elongation seems to be independent of moisture conditions, and usually occurs within two months after initiation (Kramer and Kozlowski, 1960). These authors cite an instance in the Missouri Ozarks where black oak, white oak and post oak were reported to have a height growth season of only 19 days. A study made by Boggess (1956) in southern Illinois indicated that shortleaf pine will resume diameter growth following a mid-growing season drought whereas white oak will not.

Black oak and white oak are the main competitors with white pine in Podzol Zone I. Since these oak species do not respond to late growing season soil moisture increases to the same extent as do pines, the climate of the Podzol Region may be less favorable for them than for the pines. In Newaygo County (within Podzol Zone I) the writer has observed a virgin stand of white pine and the above-mentioned oaks on a sand soil in which the pines tower to heights 1½ to 2 times as great as those of the oaks. It seems likely that this dominance, coupled with a long life-span and a great old-age fire resistance, would enhance the probability of achieving the establishment and survival of natural reproduction of white pine.

The southern boundary of Podzol Zone II also marks the southern limit of forests dominated by red and white pines. This boundary is also coincident with the northern limit of Brunizems in Michigan. Although these limits may all be controlled by some factor(s) not yet analyzed, along the western half of the boundary they are approximated by the 100 mm iso-deficit line of the driest two consecutive years (based on records from 1929 through 1950; see Figure 9). Along the eastern half of the Zone I - Zone II boundary mean annual snowfall and water surplus values are quite low and mean annual PE values are more similar to those of the Gray-Brown Podzolic Soil Region than those of the Podzol Region. That drought and high temperatures could feasibly be limiting factors for red pine can be interpreted from the fact that summer droughts and high surface soil temperatures frequently kill or injure young red pine seedlings (Rudolf, 1957). However, it is also possible that red pine is unable to compete successfully for light with the somewhat more shade-tolerant oaks which are abundant on all sandy soils south of Podzol Zone II.

Since Podzol development has proceeded more rapidly in Zone III than in the other zones, it is possible that this has occurred as a result of the greater snowfall and autumn soil moisture recharge. In the autumn, soil temperatures decrease more slowly than do air temperatures, thus November finds most soil temperatures high enough for considerable chemical and biological activity. In the case of Podzol Zone III, such activity would be particularly favored because of the relatively heavy autumn rainfall which would partly or completely recharge many soils, particularly those with a low available water-holding capacity (see Figure 10). These moist soils most likely remain in an

FIG. 10
MEAN STATUS* OF AVAILABLE SOIL MOISTURE in November



active state throughout the winter as a result of the insulation provided by a persistent snow cover. In the Podzol Region of the British Isles, for instance, where snowfall is abundant, January soil temperatures at the one-foot depth range from 37.4°F to 39.2°F (Jen-Hu-Chang, 1958). In the Podzol Region of Michigan, McKenzie *et al.* (1960) found that Kalkaska sand was moist and unfrozen under a cover of snow in two consecutive winter seasons of study (1953-54). McKenzie's study indicates that these conditions favor reduction reactions, particularly in the A_1 horizon. Other studies indicate that slight decomposition of soil organic matter takes place even at 0°C (Kononova, 1961) and that some Podzols contain fungi in an active vegetative condition up to late fall or early winter (Doeksen and Van Der Drift, 1963).

Relatively favorable soil moisture conditions in late summer and early fall could also be especially favorable for the growth of white pine and possibly other coniferous species which are present or have been present during the development of the soils in Podzol Zone III. In addition, the relatively low drought intensity (as indicated by computed soil moisture deficits) of this zone could also be an important factor by increasing the edaphic range of mesophytic species toward sandier soils (*vide* Hills, 1952).

CHAPTER 3. BIOLOGICAL RELATIONSHIPS

Natural Vegetation in Podzol Regions

Temperate climate Podzols are most frequently found under coniferous forests (Robinson, 1949) and the southern extent of Podzol regions often coincides with the southern extent of certain coniferous forest types (Veatch, 1932; Tamm, 1932). Possibly for these reasons, some workers have deduced that northern Podzols develop under northern conifers (Kellogg, 1941), even though there are numerous instances of other vegetation types occurring on Podzols.

Since a mor humus type is generally conceded to be a component part of natural Podzols, it seems pertinent that the following tree species in the Podzol Region of eastern North America are commonly associated with soils having this feature*: jack pine (_Pinus banksiana_), red pine (_Pinus resinosa_), white pine (_Pinus strobus_), black spruce (_Picea mariana_), white spruce (_Picea glauca_), red spruce (_Picea rubens_), balsam fir (_Abies balsamea_), eastern hemlock (_Tsuga canadensis_), red maple (_Acer rubrum_), paper birch (_Betula papyrifera_), yellow birch (_Betula lutea_), American beech (_Fagus grandifolia_) and sugar maple (_Acer saccharum_) (Romell and Heiberg, 1931; Lunt, 1932; Donahue, 1939; Wilde, 1958 and personal observations). Associations of the latter three species, however, are more commonly found on mull humus types than on mor humus types except where the proportion of beech is high (Romell and Heiberg, 1931). Upland species growing in the same areas

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*Only those humus layers are included which meet the mor humus specifications outlined by Hoover and Lunt (1952).

but found mostly on mull humus types are: red oak (Quercus rubra), American basswood (Tilia americana), white ash (Fraxinus americana), ironwood (Ostrya virginiana), American Elm (Ulmus americana), black cherry (Prunus serotina) and butternut (Juglans cinerea). Aspens (Populus tremuloides and gradidentata) are present throughout the region and their abundance is usually a reflection of past fires or other denuding disturbances (Spurr, 1964), thus they are usually associated with mull or duff-mull humus types since mor humus types are usually degraded by fires and disturbances which open up the forest canopy (Romell, 1935).

Plice (1934) noted that the heaviest and most pronounced mor humus is found under pure hemlock stands. Under this humus type, the A2 (Em) horizon reaches maximum thickness and cleanness of color. In addition, the H-layers (Oh horizons) are more acid under pure hemlock than under any other forest type studied in the northeastern states, the pH range being from 2.5 to 4.1. Nearly comparable humus layers, however, have been found in Podzols under spruce-fir stands in New Hampshire (Lunt, 1932) and under black spruce stands in Quebec (Lafond, 1958).

The southern boundary of the Podzol Region of Michigan coincides with the southern limit of the area in which white pine (Pinus strobus) is an important component of the recent natural vegetation (Veatch, 1932; see Figure 3) and closely parallels the southern botanical range limit of hemlock in that state (vide Hough, 1960). Podzol Zone I essentially coincides with the vegetation "tension zone" and is bounded on the north by the southern range limit of red pine (see Figure 3). White pine was the only pine of importance in this zone and it occurred mainly in mixtures with oak on the well-drained sites. In Podzol Zone II,

jack pine (Pinus banksiana) and red pine (Pinus resinosa) were also present (Figure 3). In this zone, hemlock was more prevalent (Hough, 1960) and the pines occurred in pure stands* as well as in mixtures with hardwoods. The pure stands of pines were present almost exclusively on sands, the most prevalent of these being Rubicon sand (see soil survey reports of Newaygo, Montcalm, and Midland counties). Northern hardwoods were generally prevalent on medium-textured and fine-textured soils in this zone with some notable exceptions in the northeastern part of the Lower Peninsula where white pine dominated on some clay loams and silty clay loams (Veatch, 1953, 1959 and personal communication); these soils belong to the Gray-Wooded great soil group (NCR-3 Soil Survey Committee, 1960). In Podzol Zone III, northern hardwoods were more prevalent and even occurred on some well-drained sands, while pines or oaks and pines occupied other well-drained sands. Here, the medium-textured soils invariably supported northern hardwoods with scattered white pines and hemlock often present, this relationship extending on into the Upper Peninsula.

Forest Succession

The pattern of fire-free forest succession in the Lake States is said to be from jack pine to red and white pines to shade-tolerant species such as sugar maple, balsam fir and black spruce in the case of sands (Spurr, 1964). Cliseral-successional changes from jack pine to red and white pines is suggested for sands in northern Lower Michigan while white spruce and balsam fir through white and red pines to hemlock

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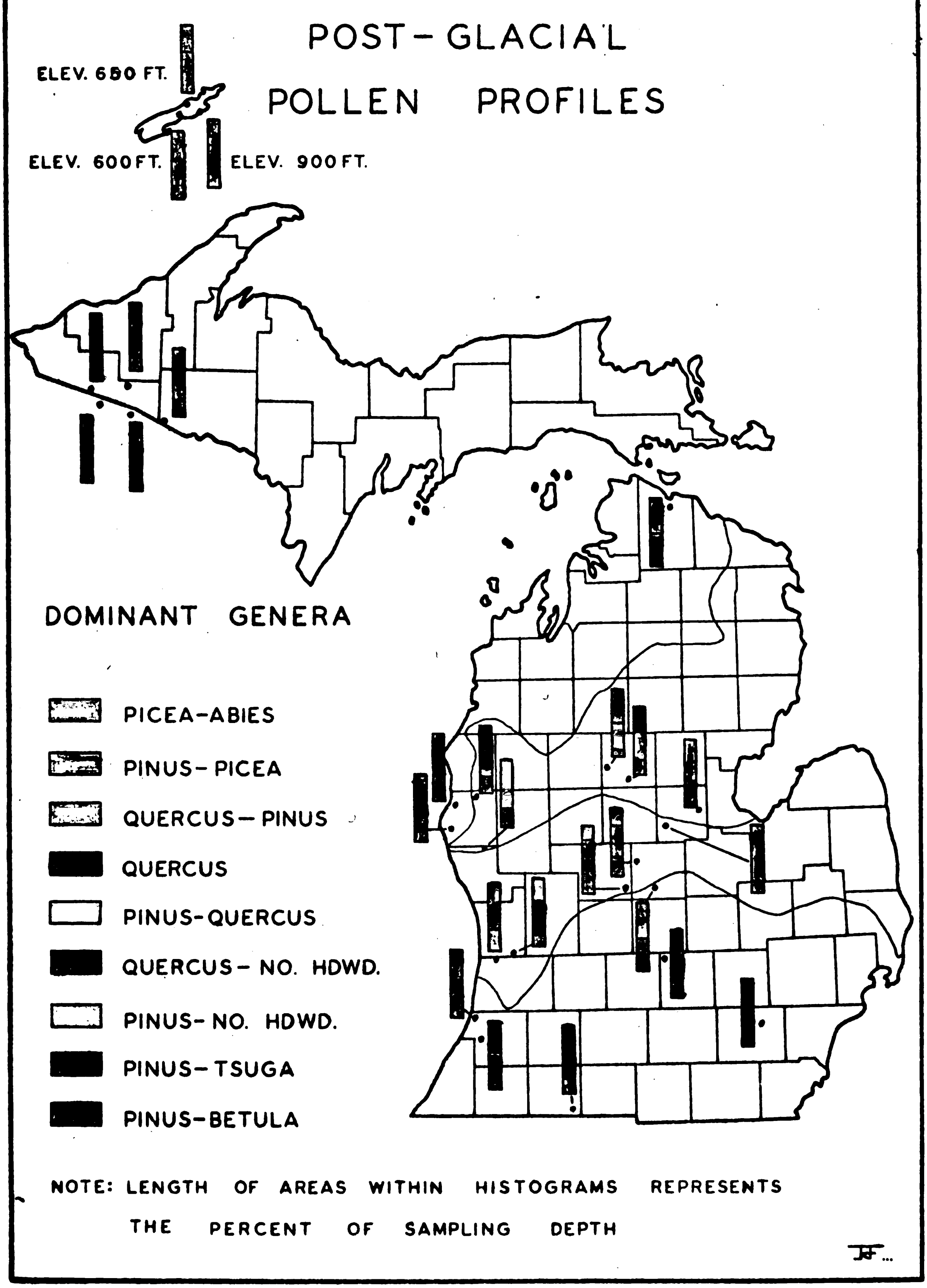
*"Pure stands" refer to stands composed of at least 80% of the stated component.

and northern hardwoods is suggested for the finer-textured soils (Kilburn, 1957).

Within Podzol Zone III, sands occur which have (or had) pure stands of northern hardwoods on them. To take these and other sand sites into account, perhaps Kilburn's cliseral-successional pattern should be revised to: from jack pine to jack pine and oaks on some sands (role of fire may be important), to red and white pines in the case of other sands and from white spruce and balsam fir through white and red pines to hemlock and northern hardwoods on still other sands and finer-textured soils. All these sequences were probably initiated by relatively short-lived stages characterized by calcium tolerant, shade intolerant species similar to those mentioned by Olson (1958), Crocker and Major (1955), and Wright (1964), some of which produce easily decomposed pollen and therefore may not be accurately represented in pollen spectra.

Regardless of difficulties of interpretation, pollen studies do indicate that a spruce-fir period dominated all forested land surfaces in Michigan following Cary glaciation (Potzger, 1946, 1948; Wilson and Potzger, 1943; Parmelee, 1947; see Figure 11). Even in southwestern Michigan where oaks and northern hardwoods now dominate the upland sites, spruce and fir reigned supreme for approximately 4500 years following Cary glaciation (Zumberge and Potzger, 1956). According to these findings, pine was the major vegetation type for the succeeding 3500 years and it was not until about 5000 B.P. (years before present) that hardwoods and hemlock entered the scene. In Cheboygan County, about 250 miles further north and well within the Podzol Region, Kilburn (1957) estimates that spruce and fir forests were dominant

FIG. 11


POST-GLACIAL
POLLEN PROFILES
ELEV. 650 FT.
ELEV. 600 FT.
ELEV. 900 FT.
DOMINANT GENERA
PICEA-ABIES
PINUS-PICEA
QUERCUS-PINUS
QUERCUS
PINUS-QUERCUS
QUERCUS-NO. HDWD.
PINUS-NO. HDWD.
PINUS-TSUGA
PINUS-BETULA
NOTE: LENGTH OF AREAS WITHIN HISTOGRAMS REPRESENTS
THE PERCENT OF SAMPLING DEPTH
JF...

for the first 3000 years following Valders glaciation and that pine forests were prevalent for the succeeding 1000 to 2000 years. Although no mention is made of succession to northern hardwoods on sand, Kilburn infers that conversion to northern hardwoods and hemlock on loamy sands occurred somewhat later than on loams, possibly from 2000 to 3000 years ago. This chronology would of course imply that coarse-textured drift of Valders age has supported predominantly coniferous forests for at least 8000 years.

Pollen data are scarce for the Upper Peninsula of Michigan, but studies in northern Wisconsin (Potzger, 1946; Wilson, 1938; Wilson and Webster, 1944) indicate a forest succession similar to those of the northern part of the Lower Peninsula of Michigan with the exception that birch is outstanding in some of the Wisconsin pollen profiles; macrofossil data from Minnesota indicate that paper birch was the birch species which invaded the deteriorating spruce forest (Wright, 1964), while upper level birch pollen in north central Wisconsin probably represents mainly yellow birch (Potzger, 1946). The peat sampled by Wilson and Webster on an outwash plain in north central Wisconsin indicates an initial white spruce maximum that was quickly replaced by a pine maximum which persisted to the present time. In the upper one-third of the profile a definite increase in birch (probably yellow birch) and hemlock pollen was present. Two other bogs, located in areas of finer-textured soils, showed an increase in spruce near the surface, more or less accompanying the birch and hemlock increase occurring in all three profiles.

Fraxinus (ash) was present in southern Delta County by 5720 ±250 years B.P. as determined by a radiocarbon dating on a piece of buried wood*.

The above studies suggest that oak was more prevalent in Podzol Zone I than in Podzol Zone II. They also indicate that hemlock was relatively abundant north of the tension zone whereas hemlock pollen percentages were consistently less than 10% in Podzol Zone I bogs. No hemlock pollen was found in the bogs of Douglas County, Wisconsin (extreme northwest corner of the state) by Wilson (1938) suggesting that hemlock did not play a significant role in post-Pleistocene plant succession in the less humid portions of the Lake States Podzol Region. In Douglas County, only weakly developed Podzols (no dark orterde horizons) are found and these only on sand parent material (NCR-3 Technical Committee on Soil Survey, 1960). According to Wilson the forest history of these sands was from jack pine and spruce (concurrent with Glacial Lake Duluth) through jack pine and red pine (during Glacial Lake Algonquin times) to red pine, jack pine and oak (beginning in Lake Nipissing times). The oak component was likely present to the greatest extent on the weakly podzolized site (Omega sand, which is usually classified as a Brown Podzolic soil). Appreciable quantities of oak were characteristic of the natural vegetation (recent) on this soil series and not characteristic of the Podzol sands (Rubicon and Vilas series) in this area although northern red oak can be found on some areas of Rubicon and Vilas soils.

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*Personal communication from A. E. Slaughter, Geological Survey, Division of the Department of Conservation, State of Michigan, at Escanaba. The wood was identified by Dr. Eldon A. Behr, Department of Forest Products, Michigan State University. Judging from the site description given by Mr. Slaughter, the tree was evidently inundated initially by the rise of water levels from the Lake Chippewa stage to the Lake Nipissing stage in the Lake Michigan Basin (see Hough, 1958).

Vegetation Changes and Associated Changes in Soil Morphology

Discussing the soil types of south Sweden, Tamm (1932) is of the opinion that there Brown Forest soils (a group of soils in Europe some of which may be equivalent to the Brown Forest soils of the U. S. and some of which may be equivalent to Gray-Brown or Brown Podzolic soils of the U. S.) are the climatically determined soils and he describes their occurrence on many different parent materials if the natural vegetation of beech and oak forests is present. Where, however, the broadleaved forest has been replaced by conifer forest or Calluna heath, as often happens under the influence of man, Brown Forest soils developing into Podzols are found. Tamm also describes the phenomenon whereby a clearly defined Podzol may acquire a mull humus layer and a less acid reaction if beech or conifers are replaced by birch. He also points out that if beech or spruce colonise or are planted under the birch on such soils then a mor humus will be formed again. Handley (1954) cites references to the fact that on base-rich soils, European beech gives rise to a mull humus layer whereas on a base-poor soil, it gives rise to a mor.

Similar phenomena have been observed by Fisher (1928) and Griffiths, Hartwell and Shaw (1930) in New England, where white pine has developed on abandoned fields. After 80 years there is almost no vegetation under the white pine, and under the thin layer of dry needles there is a thick layer of raw humus and "a strongly podzolized horizon". On an adjacent plot hardwood forest has been developing on a similar white pine plot which had a similar profile at the time the white pine was removed; now there is a true mull humus present—all accumulated raw humus has merged with the mineral soil and less than a single year's leaf fall remains on the surface.

More recently Bornebusch (vide Handley, 1954) has described profound changes in soil morphology brought about through the influence of *Quercus rubra* (introduced from the U. S.) planted on mor humus layers produced by *Pinus sylvestris* and *Picea excelsa* on sandy soils in Denmark. In 20 years the bleached A_2 had become obscured; the mor layer had largely disappeared and was replaced by a brownish, earthworm mull humus layer.

Possibly related to the above studies are the findings of Mikola (1954) who noted that soil basidiomycetes decomposed leaf litter more rapidly than needle litter and those of Ivarson and Sowden (1959) who found that mull-forming litters decomposed more rapidly than mor-forming litters.

Although several explanations of these differential rates of decomposition have been given, the work of Lossaint (1953) indicated that the rate of decomposition of litter from 9 species was directly related to the N and water-soluble Ca content of the litter.

Chemical Element Pools in Forested Ecosystems

To obtain a full understanding of some of the afore-mentioned phenomena, it is becoming increasingly apparent that a knowledge of complete ecosystems is necessary. For example, recent studies on forest ecosystems have provided useful information concerning the distribution of mineral elements once they have been initially removed from the soil by plant roots. Estimates of the composition of standing crops of living trees give some notion as to what has been in the soil but is not included when soil analyses are made. The following tables represent three floristically different standing tree crops (based on weighing and sampling the various parts of sample trees):

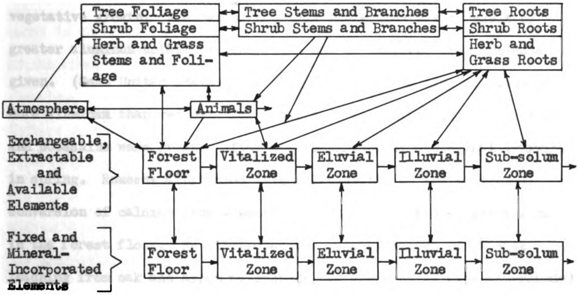
Site	Species	Pounds per Acre Dry Matter	N	P	K	Ca	Mg
Natural Stand— Great Smoky Mountains*	Beech	110,490	-	31.1	121.2	264.2	39.3
	Birch	38,735	-	9.6	46.2	103.6	14.7
	Fir	1,675	-	0.3	1.1	2.9	0.3
	Spruce	561	-	0.1	0.3	1.1	0.1
	Total	151,461	-	41.2	168.8	371.8	54.5
Natural Stand— Great Smoky Mountains*	Spruce	164,788	-	22.2	102.9	251.1	35.4
	Fir	93,386	-	13.3	57.6	152.0	19.0
	Birch	31,784	-	8.4	36.7	81.4	11.9
	Total	289,958	-	43.9	197.3	484.6	66.2
64 year old plantation on dune sand —Scotland**	Scots pine	106,000	183.0	20.3	89.0	180.0	31.8***

*Shanks *et al.*, 1961a
**Wright and Will, 1958
***Ovington and Madgwick, 1959

The greater amount of standing stock in the spruce-fir stand compared to the beech-birch stand may be a reflection of more efficient site utilization, a reflection of a difference in the sites or simply a reflection of an innate difference due to the growth form characteristics of the spruce as compared with the beech dominants. The greater biomass in the spruce forest results in more nutrient element material in the above-ground portion of that ecosystem than in that of the hardwood ecosystem. Results obtained by Ovington (1956) indicate a similar trend in the cases studied. The chemical element concentration in the vegetative material, however, is also of considerable significance to the decompositional processes taking place in such ecosystems. For example, data for the three tree crops above indicate a lower concentration of all the elements in the conifer stands as compared to the beech-birch stand.

To obtain a clear picture of what takes place in such ecosystems, studies need to encompass the other portions of these ecosystems as well. For instance, the various chemical element pools in forested terrestrial ecosystems can be visualized using a model such as the following one which also depicts the possible directions of exchange.

Chemical Element Pools in Upland Forested Terrestrial Ecosystems*



*sizes of rectangles do not signify relative pool capacities or quantities.

The forest floor should logically provide the most constant source of biologically controlled chemical environment for the underlying horizons of the soil profile. The forest floor not only reflects the chemical element composition of the entire supra-solum portion of the biosphere but it has features which can alter the form of the chemical elements and compounds which enter it from the atmosphere. The major annual chemical element contribution to forest floors, however, is from tree foliage thus forest floor differences are largely reflections of foliar differences when similar atmospheric conditions prevail.

Data presented by Remesov (1958) suggest that seasonal transfers of some chemical elements from available element pools in the soil to suprasolum pools can retard their removal from the ecosystem by leaching. For example, aluminum losses were less when vegetation development in the spring preceded spring leaching. Losses of aluminum from pine-dominated watersheds were consistently less than those from oak- or aspen-dominated watersheds when leaching was subsequent to the beginning of spring vegetative growth. Whether or not this difference was a result of greater aluminum uptake by pine could not be inferred from the data given. (Some United States data suggest that white pine may take up more aluminum than red oak, for example.) Leaching losses of calcium and potassium were greater after the resumption of biological activity in spring. Remesov attributed this relationship to the biological conversion of calcium from a water-insoluble to a water-soluble form in the forest floor. He attributed the greater amount of calcium leaching from oak and aspen watersheds (as compared to pine watersheds) to the higher calcium content of the oak and aspen leaf litter. Leaching losses in the studies of Remesov were confined to spring. According to Volubuyev (1959) Podzol regions have spring and fall leaching seasons. On sand soils in Podzol Zone III in Michigan, water balance computations indicate that ecosystem losses may occur in fall due to leaching (Messenger, 1962; see Figure 10). Thus the ecosystem distribution of leachable elements during the fall leaching season could also influence losses therefrom. In most of the Podzol Region of Michigan, precipitation exceeds potential evapotranspiration from September through April or May. Studies cited by Kozlowski (1960) indicate that chemical elements in tree foliage do not increase after September and that calcium content is at a maximum in early fall whereas the spring leaching period is characterized by increasing absolute foliar contents of most elements. If foliar contents reflect root uptake, fall leaching would not be reduced as much by plant uptake as spring leaching would be.

Elemental Composition of Tree Foliage and Litter

Based on some of the above relationships, a number of workers have approached humus type and soil development from the standpoint of differences in the elemental composition of tree foliage. Even though the form of the chemical elements in tree foliage is important in such studies (Handley, 1954), most analyses have been concerned only with the concentration of the chemical elements regardless of their form. Several studies of this nature have been made on the foliage from trees which are found in the Podzol Region of North America. Since the elemental composition varies with leaf age, soil conditions and climate (Kramer and Kozlowski, 1959) the following tables are presented so that foliar comparisons can be made: (1) between different species in the same general area growing on the same or similar soils, and (2) between individuals of the same species growing on different soil types. Tables 1 and 2 summarize the intact foliage and freshly fallen litter data from the literature which point to species differences in foliar composition of major nutrients. For each site the species are arranged in order of decreasing calcium concentration. These tables are not combined because of known variations in foliar composition resulting from (1) translocation of elements back into the twigs prior to leaf fall and from (2) leaching of soluble elements during leaf senescence and following leaf fall. Comparisons between the two tables show a general decrease in N, P and K with leaf age thus suggesting that one or both of the above types of foliar decreases have been operative. The crown position of the foliage samples analyzed for Table 2 were not given. Some investigators, however, have found variations in foliar composition attributable to the portion of the crown sampled (Kramer and Kozlowski, 1960).

TABLE 1. Composition of Freshly Fallen Leaves from Different Tree Species Growing on Similar Soils in the Same Vicinity

Site	Species	%N	%Ca	%K	%Mg	%P
Cass Lake fine sand near Star Island, Minn. (Alway *et al.*, 1933)	Basswood	0.97	3.14	-	-	0.18
	Sugar Maple	1.32	2.57	-	-	0.10
	Red Oak	0.64	0.96	-	-	-
	White Pine	0.53	0.97	0.17	-	0.07
	Red Pine	0.67	0.96	0.24	-	0.07
	Jack Pine	0.59	0.63	0.18	-	0.05
Scarboro loamy sand near Litchfield, Conn. (Scott, 1955)	Sugar Maple	-	1.08	0.42	0.44	0.10
	Red Maple	-	0.93	0.39	0.48	0.12
Merrimac loamy sand near Litchfield, Conn. (Scott, 1955)	Red Oak	-	0.64	0.40	0.26	0.24
	White Pine	-	0.45	0.36	0.22	0.15
Sandy loam Podzol, Adirondacks (Chandler, 1943)	White-Cedar	0.60	2.16	0.25	0.15	0.04
	Balsam Fir	1.25	1.12	0.12	0.16	0.09
	Red Spruce	0.89	0.79	0.35	0.20	0.10
	Hemlock	1.05	0.68	0.27	0.14	0.07
	White Pine	1.14	0.60	0.18	0.16	0.05
	Red Pine	0.69	0.58	0.35	0.18	0.07
Loam and silt loam Gray-Brown Podzolic soils, central New York (Chandler, 1941)	Basswood	1.04	3.24	0.39	0.39	0.14
	Black Cherry	0.55	2.58	0.47	0.44	0.18
	Ironwood	1.01	2.52	0.35	0.35	0.09
	White Ash	0.59	2.28	0.46	0.29	0.15
	American Elm	0.77	2.06	0.44	0.32	0.15
	Aspen	0.70	1.85	0.36	0.23	0.08
	Sugar Maple	0.43	1.65	0.45	0.28	0.12
	Red Oak	0.67	1.49	0.55	0.31	0.11
	Red Maple	0.41	1.35	0.30	0.32	0.11
	White Oak	0.50	1.22	0.52	0.24	0.12
	Beech	0.59	1.09	0.65	0.26	0.10

TABLE 2. Composition of Mature Foliage* from Different Species on Similar Soils in the Same Vicinity

Site	Species	%N	%Ca	%K	%Mg	%P
DeKalb soil series (no lime in root zone), Warren County, Penna. (Plice, 1933)	White Ash	-	2.3	-	-	-
	Yellow Birch	-	1.6	-	-	-
	Eastern Hemlock	-	0.8	-	-	-
	Northern Red Oak	-	0.7	-	-	-
	White Pine	-	0.5	-	-	-
Glacial till soil (no lime in root zone) in Adirondacks (Plice, 1933)	White Spruce	-	1.9	-	-	-
	Eastern Hemlock	-	1.1	-	-	-
	Balsam Fir	-	0.9	-	-	-
	Black Spruce	-	0.9	-	-	-
Dunkirk soil series (lime present in root zone) near Ithaca, N.Y. (Plice, 1933)	White-cedar	-	2.6	-	-	-
	American Elm	-	1.6	-	-	-
	Sugar Maple	-	1.1	-	-	-
	White Oak	-	0.9	-	-	-
	Red Maple	-	0.8	-	-	-
	Tamarack	-	0.6	-	-	-
	Pitch Pine	-	0.4	-	-	-
Silt loam glacial till soil (lime within 1 foot of soil surface) in central New York (Bard, 1945)	Basswood	2.68	2.88	2.16	-	0.26
	Ironwood	2.01	2.62	0.96	-	0.15
	Black Cherry	1.67	2.13	1.63	-	0.18
	Yellow Birch	2.56	1.86	1.10	-	0.18
	White Ash	2.27	1.70	1.70	-	0.18
	Sugar Maple	1.81	1.55	0.78	-	0.09
	American Elm	2.86	1.54	1.00	-	0.14
	Red Oak	1.64	1.25	1.50	-	0.14
	American Beech	2.37	0.97	1.00	-	0.14
Silt loam glacial till soil (lime at about 30 inches depth) in central New York (Bard, 1945)	Basswood	2.32	2.87	2.35	-	0.27
	Ironwood	1.62	2.59	1.10	-	0.15
	White Ash	1.91	1.84	1.54	-	0.28
	Sugar Maple	1.68	1.63	1.02	-	0.16
	White Oak	2.33	1.60	1.55	-	0.24
	Red Maple	1.44	1.42	1.16	-	0.16
	American Beech	2.21	1.21	1.39	-	0.14
	Red Oak	1.75	1.02	1.20	-	0.18
	Hemlock	1.11	0.70	0.90	-	0.18
Silt loam glacial till soil (no lime in root zone) in central New York (Bard, 1945)	Basswood	2.44	2.96	2.30	-	0.33
	Ironwood	1.99	2.47	1.30	-	0.19
	White Ash	1.90	1.68	1.37	-	0.27
	Big-t. Aspen	2.10	1.67	1.00	-	0.26
	White Oak	2.06	1.41	1.46	-	0.24
	Yellow Birch	1.92	1.37	1.35	-	0.25
	Red Maple	1.43	1.14	1.02	-	0.25
	Sugar Maple	1.50	1.11	1.24	-	0.21
	Red Oak	2.29	0.91	1.52	-	0.25
	American Beech	2.03	0.85	1.21	-	0.17
	Hemlock	1.33	0.71	1.20	-	0.18

TABLE 2 (Cont.)

Site	Species	%N	%Ca	%K	%Mg	%P
Site #76b, Dane County, Wisconsin (Gerloff *et al.*, 1964)	Red Oak	0.96	1.18	0.29	0.50	0.12
	Sugar Maple	0.73	1.01	0.39	0.45	0.12
Site #18b, Dane County, Wisconsin (Gerloff *et al.*, 1964)	Basswood	1.39	1.11	0.89	0.52	0.17
	Ironwood	1.44	1.03	0.43	0.58	0.17
Site #11a, Dane County, Wisconsin (Gerloff *et al.*, 1964)	Butternut	1.79	1.11	0.82	0.72	0.44
	Black Cherry	1.58	0.96	1.35	0.70	0.73
Site #18a, Dane County, Wisconsin (Gerloff *et al.*, 1964)	White Oak	1.03	1.13	0.70	0.32	0.12
	Ironwood	1.49	1.06	0.64	0.54	0.16
	Big-t. Aspen	1.11	0.99	1.78	0.33	0.21
Site #6, Dane County, Wisconsin (Gerloff *et al.*, 1964)	Black Cherry	2.43	1.16	1.57	0.46	0.26
	White Oak	2.19	0.82	0.85	0.36	0.19
	Red Oak	1.97	0.75	5.39**	0.40	0.14
	Black Oak	1.92	0.70	0.77	0.42	0.14
Site #62, Vilas County, Wisconsin (Gerloff *et al.*, 1964)	White Spruce	0.95	0.87	0.54	0.23	0.17
	Balsam Fir	1.22	0.75	0.46	0.13	0.13
Site #55, Vilas County, Wisconsin (Gerloff *et al.*, 1964)	White Pine	1.48	0.32	0.54	0.23	0.15
	Red Pine	0.95	0.23	0.41	0.17	0.11

*Conifer needles of the current year were used in the Wisconsin study; it is assumed that in the other studies the conifer needles analyzed were variable in age.

**This value seems to be too high.

TABLE 3. Composition of Freshly Fallen Leaves from the Same Species on Different Soils in the Same Vicinity

Vicinity: near Litchfield, Connecticut (Scott, 1955)

		Ridgebury Sandy Loam (GH*); mull	Scarboro Sandy Loam (HG*); mor	Merrimac Loamy Sand (BP*); mor	Merrimac Sandy Loam (BP*); mor
Red Maple	%Ca	0.99	0.93	-	-
	%K	0.47	0.39	-	-
	%Mg	0.46	0.48	-	-
	%P	0.11	0.12	-	-
White Pine	%Ca	0.66	0.69	0.44	0.49
	%K	0.45	0.43	0.38	0.37
	%Mg	0.33	0.32	0.23	0.31
	%P	0.10	0.11	0.14	0.11

Vicinity: New York (Chandler, 1943)

		Sandy Loam Podzol	Silty Clay Loam Gray-Brown Podzolic Soil
White Pine	%Ca	0.60	0.60
	%K	0.18	0.18
	%Mg	0.16	0.21
	%P	0.05	0.07

*GH = Gray Hydromorphic; HG = Humic Gley; BP = Brown Podzolic

TABLE 4. Composition of Mature Foliage from the Same Species on Different Soils in the Same Vicinity

Vicinity: central New York (Bard, 1945)

		Silt Loam Glacial Till Soil With Lime Within 1 Foot of Soil Surface	Silt Loam Glacial Till Soil With Lime at About 30 Inches Below Soil Surface	Silt Loam Glacial Till Soil With No Lime in Root Zone
Basswood	%N	2.68	2.32	2.44
	%Ca	2.88	2.87	2.96
	%K	2.16	2.35	2.30
	%P	0.26	0.27	0.33
Ironwood	%N	2.01	1.62	1.99
	%Ca	2.62	2.59	2.47
	%K	0.96	1.10	1.30
	%P	0.15	0.15	0.19
White Ash	%N	2.27	1.91	1.90
	%Ca	1.70	1.84	1.68
	%K	1.70	1.54	1.37
	%P	0.18	0.28	0.27
White Oak	%N	-	2.33	2.06
	%Ca	-	1.60	1.41
	%K	-	1.55	1.46
	%P	-	0.24	0.24
Yellow Birch	%N	2.56	-	1.92
	%Ca	1.86	-	1.37
	%K	1.10	-	1.35
	%P	0.18	-	0.25
Red Maple	%N	-	1.44	1.43
	%Ca	-	1.42	1.14
	%K	-	1.16	1.02
	%P	-	0.23	0.25
Sugar Maple	%N	1.81	1.68	1.50
	%Ca	1.55	1.63	1.11
	%K	0.78	1.02	1.24
	%P	0.09	0.16	0.21
Red Oak	%N	1.64	1.75	2.29
	%Ca	1.25	1.02	0.91
	%K	1.50	1.20	1.52
	%P	0.14	0.18	0.25
American Beech	%N	2.37	2.21	2.03
	%Ca	0.97	1.21	0.85
	%K	1.00	1.39	1.21
	%P	0.14	0.14	0.17
Eastern Hemlock	%N	-	1.11	1.33
	%Ca	-	0.70	0.71
	%K	-	0.90	1.20
	%P	-	0.18	0.18

The studies made on foliar N suggest that the freshly fallen foliage of jack pine, red pine, white pine and northern red oak have similar low contents as compared to sugar maple and basswood when all six species are growing on sand. On better sites, white pine seems to have considerably higher contents than red pine and similar values to those of hemlock (Table 1). Mature foliage studies in Wisconsin also indicate that white pine contains a higher percentage of foliar N than does red pine (Table 2).

The mature foliage of hemlock, as indicated in Table 2, contains lower percentages of N than any of the associated hardwoods. Since the age of the hemlock foliage is not known, interpretation of this comparison is difficult. Variations with age may not be great, however, since Gerloff et al. (1964) give a percentage of 1.21 for current mature foliage while the freshly fallen litter value reported by Chandler (1943) is 1.05. The values reported by Bard for mature hemlock foliage of unknown age are 1.11 and 1.33. The mature foliage data in Table 2 also indicate that white ash, yellow birch and beech have higher foliar N values than sugar maple. On acid sites, northern red oak also has higher percentages of N than sugar maple. Basswood tends to have high values of foliar N wherever it occurs.

Studies made on foliar Ca from different species growing on the same or similar sites, Table 1, suggest that freshly fallen jack pine needles have a lower content than either red or white pine. The foliages of pine, hemlock and beech consistently have lower Ca concentrations than associated hardwoods except red oak. The foliages of basswood, ironwood, butternut, black cherry, white-cedar and white ash contain relatively high concentrations of Ca.

Table 2 indicates that the mature foliages of basswood, white ash and black cherry consistently have relatively high concentrations of potassium. When associated with hardwoods, the mature foliage of hemlock has potassium values similar to those of its associates except that basswood foliage consistently has higher values.

The hardwoods in Tables 1 and 2 have foliar magnesium values which vary along a continuous gradient with butternut, black cherry, ironwood and basswood at the high end and white oak, aspen and beech at the low end. A relatively low range of foliar Mg values is indicated for all of the conifers. Despite the paucity of site-mate comparisons between hardwoods and conifers, it is interesting to note that the highest value reported for the conifers is the same as the lowest value reported for the hardwoods. Site-mate comparisons made by Ovington (1956) in Great Britain indicate that with the exception of certain oak species, hardwoods contain higher foliar Mg concentrations than do the conifers.

Site-mate comparisons indicate that the foliages of basswood, black cherry and white ash contain relatively high concentrations of phosphorus and that the foliages of beech and pines have low concentrations of that element.

Several species in the foregoing studies show evidence of a foliar nutrient element response to site. Most of the hardwood species studied by Bard, Table 4, show increasing foliar N concentrations with decreasing depth to carbonates. Northern red oak and hemlock, however, show <u>decreasing</u> contents of foliar N with decreasing depth to carbonates; this trend may be a general one for these species since the maximum recorded value for northern red oak foliar N was obtained for leaves collected from a northern red oak plantation on an acid sand in England. The average %N there was 2.87, far higher than the values for any of the

seven species of evergreen conifers planted on the same site but similar to the values for three other members of the Fagaceae family on the same site (vide Ovington, 1956).

Data presented by Chandler (1943) was thought by that author to confirm the lack of foliar calcium response by white pine to soil conditions but data obtained by Scott suggest a response by this species, the two well-drained Brown Podzolic soils giving rise to lower foliar Ca values than two less well-drained soils (see Table 3). Comparing the data of Plice and Gerloff et al. with the above two, it appears that the range of white pine foliar calcium is from about 0.3% to 0.7% with the upper range occurring in the freshly fallen foliage from high water table sites. (The calcium values reported by Alway et al. are not included in this comparison since they seem out of line with presently existing data and were earlier considered abnormally high by Plice.)

A lack of response by some pines is attested to by the data of Ovington (1959) who states that Scots pine trees (associated with Podzols in Europe) show no foliar calcium increase with increasing availability of soil calcium on well-drained sites. Bard's study, Table 4, indicates the possibility that hemlock foliar calcium does not vary due to site differences between well-drained, medium-textured soils showing considerable variability in acidity, readily extractable calcium and depth to carbonates. Most hardwoods in Bard's study contained higher foliar Ca contents when growing on high or medium lime tills as compared to no lime tills, but basswood and white ash maintained high and similar values on all sites. Scott's data, Table 3, however, show no foliar response by red maple within the range of site conditions studied, both values being lower than for the no lime till site in Bard's study. The soils in Scott's study were loamy sands and sandy loams as compared to silt loams in that of Bard's.

Foliar potassium response to site by pines is not apparent in the above studies although it has been shown that foliar potassium can be increased by fertilizing K-deficient stands of red pine (Heiberg and White, 1951). In the case of sugar maple, yellow birch, eastern hemlock and ironwood, foliar potassium increases as the depth to carbonates increases. White ash reacts exactly the opposite.

A foliar magnesium response to site is apparent for white pine in Tables 3 and 4.

A foliar phosphorus response of white pine to site differences is apparent in Table 3. Most hardwood species show increasing foliar P with increasing depth to lime, this relation being most marked and consistent in the case of sugar maple and northern red oak.

Data on foliar composition of minor elements in natural stands in eastern North America is scanty.

Comparisons between species on the same plots in Scott's study are limited to the following:

Species	ppm Fe	ppm Al	ppm Mn
White Pine (Plot II)	275	325	550
Sugar Maple (Plot II)	200	150	1000
Red Maple (Plot II)	200	150	1650
White Pine (Plot III)	200	350	2650
Red Oak (Plot III)	150	150	4750

Comparisons between species on the same sites in the study of Gerloff *et al.* are as follows:

Site No.	Species	ppm Fe	ppm Mn
76b	Sugar Maple	157	805
	Red Oak	76	763
55	White Pine	267	184
	Red Pine	206	260
62	Balsam Fir	120	862
	White Spruce	89	672
18b	Ironwood	239	2848
	Basswood	164	124
11a	Butternut	196	149
	Black Cherry	159	620
6	Black Cherry	221	585
	Black Oak	206	1459
	White Oak	126	1374
	Red Oak	125	1736
18a	Ironwood	278	968
	Big-t. Aspen	106	50
	White Oak	104	815

Comparisons within species but between soil types in Scott's study are limited to the following:

Species	Soil type	ppm Fe	ppm Al	ppm Mn
Red Maple	Ridgebury sandy loam (GH*); mull	200	150	700
Red Maple	Scarboro loamy sand (HG*); mor	200	150	1650
White Pine	Ridgebury sandy loam (GH*); mull	225	250	550
White Pine	Scarboro loamy sand (HG*); mor	275	325	550
White Pine	Merrimac loamy sand (BP*); mor	175	325	2500
White Pine	Merrimac sandy loam (BP*); mor	225	325	525

*GH = Grey Hydromorphic; HG = Humic Gley; BP = Brown Podzolic

A chain of site-mate comparisons, disregarding leaf age, indicate that the foliages of ironwood, black oak, black cherry, butternut, sugar maple, red maple and white pine contain higher concentrations of iron than those of white oak, red oak, big-toothed aspen and red pine.

A chain of site-mate comparisons indicates the following decreasing order of foliar Mn concentrations: red maple, ironwood, sugar maple and red oak > white pine, black oak, white oak and black cherry > butternut, basswood and big-toothed aspen. The latter three species apparently have especially low Mn contents.

Scott's data indicate that white pine foliage contains higher concentrations of aluminum than those of red oak, red maple and sugar maple.

Evidence for foliar manganese responses to site also exist in Scott's study. Red maple has a higher foliar manganese content on a mor humus-covered Humic Gley loamy sand than on a mull humus Grey Hydromorphic sandy loam. White pine has a much higher foliar manganese content on a mor humus-covered Brown Podzolic loamy sand than on less well-drained or finer-textured soils.

Ovington (1956) found that Austrian pine and Douglas-fir both had about five times as much foliar manganese when growing on an acid sand as when growing on an alkaline sand. In twenty-two out of twenty-three foliar samples involving sixteen species, foliar manganese was present in larger quantities than foliar P with greater amounts in the coniferous foliage than in the hardwood (families Fagaceae and Betulaceae only) foliage.

From the above-mentioned studies, it is clear that foliages from the mull-associated species, basswood, ironwood, butternut, black cherry and white ash, consistently contain relatively high concentrations of calcium and either relatively high or intermediate concentrations of

potassium and magnesium. The foliage of red oak, which is also associated with mull humus types, seems to be outstanding with respect to its higher calcium content on high calcium soils and its higher N and P content on low calcium soils. On both types of soil red oak foliage maintains intermediate to high values of K and Mg and may contain relatively high concentrations of Mn on some sites. These latter characteristics may be related to the relatively high antacid buffering capacity of red oak litter mentioned below.

Species such as pines, hemlock and beech which are more often abundant on mor than on mull humus types, have relatively low values of foliar Ca, P and Mg. White spruce and balsam fir, also commonly associated with mor humus types, contain intermediate values of foliar Ca and P but there is some indication in the data that they usually have relatively low values of foliar Mg and occasionally very low values of foliar K. Species such as sugar maple and yellow birch which may be abundant on both humus types apparently have intermediate and/or variable concentrations of most of the elements studied so that the nature of the humus layer may depend largely on the available chemical elements and the associated species.

Plice (1934) studied the antacid buffering capacity of the litter from various tree species on a range of sites near Ithaca, New York with the following results:

Species	H-ion Inactivated by 5g. of litter (me. out of 4 added)
Elm	3.96; 3.84
Red Oak	3.4; 3.4
Sugar Maple	3.3-3.4
Red Maple	3.2
Yellow Birch	3.0-3.4
White Ash	3.0; 3.0
Beech	2.4-3.0
White Pine	2.0-3.0
White Spruce	2.0
Balsam Fir	2.0
Red Pine	2.0; 2.0
Black Spruce	2.0
Jack Pine	1.5
Hemlock	0.9; 2.0

Plice concluded that both the chemical element content and the antacid buffering capacity were influential in determining the humus type.

Polyphenols in Tree Foliage and Litter

Handley (1954), after extensive research, concluded that leaf proteins stabilized by materials similar to tannins are an important factor in the processes leading to mor humus formation. These stabilized proteins occur in the mesophyll tissues and are, under certain conditions, so resistant to decomposition that the various parts of the debris in which they do not occur (especially the vascular tissue) decompose and leave, as a layer lying on the surface of the mineral soil, an amorphous residue of leaf mesophyll cell walls protected from decomposition by the

resistant stabilized protein. Davies et al. (1960) point out the likelihood that these tannin-like materials stabilizing leaf protein are polyphenols.

Coulson et al. (1960), using paper chromatography and electrophoresis, examined the polyphenols of fresh green leaves, dried leaves, litter and superficial humus from mull-Brown Earth and mor-Podzol sites. They found a greater diversity and quantity of phenolic substances in the extract of the fresh European beech leaves from the mor-Podzol sites than in the extracts of European beech, sycamore and oak leaves from mull-Brown Earth sites. There was a change in quantity of simple polyphenols ranging from a maximum in living leaves, decreasing through senescent leaves to dead leaves to freshly fallen leaves, to a minimum in decayed leaves and humus or stored dry leaves. However, tannin-stripping and hydrolysis-reduction of decayed leaves and superficial humus released additional polyphenolic substances from both mull and mor humus types.

The above-mentioned studies also point out that when polyphenols are polymerized beyond a certain molecular size they are rendered incapable of any tanning action. Coulson et al. also state that polymerization is favored by base-rich conditions and they suggest that beech leaves falling on a base-rich surface may explain why European beech gives rise to a mull humus type when growing on base-rich soils and to a mor humus type when growing on base-poor soils. The lower foliar calcium concentration exhibited by European beech on base-poor soils as compared to base-rich soils has been reported by Handley (1954). It seems likely that a low foliar base content as well as an acid soil surface would reduce polymerization and thereby increase the tanning potential of the polyphenols which are present.

Soil Organisms in Mull and Mor Humus Types

While certain foliar characteristics may instigate humus type differences, it is probable that these differences are brought about by differences in the predominant groups of soil animals attacking the foliage. Mull appears to be the characteristic humus formed when earthworms are the predominant group; transitional types of humus when the dominant soil fauna are millipedes, woodlice or larvae of the larger insects or termites; and typical mor when they are mites and springtails. The functional relationship seems to be that a greater proportion of the organic matter on mull humus sites passes through the alimentary canal of the larger soil animals into the mineral soil (Russell, 1961).

Although several studies have indicated extremely low rates of leaf tissue decomposition by micro-organisms when animals are completely excluded (vide Edwards and Heath, 1963), evidence exists that micro-organisms play a role in the preparation of leaf litter for use by the larger soil animals and may be necessary for complete decomposition of organic matter following its mastication by the larger soil fauna. Darwin, for instance, considered half-decayed leaves to be the earthworm's chief article of diet and van der Drift concluded from his studies that the main result of the activities of most soil fauna is mechanical break-down of leaf litter (vide Handley, 1954).

In typical mor humus types, the fungi are often considered to be the predominant group of micro-organisms, and they convert much of the leaf litter into their own protoplasm which is a form that the mites in particular can digest (Russell, 1961). A study by Kendrick (1959) on Scots pine needles indicates that successive waves of fungal colonization initiates the decomposition process

and complete physical reduction is eventually brought about by soil fauna which results in an Oh horizon composed largely of partly humified animal feces and numerous dead, dematiaceous hyphae, conidiophores and conidia. A similar process may have led to the observations of Romell (1935) who stated that heavy greasy mor humus layers in the northeastern United States seem to be built up chiefly by dead fragments of brown hyphae.

In mull humus types, however, bacteria are probably the most important microbial agents of decomposition (Russell, 1961) and they seem to be more abundant in the presence of earthworms (Went, 1963).

Several conditions seem to be related to these differences in soil organism populations and activity. Aside from moisture requirements (vide Wilde, 1958), studies show that earthworms seem to have definite preferences for the leaves of certain species of plants. One such study in Europe indicated that in general, the earthworms characteristic of mull soils show a preference for the litter of elm and birch, consume only small amounts of beech and oak litter and do not consume pine and spruce needles at all (vide Handley, 1954). In the United States, they show similar preferences for foliage rich in bases (such as ash leaves) a reluctant ability to handle the tough leathery leaves of oak and beech, and a distaste for acid conifer needles (Spurr, 1964).

Edwards and Heath (1963) noted that tanned European beech leaves were not eaten by a soil fauna including earthworms while green or yellow leaves of the same species were heavily attacked. Recent findings also indicate that fungi can utilise organic substances containing concentrations of phenols sufficient to inhibit bacterial attack (Kononova, 1961 and Basaraba, 1964). A related study indicated that marked differences in fauna populations between litter samples rich in mycelia and samples not so endowed were correlated with the lower pH and higher tannin content of the mycelia-rich samples (Kuehnelt, 1963).

Processes and Products of the Organic Horizons

Lafond (1949) measured the oxidation-reduction potential of firmly packed mull and mor material which had been allowed to stand overnight in a water-logged condition. He found that as a rule mull humus has a positive oxidation-reduction potential whereas mor has a very low negative potential. Other studies indicate that ferrous iron becomes prominent at Eh (oxidation-reduction potential) values below about 0.2 volt during periods of intense microbiological action. Manganese is affected similarly but aluminum is not (Alexander, 1961).

In the Podzol Region of Michigan, McKenzie *et al.* (1960) found that the A1 (or Vh) horizon of a well-drained sandy Podzol (Kalkaska sand) exhibited the lowest redox potential in the profile and was consistently at its lowest seasonal value in winter under a cover of snow during the two-year duration of the study.

Romell (1935) states that in the latter part of the 19th century it was noticed that mull and mor give extracts of different colors, either with distilled water or with weak ammonia. He claims that mull extracts have a "less intense humus color." This water soluble, intensely humus-colored extract from mor is probably similar to the extracts obtained by Berzelius who is credited with the original description of crenic acid and apocrenic acid (Kononova, 1961). According to Kononova, apocrenic acid is formed by the atmospheric oxidation of crenic acid. She further states that Berzelius describes crenic acid as having a yellowish color, a sharp taste and being amorphous while apocrenic acid is described as having a brownish color; both possess acid properties. Kononova also mentions that Berzelius made comprehensive studies of the K, Na, NH_4, Ba, Ca, Mg, Al, Mn, Fe^{++} and Fe^{+++} salts of crenic and apocrenic acids. According to a number of Russian soil scientists, crenic acid is profusely produced by the activity of fungi in Podzol humus layers (Vilenskii, 1957; Williams, 1914).

Oden (vide Kononova, 1961) introduced the term "fulvic acids" for the group of humic substances occurring in peat waters. He described these substances as compounds of high molecular weight characterized by a reduced (less than 55%) carbon content and high solubility in water, alcohol and alkali; their salts are also readily soluble in water. At low concentrations these substances are slightly yellow in color. These characteristics apparently led Oden to the assumption that fulvic acids are analogous to crenic acid and apocrenic acid. Subsequently, fulvic acid was studied by many investigators as the acid soluble portion of alkali-extracted organic matter (Kononova, 1961). These studies indicated the presence of pentosans, uronic anhydride, amino-nitrogen, phosphorus, several sugars, and phenolic glucosides. Infra-red spectroscopy and X-ray analysis revealed that fulvic acids possess "structural units" of aromatic compounds, nitrogen-containing substances and reducing substances.

Recent studies by Wright and Schnitzer (1963) on a Canadian Podzol indicated that the extracted organic matter from the Oh and Bh (Ihbi?) horizons contained 30% and 85% fulvic acid, respectively. As much as 60% of this fulvic acid was composed of functional groups such as

carboxyl, hydroxyl and carbonyl which appeared to be attached to a predominantly aromatic "nucleus."

Yarkov (1954) demonstrated that the mobility of complex organo-mineral compounds of fulvic acids with R_2O_3 depends on the oxidation-reduction conditions of the soil medium produced by the seasonal moisture regime (vide Kononova, 1961).

Bloomfield (1957), Kaurichev et al. (1958) and Coulson et al. (1960) mention that polyphenols capable of forming complexes with iron are present in Podzol humus layers. Bloomfield considered the polyphenols to be important in the dissolving and reduction of R_2O_3. Coulson et al. showed that D- and epi-catechin (two of the major polyphenols of beech leaves) are capable of reducing iron and obtained evidence of the formation of ferrous iron-polyphenol complexes. Aeration had an adverse effect on the formation of these complexes. The movement of aluminum, however, did not appear to be influenced by these polyphenols but was more effectively leached by strongly acid extractants, the most effective of these having a pH of 3.72.

Hesselman (1917) concluded from his studies that, in general, conifer mor humus is characterized by active ammonification but no nitrification. Romell (1931) found that intensity of nitrification in mor humus layers was correlated directly with pH. Ivarson and Sowden (1959) stated that their coniferous litter-Podzol soil (horizon not mentioned, presumably the A horizons were used) mixture produced no nitrate during the course of their experiment (165 days).

Lunt (1932), working with New England forest soils, found that mull types of humus found in fast-growing hardwood stands nitrified

to a considerable degree with the accumulation of only a relatively small amount of ammonia. On the other hand, large quantities of ammonia accumulated in the thick mor humus found in mature hemlock-hardwood and mature white pine stands. Studies of the possible causes of this pattern revealed that pH, Ca content and sometimes total N were correlated positively with nitrogen transformation. These correlations were quite pronounced in the Oh horizons. The addition of lime generally caused the formation of nitrates at the expense of ammonia, though no appreciable effect could be obtained in the humus layers from red pine plantations.

The work of Lunt agrees with earlier studies by Nemec (1930) and concurrent research by Remesov (1937) who both found that nitrification is greatly retarded in humus layers under stands of spruce and pine. Ammonification, however, took place readily and accumulation of large amounts of ammonia occurred under these conifers. These researchers explained the lack of nitrification by their discovery of a negative correlation between the bitumin* content and the rate of nitrification in the humus layers. With bitumin contents of 5% or more nitrification was practically nil.

Chase and Baker (1954), working with Canadian Podzols, found that heavy applications of calcium carbonate were required before any of the added ammonium nitrogen was converted to nitrate. On an acid Canadian Podsol under maple, Corke (1958) found that limestone-phosphate fertilization had greatly increased the number of ammonifying and nitrifying bacteria 8 years after treatment;

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*Bitumins is apparently a collective term for humus constituents such as fats, waxes and resins which are soluble in alcohol and benzene (see Vilenskii, 1957).

simultaneously, an increase in ammonifying fungi occurred under conifers following this type of treatment. When ammonium sulfate was perfused through the A_0(0) horizon from the maple plots which had been treated with limestone and limestone phosphate, a fairly rapid oxidation of NH_4-N to NO_3-N took place. In order to obtain similar nitrification rates from the unamended plots, large amounts of $CaCO_3$ had to be added prior to incubation. No mention was made, however, as to whether or not the coniferous Oh horizon could be stimulated to form nitrates.

Remesov (1937) states that the accumulation of large quantities of ammonium in humus layers may promote dispersion of some of the humus and thereby convert it into forms more liable to leaching.

CHAPTER 4. TIME RELATIONSHIPS

In his monograph on soil studies in the region of coniferous forest in northern Sweden, Tamm (vide Jenny, 1941) states that in a drained lakebed perceptible podzolization can occur in 100 years; under a mattress of raw humus, enough Podzol formation had taken place during that time to permit a photographic recording of a thin bleached A_2 horizon and a dark orterde zone (Podzol "B").

A study in Alaska made by Crocker and Dickson (1957) indicated that in 200 years of soil development, a trace of Podzol formation was evident in the sandier materials although no profile descriptions nor chemical analyses were presented for corroboration of the visual evidence. The youngest well-developed Podzols described in this area were 3000 to 4000 years old (Chandler, 1942; Crocker and Dickson, 1957).

Time of Land Surface Exposure in Michigan

Land surfaces in the Podzol Region of Michigan have been exposed for periods of time not exceeding 13,000 years (Zumberge and Potzger, 1956). For areas covered by the Valders substage of Wisconsinan glaciation, this maximum limit is reduced. According to the most recent radiocarbon dates (Broecker and Farrand, 1963), these areas have been exposed for a maximum of 11,850 years. In the Lower Peninsula, Valders drift is almost confined to Podzol Zone III (vide Zumberge and Potzger, 1956).

In Cheboygan County, Michigan (Podzol Zone III), Franzmeier (1962) studied a chronosequence of Podzols formed in sand primary materials. This sequence consisted of weakly developed Podzols recently under predominantly pine and oak on Lake Algoma and Lake Nipissing surfaces, a

more strongly developed Podzol which recently supported mostly hemlock or balsam fir on a Lake Algonquin surface and somewhat more strongly developed Podzols (on the basis of darker upper illuvial horizons) under northern hardwoods (one site) and aspen (another site) on Valders moraines.

Time With Respect to Regional Changes in Climate and Vegetation

If the regional climate and vegetation had been uniform during the last 13,000 years, the time of land surface exposure would be the only variable soil-forming factor in the Podzol Region (providing topography and parent material are held constant). Since the Podzol Region of Michigan has been subjected to post-glacial climate and vegetation changes, land surfaces of widely different ages must have been affected by different combinations of climatic factors.

For instance, Isle Royale was completely inundated until post-sub-Duluth time (Hough, 1958). Potzger (1954) found that a bog on a post-sub-Duluth, pre-Minong surface 900 feet above sea level indicated an initial post-inundation forest of pine and spruce. Two bogs on a post-Minong, pre-Nipissing surface 650 feet above sea level indicated an initial post-inundation forest dominated by pine. The bogs at lower elevations, which are all on Nipissing and post-Nipissing surfaces, indicated that initial post-Nipissing forests were dominated by pine, spruce and birch. Potzger states that the pine-dominated parts of the pollen profiles undoubtedly represent the "major xerothermic" period in that area; thus initial soil formation on the post-Minong, pre-Nipissing surface took place during a different climate-vegetation regime than existed during initial soil formation on either the older or the younger surfaces.

The Isle Royale pollen data suggest that pine forests were replacing spruce forests by sub-Duluth time (around 10,000 years B.P., vide Broecker and Farrand, 1963) and were prevalent in early post-Minong time (correlative with Lake Chippewa times in the Lake Michigan basin according to Hough). The time range of 10,180 ± 160 to 9,150 ± 130 years B.P. given by Fries (1962) for the decline of spruce in nearby Lake County, Minnesota seems to be compatible with the lake chronology of Broecker and Farrand (which entails a drop from Lake Algonquin levels to Lake Chippewa levels between about 10,500 years ago and 9,570 ± 150 years ago). The data presented by Fries suggests that pine was dominant from 9150 ± 130 years B.P. until the late post-glacial increase of spruce and fir occurred. His data also suggest that jack pine was the predominant pine until 7300 ± 140 years B.P.

Based on the above studies, that of Potzger (1946) and those of Wilson and Webster (1942a and 1942b), the following post-Valders climatic and vegetational conditions are inferred for the Upper Peninsula of Michigan:

Time (BP)	Climate	Regional Forest Vegetation
11,850 ± 100 to 10,180 ± 160	Cold, mesic	Spruce-Fir
10,180 ± 160 to 9,150 ± 130	Warmer, less mesic	Increase in pine and thermophilous deciduous species; hemlock appears in some areas
9,150 ± 130 to 7,300 ± 140	Even less mesic	Pine dominance (mainly jack pine); low or no hemlock; low white spruce; low thermophilous deciduous species
7,300 ± 140 to approx. 3500	More mesic	Increase in white pine; increase or reappearance of hemlock; increase in birch
approx. 3500 to lumbering era	Cooler and even more mesic	Increase in hemlock, spruce fir and birch

The following are estimates of the same types of relationships for the sandy primary materials of northern Lower Michigan:

Time (B.P.)	Climate*	Regional Forest Vegetation**
13,000	Cool to cold, moist	Spruce-Fir
11,000	Cool to cold, moist	Spruce-Fir
8,500	Moderating climate	Spruce, fir and jack pine
7,000	Warming climate	Pines, oak
3,500	Warmest and driest since retreat of ice	Pines, oak and northern hardwoods
2,500	Deterioration (cooler)	Pines, northern hardwoods and oak

*Based on Zumberge and Potzger's interpretations
**Based on Kilburn's work

In general, both sets of data suggest that the older sandy land surfaces in the Podzol Region of Michigan were initially exposed to a cool to cold moist climate and supported pioneer stands of spruce and fir. The middle-aged surfaces were initially exposed to a warmer and drier climate and were probably initially forested by such species as pine and/or oak on the drier sites with arborvitae (white-cedar), balsam fir and white spruce on the cooler and more moist sites. Surfaces exposed since Lake Nipissing or Lake Algoma times were initially exposed to a cooler and possibly moister climate and probably supported pioneer forests with less oak than occurred in the initial forests on the middle-aged surfaces. Aspens also may have been involved in the initial stages of early, middle and late successions even though their fossil record is missing (*vide* Wright, 1964).

Small percentages of maple, hemlock, beech and other non-boreal

hardwoods appear at the end of the spruce-fir pollen zones in peat profiles from northern Lower Michigan and north central Wisconsin. Indications of beech-maple forests in these areas, however, are restricted to the last 3000 to 4000 years.

Another time-related factor which should not be overlooked is the time during which the "lake effects" have been in existence. These phenomena are directly or indirectly responsible for much of the character of the climate in the Podzol Region of Michigan. One of the most striking of these effects is the fall and winter precipitation. For example, Grand Marais, Minnesota, receives about 63 inches of snow per year while Houghton, Michigan, receives about 120. Podzols are characteristic in the Houghton area but not in the Grand Marais, Minnesota area. Milwaukee, Wisconsin, receives about 39 inches of snow per year while Grand Rapids, Michigan, receives about 69. Podzols are present only in the latter location. In winter, the warmer the lake waters are, the greater will be the instability of the air which has passed over them and the greater will be the snowfall on the downwind side of the lakes. Consequently, relatively little snow falls on the downwind side of the lakes when they are frozen over. By the end of February, 1963, ice covered 95 per cent or more of Lakes Superior, Michigan and Huron. Lake Michigan was frozen over north of a line between Milwaukee, Wisconsin, and Muskegon, Michigan, from February 26 to the end of the month, the only other such known occurrence having been in February, 1936 (Weather Bureau, U.S. Department of Commerce, 1963a). Every section of the state received less than normal precipitation in February, 1963 and the Upper Peninsula received less than normal in March, 1963 as well, with departures from the normal being greatest in the western part. Chatham and Munising (both in Alger County, Michigan) had negative precipitation departures of more than one inch in March. The following table compiled from Climatological Data (Weather Bureau, U.S. Department of Commerce, 1963b, c, d, e, f and g) illustrates these 1963 departures (in inches) from normal precipitation in regions at comparable latitudes but varying in their climatic dependency on the Great Lakes.

	East Central Minnesota	Northwest Wisconsin	West Upper Michigan
February, 1963	-0.32	-0.26	-0.61
March, 1963	+0.04	-0.14	-1.61

	Southeast Minnesota	East Central Wisconsin	West Central Lower Michigan
February, 1963	-0.39	-0.63	-0.91
March, 1963	+0.08	+0.50	+0.50

The above data suggest that during most of post-Valders—pre-Nipissing times lake effects must have been less pronounced than at present if it is inferred that: (1) winters were somewhat colder during the spruce-fir period and (2) that a drop of lake levels to extremely low levels took place during the decline of the spruce-fir period. During the Lake Chippewa period, spring and summer temperatures in southern Michigan would have logically increased whereas fall and winter temperatures would likely have been more continental, similar to those in southern Wisconsin and northern Illinois at that time. Fall and winter precipitation would have been commensurately lower as well. While the bulk of the Prairie Peninsula may have been formed prior to this period, as suggested by Benninghoff (1964), the Lake Chippewa period seems to be a likely time for the formation of the southern Michigan prairies with the disjunct Newaygo prairies developing

as a partial result of: (1) their position at a latitude between that of Southern Lake Chippewa and Lake Chippewa (see Hough, 1958) and (2) the prevalence of westerly winds (Weather Bureau, 1959). The subsequent rise of water to the Lake Nipissing level must have initiated an increase in the "lake effects" which would mean cooler springs and summers, less annual evapotranspiration, milder fall and winters and more fall and winter precipitation. These changes plus a regionally cooler climate beginning between 2000-2500 years B.P. (Deevey and Flint, 1957) could possibly explain the increase in white pine indicated in the upper levels of several pollen profiles in the Lower Peninsula of Michigan (post-Nipissing phenomenon according to Zumberge and Potzger, 1956). These climatic changes could also have simultaneously favored the increase of: (1) mesophytic species such as hemlock and northern hardwoods and (2) the rate of leaching and Podzol development. Thus the hypothesis (Zumberge and Potzger, 1956) that Lake Nipissing times were the most xeric in Michigan seems untenable unless it is assumed that expansion of beech and hemlock can take place under such conditions and a rather drastic regional dryness occurred during that period thereby overcoming the lake effect.

<u>Time With Respect to Local Changes in Soil-Forming Factors</u>

The emergence of some land surfaces must have been rather rapid while others emerged slowly (Veatch, 1940). The slow subsidence of lake levels could not only affect the natural drainage of developing soils but proximity to the lake could keep summer temperatures relatively low and winter temperatures relatively high compared with more inland positions. For example, if Lake Nipissing receded steadily down to the Lake Algoma level on a stable land surface, the water table in Lake Nipissing beach sands would have been within 5 feet of the soil surface for approximately 500 years. If Lake Algoma levels dropped steadily to those of the present lakes, this time would be about 1250 years for Lake Algoma beach sands. At the other extreme, deep outwash plains subsequently dissected by meltwater from the retreating ice front were high and dry shortly after their deposition. Surfaces exposed by the drop of water levels from Lake Algonquin to Lake Payette at an average rate of at least 14 feet per 100 years (vide Hough, 1958 and Broecker and Farrand, 1963) were soon without lacustrine water table influence as well.

CHAPTER 5. PODZOL PROPERTIES AND PEDOGENIC PROCESSES

The Inorganic Constituents

Determinations of total Fe_2O_3 in Podzol profiles usually indicate that at least one illuvial (I) horizon has a concentration twice as great as that of the eluvial (E) horizon and that the eluvial horizon has at least 20% less than the C(P or W) horizon (vide Lunt, 1932; Wilde et al., 1949; Wicklund and Whiteside, 1959; Muir, 1961). These studies also indicate that I/E* ratios of total Al_2O_3 are lower than those of Fe_2O_3 except under pure stands of conifers where the reverse is true. Illuvial peaks of total P_2O_5 in the Podzols studied were inconspicuous except where ortstein was present. Otherwise, P_2O_5 maximums occurred in the humus layers. In the Wisconsin Podzols, total K_2O concentrations were considerably lower in the eluvial horizons than in the other horizons. The New Brunswick Podzols, however, did not exhibit this type of distribution pattern for K_2O; instead, the values were rather constant down to the lower I or upper W horizons where they increased. Total CaO concentrations in the Podzols studied were highest in the O horizons (exclusive of profiles having carbonates in the P horizons) and lowest in the E horizons. Minimum concentrations of MgO were present in the E horizons with maxima in either the I horizons or the P horizons of carbonate-free profiles. Where total SiO_2 was determined in the above-mentioned studies, the results indicated that Podzols of all textures had eluvial horizons with SiO_2 concentrations above 79%. In the Wisconsin sands, Podzol development seems to increase with increasing E/P ratios of total SiO_2. An increase of this ratio in the New Brunswick Podzols is coincident with a greater net increase in

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$$^*I/E = \frac{\text{illuvial horizon(s)}}{\text{eluvial horizon(s)}}$$

illuvial Al_2O_3.

Yassoglou and Whiteside (1960) determined the amount of soluble (NH_4OAc extractable) aluminum in some Michigan Podzols containing fragipans and found that the morphological degree of Podzol development varied directly with the content of soluble, illuvial Al_2O_3.

Franzmeier (1962) determined the citrate-dithionite extractable iron and aluminum of several sandy Michigan Podzols. Concentrations of the sesquioxides increased with the morphological degree of Podzol development (based on color of the upper illuvial horizon) up to the moderately developed Blue Lake soil. This moderately developed Podzol (a continuous ortstein is not present) with the greatest concentration of Fe_2O_3 of any soil in the study was formed in Valders-aged parent material. From the available evidence, this soil supported a conifer (white pine and hemlock)- northern hardwood stand prior to being clear-cut. The highest concentration of Al_2O_3 was shared by the above-mentioned Podzol and an Algonquin-aged Podzol which supported a pre-disturbance stand of mesophytic conifers (either hemlock or fir or both) with somewhat of an admixture of red maple (Acer rubrum).

The above study further indicated that in the lowest illuvial horizons of one of the weakly (Rubicon series) and all of the moderately developed Podzols (Kalkaska and Blue Lake series) extractable aluminum concentrations were consistently higher than those of iron.

In these profiles, the upper illuvial horizons consistently contained the highest concentrations of translocated humus. In addition, these horizons had the maximum Fe_2O_3 concentration in each profile except where ortstein chunks were present.

Available phosphorus distributions in Franzmeier's Podzols are also of interest. In the weakly developed Podzols, the illuvial zones show maximum concentrations in their upper horizons while in the Podzol sequum of the moderately developed Podzols, maximum concentrations of available phosphorus occur in the lower illuvial horizons. This distribution in the moderately developed Podzols is most obvious in the Blue Lake profiles which have Bhir (Ihbi) horizon concentrations that are almost twice as high as those in the overlying Bh (Ihib) horizons. Total analysis of one Blue Lake profile revealed that the upper illuvial horizon had actually gained in total amounts of phosphorus. The next illuvial horizon down portrayed a net loss of total phosphorus but contained almost twice as much available phosphorus as the horizon above.

The Organic Constituents and Proposed Mechanisms of Eluviation and and Illuviation in Podzols

Podzol illuvial horizons are characterized by accumulation of sesquioxides; however, organic matter accumulations are invariably present as well. Franzmeier's studies indicate that organic matter: extractable sesquioxide ratios are consistently greater than unity in these horizons regardless of the degree of Podzol development. If the extractable sesquioxides represent that portion of the total which is moving or has moved, and the computation of organic matter content is realistic, then the data indicate an essential role for organic matter beyond the mere creation of acidity. Because of the omnipresence of organic matter in Podzol illuvial horizons, most of the modern hypotheses concerning the mechanism or mechanisms of iron and aluminum movement into the illuvial horizons involve the leaching of organic substances (from O horizons or live foliage) which are capable of

combining with iron and aluminum (Stobbe and Wright, 1959).

Several Russian investigators (vide Kononova, 1961 and Vilenskii, 1957) believe that crenic acid is responsible for: (1) the dissolution of calcium carbonate, (2) reaction with iron and manganese compounds and (3) disruption of kaolinite thereby releasing silica and aluminum, the latter forming a crenate (i.e., a salt of crenic acid and aluminum) which is water soluble. Upon reaching a zone of oxidation, these crenates of Fe, Mn and Al are converted to apocrenates which are not water-soluble and thus precipitate out of solution (see Kononova, 1961 and Vilenskii, 1958).

Wright and Schnitzer (1963) postulate that the formation of fulvic acid might be visualized as arising through some alteration of humic acid, including an increase in oxygen content, an increase in carboxyl groups at the expense of aliphatic and/or alicyclic material, and a decrease in carbon, hydrogen and nitrogen. With increasing oxidation the material becomes more water-soluble and eventually dissolves in water. As the dissolved fulvic acid moves down the profile it combines with polyvalent cations such as iron and aluminum to form water-soluble complexes some of which probably involve two or more donor groups of the ligand resulting in the formation of metal chelates. The authors suggest that there is a strong possibility that on its path down the profile fulvic acid forms, at first, water-soluble multidentate chelates which later may precipitate lower in the profile upon reacting with more of the same metals or with extremely small amounts of ionic calcium and/or magnesium. Wright and Schnitzer also suggest that Fe-organic matter complexes are more susceptible to flocculation by Ca and Mg than the Al-organic matter complexes which may result in a deeper penetration of the latter.

On the other hand, certain researchers believe that organic acids such as oxalic and citric may form complexes with Fe and Al which subsequently move into the illuvial horizons (see Stobbe and Wright, 1959).

Recently, the importance of polyphenols has been stressed in conjunction with the movement of iron (Bloomfield, 1957; Coulson, et al., 1960; Davies et al., 1960). Coulson et al. treated model soils (consisting of alumina and diatomaceous earth impregnated with ferric chloride) with catechin* solutions and fresh European beech leaf extracts. Both treatments produced dark-colored subsoil bands in which substantial amounts of ferric iron had been converted to ferrous iron. Extracts of green beech leaves from a mor humus site were more effective than those from a mull humus site. Similar treatments of Triassic sand columns also resulted in the reduction of iron but apparently no subsoil bands were produced; the ferrous iron appeared to be present in a complex form possessing no residual electric charge. Leaching of aluminum seemed to be related only to the pH of the solutions. Regarding the Podzol-forming process, Davies et al. state that, upon reaching the soil, the fate of polyphenols is determined by the soil reaction—the more acid the soil, the more stable the polyphenol. Further, these investigators suggest that the polyphenols responsible for movement of iron in soils are likely to be those washed from the growing leaves into the soil, and not those from litter or humus. Therefore, if the soil is acid (pH of 4-5 is optimum), the leaf polyphenols will readily reduce ferric iron and form stable

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*Catechins are a group of polyphenols found in tree foliage.

complexes with the resultant ferrous iron. Since these complexes are water-soluble and non-ionic, they will move freely in the profile until they are deposited in a clearly defined horizon, thus forming the Podzol illuvial zone. These authors do not postulate a mechanism for this deposition, however.

Concerning deposition in the illuvial horizon, several workers (see Stobbe and Wright, 1959) have stressed the importance of oxidizing conditions and microbial attack of the organic matter as it moves into this zone. Bloomfield (1957) suggested that drying and/or aeration may bring about the precipitation of sesquioxides. He also found that the immobilization of sesquioxides is associated with the sorption of the complexes on the mineral soil particles, particularly on the sesquioxides. Martin (1960) concluded, based on his studies of the illuvial process of Podzols, that the simultaneous presence of Al, Fe and humus in the illuvial horizon can be accounted for solely by the flocculating properties of Al ions.

<u>Studies on Podzol Development in Michigan</u>

Most studies of Podzol genesis in Michigan have been of a mineralogical nature and this subject is thoroughly reviewed by Franzmeier (1962).

His study of Podzol sands led him to postulate the following course of development. An early accumulation of available phosphorus occurs in the very slightly developed illuvial horizon along with comparatively low concentrations of iron and aluminum. This stage is referred to as the "inorganic phase." Following this stage, an "organic-accumulation phase" begins and Ih horizons form. Sesquioxides and probably silicate clays continue to be mobilized in this phase, but accumulations of these constituents tend to be in different horizons. Several mechanisms of mobilization and various combinations of the active components are probably operative during this phase. The active sesquioxide and organic components are adsorbed or precipitated as amorphous coatings on slightly crystalline coatings in the Podzol illuvial horizons developed during the "inorganic phase." The thickness of the amorphous coatings gradually increases until they flake off and become inter-granular deposits. Here, acting as nuclei for further precipitation and adsorption of material from solution, they cause an increase in the amount of inter-granular material. Since these aggregates are relatively weakly held together, chemical, physical and biological agents prevent them from growing indefinitely. Most of the aggregates are about 0.02 to 0.1 mm in diameter. As the large pores become filled with this debris, the capillary pore space, readily available water-holding capacity, exchange capacity and exchangeable bases increase. Conditions are thus made more mesophytic and these changes are associated with the maple-beech succession of the pine-hardwood association.

On the basis of his chronosequence study, Franzmeier further concludes that, during the entire course of Podzol formation, physical weathering caused a breakdown of sand grains to silt size (especially near the soil surface), and the total clay content of the solum increased.

CHAPTER 6. WELL-DRAINED SOILS DEVELOPED IN YELLOWISH SANDS IN THE PODZOL REGION OF MICHIGAN

The Podzol Region of Michigan contains a very large acreage of soils developed in yellowish (Munsell hues of 7.5YR to 10YR) sand. However, compared to Gray-Brown Podzolic Region soils developed in yellowish sand, those in the Podzol Region vary greatly in their morphology.

Well-drained Podzol Region sand soils, exclusive of those on the younger land surfaces, may belong to any one of the following three great soil groups: (1) Podzol, (2) Brown Podzolic or (3) Brunizem. In addition, transitions between (1) and (2) and (3) may occur. However, the Brunizem intergrade only occurs in Podzol Zone I (Figure 2) under white pine-mixed oak (mainly white and black) stands adjacent to the Brunizem areas (personal observations by the writer). On the younger, well-drained land surfaces Regosols can also be found (personal observations).

The physical geography of the well-drained sand soils in the Podzol Region is presented in the following sections.

PODZOL SANDS

Eastport sand

This very weakly developed Podzol is found only on surfaces abandoned by Lake Algoma (personal observations and Veatch, 1953) near Lake Michigan or Lake Huron. It has a shallow (usually less than 2½ feet deep) solum, contains no dark (Munsell values and chromas less than 4/4) illuvial horizons, nor reddish horizons (hues redder than 10YR), and overlies a calcareous or alkaline C horizon. In Delta County under relatively undisturbed conditions, the humus type is usually a strongly acid to very

strongly acid mor or duff-mull.

The natural vegetation (recent) on this soil in Delta County varies from an overstory of white and red pines with an understory of arborvitae (Thuja occidentalis) and balsam fir to stands of northern hardwoods, red oak and white pine. According to personal communication with S. G. Shetron (formerly of the S.C.S. now graduate student at the University of Michigan), the undisturbed Eastport sands in the northwestern part of the Lower Peninsula have similar vegetation types. The Sanilac County (east central Lower Peninsula) soil survey report (1961) indicates that "scattered scrub oaks" may have been a part of the natural vegetation on Eastport sand in that county.

Eastport sand has developed under a more marine climate than exists in areas further from the Great Lakes. This is particularly true on the west coast of Lower Michigan where mean January temperatures may be as much as 5°F warmer than more inland stations at the same latitude. Mean July temperatures are only slightly cooler in the coastal areas, however. The frost-free season may be as much as a month longer on the coast than inland. Eastport sands which have developed in Podzol Zone III receive appreciably more fall precipitation and annual snowfall than the east coast Eastport sands (U.S. Weather Bureau, 1955; Brunnschweiler, 1962).

Deer Park sand

Deer Park sand, like Eastport sand, occurs on Lake Algoma surfaces. It, too, is a very weakly developed Podzol (no dark illuvial horizons and no reddish illuvial horizons), but the solum overlies several feet of acid sand. Generally, this soil has a deeper water table than Eastport sand sites (Veatch, et al., 1929; see Appendix V).

The natural vegetation on this soil is quite uniform, being composed of red, white and jack pines with some admixture of northern red oak (*Quercus rubra* and *Quercus rubra* v. *borealis*).

Rubicon sand

Rubicon sand is a weakly developed Podzol; i.e., it has reddish illuvial horizons, but no appreciable (thicker than an inch) dark horizon in the illuvial part of the solum. The solum is variable in thickness, but the maximum may be greater than either of the two preceding soils, tongues sometimes approaching 5 feet in Delta County.

This soil can be found throughout Podzol Zones II and III and may occur on any land surface that is 3500 years old or older (personal observations by the writer in Delta and Alger counties; and Veatch, 1953).

The natural vegetation of Rubicon sand (as defined by the National Cooperative Soil Survey) is quite uniform in the Upper Peninsula, being composed of red and white pines mainly. Northern red oak and red maple may be present in small quantities in undisturbed stands, however. In the Lower Peninsula, northern red oak was present in most stands and probably in greater numbers. In addition, white oak was sometimes present (Stewart, 1927a and 1927b and Elliot, 1953). In Delta County, white pine is dominant and hemlock is present where Rubicon sand grades into the moderately well-drained Croswell sand. Where the imperfectly drained Au Gres sand is encountered, balsam fir is frequently a component of the forest as well as hemlock. As the degree of Podzol development approaches that of a moderately developed Podzol, hemlock and northern hardwoods may both be present; in this case, hemlock is usually more prevalent than northern hardwoods. In Kalkaska County (Podzol Zone III

in the Lower Peninsula), Stewart (1927) describes a virgin timber stand on Rubicon sand which consisted of basal area percentages of: 69% white pine, 7% red pine, 20% hemlock and 4% northern hardwoods (sugar maple, beech and yellow birch). This stand data suggests a transition to the moderately developed Podzol, Kalkaska sand. A more typical example is the basal area composition of another virgin stand in the same county which contained 23% white pine, 75% red pine and 2% hardwoods (red maple, red oak and poplar). Stewart described a third virgin stand in the adjoining county (Crawford) which consisted of 100% red pine.

Kalkaska sand

Kalkaska sand is a moderately developed Podzol; i.e., the illuvial zone contains both dark horizons and reddish horizons, with the dark horizons averaging several inches in thickness. In addition, at least one dark horizon must be continuous and an inch or more thick.

Kalkaska sand is largely restricted to Podzol Zone III; however, it also occurs near Lake Huron in Podzol Zone II (Schneider, 1961). It is more frequently found on surfaces which pre-date Lake Nipissing but can be found on Lake Nipissing-abandoned surfaces in Delta County*.

The recent natural vegetation of Kalkaska sand varies from nearly pure stands of white pine (observations by the writer and Sanilac County Soil Survey Report) to 100% northern hardwoods. In Alger County, one virgin stand contained 74% sugar maple, 18% beech, 7% yellow birch and 1% ironwood (*Ostrya virginiana*) while another contained 45% beech, 28% sugar maple, 22% yellow birch, 4% red maple and 1% balsam fir

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*Kalkaska sand on Lake Nipissing surfaces: (1) SW¼ SW¼ Sec. 4 T 40 N R 21 W, Rapid River Quadrangle, USDI Geological Survey; 1958, (2) SE¼NE¼Sec. 23 T 39 N R 22 W Rapid River Quadrangle, USDI Geological Survey; (3) SE¼NW¼Sec. 14 T 40 N R 20 W Garden Quadrangle, USDI Geological Survey, 1958.

(Stewart, 1929). Other stands (non-virgin) on Kalkaska sand in the same area contained black cherry (*Prunus serotina*) and hemlock in addition to beech, birch and maple. The nearly virgin Cross Village stand in Emmet County (Lower Peninsula) is a mixture of northern red oak, hemlock, sugar maple, beech, white pine, hornbeam and yellow birch (personal communication from J. E. Cantlon, Botany Department, Michigan State University).

Wallace sand

Wallace sand represents the maximum development of Podzol morphology in Michigan. The bleached eluvial horizon is irregularly thicker than those of other Podzol sand soils; the illuvial zone is highly indurated (contains much ortstein) in addition to having the dark and reddish horizons. Eluvial and illuvial tongues are characteristic, the latter sometimes extending to depths of 5 feet.

Wallace sand occurs locally throughout Podzol Zone III and to a lesser extent in Podzol Zone II where it is not extensive enough to be mapped as a single unit but it is combined with associated soils such as Weare fine sand (Johnsgard, 1950. Weare is now correlated with the Kalkaska and Rousseau series.) and Kalkaska sand (Schneider, 1961).

In Delta County, Wallace sand can be found on any land surface which pre-dates Lake Algoma (personal observations)*.

In most soil survey reports (Veatch *et al.*, 1932 and 1934; Wonser *et al.*, 1938; Foster *et al.*, 1939; see Appendix V) the recent natural

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*Wallace sand on Lake Nipissing surface: SE¼SW¼ Sec. 12 T 39 N R 22W, Rapid River Quadrangle, USDI Geological Survey, 1958.

vegetation is reported to be mainly white and red pines. Personal observations by the writer confirm the existence of this vegetation type; however, two relatively undisturbed sites were found which were largely composed of hemlock, yellow birch and red maple.* There are no records, as far as the writer is aware, of pure hardwood stands on Wallace sand.

BROWN PODZOLIC SANDS

Only one soil series belonging to the Brown Podzolic great soil group has been adequately described in the yellowish sand soil area of Michigan. This series has been given the name Grayling and is represented by only one soil type, Grayling sand. Recently, however, some sand soils originally identified as Grayling sand were found to have loamy sand or sandy loam subsoil bands; these soils are currently being classified as Graycalm sand but little information is available on their distribution or range in natural vegetation.

Grayling sand

Grayling sand differs from the Podzol sands by having an eluvial horizon less than 2 inches thick and by having an illuvial zone less than 2 feet thick. The illuvial horizons have yellowish (10YR) colors or dull (chromas less than 6) reddish colors and overlie several feet of acid (pH values usually between 5 and 6) sand. This soil often grades laterally into Rubicon sand or into Croswell sand, a moderately well-drained Podzol.

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*One of these sites is in the study area (see previous footnote). The other is in Marquette County and was shown to the writer by Donald Buchanan (USDA Soil Conservation Service).

Grayling sand is usually found on "dry sandy plains" or "the drier pine plains" (Mick, et al., 1951; Veatch, et al., 1936). It occurs most frequently in glacial deposits (see Appendix V) and in Delta County it can be found in fluvio-glacial deposits which were inundated by the later stages of Glacial Lake Algonquin. In Delta County, Grayling sand occurs only on surfaces which are over 3500 years old.

The natural vegetation of Grayling sand in the Upper Peninsula consists largely of jack pine, "scrub oak"* and scattered red pine (see Appendix V). In the Lower Peninsula, south of Indian River, white oak (Quercus alba) and black oak (Quercus velutina) are also forest components on Grayling sand.

BRUNIZEM SANDS

The only Brunizem soil series in the Podzol Region of Michigan has been given the name of Sparta and includes types which have all developed in well-drained sands.

Sparta is quite restricted in its range in Michigan, occurring only in Podzol Zone I. It is described as having an A_1 horizon 8-20 inches thick with a brighter colored illuvial (?) horizon immediately beneath (see Appendix V).

Veatch (1938 and 1940) states that the Sparta series in Michigan developed in basins which were formerly occupied by shallow grassy or marsh lakes. He postulates that these lakes dried up during a post-glacial "dry period."

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*"Scrub oak" probably represents Quercus rubra v. borealis, Quercus ellipsoidalis and/or hybrids of Quercus ellipsoidalis and Quercus rubra v. borealis (personal communication from Dr. J. E. Cantlon, Botany Department, Michigan State University).

Hauser (1953) states that these areas are vegetated by assemblages of characteristic prairie species such as Andropogon gerardi, Andropogon scoparius, Sorghastrum nutans, Koeleria cristida, Eragrostis pectinacea, Liatris aspera and Hieracium longipilum. However, the high incidence of Carex pensylvanica and certain weedy plants is not typical of other prairies. Many species in the Newaygo prairies are also found in the Sand Barrens of central Wisconsin but a few species are more typical of the Bracken Grasslands in northern Wisconsin, viz. Poa compressa, Poa pratensis and Rumex acetosella (vide Curtis, 1959). The Bracken Grasslands are in a great soil group transition zone similar to that in Newaygo County but they occur on loams to fine sands and are not mapped as Brunizems. Curtis states, however, that the Bracken Grassland soils have a fairly deep incorporation of organic matter and little evidence of a highly leached A_2 horizon.

Part II. The Present Study

CHAPTER 7. CLIMATE OF THE UPPER PENINSULA

The climate of the Upper Peninsula was analyzed by means of water balance computations (according to the Thornthwaite System) and summaries of mean fall precipitation, mean annual snowfall and months of maximum precipitation. These variables were chosen because of their correlation with soil and vegetation characteristics in the Lower Peninsula. The data used in the analyses were obtained from U.S. Weather Bureau publications (Weather Bureau, 1954, 1958, and 1959b). The detailed procedures used are the same as those used to obtain the same information for the Lower Peninsula (see Brunnschweiler, 1962 and Messenger, 1962) except that months of precipitation maxima and co-maxima were determined on the basis that all other months had mean values at least 10% lower instead of 20% lower.

The regional distribution of precipitation regimes for the Upper Peninsula can be seen in Figure 12. The southwestern section of the peninsula has a continental type of regime. The remainder of the peninsula has a regime which reflects a greater lacustrine influence on the climate with a September maximum or co-maximum of precipitation.

The mean fall precipitation is plotted in Figure 13. The isohyets indicate that the western one-half of the peninsula receives less than 9 inches. Within that area, most of Menominee, Dickinson and Iron Counties receive less than 8 inches.

Mean annual snowfall, shown in Figure 14, is highest near Lake Superior; from Ironwood through the Keweenaw Peninsula it averages over 120 inches. In southwestern Delta County and throughout most of Menominee County, mean annual snowfall is less than 60 inches.

Average annual PE values are plotted in Figure 15. The lowest values

FIG. 12

SEASON OF MAXIMUM PRECIPITATION

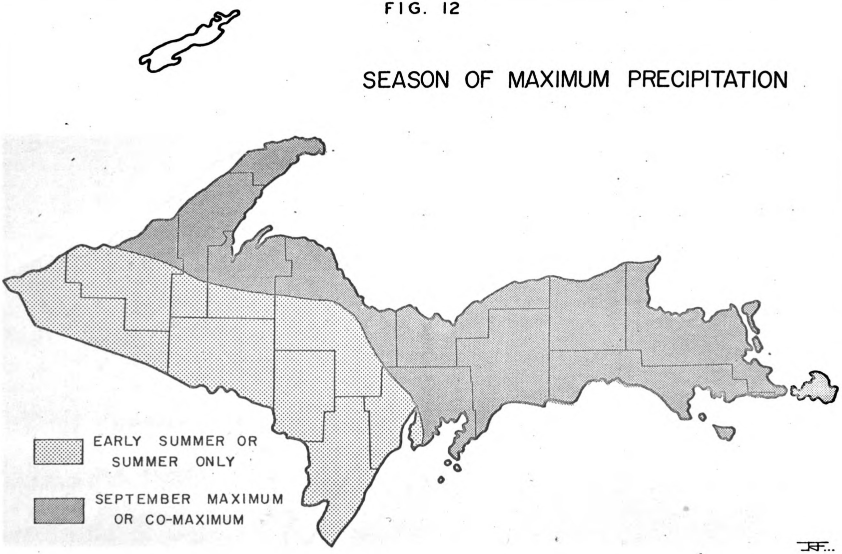


FIG. 13

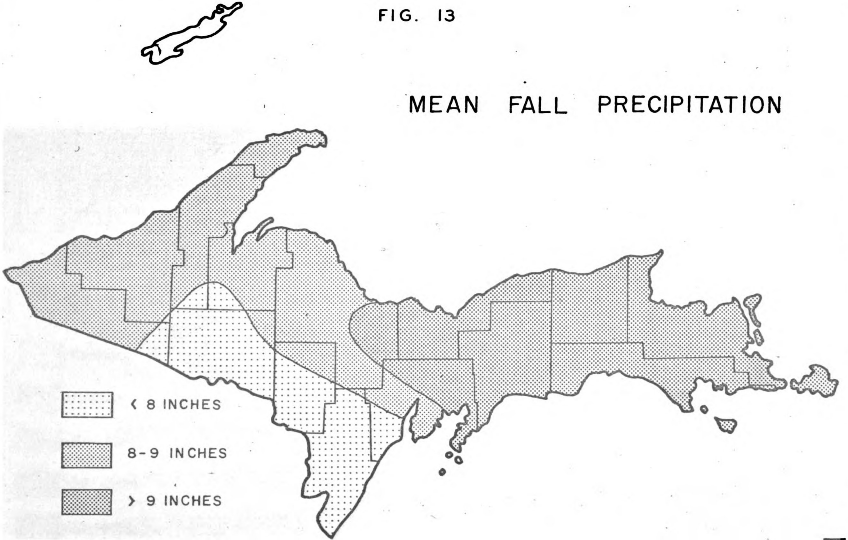


FIG. 14

MEAN ANNUAL SNOWFALL

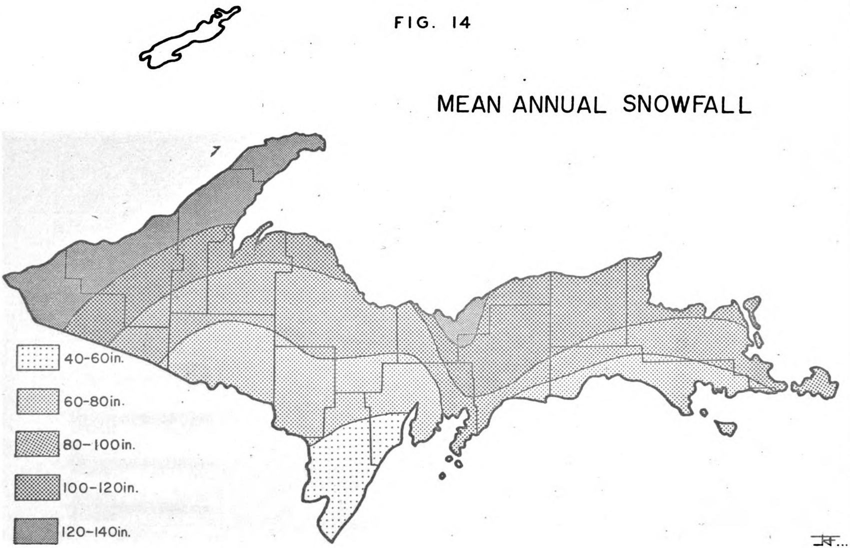
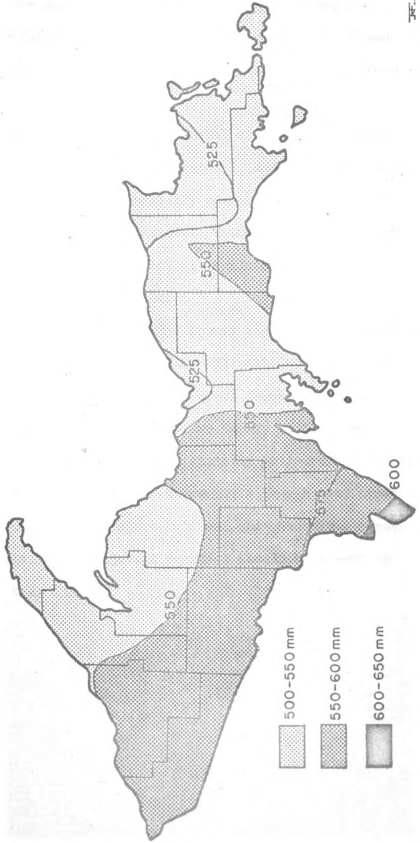


FIG. 15

MEAN ANNUAL PE



are in coastal areas in the eastern one-half of the peninsula and the highest values are in the southern one-half of Menominee County.

Mean annual water deficits are plotted in Figure 16. The values are comparatively low for the state and are almost negligible at Ironwood and Ishpeming.

The mean annual water surplus and the normal status of available soil moisture in November are plotted in Figures 17 and 18. These maps indicate: (1) that sand soils would normally reach field capacity in November in all of the Upper Peninsula except southwestern Delta County and southern Menominee County and (2) that all soils would normally have an annual surplus in excess of 75 mm.

Moisture-wise the climate of Menominee County and parts of bordering counties resembles that of the Saginaw Valley and parts of the "Thumb" area in the Lower Peninsula (which overlaps Podzol Zones I and II). The profile descriptions given in the Menominee County soil survey report (Moon et al., 1930) indicate that no strictly well-drained Podzol having a dark orterde horizon occurs in the county although sand parent material is widespread. It is therefore believed that Menominee County and an indeterminant portion of adjacent counties should be a part of Podzol Zone II rather than III.

FIG. 16

MEAN ANNUAL WATER DEFICIT

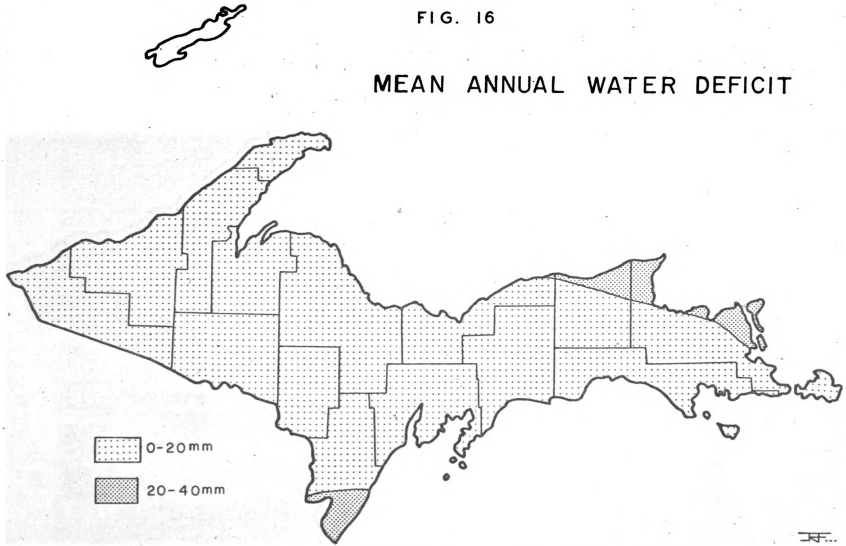


FIG. 17

MEAN ANNUAL WATER SURPLUS

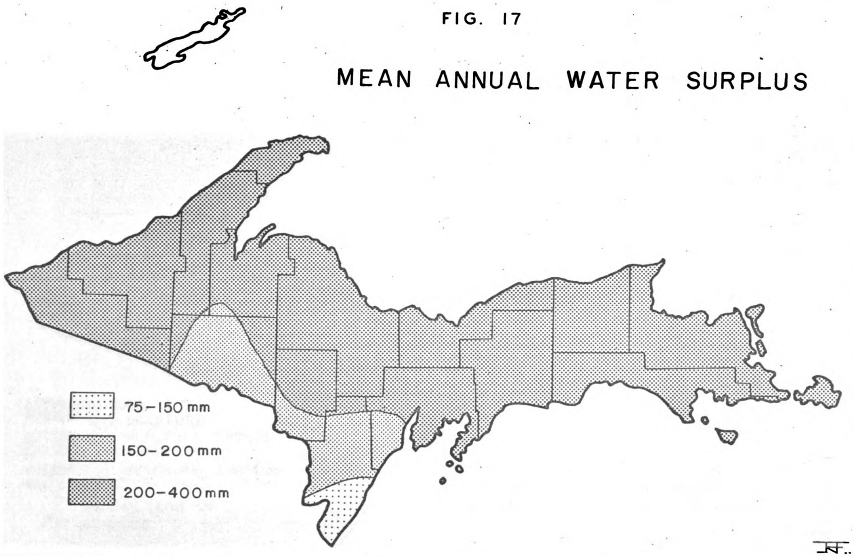
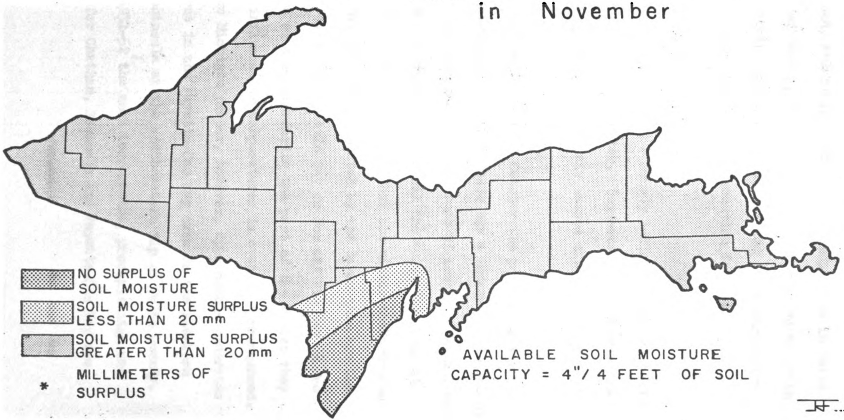


FIG. 18

MEAN STATUS* OF AVAILABLE SOIL MOISTURE in November



CHAPTER 8. DESCRIPTION OF THE STUDY AREA

Seven well-drained, relatively undisturbed sandy sites in Delta County and one in Alger County, Michigan (see Figure 19A) were chosen for a study of: (1) their soil characteristics and (2) their interrelationships to each other and the soil-formation factors.

Climate

The climate of the study area is strongly influenced by the positions of Lake Michigan and Lake Superior. Segments of the area which are frequently exposed to lake-altered air masses exhibit this effect most clearly.

During the months from May through October the prevailing wind is from the south at Escanaba. This lake breeze has a moderating influence on the temperature of Escanaba and probably much of southern Delta County. During the months from November through April the prevailing wind at Escanaba is from the north or northwest. Thus the winter temperatures in southern Delta County are less moderated by the lakes than are the summer temperatures. Green Bay, Little Bay de Noc and Big Bay de Noc freeze over during the winter, and during the part of the winter they are frozen, the lake influence on temperatures is even less pronounced. The open water of Lake Michigan proper, however, appreciably moderates the winter temperatures in the Fayette-Sac Bay area in the southern part of the Garden peninsula at the southeastern tip of Delta County.

For the period 1931-52 the mean temperature, precipitation and water balance values for Chatham, Escanaba and Fayette-Sac Bay are presented in Table 5.

FIG. 19-A

LOCATION OF STUDY AREA

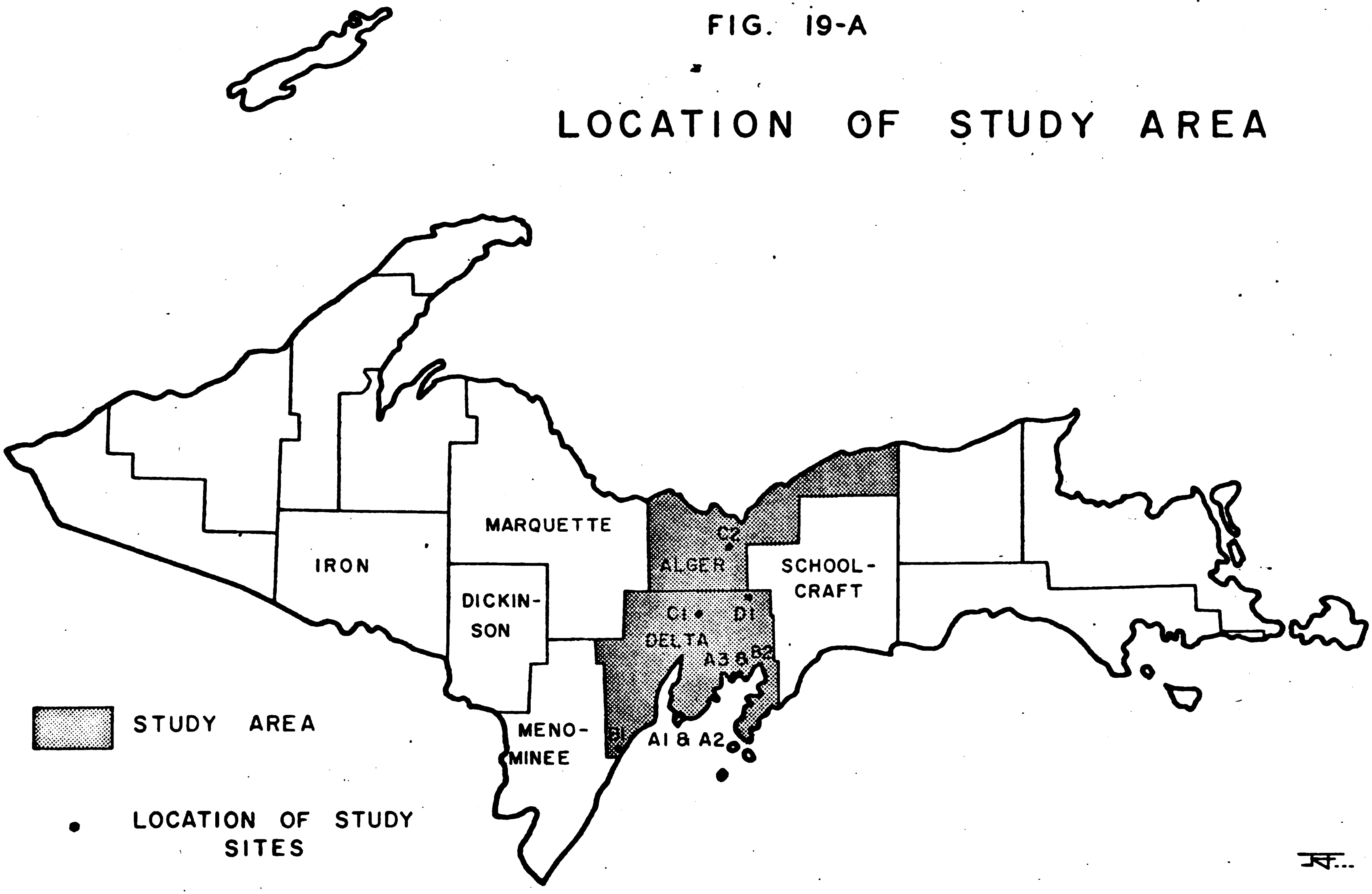


TABLE 5. SOME CLIMATIC FEATURES OF THE DELTA-ALGER STUDY AREA (1931-52)*

TEMPERATURE (°F)

	J	F	M	A	M	J	J	A	S	O	N	D	AVE
Escanaba	18.6	18.3	26.3	38.6	50.4	61.0	67.3	65.3	57.5	47.3	34.0	25.9	42.5
Chatham	17.6	17.4	24.7	37.8	49.8	60.1	65.9	64.1	56.6	46.1	32.2	21.9	41.2
Fayette-SB	20.3	19.6	27.0	38.5	49.3	59.0	66.1	65.3	58.4	48.0	35.4	25.2	42.7

PRECIPITATION (INCHES)

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Escanaba	1.61	1.29	1.68	1.95	2.86	2.96	3.54	3.03	3.04	2.09	2.30	1.37	27.72
Chatham	2.30	1.68	1.72	2.08	3.00	3.68	3.27	3.37	4.22	2.81	3.39	2.20	33.72
Fayette	2.10	1.68	2.12	2.31	3.05	3.43	3.34	3.00	3.39	2.46	3.20	1.99	32.07

SNOWFALL (INCHES)

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Escanaba	14.6	12.7	9.7	2.8	0.1	0.0	0.0	0.0	0.0	0.2	4.9	10.4	55.4
Chatham	19.4	13.6	10.8	6.4	0.6	T	T	T	T	2.6	12.7	17.9	84.0
Fayette	20.7	18.8	14.3	5.6	0.4	0.0	T	0.0	T	0.5	8.7	16.1	85.1

WATER BALANCE (MILLIMETERS OF WATER)

		IN SOIL WITH 14" CAPACITY		IN SOIL WITH 4" CAPACITY
	PE	DEFICIT (sandy loam)	SURPLUS (sandy loam)	NOVEMBER SURPLUS (sand)
Escanaba	558	15	161	0
Chatham	553	10	334	90
Fayette	546	11	280	40

*The raw data for this table were derived from U.S. Weather Bureau publications (Weather Bureau, 1959a and b).

These data show that Escanaba has climatic moisture characteristics more typical of Podzol Zone II than Podzol Zone III. Based on these data and Figures 13 and 14, it is apparent that Site B1 south of Escanaba, Figure 19, exists under a somewhat less favorable climate for dark upper illuvial horizon development than do the other sites in this study.

Surface Geology

The surface geology of Delta County and neighboring counties is depicted in Figure 19B.

Delta and Alger counties were completely covered by Valders ice (Hough, 1958). The unadulterated outwash plains occurring in these two counties, then, should be of Valders age. However, since these counties lie about 200 miles north of the point of maximum advance, Valders drift is logically somewhat younger in these northern areas than it is farther south. As a matter of fact, Hough postulates that the ice was still present in Delta County during the highest stage of Glacial Lake Algonquin. Accordingly, then, the longest period of time that any surfaces in Alger County and northeastern Delta County have been exposed to post-glacial weathering should be about 10,500 years (Broecker and Farrand, 1963).

Lake Algonquin was assumed by Leverett and Taylor (1915) to have extended into the Lake Superior basin through the Au Train-Whitefish Valley system in central Alger and Delta counties. Observations of lacustrine features were made by those workers, and subsequently by others, up to 960 feet above sea level in the vicinity of Munising in Alger County. The highest of these features was much higher than the isobase line of the highest Algonquin level derived by Leverett and Taylor from observations in other localities. As a result, these features were assumed to be of local origin. Bergquist, working in this region in the 1930's, also assumed these features to be local in

FIG. 19-B

SURFACE GEOLOGY OF DELTA AND ALGER COUNTIES

Source: Sinclar, 1960 & Bergquist, 1936

origin since they did not correspond in elevation to the highest lacustrine features farther to the east. South of Munising in southern Alger County, and northern Delta County, observations of lacustrine features are lacking. Based on this dearth of observations, the anomalous lacustrine features near Munising and the configuration of the moraine-outwash systems in that area, Hough postulated that: (1) the highest stage of Lake Algonquin did not extend into the Lake Superior basin because it was dammed by glacial ice and (2) by the time the Au Train-Whitefish valley system was ice-free, Algonquin lake waters were at such a low level as to prevent a lake connection from occurring between the Lake Superior and Lake Michigan basins in that valley.

Glacial Lake Duluth, which is assumed to have been contemporaneous with the main Algonquin stage but confined to the western part of the Lake Superior basin, is thought by Hough to have used the Au Train-Whitefish valley system as its spillway following the unblocking of this passageway by the glacial ice during the "Upper Group" of lake stages in the Lake Michigan basin. The resultant deluge is postulated to have inundated all but the highest moraines in Delta and Alger counties.

During further retreat of the ice front to the north and east, the water levels in both of the above-mentioned basins dropped to a very low elevation, the lowest of these in the Lake Michigan basin being Lake Chippewa. This subsidence occurred between about 10,500 and 9570 ± 150 years ago (Broecker and Farrand, 1963).

Following the Lake Chippewa period, water levels rose, and presumably by 5720 ± 250 years B.P., they were close to the present-

day levels (based on the buried ash tree referred to in Chapter 3). By 3500 years B.P., a stable level was reached in both basins. This level has been given the name Lake Nipissing and the present elevations of its beaches rise from 609 feet above sea level at Escanaba to 629 feet at Munising (Leverett and Taylor, 1915).

Following Lake Nipissing times, water levels dropped about 10 feet and became stable enough at that point to be classified as a separate lake stage. The name given to this stage was Lake Algoma and it has been dated at about 2500 years B.P. (Hough, 1958). Lake Algoma beaches and terraces have been identified on Garden Peninsula (eastern Delta County) at elevations of 590 to 600 feet (Leverett and Taylor, 1915; Bergquist, 1936). In Schoolcraft County, further east, beaches are also present which are transitional between the Nipissing and Algoma levels. Bergquist states that these beaches were formed either during the lowering of the Nipissing waters or by storm waves of Lake Algoma.

The Algoma shore in Schoolcraft County is not traceable as a continuous feature but occurs rather as more or less disconnected units along the Lake Michigan shore. In certain areas, the Algoma features are very definite but in the main they are either obscured by low dune developments or are missing entirely as a consequence of later wave activity. In several places a series of low fore-dune ridges or limestone rubble ridges extend outward from the Algoma shore features to the present shore. Bergquist states that these ridges may represent storm wave deposits of the present lake.

Storm waves are examples of short-period fluctuations in lake levels. The maximum rise resulting from short-period fluctuations that has been observed at gage sites on Lake Michigan is 2.8 feet at

Calumet Harbor, Illinois. However, the ability of the wind to raise water levels is greatest in bays and extremities of the lake especially when the wind is blowing toward these locations. At the east end of Lake Erie, for instance, the maximum short-period rise recorded was 8.4 feet (Laidly, 1962).

The monthly average level of Lake Michigan reached the maximum recorded value of 583.6 feet above sea level in June, 1886. This peak marked the end of a four-year period during which the monthly average level exceeded 583 feet each summer. No other comparable period has been recorded (Laidly, 1962).

The writer has identified what he believes are Algoma terraces cut into limestone bedrock at several locations on Stonington Peninsula and on the east side of Ogontz Bay in Delta County. These terraces invariably occur between the 590 and 600-foot contour lines. In some areas, terraces or low, dune-like ridges are present above Algoma wave-cut cliffs and below Lake Nipissing terraces. In several areas, a series of parallel, low, fore-dune ridges extend outward from the base of Algoma wave-cut cliffs to the present beach. A very conspicuous area of ridges such as these is to be found at the head of Big Bay de Noc although no Algoma cliff was identified at the upper end of that series of ridges.

Site Locations

Three sites are located on low dunes below Lake Algoma wave-cut cliffs. These dunes are considered to be post-Algoma in age based on their similarity to those described by Bergquist and since buried soils are present beneath a relatively unleached sand cap varying in thickness from six inches to a foot. Excavations in the vicinity of one of these sites (Site A1) revealed man-made wood chips and a buried tree trunk beneath the sand cap. Ages of two of the larger trees growing on each of these three sites did not exceed 70 years. Since lake level records for Lake Michigan indicate that from 1882 through 1886 the monthly average lake level during the peak months (summer) was between 583 and 584 feet, a portion of the surface now beneath the sand cap would have been inundated and storm waves may have inundated most of it. Since logging began in the general area between 1880 and 1890, the sand cap on these surfaces was probably deposited no earlier than 1880 and in all likelihood was deposited during and immediately following the high lake levels in the mid-1880's. Until further investigations are made, these sites will be collectively referred to as being post-Algoma in age.

These three sites are designated as A1, A2 and A3 with the numbers varying directly with the apparent degree of Podzol development. Site A1 is about 100 yards from the present beach and is adjacent to the dune heath (mainly Juniperus spp.) zone. Site A2 is about 200 yards inland and is within a few hundred yards of Site A1. Site A3 is about 16 miles northeast of Sites A1 and A2; it is also about 200 yards inland. Sites A1 and A2 are bounded on the south and west by water and on the north by a boggy area. Site A3 is bounded by water to the south, by bog to the east and northeast, but by well-drained uplands to the west and northwest (site locations are shown in Figures19A and B).

Two sites are located at levels between those of the A sites and Lake Nipissing terraces. The parent material at each site is composed of a stratum of medium to fine sand overlying a calcareous stratum of coarse sand, gravel and gastropod shells. These sites are designated as B1 and B2 on the basis of a darker upper illuvial horizon in the B2

soil. The B1 site is bounded by moist sites and is about 100 yards from the Bark River. The B2 site is bounded by dry sites and is about 500 yards northwest of Site A3.

Two sites are located in the area which was inundated by the waters from Lake Duluth as they spilled southward into the Lake Michigan basin. Both of these sites lie well above the highest Lake Nipissing features therefore the land surfaces are of Sub-Duluth (Hough, 1958) age. These two sites are designated as C1 and C2 on the basis of a darker upper illuvial horizon in the C2 soil. Site C1 is bounded on the west by an extensive lowland area which begins at the bottom of the escarpment which leads down from the terrace on which Site C1 is located. Site C1 is about 100 yards from the escarpment. Site C2 is surrounded by well-drained sands with occasional pits typical of outwash plains. Both of these sites lie inland more than 10 miles from either Lake Michigan or Lake Superior.

Site D1 is located near the top of a moraine which apparently was not inundated by the Sub-Duluth deluge. This moraine is a part of the Newberry Morainic System (Bergquist, 1936), and as such, would be of Valders age. Site D1 is well inland from the Great Lakes but is situated about 3/4 of a mile south of an extensive area of small lakes, all of which lie at elevations 100 to 130 feet lower than Site D1.

The approximate ages in years of the surfaces at these sites are therefore assumed to be as follows:

soil. The B1 site is bounded by moist sites and is about 100 yards from the Bark River. The B2 site is bounded by dry sites and is about 500 yards northwest of Site A3.

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The approximate ages in years of the surfaces at these sites are therefore assumed to be as follows:

SITE	AGE-HOUGH CHRONOLOGY	AGE-BROECKER AND FARRAND CHRONOLOGY
A1	post-Algoma (writer's estimate)	-
A2	post-Algoma (writer's estimate)	-
A3	post-Algoma (writer's estimate)	-
B1	3000 (writer's estimate)	-
B2	3000 (writer's estimate)	-
C1	7500	10,000
C2	7500	10,000
D1	8500	10,500

CHAPTER 9. METHODS USED IN ECOSYSTEM INVESTIGATIONS

Forest Composition

Forest composition at each site was determined by the use of a basal area prism with a soil pit as plot center. In these descriptions, the following terms are used: (1) "dominants" which refers to those trees having their crowns above, or at the same level as, crowns of the neighboring trees; (2) "intermediates" which refers to those components from one inch in diameter (at breast height) up to, but not including, the dominant trees; (3) "reproduction" which refers to tree reproduction and includes seedlings and saplings up to one inch in diameter. In the individual site descriptions, these terms are abbreviated to D, I and R.

Humus Types

The humus types of the profiles studied are classified according to the system developed by the Committee on Forest Humus Classification, Forest Soils Subdivision, Soil Science Society of America (Hoover and Lunt, 1952). These designations are cited preceding each profile description.

The initial appearance of the *in situ* Rubicon sand humus layer, Site C1, suggested a mor humus type. Closer inspection, however, revealed that what appeared to be an H-layer was actually a mixture of bleached sand grains and black humus which graded rather abruptly into the underlying Em (A2) horizon. The estimation of the percent organic matter based on organic carbon content revealed that this dark horizon contained only about 7% organic matter therefore the humus layer seemed to be most appropriately classified as a Shallow Sand Mull.

There was some question as to whether the upper humic horizon of Site A3 met the specifications for an H-layer since it contained

scattered, bleached sand grains. Since this horizon was found to contain 29% organic matter and graded gradually into the Vh horizons below, the upper humic horizon was considered to be an H-layer and the humus type was classified as a thick duff-mull. In a recent paper, White (1965) states that there is no evidence of biological incorporation of organic matter in some Lake States humus types which morphologically appear to be duff-mulls. The Vh (A1) horizons underlying the Oh horizons of such soils usually contain less than 4% organic matter and therefore it was felt that such humus types should be classified as mors rather than duff-mulls. It is possible that the humus layer of Site A3 is also of this type but confirming data other than % O.M. is lacking. Consequently, the humus layer is tentatively classified strictly according to its morphology.

The humus layers of Profiles A1, B2 and D1 definitely lack an H-layer and exhibit a gradual decrease in organic matter with depth. In Profile D1, however, there was a gradual decrease from the Vh1 to the Vh2 and then an abrupt decrease from the Vh2 to the Vh3. It seems plausible that the Vh3 contains mostly infiltrated rather than biologically incorporated organic matter. In Profile B2 also, the lowermost Vh horizon may contain mostly infiltrated organic matter. Since these problems cannot be resolved with the data at hand, these humus layers are classified as mulls. Due to the looseness and low organic matter content of the humus layer in Profile A1, it is classified as a sand mull. The other two are classified as coarse or medium mulls.

The lack of an Oh horizon on a well-developed Podzol may be a residual effect from disturbances during earlier lumbering operations.

However, the height of the trees and the density of the stand are such that the writer feels that an Oh horizon would have subsequently developed if the foliar composition of the stand were conducive to such a development.

Soil Profile Descriptions

Soil profile descriptions were made at the time of sampling (July and August, 1961). Horizon designations are those suggested by Whiteside (1959). Designations for the horizons in the following profile descriptions have the following equivalents in the nomenclature outlined in the 1962 supplement to the Soil Survey Manual (Soil Survey Staff, 1951):

Of = 01 (F layer)

Oh = 02 (H layer)

Vh = A1 (and H layers containing less than 20% organic matter)*

Em = A2

Ihib = Bhir

Ihbi = Bhir

Ihbic = Bhir (or Bhm if cemented horizon is at least 90% continuous)

Iib = Bir

Ibi = Bir

W = C (or C1 formerly)

P = C (or C2 formerly)

U = II C (or formerly, D)

p = b (buried soil)

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*The above mentioned supplement stipulates that organic horizons of mineral soils should contain more than 20% organic matter if the mineral fraction has no clay. This criterion was used to separate Oh from Vh horizons in this study.

Colors are for moist soils; color names are those of the ISCC-NBS (U.S. National Bureau of Standards, 1955). Acidity was determined with a Hellige-Truog pH kit (pH meter values are listed with the soil test data).

SITE A1: SAND REGOSOL UNDER BALSAM FIR

Location: SE¼SE¼, Sec. 11, Twp. 38N, Rge. 22W

Drainage: well-drained (water table at 7 feet in summer of 1961)

Slope and aspect: negligible

Topography: slightly undulating to level

Landform: low dunes

Elevation: between 580 and 590 foot contours on topographic map

Forest characteristics: basal area/acre = 90 sq. ft.;
balsam fir - 89%, DR;
paper birch - 11%, D.

Humus type: deep sand mull

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+1 to 0	balsam fir debris; white fungal mycelia; pH variable, spots of 5.0, 6.5 and 8.0.
Vh1	0 - 1	sand; black; pH 8.0.
Vh2	1 - 4½	sand; brownish gray (10YR 3/1); pH 8.0.
P	4½ - 10	sand; light yellowish brown (10YR 6/4); pH 8.0.
pVh	10 - 14½	sand; dark grayish yellowish brown (10YR 2/2); pH 8.0.
pIIb	14½ - 17½	sand; moderate yellowish brown (10YR 5/4); pH 8.0.
P	17½ - 66	sand; light yellowish brown (10YR 6/4); pH 8.0.

SITE A2: EASTPORT SAND UNDER PINE

Location: SW¼SW¼, Sec. 12, Twp. 38N, Rge. 22W

Drainage: well-drained (water table at 5½ feet in summer of 1961)

Slope and aspect: negligible

Topography: slightly undulating to level

Landform: low dunes

Elevation: 590 feet

Forest characteristics: basal area/acre = 140 sq. ft.;
white pine - 29%, D;
balsam fir - 21%, I;
aspen - 21%, D;
white-cedar - 21%, I;
red pine - 7%, D;
paper birch - 7%, D.

Humus type: thick mor

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+2¼ to +1½	mostly coniferous debris; yellow and white fungal mycelia; pH variable, spots of 5.0 and 6.5.
Oh	+1½ to 0	black humus with scattered, bleached sand grains; pH 4.0.
Em	0 - 1¼	sand; grayish yellowish brown (10YR 5/2); pH 4.0 - 5.0.
Iib	1¼ - 6¼	sand; strong yellowish brown (10YR 5/6); pH 5.2.
I/pV	6¼ - 12¼	sand; moderate yellowish brown (10YR 4/3); pH 8.0.
P	12¼ - 66	sand; light yellowish brown (10YR 6/4); pH 8.0.

SITE A3: EASTPORT SAND UNDER RED OAK

Location: NW¼SE¼, Sec. 24, Twp. 40N, Rge. 20W

Drainage: well-drained

Slope and aspect: negligible

Topography: slightly undulating to level

Landform: low dunes

Elevation: between 580 and 590 foot contours

Forest characteristics: basal area/acre = 120 sq. ft.;
red oak - 67%, D;
white pine - 25%, D;
sugar maple - 8%, DIR.

Humus type: thick duff-mull

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+1½ to 0	pine and hardwood debris; white fungal mycelia; pH 6.2.
Oh	0 - 1	dark grayish yellowish brown to brownish gray (10YR 2/1-3/1) humus; scattered, bleached sand grains; pH 5.0.
Vh1	1 - 1¼	brownish gray (10YR 3/1) humus and sand mixture; pH 4.0.
Vh2	1¼ - 2¼	sand; light brownish gray (10YR 5/1); pH 4.0.
Em	2¼ - 4½	sand; light grayish brown (7.5YR 6/2); pH 5.0.
Iib	4½ - 10¼	sand; strong yellowish brown (10YR 5/6); pH 5.2.
pVh	10¼ - 11-3/4	sand; brownish grey (10YR 4/1); pH 6.0.
pEm	11-3/4 - 12-3/4	sand; light grayish yellowish brown (10YR 6/3); pH 6.0.
pIib	12-3/4 - 16-3/4	sand; strong yellowish brown (10YR 5/6); pH 6.0.
W	16-3/4 - 38	sand; light yellowish brown (10YR 6/4); pH 7.0.
P	38 - 66+	sand; light yellowish brown (10YR 6/4); pH 8.0.

SITE B1: RUBICON SAND UNDER HEMLOCK

Location: NE¼NE¼, Sec. 27, Twp. 37N, Rge. 24W

Drainage: well-drained

Slope and aspect: zero

Topography: slightly undulating to level

Landform: low dunes ("Upper Algoma")

Elevation: 595 feet

Forest characteristics: basal area/acre = 220 sq. ft.;
eastern hemlock - 36%, DIR;
yellow birch - 23%, D;
white pine - 18%, D;
paper birch - 14%, D;
white spruce - 5%, D;
balsam fir - 4%, DR;
red maple - 0, R.

Humus type: thick mor

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+3 to +2	Gymnosperm and Angiosperm debris; white fungal mycelia; pH variable, from 4 to 7.
Oh	+2 to 0	black to dark gray humus with scattered bleached sand grains; white and yellow fungal mycelia; pH 4.0.
Vh	0 - ½	sand; grayish brown (5YR 4/2); pH 4.0.
Em	½ - 7½	sand; light grayish brown (7.5YR 6/3); pH 4.0.
Ihib	7½ - 9½	sand; strong brown (5YR 4/8); pH 4.0.
Iib	9½ - 40	sand; strong yellowish brown (7.5YR 5/8); pH 6.0.
P	40 - 66	sand; light yellowish brown (10YR 6/4); pH 8.0.
U	66+	sand, gravel, gastropod shells and shell fragments; pH 8.0.

SITE B2: EAST LAKE SAND UNDER RED OAK

Location: SE$\frac{1}{4}$NW$\frac{1}{4}$, Sec. 24, Twp. 40N, Rge. 20W

Drainage: well-drained

Slope and aspect: 3% east

Topography: undulating

Landform: low dunes ("Upper Algoma")

Elevation: 595 feet

Forest characteristics: basal area/acre = 130 sq. ft.;

red oak - 54%, DI;

sugar maple - 31%, DIR;

beech - 8%, DI;

basswood - 8%, DI.

Humus type: very deep coarse or medium mull

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+1/8 to 0	hardwood debris; pH 7.0.
Vh1	0 - 2	black humus and sand mixture; pH variable, spots of 4.0 and 6.5.
Vh2	2 - 5$\frac{1}{2}$	sand; brownish gray (10YR 3/1); pH 4.0.
Em	5$\frac{1}{2}$ - 6 but mostly absent	sand; grayish yellowish brown (10YR 5/2); pH 4.5.
Ihib	5$\frac{1}{2}$ - 8$\frac{1}{4}$	sand; strong brown (5YR 3/6); pH 4.8.
Iib	8$\frac{1}{4}$ - 15$\frac{1}{4}$	sand; strong yellowish brown (7.5YR 5/8); pH 6.0.
I/P	15$\frac{1}{4}$ - 26	sand; dark orange yellow (10YR 6/6); pH 6.0.
U	26+	coarse sand, gravel and gastropod shells; light yellowish brown (10YR 6/4); pH 8.0.

SITE C1: RUBICON SAND UNDER RED PINE

Location: NW¼NE¼, Sec. 7, Twp. 42N, Rge. 20W

Drainage: well-drained (water table deeper than 14 feet)

Slope and aspect: negligible

Topography: level

Landform: plain

Elevation: 750 feet

Forest characteristics: basal area/acre = 160 sq. ft.;
red pine - 100%, D;
red maple - 0, R;
balsam fir - 0, R.

Humus type: shallow sand mull

Field description of horizons:

Horizon	Depth (in)	Characteristics
Of	2¼ to 0	pine debris; white fungal mycelia; pH 4.5.
Vh	0 - 1¼	black humus and sand mixture; yellow fungal mycelia; pH 4.0.
Em	1¼ - 6	sand; light grayish brown (5YR 5/2); pH 4.0.
Ihib	6 - 13	sand; moderate brown (7.5YR 4/4); pH 5.0.
Iib	13 - 35	sand; strong yellowish brown (7.5YR 5/6); pH 6.0.
W1	35 - 156	sand; light brown (7.5YR 5/4); pH 6.0.
W2	156 +	fine sand; light brown (5YR 5/3); pH 6.5.

SITE C2: KALKASKA SAND UNDER HEMLOCK

Location: NW¼NE¼, Sec. 10, Twp. 45N, Rge. 19W, Alger County Michigan

Drainage: well-drained (water table deeper than 14 feet)

Slope and aspect: 3% south

Topography: undulating

Landform: outwash plain

Elevation: 900 feet

Forest characteristics: basal area/acre = 160 sq. ft.;
hemlock - 58%, DI;
yellow birch - 21%, D;
red maple - 14%, I;
balsam fir - 7%, I.

Humus type: thick mor

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Of	+3 to +2	coniferous and hardwood debris; white fungal mycelia; pH variable, 4.0 with spots of 6.0.
Oh	+2 to 0	black humus; yellow fungal mycelia; pH 4.0.
Em	0 - 6	sand; light grayish brown (7.5YR 6/2); pH 4.0.
Ihib	6 - 8	sand; dark brown (5YR 2/3); pH 4.0.
Ihbic	8 - 44	sand; discontinuous, indurated tongues; dark grayish brown (5YR 2/2); pH 5.5.
Ibi	8 - 26	sand; strong yellowish brown (7.5YR 5/8); pH 5.5.
I/W	26 - 38	sand; strong yellowish brown (7.5YR 5/6); pH 5.5.
W	38 - 96+	sand; light brown (7.5YR 6/4); pH 6.0.

SITE D1: KALKASKA SAND UNDER SUGAR MAPLE

Location: NW¼NW¼, Sec. 7, Twp. 43N, Rge. 18W

Drainage: well-drained (water table deeper than 14 feet)

Slope and aspect: 4% east

Topography: rolling

Landform: moraine

Elevation: 890 feet

Forest characteristics: basal area/acre = 180 sq. ft.;
sugar maple - 89%, DIR;
black cherry - 11%, DR.

Humus type: very deep coarse or medium mull

Field description of horizons:

Horizon	Depth (in.)	Characteristics
Vh1	0 - ½	black humus and sand mixture; pH 5.0.
Vh2	½ - 1	sand; very dark gray (5YR 3/1); pH 6.0.
Vh3	1 - 5	sand; dark gray (5YR 4/1); pH 5.0.
Em	5 - 7½	sand; reddish gray (5YR 5/2); pH 5.8.
Ihib1	7½ - 10	sand; dark reddish brown (5YR 2/2); pH 6.2.
Ihib2	10 - 14	sand; reddish brown (5YR 4/3); pH 6.8.
Ibi	14 - 31½	sand; strong brown (7.5YR 5/6); pH 5.5.
W1	31½ - 144	sand; yellowish brown (7.5YR 5/4); pH 6.0.
W2	144 - 168	sand with thin, orange to pink loamy sand bands; sand-brown (7.5YR 5/4); acid.

<u>Pollen Analyses</u>

Three Lakes Bog is located approximately 100 yards south of Site C2. The bog is surrounded by sand for at least 3½ miles in every direction. The soil type surrounding the bog for at least ¼ mile in every direction is Kalkaska sand (Veatch, et al., 1934 and confirmation by writer). The margin of the bog is bounded by steep slopes; consequently well-drained soils are encountered within a few feet of the bog margin. The bog contains 9½ feet of peat overlying sand into which some organic matter has been incorporated. The surface of the bog is completely covered with a mat of sphagnum interspersed with leatherleaf. The forest composition immediately around the bog contains a somewhat higher percentage of red maple and alder (Alnus rugosa) than is found farther from the bog margin. Tree species found in the upland areas around the bog which are not included in the Site C2 description are white pine, American beech and white spruce. Sugar maple was notably absent in this forest cover type which was designated as hemlock on the 1954 U.S. Forest Service Timber Survey map of Hiawatha National Forest.

Sampling of the peat bog was accomplished with the use of a Hiller borer by Dr. A. T. Cross of the Geology and Botany departments, Michigan State University, and the author. Samples were collected from three- to six-inch intervals within the peat itself and as a continuous core for the first six inches of the underlying peat-sand mixture. The samples were kept frozen until macerations were begun and kept under refrigeration between subsequent sub-samplings.

The first maceration technique employed was simply the boiling of the wet sub-sample in 10% NH_4OH. This treatment did not isolate the pollen grains sufficiently, therefore bleaching with sodium hypochlorite prior to the NH_4OH treatment was tried. This treatment, even in dilute concentrations, destroyed all the birch pollen. Sodium chlorate, however, proved to be safe to use (standard treatment used by several palynologists; see Brown, 1960).

The technique finally employed was as follows: (1) About an inch of wet peat was loosely packed into a 40 ml centrifuge tube and 10% NH_4OH was added until the peat was completely covered. The tube was then placed in a 100°C water bath for ½ hour with occasional stirring. Next the mixture was centrifuged at 2500 rpm for 5 minutes and the supernatant liquid decanted. The residue was then washed with water and centrifuged with subsequent decantation. The residue was next dehydrated with glacial acetic acid followed by centrifugation and decantation. (2) For lignin oxidation, 5 ml of glacial acetic acid, 5 ml of 50% $NaClO_3$ and 1 ml of concentrated HCl was added to the centrifuge tube and the mixture stirred and allowed to bleach. The tube was then filled with glacial acetic acid, centrifuged and decanted, then washed twice with glacial acetic acid with centrifugation and decantation. This technique is recommended by Faegri and Iversen (see Brown, 1960). (3) For cellulose decomposition, an Erdtman (see Brown, 1960) acetolysis mixture (9 parts acetic anhydride to one part concentrated H_2SO_4) was added to the residue, and the mixture placed in an 80°C water bath. The bath was then brought to the boiling point and allowed to boil for two minutes. The tube was then centrifuged, the liquid decanted and the residue washed with glacial acetic acid followed by centrifugation and decantation. The residue was finally washed with water (followed by centrifugation and decantation) until a clear supernatant liquid was obtained. The resultant residue was then strained through a double layer of cheese cloth with concurrent washing. The suspension was concentrated by centrifugation and transferred to vials from which slide preparations were made.

Pollen counts were made on glycerine mounts only. Size frequency

distributions were made on pine pollen grains using the distance between upper wing insertions as the criterion. The resulting bar graph indicated a normal curve distribution around a distinct 44-micron peak and a suggestion of another peak at 55 microns. The 44-micron peak was attributed to the presence of jack pine and red pine pollen based on the study of Cain and Cain (1948). Based on the presence of a "saddle" in the distribution curve at 50 microns, all pine pollen grains having dimensions greater than 50 microns were considered to be from white pine. Two hundred tree pollen grains were counted per slide. Non-arboreal pollen was not considered except to note that it was not prevalent at any level.

Foliar Analyses

A composite foliage sample was collected from one tree of one or more representative species on each of five plots. The samples were collected between 9 a.m. and 12 noon during the first two weeks of September, 1961. Collections were made from the southern, lower one-third of the crowns only. In the case of conifer foliage, only the current year's growth was sampled.

The samples were subjected to oven-drying on the day of their collection; drying was accomplished at 70°C. The oven-dried samples were ground in a Wiley mill and then turned over to Dr. A. L. Kenworthy of the Horticulture Department at Michigan State University. With the exception of total nitrogen, the elemental analyses were done spectroscopically.

Soil Microflora Studies

The humus-containing horizons from all A, B and C sites were sampled to obtain a quantitative estimate of the bacteria, actinomycetes and fungi. Two samples were taken from each horizon; one sample was frozen for later determination of moisture content and nitrifying capacity; sub-samples were taken from the other sample for slide preparation. Slides were prepared within 24 hours after the collection of the samples; the preparation technique used was that of Jones and Mollison (1948). Three slides were prepared from each sub-sample; counts were made by the use of random traverses. Stained bacterial cells were counted with no regard for cell-size differences. In the case of fungal hyphae, however, four diameter classes were established and length measurements were made with the use of a calibrated ocular grid; separate counts were made for unstained hyphal fragments. Actinomycetes were enumerated by length measurements of stained filaments only.

Total Soil Carbon and Organic Matter Determinations

Total carbon was determined in duplicate by the wet combustion method of Allison (1960). The values obtained can be interpreted as organic carbon except for those of the Vh2 horizon of Profile A1; this horizon contained carbonates as well as organic matter.

Bulk Density of Soil Horizons

In order to evaluate the total amounts of organic matter (and other constituents) as well as concentrations it was necessary to estimate the bulk density of the various horizons. This was done by weighing the quantity of dry soil necessary to fill a sampling spoon calibrated to hold 2.5 grams of a soil having a bulk density of 82.6 lb./cu. ft. or 2,000,000 lb./acre furrow slice (AFS). The weight of soil per AFS was calculated by the ratio:

$$\frac{\text{wgt. of sample}}{\text{lb./AFS}} = \frac{2.5}{2,000,000}$$

The percentage of the various constituents times the weight of soil per AFS (in pounds) then gives the pounds of the constituents per AFS. Pounds of constituents per horizon-acre (#/HA) = $\frac{\text{thickness of horizon}}{6\ 2/3}$ x #/AFS. The thickness used for P, W and U horizons was determined by subtracting the solum thickness from 66 or 96 inches. Although sampling at 96 inches was only done in the case of Profile C1, visual examination and pH readings in the field did not indicate the necessity for sampling at this depth.

Total Soil Nitrogen Determinations

Total nitrogen was determined in duplicate by the Kjeldahl method essentially as described by Jackson (1958), except that no selenium was used.

Soil Organic Matter Fractionation

Alkali-soluble organic matter was extracted and fractionated according to the method outlined by Stevenson (1960). The lignin of the humic acid fraction was subjected to a thermo-decomposition process (see Johnston, 1964) and the products of decomposition were determined by paper and gas chromatography*. No analyses were made on the fulvic acid fraction.

Crenic Acid and Nitrate Production of Soil Horizons

The Oh, Vh and Ih samples used for this study were frozen shortly

*Degradation and chromatography was performed by Dr. Harry H. Johnston of Wilmington College, Wilmington, Ohio.

after their collection and kept frozen until sub-samples were taken. In the laboratory, either 5 or 10 gram sub-samples were placed in carbon filter tubes and leached to determine the initial nitrate content. Leaching was accomplished by using 60 ml of distilled water and vacuum, then adjusting the leachate volume to 60 ml. One to four ml aliquots were taken from the leachate for nitrate determination using phenoldisulfonic acid (Stanford and Hanway, 1955). The leached sub-samples were brought to a constant moisture tension by using full vacuum; then they were transferred to an incubator at 30°C. Following the initial incubation period, the sub-samples were leached at weekly intervals with 60 ml of distilled water and then re-incubated. The water-soluble organic matter (designated as crenic acid) appearing in the leachates was measured relatively by determining the percent transmittance of the leachate at a wave length of 370 mμ (maximum absorption was actually in the ultra-violet, beyond the range of the colorimeter used). A Beckman glass electrode pH meter was used for determining the acidity of the leachates.

Soil treatments consisted of: (1) inoculation with a 1:10,000 suspension of an actively nitrifying garden soil; (2) fertilization with 50 ppm P (as ordinary super phosphate) and 0.25% Ca (as lime); and (3) both of the above treatments combined. Two replicates of 10 grams each were used for the controls and single 5-gram samples were used for the treatments.

Extractable Iron and Aluminum in Soil Horizons

Iron and aluminum were extracted from duplicate 10-gram samples of soil by the sodium dithionite-citrate-bicarbonate method (Jackson and Mehra, 1960). An aliquot of the extract was taken and the organic matter therein digested in a ternary mixture of concentrated acids (100 ml HNO_3, 10 ml H_2SO_4 and 40 ml $HClO_4$). Heating was continued until the solutions were evaporated to dryness. The resulting white residue was taken up in dilute (1N) HCl and brought up to 50 ml with distilled water. Aliquots were then taken for iron and aluminum determinations.

Iron was determined by the KSCN colorimetric method (Jackson, 1956).

Aluminum was determined by the aluminon method using the modifications recommended by Franzmeier (1962) in his work with similar soils.

Available Phosphorus* in Soil Horizons

Available phosphorus was extracted from a 2.5 g sample of soil (approximately 2.5 g in the case of horizons below the upper humus horizon) with 20 ml of 0.03N NH_4F mixed with 0.025N HCl (Bray and Kurtz, 1945). The suspensions were shaken for one minute and then filtered. Phosphorus in solution was determined colorimetrically using the ammonium molybdate-hydrochloric acid solution of Dickson and Bray (1940) and the 1-amino, 2-naphthol, 4-sulfonic acid reducing agent developed by Fiske and Subbarrow (1925).

Exchangeable Bases* in Soil Horizons

Exchangeable bases were extracted by adding 20 ml of neutral 0.1N NH_4OAc to 2.5 g of soil (approximately 2.5 g in the case of horizons below the upper humus horizon), shaking the suspension for one minute and filtering. Calcium, magnesium and potassium were determined on the extracts using a flame photometer.

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*Determinations made by Soil Testing Laboratory, Soil Science Department, Michigan State University.

Reaction* of Soil Horizons

Reaction was determined in a soil-water paste (1:1 volume ratio) with a Beckman glass electrode pH meter.

Mechanical Analyses of Soil Horizons

Mechanical analyses were made by the pipette method (Kilmer and Alexander, 1949) for the <50 micron particles and by dry sieving in the case of the sands. Determinations were made in duplicate.

A 10.0 gram sample was placed in a tall 600 ml beaker and the organic matter in it digested with 30% H_2O_2 (technical grade) and heating. At the end of the digestion, while the suspensions were still hot, 1N HCl was added to the samples containing carbonates until further additions induced no reactions. The samples were then filtered through a 9 cm Buchner funnel with suction, using a hard (Whatman No. 50) filter paper. The residues in the funnels were washed several times to remove chloride and then transferred to shaker bottles. The suspensions in the shaker bottles were titrated with 0.1N NaOH to the phenolphthalein endpoint (pH 9) and then shaken for 24 hours in a reciprocating shaker. The dispersed samples were then washed through a 300-mesh sieve. The sand collected in the sieve was oven-dried, fractionated by shaking in a nest of sieves on a mechanical shaker for 15 minutes, and then the resultant fractions weighed. The silt and clay passing through the 300-mesh sieve into a sedimentation cylinder was diluted with distilled water up to a known volume and allowed to come to room temperature (constantly 20°C). The suspension

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*Determinations made by Soil Testing Laboratory, Soil Science Department, Michigan State University.

was then transferred to a 2-liter beaker and while stirring, 25 ml aliquots were removed with a pipette, transferred to weighing bottles, oven-dried, and then weighed. The remaining suspension in the beaker was transferred back to the sedimentation cylinder which was then shaken end-over-end (to disperse the sediments evenly throughout). The suspension was then allowed to stand for the lengths of time (calculated on the basis of Stoke's law) necessary for particles of a certain size and density to pass a given point in the suspension. At these calculated times, aliquots were taken with a pipette as before, oven-dried and then weighed.

CHAPTER 10. RESULTS AND DISCUSSION

Pollen Analyses of Three Lakes Bog

The results of the pollen grain counts are shown in Table 6 and illustrated graphically in Figure 20.

The data indicate that the beginning of pollen accumulation in Three Lakes Bog was during the jack pine period suggested by Zumberge and Potzger (1956). If Broecker and Farrand's proposed chronology of lake events is correct, the bog could not have been in existence prior to about 10,000 years B.P., since the area was inundated by the Sub-Duluth deluge at approximately that time. According to Fries (1962), this period was characterized by decreasing spruce and increasing pine (especially jack pine) with pine dominance in existence by 9,150 ± 130 years B.P. Evidence that pollen accumulation in Three Lakes Bog began at the beginning of the pine period and not later is derived from the data of Wilson and Webster (1942) which indicates that the initial dominance, the subsequent decline and resumption of dominance by jack pine pollen occurred at the beginning of the pine period in north central Wisconsin. Fries' data indicate that jack pine dominance lasted until about 7300 ± 140 years B.P. in northeastern Minnesota with other pines being dominant from that time until the late post-glacial increase of spruce and fir occurred. Pollen from Three Lakes Bog, however, indicates that jack pine remained dominant until the late post-glacial increase of spruce and fir occurred. This variance is probably related to the large area of sand soils in which Three Lakes Bog is located.

Following the initial jack and red pine dominance, white pines apparently began to succeed the other pines concurrent with an increase

FIG. 20

POLLEN DIAGRAM OF THREE LAKES BOG

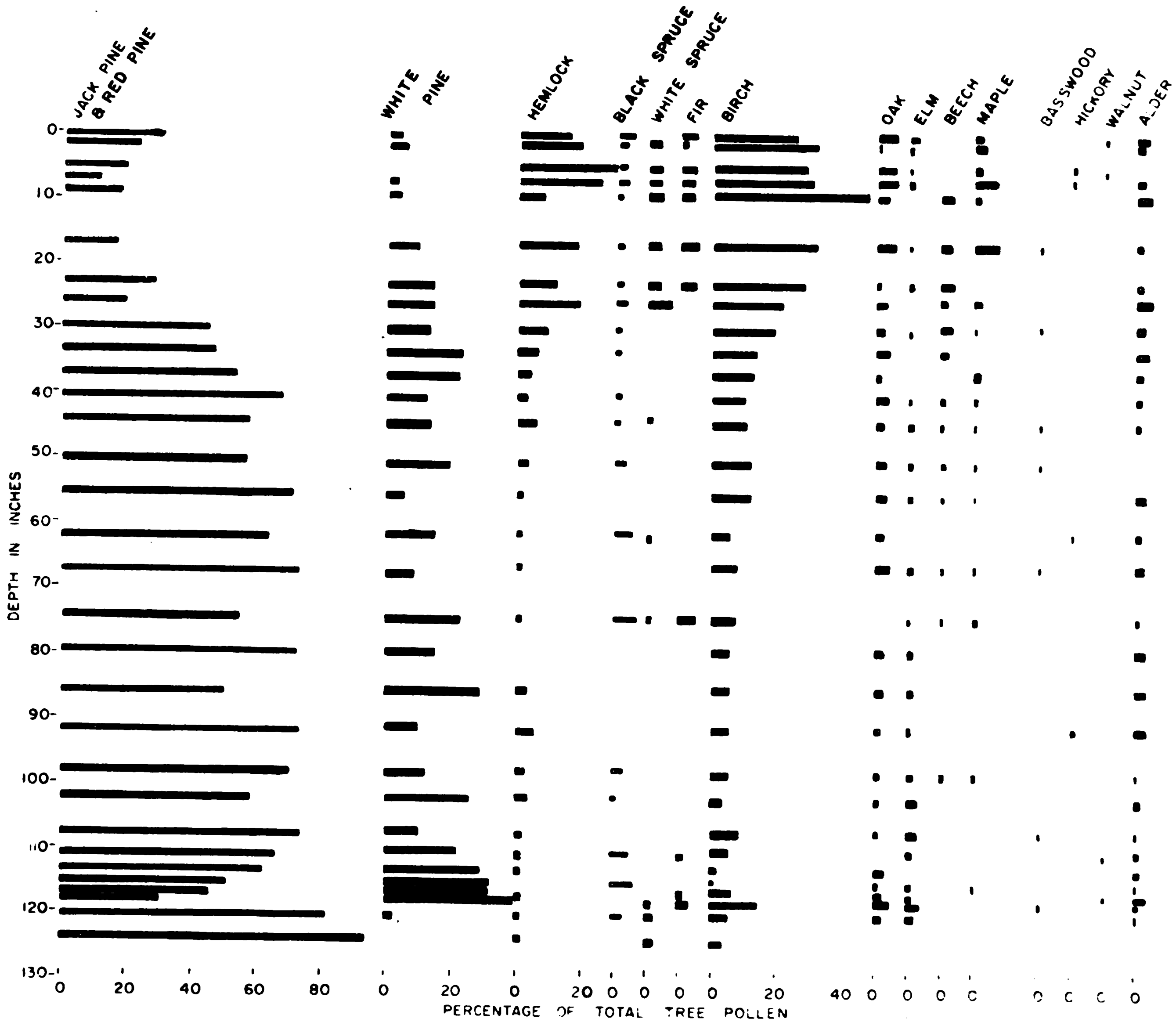

TABLE 6. TREE POLLEN PERCENTAGES IN THREE LAKES BOG

Depth in Inches	Pines and Spruce	Jack and Red Pine	White Pine	Black Spruce	White Spruce	Balsam Fir	Hemlock	Birch	Oak	Elm	Beech	Maple	Hickory	Basswood	Walnut
0	37.5	30.8	3.0	3.8	0	3.8	16.0	25.0	5.5	2.0	0	1.5	0	0	0.5
2	32.0	23.0	4.5	1.9	2.6	0.7	19.0	31.5	0.5	0.5	0	2.5	0	0	0
5	28.5	19.6	0	2.5	3.0	3.4	29.5	28.0	5.0	0.5	0	1.5	0.5	0	0.5
7	19.5	11.7	2.0	2.3	2.7	3.0	25.0	30.5	5.5	1.0	0.5	6.0	0.5	0	0
9	24.0	16.8	3.8	0.5	2.9	3.5	7.5	47.0	3.0	0	3.0	1.0	0	0	0
17	27.0	14.6	8.6	1.6	2.2	4.0	18.0	31.5	5.0	0.5	2.0	7.5	0	0.5	0
23	44.0	28.4	14.2	1.8	2.8	4.0	10.5	26.5	0.5	1.0	3.0	0	0	0	0
26	42.0	19.3	14.3	2.5	5.9	3.5	18.0	20.5	2.5	0	1.0	1.5	0	0	0
30	59.5	45.2	13.1	1.2	0	2.5	8.0	18.0	1.5	0.5	2.5	0.5	0	0.5	0
34	72.0	47.5	23.0	1.4	0	0.5	5.5	12.5	3.5	0	1.0	0	0	0	0
37	73.5	52.9	21.6	0	0	1.0	3.5	12.0	1.0	0	0	1.5	0	0	0
40	80.5	67.6	11.3	1.6	0	0.5	2.0	9.0	3.0	0.5	0.5	0.5	0	0	0
44	71.5	55.8	12.9	1.4	1.4	1.0	7.5	10.0	2.0	1.0	1.0	1.0	0	0.5	0
50	78.0	56.2	18.7	3.1	0	0	3.0	11.5	2.5	1.0	0.5	0.5	0	0.5	0

55	76.0	71.4	4.6	0	0	1.0	0.5	11.5	3.0	1.0	0	0.5	0	0	0
62	86.5	64.0	15.6	5.3	1.7	0	1.0	5.5	2.0	0	0.5	0	0.5	0	0
67	81.0	72.9	8.1	0	0	0	0.5	7.5	4.5	1.5	0.5	0.5	0	0.5	0
74	90.5	54.0	23.5	6.4	1.8	4.5	0.5	7.0	0	0.5	0	1.0	0	0	0
80	87.5	71.8	15.7	0	0	0.5	0	5.0	2.5	1.5	0	0	0	0	0
86	78.5	50.2	28.3	0	0	0	3.5	5.5	2.0	1.0	0	0	0	0	0
92	81.5	73.4	8.2	0	0	0	5.0	5.0	1.5	1.0	0.5	0	1.0	0	0
98	85.0	69.7	11.9	3.4	0	0	2.0	5.0	1.0	1.5	0	0.5	0	0	0
102	85.5	58.1	25.7	1.7	0	0	3.5	3.5	1.0	2.5	0	0	0	0	0
108	83.5	73.5	10.0	0	0	0	1.5	8.0	0.5	2.5	0	0	0	1.0	0
111	91.0	65.5	21.8	5.5	0	0.5	0.5	4.5	0	1.0	0	0	0	0	0.5
113	92.0	62.6	29.4	0	0	0	0	1.5	2.5	0	0	0	0	0	0
115	89.5	50.1	32.2	7.2	0	0	0.5	6.0	1.0	1.0	0	0.5	0	0	0
117	81.5	45.6	31.0	4.9	0	0.5	1.5	6.5	2.0	1.5	0	0	0	0	0.5
119	74.5	30.2	40.3	0	1.4	2.5	0	14.0	4.0	3.5	0	0	0	0.5	0
121	88.5	81.4	1.8	3.5	1.8	0	0.5	5.5	2.0	2.0	0	0	0.5	0	0
124	95.5	93.2	0	0	1.9	0	0.5	3.0	0	0	0	0	0	0	0

in other genera such as Betula, Quercus and Ulmus. Subsequent to a short period of white pine prevalence, however, the reverse of natural succession seems to have occurred (i.e. white pine to red and jack pine). This trend points to the possibility of a drying climate which would affect soil moisture conditions relatively more on slightly developed sand soils than on medium-textured soils. Although this trend may have been brought about by regional factors, it is likely significant that Green Bay was completely dry during Lake Payette and Lake Chippewa times, thus the southerly winds characteristic of May through October at the north end of Green Bay were likely considerably warmer and drier than previously or subsequently.

This secondary dominance of jack and red pine pollen persists from the 110 to the 40-inch level where once again succession toward white pine is indicated. From the 40-inch level upward, natural succession under moister conditions may be indicated by the increase in hemlock, birch and beech pollen. The slightly later increase in spruce and fir beginning at the 25-inch level is typical of a number of bogs in northern Wisconsin, northern Minnesota and Isle Royale. This trend marks the end of the "hypsithermal" interval (Fries, 1962) which is dated at about 2000 years B.P. (Deevey and Flint, 1957). Moister conditions were likely brought about by the rise of water levels to the Nipissing level while subsequent cooler conditions with a concurrent drop of lake levels could have been induced by an increased dominance of dry polar air in winter.

From the 10-inch level upwards, no climatic implications are attached to the fluctuations of percentages since lumbering activities may have influenced them. In comparing the pollen percentages at the 10-inch level with the pre-lumbering forest composition around the bog,

it becomes obvious that jack and/or red pine pollen overrepresents the local abundance of these species since about 17% of the pollen is jack and/or red pine with no evidence of jack or red pine trees within ¼ mile of the bog. White pine pollen percentages, however, do not seem to be much out of line with the relative abundance of that species in the local area. Oak and elm pollen percentages likewise do not represent local trees. Red maple trees in the vicinity of the bog are definitely underrepresented by the pollen, however. These relationships agree with the findings of Benninghoff (1960) and Wilson and Potzger (1943). The presence of hickory and butternut or white walnut (Juglans cinerea) pollen throughout most of the profile probably represents "long-range drift." The unusual occurrence (compared to northern Wisconsin bogs) of both of these pollen types in the upper foot of the profile needs explanation. The nearest known source area for hickory pollen today is 60 to 70 miles southwest of Three Lakes Bog in Dickinson County, Michigan (conversation with an unidentified forester in the Michigan Department of Conservation). The nearest known butternut trees are on Stonington Peninsula, some 25 to 30 miles south of Three Lakes Bog (personal observation and correspondence with J. O. Veatch). House plantings at closer locations is perhaps possible but no such observations are on record as far as the writer is aware nor were any observed by the writer.

The fact that Valders ice did not extend into the high country southwest of Dickinson County (Hough, 1958; Thwaites, 1943) may indirectly account for the occurrence of the small percentages of oak, elm, basswood, hickory and butternut pollen present at the lower levels of the bog profile. Curtis (1959) cites evidence indicating that

Valders ice did not exert a refrigerating effect capable of completely eliminating oak and associated thermophilous species from the surrounding areas. In this event, post-glacial cliseral and successional changes must have been consistently more advanced in the peri-Valders area of the Upper Peninsula than in the Delta-Alger County area, not only because of the time factor but because of the warmer, more continental growing season in the peri-Valders area of western Upper Michigan and adjacent Wisconsin. May and June temperatures at Iron Mountain (Dickinson County) average 3-4 degrees higher than those of the Delta-Alger area, for instance.

The interpretations presented above are subject to additional inaccuracy resulting from the possibility that peat accumulation rates and absolute pollen rain have varied greatly during the past. Certain pollen grains such as those of Populus do not preserve well and thus the post-glacial importance of that genus is difficult to evaluate. Some pollen profiles in Minnesota show high percentages of Populus pollen within the spruce zone and the supraadjacent transitional zone (Wright, 1964). Quaking aspen, however, grows into drier climates than the conifers (Spurr, 1964) and thus post-glacial Minnesota conditions may have been more favorable for their relative abundance than post-glacial Upper Peninsula conditions.

Correspondence of surface pollen percentages to sample plot forest composition (% of total basal area) also might not agree closely because of the possible lack of representativeness of the sampling point with respect to the total stand.

Foliar Analyses

The foliar analyses by plot and species are shown in Table 7. The

TABLE 7. CHEMICAL COMPOSITION OF NEEDLES AND LEAVES

Site	Great Soil Group or Soil Type	Species	N %	K %	P %	Ca %	Mg %	Mn ppm	Fe ppm	Cu ppm	B ppm	Zn ppm	Mo ppm	Al ppm
A1	Regosol sand	B. Fir	1.07	0.46	.151	0.83	0.11	54	41	3.0	28.3	44	3.8	26
A2	Eastport sand	R. Pine	0.92	0.55	.159	0.16	0.10	46	25	6.8	13.5	34	0.9	23
A2	Eastport sand	W. Pine	1.19	0.50	.168	0.24	0.11	22	44	4.3	19.0	36	1.0	30
A3	Eastport sand	R. Oak	1.96	0.60	.202	0.94	0.23	167	75	8.4	40.4	38	4.2	40
B1	Rubicon sand	Hemlock	1.77	0.88	.273	0.52	0.16	291	72	6.0	33.0	19	2.4	195
B1	Rubicon sand	Y. Birch	2.32	0.86	.299	1.92	0.45	343	146	12.0	87.0	329	8.2	96
B2	East Lake sand	S. Maple	1.60	0.78	.411	1.10	0.18	1114	78	3.0	45.5	24	4.6	30
B2	East Lake sand	A. Beech	1.13	1.16	.245	0.77	0.16	841	118	18.5	36.8	47	3.6	44
C1	Rubicon sand	R. Pine	0.52	0.70	.159	0.16	0.10	348	34	7.6	22.5	30	0.7	114
C1	Rubicon sand	W. Pine	1.23	0.62	.159	0.30	0.15	156	75	12.9	21.3	38	1.4	125

pioneer conifers (pines and balsam fir) have lower contents of N, K, Mg, P, and B than do the northern hardwoods, except that beech has relatively low N and Mg contents. Sugar maple and beech have high contents of Mn compared to all other species analyzed. In the case of calcium, balsam fir foliage from a calcareous site has a content considerably greater than that of the pines on a calcareous site. Regardless of exchangeable soil calcium quantities, the pines in this study contain lower amounts of foliar calcium and molybdenum than any of the other trees analyzed.

Foliar composition differences due to site are apparent in the case of red and white pine. Manganese and aluminum contents are much greater in the foliage from the Rubicon site (C1) than from the Eastport site (A2); in addition, potassium, iron, copper and boron contents are somewhat higher in C1 pine foliage than in A2 pine foliage.

Lack of response to site seems evident in the case of red pine foliar calcium, phosphorus and magnesium. Foliage samples from both red pine sites (A2 and C1) contain identical amounts despite wide differences in available P and exchangeable Ca and Mg in the soils.

Definite differences between species are indicated where two or more kinds of trees were sampled on the same soil type. The red oak sample contained decidedly higher concentrations of all the elements except K, Zn and Al when compared with the pines. The white pine samples contained more N, Ca and Fe than the red pine samples with the difference tending to be greater on the better developed Podzol. On the other hand, the red pine foliage contained decidedly more Mn than did the white pine foliage; the ratio between the two species was similar on both sites, averaging about 2.16/1. The yellow birch sample contained decidedly higher concentrations of Ca, Mg, Fe, Cu,

B, Zn, and Mo than did the hemlock sample; greater amounts of N and Mn in the yellow birch foliage are also indicated, but to a lesser degree. The hemlock foliage, however, has concentrations of Al amounting to twice that of the yellow birch foliage. The sugar maple foliage sample contains considerably more N, P, Ca and Mn than does the beech sample, whereas the beech foliage apparently has higher concentrations of K, Fe, Cu, Zn and Al.

Similarities between site-mates also seem to be present. Foliar K values of the two pines and red oak are quite similar on Eastport sand. The pines have similar values of K and P on Eastport sand and Rubicon sand. The yellow birch and hemlock samples contained similar concentrations of potassium and phosphorus. Concerning sugar maple and beech foliage, only Mg seems to be similar, but both the sugar maple and the beech samples contained concentrations of Mn that were at least twice as high as those of the other samples.

The foliar calcium values for pines, hemlock and beech in this study are low but are within the ranges reported by others, Tables 1 and 2. The order of percentages for the various species is essentially the same as that of Bard for hardwoods and hemlock and the same as that of Plice for fir and pines.

Foliar potassium values for white pine and balsam fir foliages are very similar to those of Gerloff et al. reported in Table 2. For hemlock and beech, potassium values are similar to those of Bard listed in Table 2. For other northern hardwoods, potassium values are higher than those of Gerloff et al. but lower than those of Bard. Balsam fir had the lowest foliar K in this study and in that of Chandler. Foliar phosphorus values for the conifers are similar to those found by Gerloff et al.

Values for hardwoods are similar to or higher than those of Bard. Bard's data indicate that, for most species, foliar P increases with depth to lime. This trend is most obvious in the case of sugar maple but also seems to be quite consistent in red oak foliage. From this trend it might be inferred that more acid sites than those studied by Bard would give rise to still higher values of foliar P in the case of some species. Therefore the relatively high values of foliar P for sugar maple, beech and yellow birch reported here may be largely related to the soil acidity.

Foliar N values in this study are similar to or somewhat lower than those of Gerloff et al. but the values for hardwoods (except beech) are similar to those given by Bard for mature foliage. Values are within the ranges reported in individual studies except for the high value for hemlock which may be due to sampling inadequacy or to the nature of the site. Orders of percentages between species compare favorably with the data of Bard in the case of hardwoods (except for beech) and with Chandler in the case of pines and fir.

Better correspondence might have been obtained between the data collected in this study and that collected in others had sites been similar, if there had been replications in this study and if the sampling procedures in all the studies involved had been standardized (vide Kramer and Kozlowski, 1960).

"A" site components seem to be characterized by having relatively low concentrations of foliar K, P and Mn. Perhaps their status as pioneer trees on relatively unweathered calcareous sands is dependent on their low requirements for these three elements. For instance, white spruce, which is a frequent component on these types of sites, was found to have a low foliar deficiency level of potassium (Heiberg and White, 1951). The pioneer pines, however, undoubtedly cycle much less Ca than do fir and spruce on these calcareous sands.

On the weakly and weakly to moderately developed Podzol sites with calcareous "U" horizons (Sites B1 and B2), hemlock is conspicuous with respect to its low foliar calcium content and its extremely high foliar aluminum content. On Site B1, hemlock and yellow birch are site-mates and have similar concentrations of foliar K and P. The similarities end there, however, with the consequence that these two species most likely do not affect the upper soil horizons in a like manner. Specifically, yellow birch probably tends to raise the percent base saturation while hemlock tends to lower it.

Sugar maple and beech occur together on Site B2, and their foliage seems to be similar with respect to magnesium and high concentrations of manganese found in them both. In this case, perhaps similar <u>tolerances</u> to high soil manganese is important. Wilde (1958), for instance, mentions that high contents of soluble manganese in Podzols seem to limit root penetration. If the high concentration of foliar P in the sugar maple sample is representative, the presence of this species should have an appreciable effect on the chemical and biological properties of the upper soil horizons.

During the course of natural forest succession and soil development at these sites, certain trends in mineral cycling seem to be indicated. Foliage of pioneer balsam fir stands bring considerable quantities of calcium into the surface horizons of the soil. Should pines be the pioneer forests, however, much smaller amounts of calcium are brought to the surface along with only small amounts of the other elements as well. The data point to the possibility that upon the continued

dominance of the pines, strongly acid, weakly-developed Podzols eventually form with the consequence that greatly increased amounts of Al and Mn are brought to the surface. At this stage white pine tends to bring considerably more N, Ca, Mg, Fe, Cu and Mo into circulation than does red pine, while the latter species cycles much more Mn than does white pine. As in the pioneer stage, the amounts of K and P cycled by each species are similar, with the concentrations of P being no greater than in the earlier stage of succession.

If, however, succession to mixed stands of white pine, hemlock and yellow birch takes place prior to deep leaching of the carbonates, weakly developed Podzols (such as that at Site B1) may still form, but the mineral cycling pattern will probably differ considerably from that of the pine-dominated, weakly-developed Podzol sites (such as Site C1). Compared to red pine foliage from the carbonate-containing sands the foliages of hemlock and yellow birch contain concentrations of N, Ca, Fe and Mo that are at least twice as high, and P and B concentrations which are somewhat higher. Cycling of aluminum by hemlock is intense.

Succession to sugar maple and beech involves the introduction of foliage with high concentrations of K (beech) or P (sugar maple) and Mn (both species), thus subsequent leaching losses of these elements may be thereby reduced.

Although red oak is not necessarily a constituent of the seres leading up to the sugar maple-beech climax, this oak does occur throughout the Podzol Region of Michigan, and is numerically dominant in some natural stands and on many cut-over pine-oak sites. It is associated with red and white pine as well as northern hardwoods. The red oak

foliage from Site A3 indicates that on very weakly developed Podzol sands, this species cycles concentrations of potassium similar to those of the pines. Phosphorus concentrations are intermediate between those of the pines and those of the northern hardwoods, while nitrogen, calcium and magnesium concentrations are more similar to those of the northern hardwoods.

Acid fall leaching under pines should be quite severe since the forest floor is very strongly or extremely acid prior to September and the foliage indicates that subsequent increments of litter will not be rich in bases either. In northern hardwood stands, however, the flood of relatively basic leaves added to the forest floor in October should reduce the potentiality for subsequent acid leaching by forest floor constituents. Spring leaching, however, may be considerable due to the increasing release of hydrogen ions (in the process of root respiration) and the replacement of basic cations, some of which may not be taken up by plant roots and may thus be leached from the ecosystem.

Mor Humus Formation

Based on the theory of mor humus formation developed by Handley (1954) and Davies *et al.* (1960)* it seems likely that nitrogenous constituents in the mesophyll tissues of dying pine, hemlock, and beech foliage become stabilized by polyphenols. Since polymerization of polyphenols is favored by base-rich conditions, and polymerization beyond a certain molecular size precludes any tanning action by

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*The theory proposes that polyphenols in dying leaves stabilize the proteins in the mesophyll tissues. These stabilized proteins protect the mesophyll cell walls from decomposition and together they form an amorphous residue lying on the surface of the mineral soil.

polyphenols (Coulson et al., 1960), it is probable that the low calcium and magnesium content and/or the low antacid buffering capacity of the foliage of the above species is conducive to the tanning process. This hypothesis seems logical since the chemical characteristic that most clearly separates the mull horizons from the mor horizons in this study is the exchangeable Ca (#/AFS): organic matter (%) ratio which is above 200 in all the Vh horizons and below 100 in all the Oh horizons.

Soil Microflora Studies

Direct microscopic counts of microflora in the Oh horizon of the Site B1 soil and in the Vh1 horizon of the Site D1 soil are tabulated in Tables 8 and 9. These horizons represent the extremes of mor and mull humus types found in this study.

Counts of bacterial cells did not reveal a maximum per gram of soil in the mull humus horizon but there were twice as many cells per gram of organic matter in the mull horizon as in the mor horizon. The mull horizon contained vastly greater amounts of actinomycete filaments; and per gram of organic matter, this horizon contained 25 times as much as the mor Oh horizon. Amounts of unstained fungal hyphae were greater in the mor Oh horizon than in the mull Vh1 horizon. Again, however, amounts of stained and unstained hyphae per gram of organic matter were greater in the mull Vh1.

The presence of greater amounts of actinomycete filaments in the Vh1 horizon is in accordance with previous studies which indicate that environments having a pH greater than about 5.0 are more favorable than those having a lower value (Alexander, 1961). High numbers of bacterial cells/g of soil in the mor Oh horizon are likely the result of the high

TABLE 8. DIRECT MICROSCOPIC COUNTS OF MICROORGANISMS IN THE Oh HORIZON, SITE B1*

	Bacterial Cells	Actinomycete Filaments	Fungal Hyphae									
			Stained					Unstained				
Diameter Groups (u)	- - -	- - -	2-3	4-6	7-13	14-26	Total	2-3	4-6	7-13	14-26	Total
No./g moist soil	1.2×10^8	-	-	-	-	-	-	-	-	-	-	-
No./g O.D. soil	1.8×10^8	-	-	-	-	-	-	-	-	-	-	-
No./g O.M.	5.5×10^8	-	-	-	-	-	-	-	-	-	-	-
Meters/g (moist soil)	-	4.66	18.6	85.9	1.75	0.00	106	675	1057	31.1	0.00	1763
Meters/g (O.D. soil)	-	6.96	27.8	128	2.61	0.00	159	1007	1577	46.4	0.00	2631
Meters/g O.M.	-	21.1	84.2	388	7.91	0.00	482	3051	4778	141	0.00	7973
Volume (cu.cm.)/g (Moist soil)	-	-	.000	.002	.000	0.00	.003	.003	.021	.002	.000	.026
Volume (cu.cm)/g (O.D. soil)	-	-	.000	.003	.000	.000	.004	.004	.031	.003	.000	.038
Volume (cu.cm.)/g Organic Matter	-	-	.003	.009	.000	.000	.012	.012	.094	.009	.000	.127
Surface Area (sq. cm./g) (moist soil)	-	-	1.46	13.5	.550	.000	15.5	52.9	166	9.77	.000	228
Surface Area (sq.cm.) /g O.D. soil	-	-	2.18	20.1	.821	.000	23.1	79.0	248	14.6	.000	342
Surface Area/g of Organic Matter	-	-	6.61	60.9	2.49	.000	70.0	239	752	44.2	.000	1035

*Moisture content = 32.8%; O.M. content = 32.72%; % N in O.M. - 2.82; exchangeable Ca = 1210#/AFS; pH = 4.4; avail. P = 30#/AFS

TABLE 9. DIRECT MICROSCOPIC COUNTS OF MICROORGANISMS IN THE Vh1 HORIZON, SITE D1*

	Bacterial Cells	Actinomycete Filaments	Fungal Hyphae									
			Stained					Unstained				
Diameter Groups (u)	- - -	- - -	2-3	4-6	7-13	14-26	Total	2-3	4-6	7-13	14-26	Total
No./g moist soil	7.8×10^7	-	-	-	-	-	-	-	-	-	-	-
No./g O.D. soil	1.7×10^8	-	-	-	-	-	-	-	-	-	-	-
No./g O.M.	1.3×10^9	-	-	-	-	-	-	-	-	-	-	-
Meters/g moist soil	-	31.3	18.6	19.3	3.7	0.00	41.6	69.3	158	31.7	16.4	276
Meters/g O.D. soil	-	68.0	40.4	42.0	8.0	0.00	90.4	151	345	68.9	35.7	600
Meters/g O.M.	-	523	311	323	61.5	0.00	695	1162	2654	530	275	4615
Volume/g moist soil (cu.cm.)	-	-	.000	.000	.003	0.00	.003	.000	.003	.002	.005	.010
Volume/g O.D. soil (cu.cm.)	-	-	.000	.000	.007	0.00	.007	.000	.007	.004	.011	.022
Volume/g O.M. (cu.cm.)	-	-	.000	.000	.054	0.00	.054	.000	.054	.031	.085	.170
Surface Area/g moist soil (sq.cm.)	-	-	1.46	3.03	1.16	0.00	5.65	5.44	24.8	9.95	10.3	50.5
Surface Area/g O.D. soil (sq.cm.)	-	-	3.17	6.59	2.52	0.00	12.3	11.8	53.9	21.6	22.4	110
Surface Area/g O.M. (sq.cm.)	-	-	24.4	50.7	19.4	0.00	94.5	90.8	415	1661	1723	3890

*Moisture content = 53.56%; organic matter content = 13.16%; % N in O.M. - 4.58; exchangeable Ca = 3482#/AFS; pH = 5.2; Avail. P = 10#/AFS percentage of organic matter in that horizon; on the other hand, the relatively low numbers per gram of organic matter is possibly related to the greater decomposition resistance of mor organic matter as compared to that of mull. Although anti-bacterial substances may be partly responsible for this low density, the lower N content of the organic matter in the Oh horizon could also be of significance. The relatively high content of unstained fragments of fungal hyphae (representing dead fungi according to Jones and Mollison) in the mor Oh horizon agrees with the findings of Romell (1935) and statements made by Wilde (1960). The fact that the volumes of these fragments comprise as much of the weight of the organic matter in the mull Vhl as in the mor Oh is due to larger quantities of hyphae of large diameter in the Vhl horizon. This hyphal diameter difference points to a difference in specific composition of fungal populations in the two horizons. Comparisons of hyphae volumes per unit volume of organic matter, however, cannot be made from the data available.

Despite the possibility that the results of this study may have only limited applicability, it seems worthy to mention the possible significance of relatively high amounts of actinomycete filaments. Alexander (1961) states that these organisms are relatively scarce during the initial stages of plant residue decomposition but become more prominent later when nutrient levels are lower and competition from other organisms is less. Their competitive advantage in the latter stages of decomposition probably stems from the fact that they can utilize such carbon sources as cellulose and chitin. Since chitin is a cell wall constituent of many fungi, the larger surface area of unstained hyphae in the Vhl horizon might be a factor in promoting

the larger number of actinomycetes in that horizon. Actinomycetes have also been found to have the ability to oxidize polyphenols to quinones through their production of phenoloxidases (Kononova, 1960). Kononova further states that a number of studies have shown that the condensation of the quinones thus formed produces complex, dark-colored humic substances.

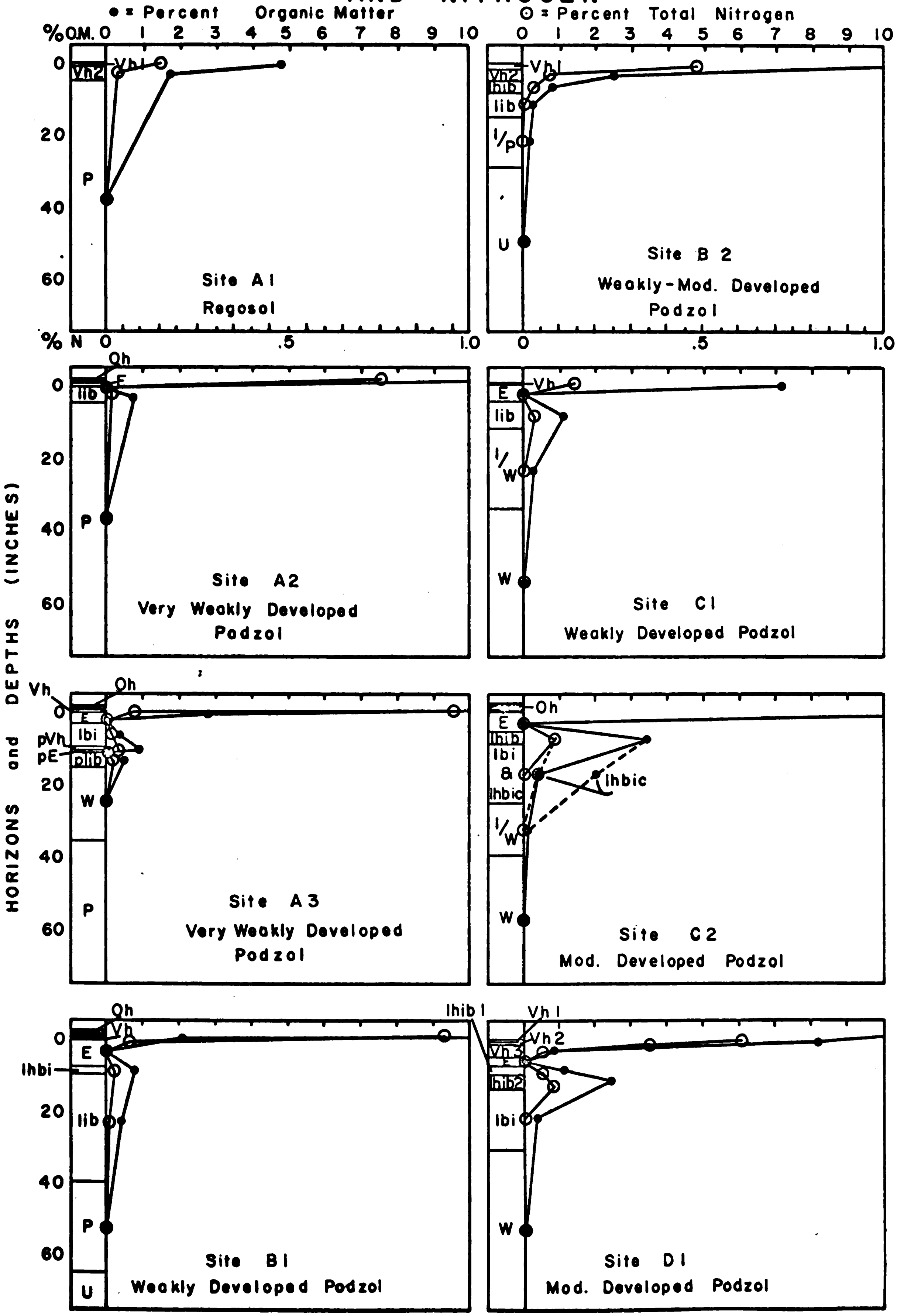
Total Soil Carbon, Soil Organic Matter and Soil Nitrogen

Total carbon concentrations were invariably highest in the surface horizons. When converted to percent organic matter, these surface horizon values range from 4.87% in the Vh1 horizon of Profile A1 to 51.04% in the Oh horizon of Profile C2 (see Appendix). Profile distributions of percent organic matter and total nitrogen are shown graphically in Figure 21. These graphs show that a secondary peak of organic matter occurs in the subsoil of all profiles with an E horizon. This peak is most pronounced in the Ihib horizons of Profiles C2 and D1 (the only moderately developed Podzols), a result expected since the dark colors of these horizons indicate a relatively high organic matter content. However, the organic matter percentage is apparently not the only factor contributing to dark illuvial horizons. For instance, the Ihib horizons of Profiles B1 and B2 contain 0.78% and 0.79% organic matter, respectively. The Munsell color notation of B1-Ihib, however, is 5YR 4/8 while that of B2-Ihib is 5YR 3/6. The upper illuvial horizons of Profiles C1 and D1 contain 1.13% and 1.16% organic matter, respectively, while their colors are moderate brown (7.5YR 4/4) and dark grayish brown (5YR 2/2), respectively.

Conversion of O.M. percentages to the estimated number of pounds per acre results in the following values for the illuvial zones:

FIG. 21

PROFILE DISTRIBUTIONS OF ORGANIC MATTER AND NITROGEN



Profile	Pounds/illuvial zone/acre
A1	-
A2	5548
A3	6364
B1	42,120
B2	19,628
C1	41,762
C2	54,356
D1	57,753

These values indicate that illuviation of organic matter has been taking place at a faster rate and/or for a longer period of time in Profile B1 than in Profile B2 although the soils are chronologically of the same age. The same thing is true of Profile C2 as compared with Profile C1. This difference in degree of development may be related to the length of time during which the sites have been characterized by mor humus layers and hemlock-hardwood forests.

Soil Organic Matter Fractionation

The percent humic acid of the illuvial horizons from Profiles B2 and D1 (hardwood mull humus sites) exceeded the percent organic matter, thus pointing to the possibility that clay was also present in the humic acid fraction obtained. Fulvic acid was present in all horizons containing organic matter, the brownish orange or brownish yellow colors resembling very closely the color of concentrated crenic acid described later.

The results of several studies indicate that hardwood lignins contain syringyl groups whereas conifer lignins do not (see Kononova, 1961). R. I. Morrison (1958) used this distinction to identify the source of organic matter in some Scottish soils and peats. The thermodecomposition technique used in the present study suggested that syringyl groups were absent even in 100% hardwood soils. Guaiacol

and phenols were present in the humic acid fraction from both mors and mulls (B1-Oh, B1-Vh, B2-Vh2, D1-Vh2) and in the Ihib of Profile B2 (in this soil, the Vh2 grades directly into the Ihib). In the D1 soil, no similar components could be found in the Ihib2 (distinct E horizon separates Vh from I horizons), suggesting that illuvial humus has a different composition than Vh humus.

Although the origin of the illuvial organic matter could not be determined as anticipated, it is clear that the organic matter of the Oh and Vh horizons studied contains materials derived from lignin polymers; thus the name "ligno-mycelial mor" (Wilde, 1958) seems quite appropriate for the humus layer of Profile B1.

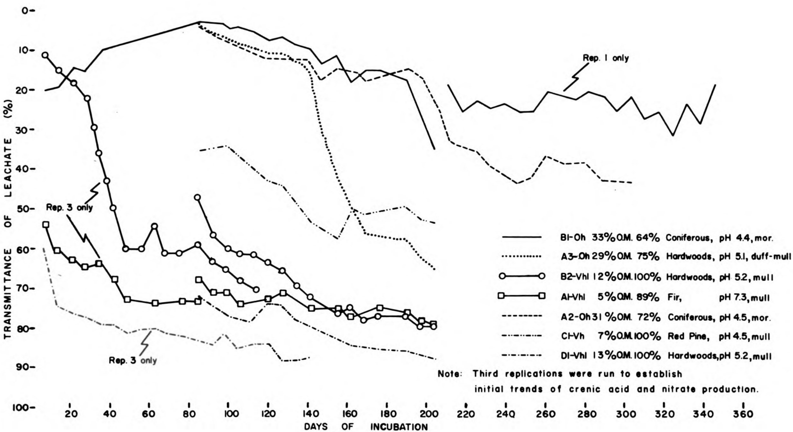
The presence of illuvial horizon humic acid does not necessarily imply movement of this fraction since humic acid can be formed from fulvic acid in the presence of iron ions in an acid medium (Sheffer and Ulrich, 1960). Martin (1960) states that the relative amounts of these two organic matter fractions seems to be controlled by the amount of ionic Al present; his studies indicate that ionic Al is capable of flocculating Podzol humus at pH values commonly found in Podzol soils.

<u>Crenic Acid Production of Soil Horizons</u>

At the onset of the incubation and leaching study, obvious amounts of acidic, yellow organic matter were noted in some leachates while others contained none. Berzelius applied the term "crenic acid" to such acidic, water-extractable organic materials. Crenic acid, or components of this fraction, have frequently been referred to as important metal-complexing agents in the formation of Podzols. The pattern of crenic acid production for each sample is shown graphically in Figure 22. The Munsell color notations of these yellow leachates were all close

FIG. 22

PATTERN OF CRENIC ACID PRODUCTION WITH TIME



to 2.5YR 8/6 when considerable amounts of the organic matter were present. Several hundred milliliters of these leachates (initial composite pH of 5.3) were concentrated by evaporation at 70°C to a volume of about 10 ml; at this point the pH of the concentrate was 4.4 and the color notation was 5YR-7.5YR 5/6-5/8 (brownish orange). The individual leachates were quite stable and precipitation did not occur when the pH was lowered to about 2.0 with HCl. Under ultra-violet light, the leachates fluoresced a light green.

When two replicates of the A3-Oh sample were depleted of the yellow organic matter by continuous leaching, one week of incubation was sufficient to bring the concentration of this material back up to values existent prior to continuous leaching. In addition, the yellow organic matter was depleted less rapidly when leached at weekly intervals than when continuously leached. These relationships are shown graphically in Figure 23. It would appear that crenic acid production was an ongoing process, probably associated with microbial degradation of litter residues in the Oh horizon.

The illuvial horizons of Profiles B1, B2 and D1 and the Vh2 horizon of Profile D1 produced clear leachates having pH values near neutrality.

<u>Nitrate Production of Soil Horizons</u>

None of the untreated samples contained nitrate initially and only the mull Vh1 samples were nitrifying by the 70th day of incubation. The average length of time required for the inception of nitrification in each sample is shown in Table 10. The pattern of cumulative nitrate production is shown in Figure 24.

FIG. 23

DEPLETION AND RECOVERY OF CRENIC ACID IN LEACHATES

From Oh Horizon At Site A 3

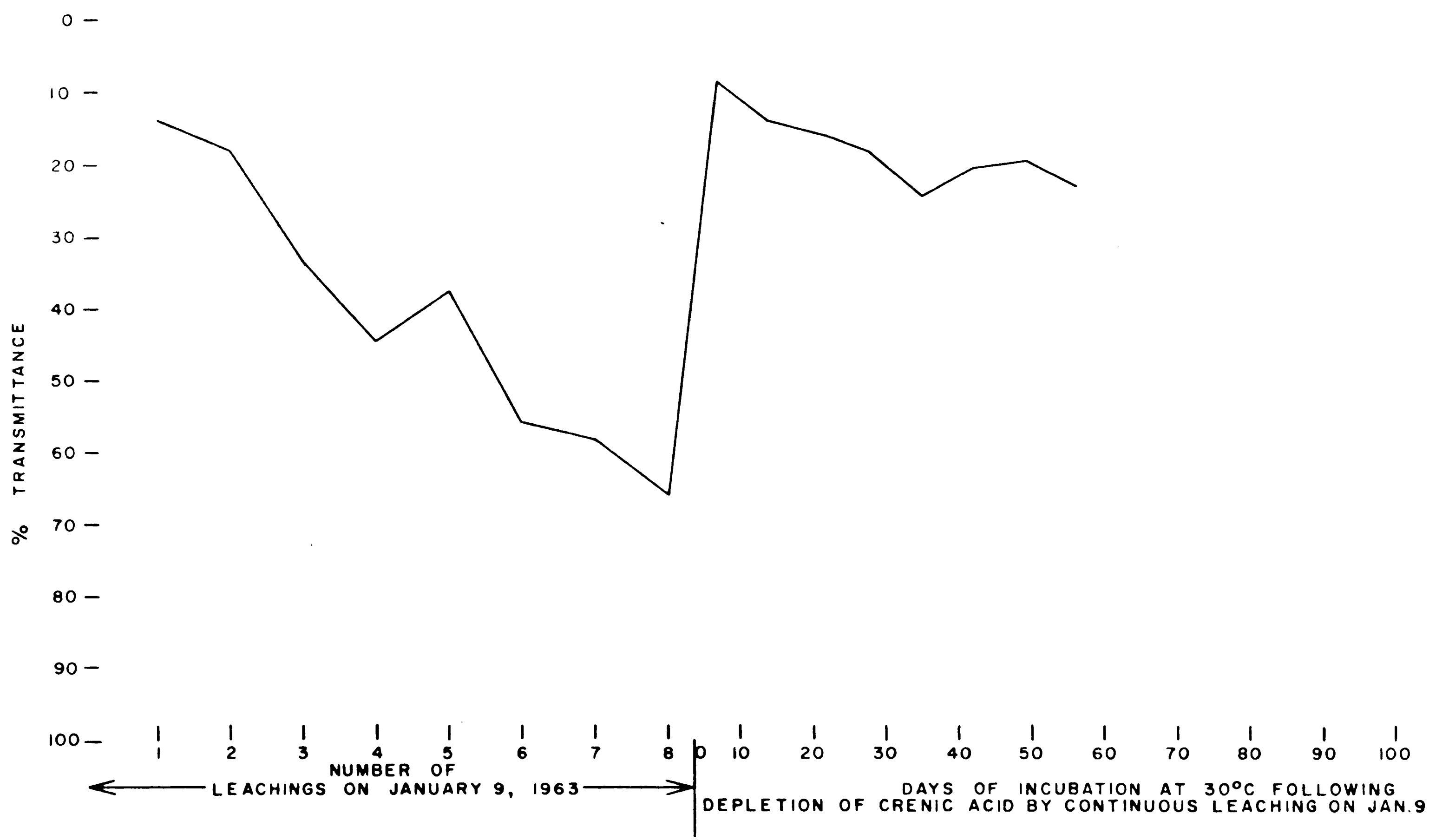


FIG. 24

PATTERN OF CUMULATIVE NITRATE PRODUCTION

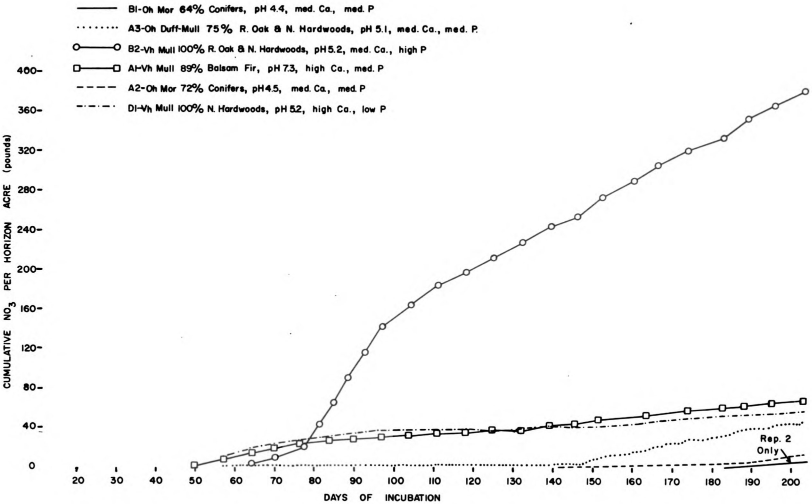


TABLE 10. RELATIONSHIP OF HUMUS TYPE, pH AND % O.M. TO THE INCEPTION OF NITRATE PRODUCTION IN SURFICIAL HUMUS-CONTAINING HORIZONS.

Site	Humus Type	Horizon	pH	%O.M.	Inception of NO3 Production
A1	Sand Mull	Vhl	7.3	4.87	Approximately 50 days
A2	Thick Mor	Oh	4.5	31.39	168-175 days
A3	Thick Duff-Mull	Oh	5.1	28.73	133-140 days
B1	Thick Mor	Oh	4.4	32.72	233-240 days
B2	Medium or Coarse Mull	Vhl	5.2	11.91	57-64 days
C1	Shallow Sand Mull	Vh	4.5	7.19	None produced in 210 days
D1	Medium or Coarse Mull	Vhl	5.2	13.16	Less than 50 days

Since three replicates were already nitrifying after the first incubation period (50 days) and therefore their inception date unknown, a third replication was initiated with four of the samples in order to determine early trends in NO_3 and yellow organic matter production. The NO_3 inception times were:

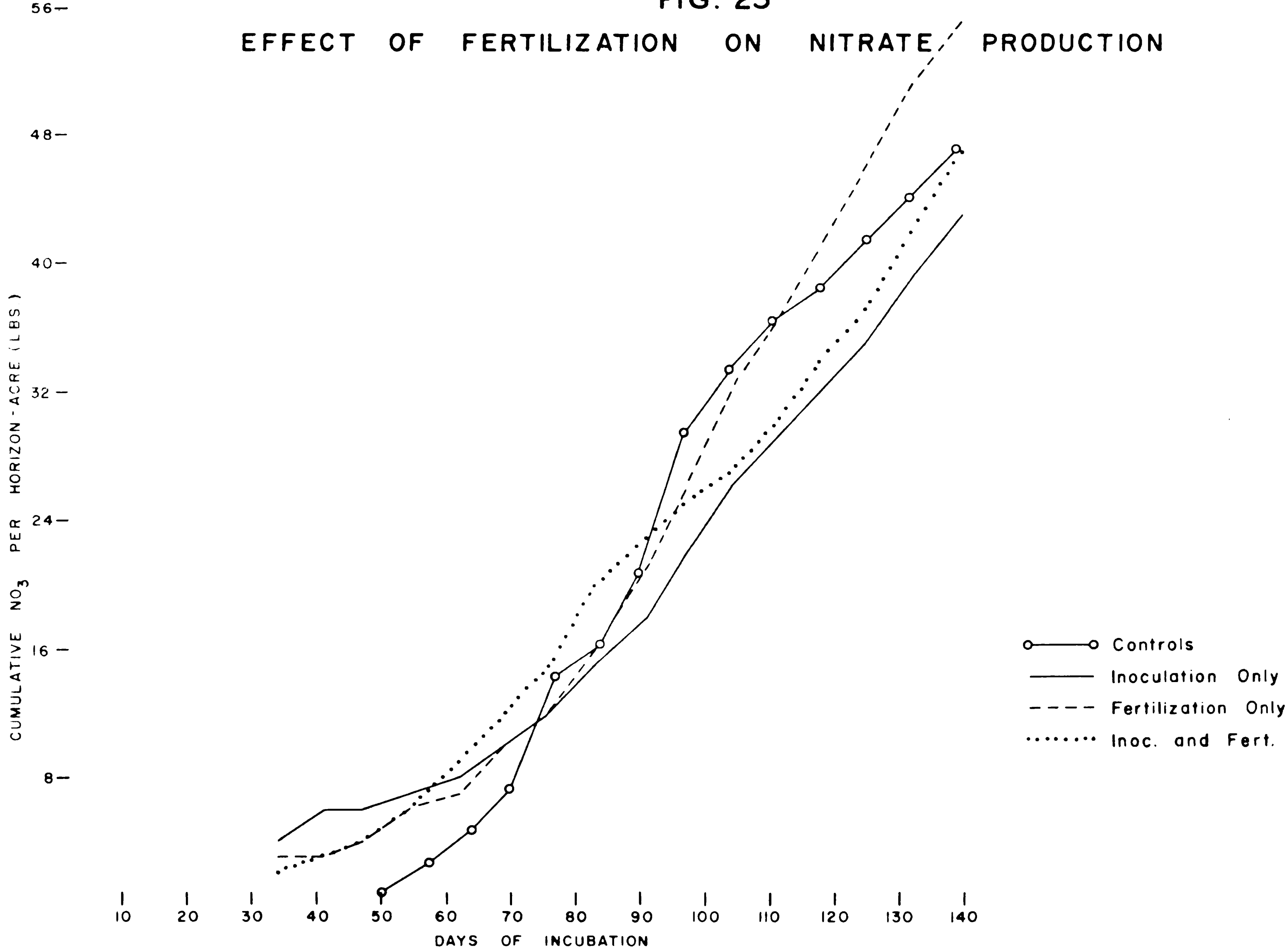
B1-Oh	-	141 days
B2-Vhl	-	21-28 days
A1-Vhl	-	7-14 days
D1-Vhl	-	0-7 days

The pattern of crenic acid production for Replication #3 is shown in Figure 22. Results were probably affected by the smaller sample sizes (5g. instead of 10g.) used in the third replication but the order of nitrification inception and crenic acid production agrees with the first two replications.

The treatments used did not appear to have any effect on total nitrate production (see Figure 25). However, inception of nitrification occurred earlier in the treated samples than in the untreated ones and

FIG. 25

EFFECT OF FERTILIZATION ON NITRATE PRODUCTION



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crenic acid production was less in the fertilized samples (see Figure 26). Since smaller samples were used for the treatments than for the controls, earlier nitrification inception may have been related to sample size rather than treatment.

Figures 27 and 28 indicate that there is a relationship between nitrate production, pH and the production of yellow organic matter. Further, the inception of nitrification is accompanied by sharp decreases in pH and sharply reduced production of yellow organic matter.

Since mor humus is a feature of most Podzols and since the Podzol-forming process is thought by some to be intimately associated with crenic acid activity, it is not surprising to find that maximum crenic acid production occurred in the mor humus horizons. However, some crenic acid was produced in the Vh1 horizon of one of the mull humus layers (Site B2).

Although nitrite and ammonium measurements were not made in the present study, studies of similar soils indicate that ammonium accumulation occurs in the absence of nitrification and Basaraba (1964) found that around 0.50% chestnut tannin was sufficient to inhibit nitrite formation. Basaraba also noted that fungi, especially Aspergillus niger, developed in soils having concentrations up to 2.00% chestnut tannin. Since Aspergillus niger utilizes tannins as a carbon source, it is conceivable that these and/or related fungi are the major ammonifying organisms which are functional at these high tannin levels. Such a circumstance could conceivably result in appreciable ammonium accumulation until the phenolic content of the humus is reduced to a level which is non-toxic to the nitrifying bacteria. The consequence of such an accumulation of ammonium may

FIG. 26

EFFECT OF FERTILIZATION ON CRENIC ACID PRODUCTION

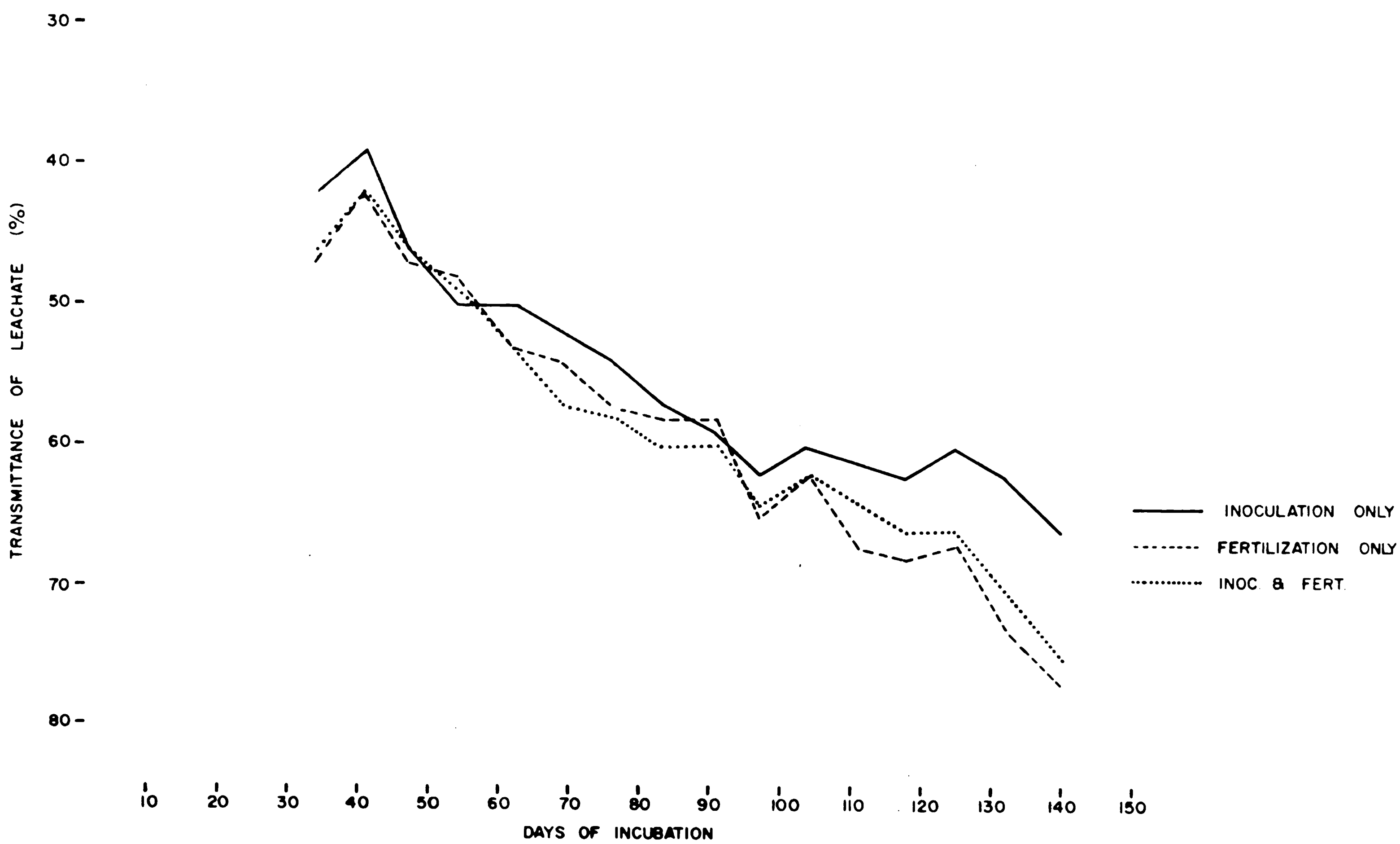


FIG. 27

INTERRELATIONSHIPS OF LEACHATE CHARACTERISTICS

(Sample A 3-Oh, Rep 2)

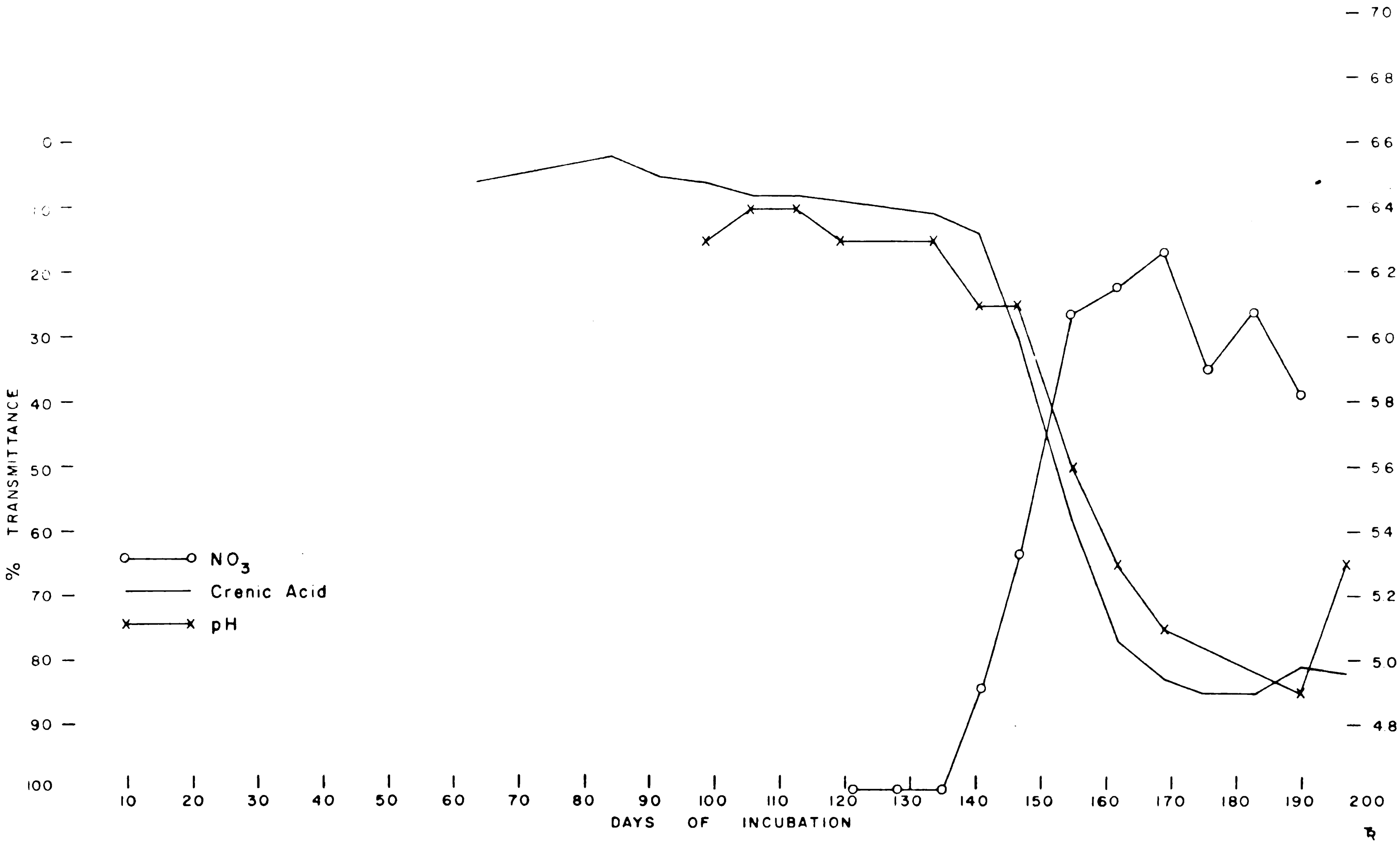
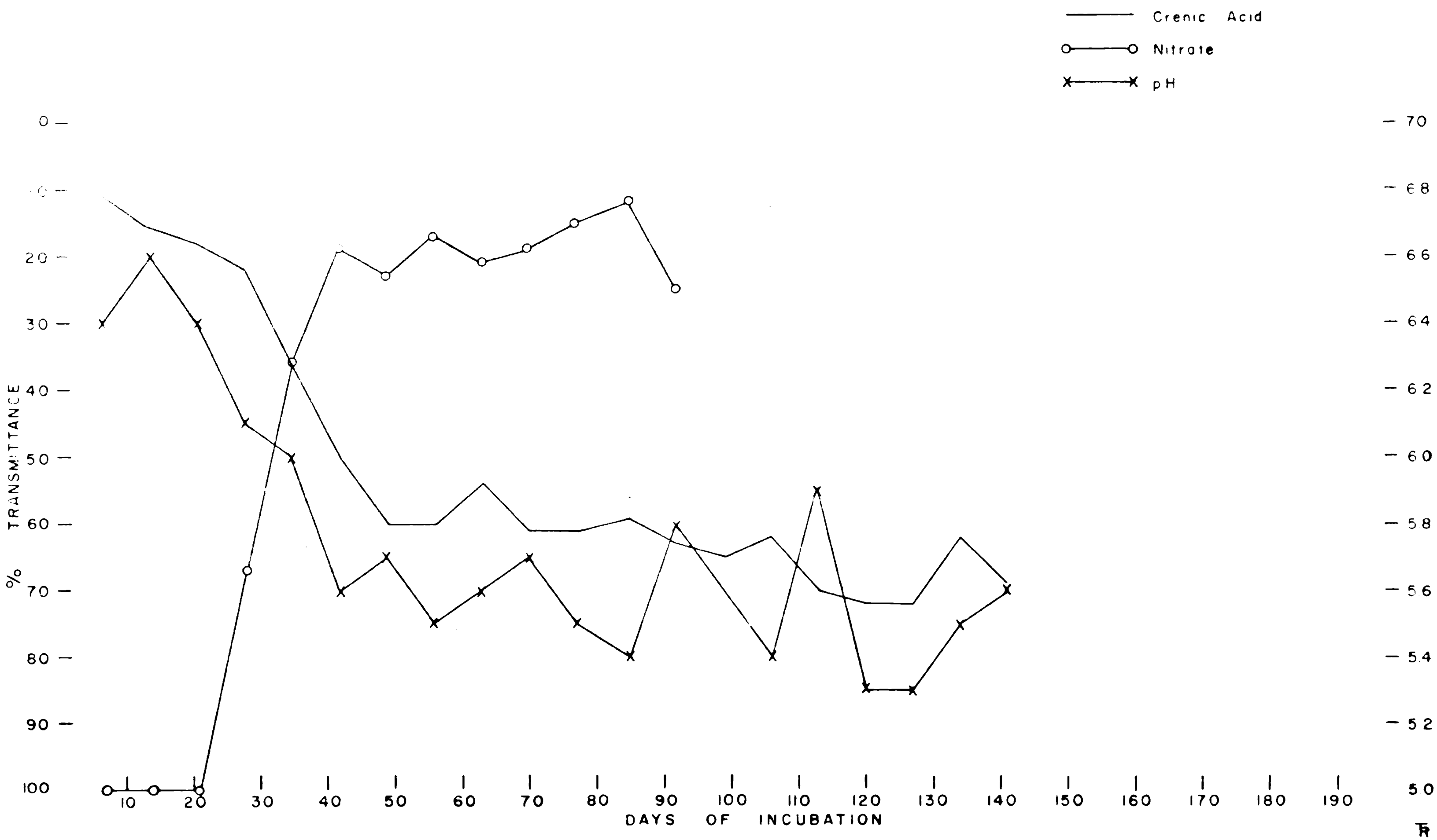


FIG. 28

INTERRELATIONSHIPS OF LEACHATE CHARACTERISTICS

(Sample B2-Vhl, Rep 3)



be the dispersion of some of the organic matter as NH_4- crenate thus making it more susceptible to leaching as suggested by Remesov. The results of this study seem to support this contention since the highest rates of crenic acid production in all of the samples took place in the absence of nitrification. Further, in samples producing large amounts of crenic acid initially, the inception of nitrification followed a slow decline in crenic acid production and was coincident with a sharp decrease in crenic acid production. This relationship suggests that much of the ammonium that was involved in crenic acid production was suddenly diverted into the nitrification process especially since logarithmic increases in nitrate production were correlated with logarithmic decreases in crenic acid production. The inception of nitrification could have resulted from the slow decrease in toxic substances removed by crenic acid leaching. The most likely toxicants involved are phenolic substances which are known to occur in humus layers and in fulvic acid (according to Oden, fulvic acid = crenic acid + apocrenic acid, vide Kononova, 1961).

While the production of crenic acid is usually attributed to the activity of fungi it is also possible that it is a bacterial decomposition product derived from dead, yellow-pigmented fungal hyphae. In this connection, the sample producing the most crenic acid (Oh horizon, Site B1) contained yellow fungal mycelia and three times as much surface area of dead (unstained) fungal hyphae as the sample producing the least amount of crenic acid (Vhl horizon, Site D1). Bacterial populations (per gram of O.D. soil prior to leaching) were similar in both samples.

Although no information was gathered on concentrations of

nitrification inhibitors in these studies, certain upper humus horizon properties seem to be related to the observed patterns of nitrification. If the horizons are grouped according to nitrate production and lag periods (see Table 11) the groups are seen to not only differ in gross nitrification patterns but also with respect to certain other soil properties. Group I horizons have low extractable aluminum concentrations and relatively high pH values. Group II horizons have high organic matter and extractable aluminum concentrations and the Group III horizon has a very high C/N ratio.

According to Alexander (1961), the rate of nitrification typically becomes negligible below a pH of 5.0. He states further that some soils nitrify at a pH of 4.5 and others do not. In this study, nitrification was negligible for four months in horizons having pH values below 5.2. High amounts of extractable aluminum seem to be more distinctly related to the lack of nitrification but no corroborating correlations could be found in the literature. Two horizons having initial pH values of 4.4-4.5 eventually nitrified while a third horizon did not; the non-nitrifying horizon had the highest C/N ratio (30) of all the upper humus horizons studied. Russell (1961) mentions that nitrification is limited by low phosphate contents. Although lag periods (pre-nitrification periods) in Group I vary inversely with exchangeable calcium, the horizon with the longest lag period produced the most nitrate by far; this horizon had an available P concentration about 5 times as high as the other two. Wilde (1958) states that the absence of large quantities of soluble organic matter is essential for the process of nitrification. The Group II horizons produced the most crenic acid and the relative amounts produced within the group were

TABLE 11. NITRIFICATION-SOIL PROPERTY RELATIONSHIPS

Nitrification Group	Site & Horizon	NO_3 (#/200 days)	Lag Period (Days)	Extract Al_2O_3 (ppm)	pH	% O.M.	Total N(%)	C/N	Avail. P (#/AFS)	Exch. Mg (#/AFS)	Exch. Ca (#/AFS)
I	D1-Vhl	733	50	250	5.2	13.16	0.603	13	10	108	3482
	A1-Vhl	473	43-50	650	7.3	4.87	0.141	20	10	108	3106
	B2-Vhl	1237	57-64	600	5.2	11.91	0.482	14	49	170	2444
II	A3-Oh	232	133-140	1550	5.1	28.73	0.957	17	24	188	1881
	A2-Oh	165	168-175	1000	4.5	31.39	0.750	24	29	99	2620
	B1-Oh	17	233-240	1650	4.4	32.72	0.923	20	30	115	1210
III	C1-Vh	0		900	4.5	7.19	0.139	30	15	114	1534

inversely related to the NO_3 produced and directly related to the lag period.

In attempting to relate the above humus (layer) properties to their respective ecosystems, several relationships seem pertinent. In the first place, Group I properties are related to the absence of vegetation having low foliar contents of calcium and high concentrations of aluminum (i.e. pines and hemlock). Group II properties are related to the presence of at least 30% pines and/or hemlock (of total basal area). Group III properties are related to the prevalence of low N red pine foliage. The occurrence of pH values above 5.0 coincides with relatively high exchangeable Ca or Mg which is in turn related to the prevalence of vegetation having high foliar contents of these elements (i.e. red oak and sugar maple on Sites A3 and B2, sugar maple and black cherry on Site D1 and balsam fir on Site A1). C/N ratios greater than 20 are related to the presence of 7% or more red pine.

In summary, it is postulated that the specific characteristics of tree foliage which are most strongly related to humus type, nitrate and crenic acid production are the Ca/Al ratio and the %N content. Ca/Al ratios and %N values may be subject to some error due to inadequate replication; also these values may change with a change in site conditions. Comparisons between species may be justified, however, since the calcium values do not seem out of line with the ranges reported in the literature and one site for each species contained carbonates within the root zone. The values indicate two distinct groupings of species with respect to their foliar Ca/Al ratios and two distinct groupings with respect to total N. On these bases, the species are divided into four groups (see Table 12).

TABLE 12. FOLIAR COMPOSITION GROUPINGS OF SPECIES

Foliar Group	Basis for Grouping	Species	Carbonates in Root Zone	Foliar Ca/Al	Foliar %N
I	High Ca/Al-High N	Sugar Maple	+	367	1.60
		Red Oak	+	235	1.96
		Yellow Birch	+	200	2.32
II	High Ca/Al-Low N	Balsam Fir	+	319	1.07
III	Low Ca/Al-Low N	White Pine	+	80	1.19
		American Beech	+	75	1.13
		Red Pine	+	70	0.92
		White Pine	0	24	1.23
		Red Pine	0	14	0.52
IV	Low Ca/Al-High N	Eastern Hemlock	+	27	1.77

The presence of stands containing no species in Group III and Group IV is correlated with the presence of relatively well-developed mull humus types which have pH values greater than 5.0, ratios of exchangeable Ca to extractable Al_2O_3 greater than 4.0 and produce no crenic acid when incubated and leached. The presence of stands containing less than 20% (of total basal area) of species in Groups III and IV is correlated with the production of relatively large amounts of nitrate and short nitrification lag periods. The presence of stands on carbonate-containing sand soils supporting more than 30% Group III and GroupIV species is correlated with the existence of extremely acid mor humus types which produce crenic acid profusely and for an extended length of time when incubated and leached in the laboratory. On a sand soil containing no carbonates, a pure stand of red pine was associated with a humus type classified in this study as a shallow sand mull which was extremely acid and exhibited a sustained but low rate of crenic acid production. The presence of stands containing more than 30% hemlock is correlated with the most acid and thickest mor humus types in the study, whether or not carbonates are present in the profile.

Extractable Iron and Aluminum in Soil Horizons

Profile distributions of extractable iron and aluminum percentages are graphically shown in Figure 29.

Profile A1 shows no sign of sesquioxide eluviation and illuviation but a slight increase of sesquioxides is evident toward the surface where some weathering seems to have taken place and where foliar iron and aluminum has probably accumulated. The calcium-saturated mull humus and the lack of crenic acid production are possibly responsible for this type of sesquioxide distribution.

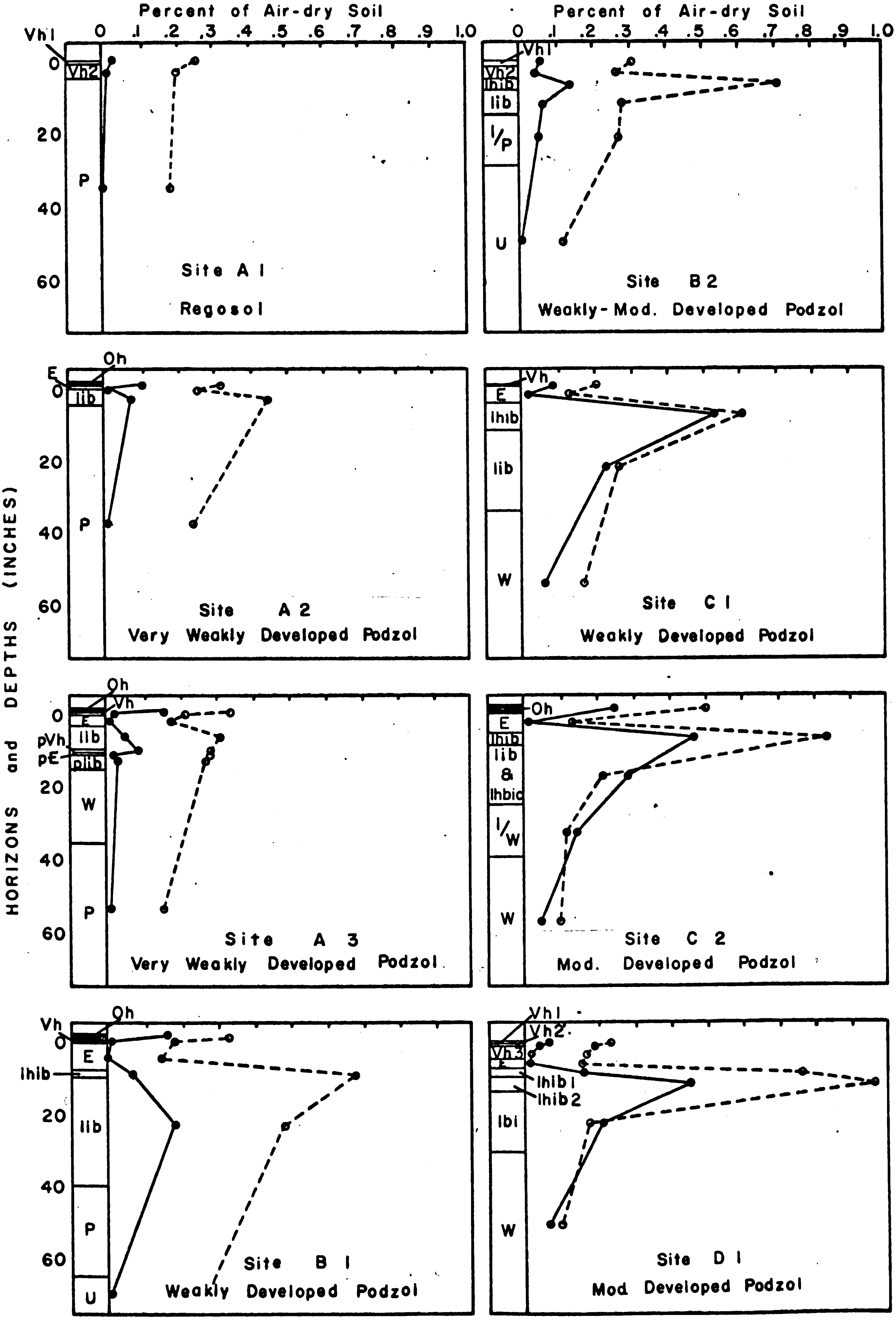
Profiles A2 and A3 show definite sesquioxide maxima below relatively thin eluvial horizons. The inception of Podzol formation in these profiles correlates with the presence of upper humic horizons which produce crenic acid. The concentration of iron is greater than that of aluminum in every horizon and profile maxima of iron are more pronounced than those of aluminum.

In Profiles B1 and B2, extractable sesquioxide maxima and percentages are greater than in the younger profiles. The B1 profile, however, contains much higher concentrations of extractable iron and aluminum in the lower part of the solum (IIb horizon) than the B2 profile does. In addition, the maximum extractable Al concentration occurs in the lower I horizon of Profile B1 but in the uppermost I horizon of Profile B2.

Laboratory studies indicate that crenic acid production by the Oh horizon of Profile B1 is quite profuse and sustained. The relatively

FIG. 29

PROFILE DISTRIBUTIONS OF EXTRACTABLE SESQUIOXIDES



• = Extractable Al_2O_3 o = Extractable Fe_2O_3

deep leaching of carbonates and the solubility of aluminum and iron in this profile may be a direct result of prolonged crenic acid production. The estimated total amount of extractable sesquioxides in the illuvial zones (see Table 13) is directly related to the depth of leaching among all the profiles having a calcareous P or U horizon. The data of Wright and Schnitzer (1963) indicate that Fe-organic matter is considerably more susceptible to flocculation by Ca and Mg than is Al-organic matter and they suggest that the latter will consequently move deeper in the profile providing most of the free functional groups have not become bonded with polyvalent cations. The recycling of aluminum in Ecosystem B1 is undoubtedly greater than in Ecosystem B2. It therefore seems logical that more Al-organic matter complexes have been formed in the upper horizons of Profile B1 and that they have been able to migrate more deeply than in Profile B2 as a consequence of a greater number of functional groups (provided by crenic acid), a lesser amount of recycled Ca and Mg encountered in the upper part of the solum and deeper leaching of the carbonates.

The decided dominance of extractable iron over extractable aluminum in every horizon of the A and B profiles is apparently a function of the lower solubility of aluminum in these relatively young soils as well as the greater ease of formation and flocculation of organo-iron complexes.

All the A and B profiles are characterized by having P and/or U horizons which contain carbonates. Extractable aluminum is nil in these horizons but extractable iron is invariably present in concentrations ranging from 0.12% in Profile B2 to 0.27% in Profile B1; these values probably represent "free Fe_2O_3". The calcium and magnesium present in these horizons, and in the W horizon (pH 7.0) of Profile A3, may be

TABLE 13. ESTIMATED POUNDS PER ACRE OF EXTRACTABLE SESQUIOXIDES

Profile	Illuvial Zone			Solum			$5\frac{1}{2}$-foot Profile			8-foot Profile		
	Fe_2O_3	Al_2O_3	Total	Fe_2O_3	Al_2O_3	Total	Fe_2O_3	Al_2O_3	Total	Fe_2O_3	Al_2O_3	Total
A1	0.0	0.0	0.0	2803	169	2972	36,917	1091	38,008	53,641	1543	55,184
A2	3382	532	3914	4931	792	5723	48,659	3525	52,184	70,355	4881	75,236
A3	5418	1032	6450	7626	1487	9113	31,242	3701	34,943	51,055	5866	56,921
B1	41,550	14,460	56,010	45,194	14,823	60,017	68,684	16,128	84,812	92,984	17,478	110,462
B2	22,092	4716	26,808	25,960	5334	31,294	39,712	7053	46,765	50,512	8403	58,915
C1	29,876	26,369	56,245	32,463	26,940	59,403	48,443	32,580	81,023	63,743	37,980	101,723
C2	20,675	23,181	43,856	24,166	24,066	48,232	31,937	28,156	60,093	40,487	32,656	73,143
D1	26,531	17,702	44,233	30,482	18,200	48,682	39,662	24,830	64,492	47,762	30,680	78,442

capable of flocculating downward moving sesquioxide-organic matter complexes in the manner described by Wright and Schnitzer. That these horizons are directly below illuvial horizons seems to support this contention. In the B site profiles the sesquioxide build-up in the upper part of the illuvial zone may reflect the flocculating effect of the sesquioxides already precipitated or it may result from the higher redox potentials in the lower illuvial horizons (see McKenzie et al., 1960).

The C and D profiles contain no free carbonates within 14 feet of depth and the W horizons are redder than the sub-solum horizons of the young profiles. Associated with these characteristics are values of extractable aluminum which are much higher than in the younger profiles. The extractable iron and aluminum distributions in Profile C1 are quite similar, with almost equal concentrations of both elements in the illuvial horizon. Although this type of pattern is unique in this study, it is very similar to those in Franzmeier's three youngest profiles. All four of these profiles are (or were recently) occupied by dominantly coniferous trees which have relatively high foliar concentrations of aluminum (especially on acid sites). The comparable values of extractable iron, on the other hand, is probably a function of the greater rate of formation and flocculation of organo-iron complexes.

Profile C2 shows that the upper illuvial horizon (Ihib) has a decidedly higher concentration of extractable iron than aluminum whereas the three illuvial horizons below the Ihib have higher concentrations of aluminum than of iron; this is particularly true of the disjunct tongues of ortstein (Ihbic) which alternate laterally with areas designated as Ibi horizon. The ortstein and lower illuvial

horizons of Franzmeier's Kalkaska sand also exhibit the dominance of extractable aluminum. The pre-lumbering vegetation on both these sites indicate a long-sustained prevalence of coniferous vegetation. High foliar aluminum contents are indicated by the prevalence of hemlock and the extractable aluminum concentration of the Oh horizon of Profile C2; this horizon contains the highest concentration of extractable aluminum of all the upper humus horizons studied.

Profile D1, the oldest chronologically, contains the most pronounced extractable iron maximum in the sequence of soils studied. The peak concentration occurs in the middle illuvial horizon (Ihib2), however, thus differing from the pattern exhibited by Profile C2 where the peak occurred in the upper illuvial horizon (Ihib1). The upper illuvial horizon of Profile D1 shows a surprisingly low concentration of extractable aluminum, the order of magnitude resembling those of the B profiles which are less than half as old chronologically. The lower illuvial horizon (Ibi) contains higher concentrations of aluminum than of iron, but both elements are present in lower percentages than occur in the Iib horizon of Profile C1 and the Ibi of Profile C2. Franzmeier's Blue Lake I (moderately developed Podzol under northern hardwoods) resembles Profile D1 by also having unusually low percentages of extractable aluminum in the upper illuvial horizon and a dominance of aluminum over iron in the lower illuvial horizon (i.e. of the Podzol sequum). Data presented previously indicate that sugar maple and possibly other northern hardwoods have higher concentrations of foliar iron than aluminum thus it is reasonable to assume that iron is selectively removed from the illuvial horizons by these species and returned to the soil surface via leaf fall. Subsequent mobilization

of this re-circulated iron may not result in its return to the horizon from which it was extracted. The data of Bloomfield (1957) indicates that sesquioxide-organic matter complexes are immobilized by their sorption on sesquioxides already present. This mechanism, coupled with selective extraction of iron, could result in a redistribution of iron within a profile (and perhaps the formation of a new upper illuvial horizon) without the necessity of additional iron-release from mineral weathering.

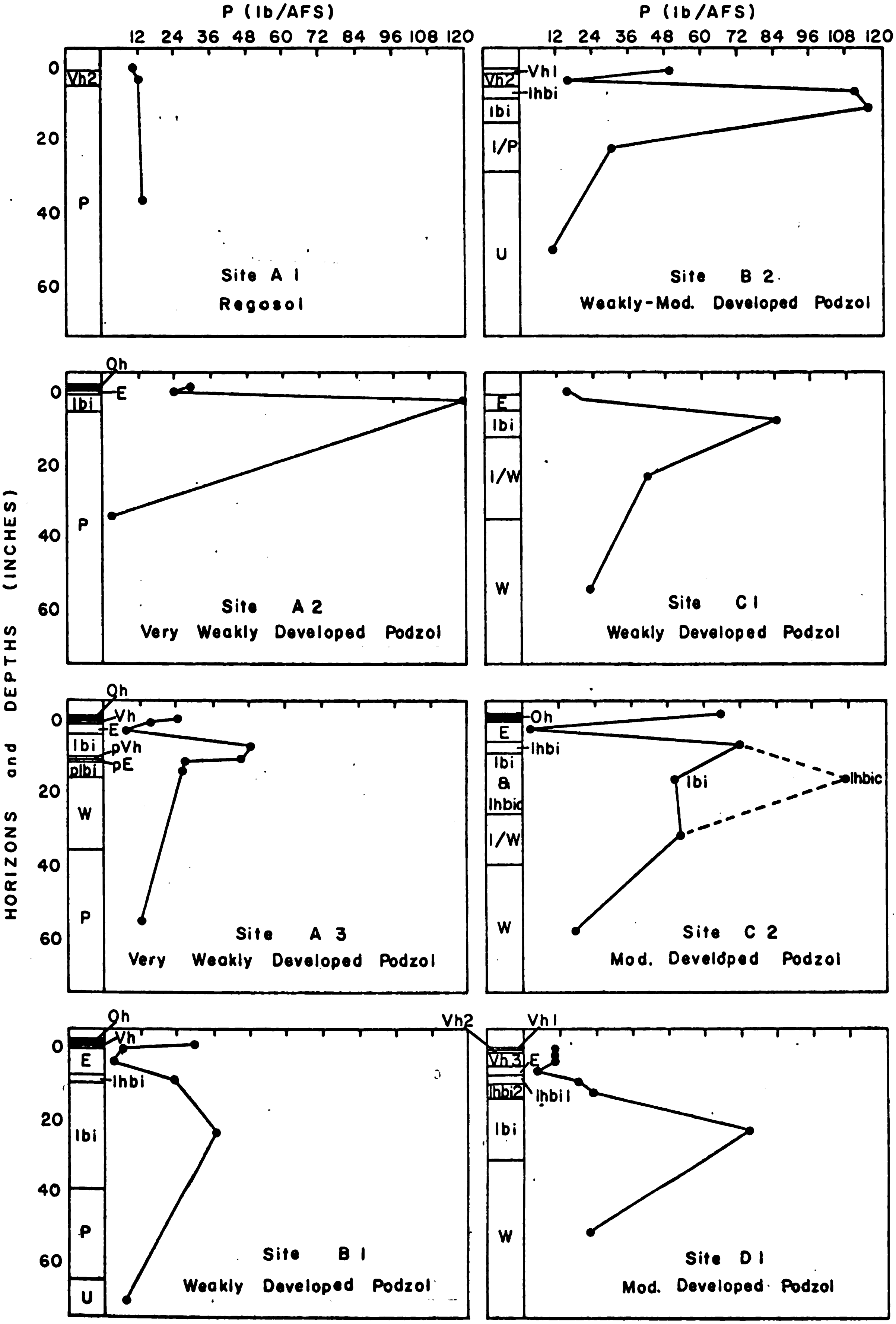
Total extractable sesquioxides should be more indicative of the degree of Podzol development than mere concentrations. Accordingly, Table 13 gives illuvial zone totals, solum totals, 5½-foot profile totals and 8-foot profile totals. These computations indicate that extractable sesquioxides in the illuvial zone and in the solum increase with the thickness of the solum in the A and B profiles. Profile totals, however, decrease with increasing hardwood occupancy within each age group of soils. An inspection of the data shows this decrease to be due to a decrease in the concentration of extractable iron in the sub-solum horizons. In the older soils, the greatest quantity of both sesquioxides is present in Profile C1 (100% pines), the only "weakly" developed Podzol in this group. In this group, extractable aluminum in the illuvial zones decreases with increasing hardwood occupancy regardless of soil age similarities or differences. This order of decreasing aluminum is also the order of increasing concentrations of extractable iron in the upper illuvial horizons (Ihib horizons).

Available Phosphorus in Soil Horizons

Profile distributions of available phosphorus are shown in Figure 30.

FIG. 30

PROFILE DISTRIBUTIONS OF AVAILABLE PHOSPHORUS



In Profile A1, available phosphorus is present in lower concentrations in the V horizons than in the primary material; in fact, the greater the organic matter content the lower the concentration of available phosphorus. In the soils producing crenic acid, however, the distribution of available phosphorus is quite different; in these soils, the upper humis horizon invariably contains concentrations which are at least twice as great as that of the underlying primary material. Distinct maxima of available P occur in all the illuvial zones with highest concentrations in either the Ibi (or Iib) horizon or the Ihbic (ortstein) horizon.

Concentrations of available P are about twice as high in the non-calcareous W horizons as in the calcareous primary materials.

Estimates of total available phosphorus by profile zones are shown in Table 14.

TABLE 14. ESTIMATED POUNDS PER ACRE OF AVAILABLE PHOSPHORUS

Profile	lb.P/illuvial zone/A	lb.P/solum/A	#Avail.P/A in 5½-foot profile	#Avail.P in 8-foot profile
A1	-	8	128	187
A2	45	57	84	98
A3	41	50	131	213
B1	151	163	193	225
B2	222	245	302	347
C1	224	242	350	454
C2	259	282	339	437
D1	213	224	331	426

While available P concentrations do not show an increase with age, estimated totals do show a general increase. If available P totals are averaged for each age group, an increase would be apparent up to the oldest group at which point a decrease occurs. Such a decrease was also present in the moderately developed Podzols of Franzmeier's study. Franzmeier suggests that the decrease might be due to either increased removal of Bray's available P by vegetation or conversion to forms not extractable by Bray's solution (i.e. calcium phosphate and/or iron phosphate).

The stand of sugar maple and black cherry at Site D1 probably has a dry weight of about 270,000 pounds per acre.* Shanks *et al.* (1961) calculated that American beech trees (total above-ground parts) contained about 0.03% phosphorus. Since sugar maple foliage has higher concentrations of phosphorus than beech, perhaps 0.04% phosphorus is a reasonable figure for the average phosphorus concentration of the whole tree. Using the above figures, the standing crop of trees would contain about 108 pounds of phosphorus per acre (71 pounds if 0.03% is used). A standing crop of pines such as that on Site C1 would likely not contain more than about 20 pounds per acre (*vide* Ovington, 1956). The unsampled litter and 2¼ inch thick F layer (Of horizon) on Profile C1, however, could contain as much as 30 pounds of phosphorus per acre (*vide* Alway *et al.*, 1933 and Trimble and Lull, 1956). The litter at Site D1 was very thin with no F layer at all at the time of sampling, thus non-soil phosphorus in the D1 ecosystem was mostly in the standing crop. From these figures, it seems possible

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*Based on relationship of basal area per acre to dry matter—DBH relationships established by Shanks *et al.* (1961) for American beech and yellow birch.

that the lower available soil phosphorus in Profile D1 as compared to Profile C1 could be due to the differences in standing crop content of this element. However, in this soil, low concentrations of available P are found in the Vh horizons having exchangeable calcium contents greater than 3000#/AFS (these are also horizons which produce no crenic acid). Since Profile D1 is found under an almost pure stand of sugar maple, a tree having relatively high foliar concentrations of phosphorus, there should be some reflection of the high foliar P in the Vh horizons unless such phosphorus is in a form which is not extractable by Bray's solution.

The surface horizons having less than 3000#Ca/AFS all have available phosphorus concentrations which vary directly with their ability to produce crenic acid in the laboratory and to a lesser extent with the foliar P content of the vegetation occupying the sites.

The above relationships between exchangeable calcium and available phosphorus also apply to some extent to the illuvial horizons. For example, the illuvial horizons having the lowest exchangeable calcium concentrations (C1-Iib, C1-Ihib, C2-Ihib and C2-Ihbic) have an average available phosphorus concentration of 77#/AFS while those having the highest exchangeable calcium concentration (D1-Ihib1 and Ihib2) contain an average of only 20#/AFS.

<u>Exchangeable Potassium in Soil Horizons</u>

The highest concentrations of exchangeable K, by far, are found in the upper humic horizons of all profiles except D1 which has a double maximum shared by the Vh2 and the Ihib2 horizons. The Vh1 horizon of Profile B2 contains by far the highest concentration of any horizon in the entire group of profiles. The lowest values per profile do not consistently occur in any particular horizon. The absolute lowest value occurs in the lower solum of Profile C2.

In the younger soils (A and B profiles), exchangeable K in the upper humic horizons increases with the stage of plant succession in each age group. In the A profiles this also means an increase with the organo-chemical (illuvial zone O.M. and sesquioxides) degree of Podzol development. In the B profiles, however, organo-chemical Podzol development varies inversely with the stage of plant succession therefore exchangeable K in the upper humic horizons varies inversely with the organo-chemical degree of Podzol development in these profiles. Despite the within (age) group differences the average exchangeable K values per group increase directly with organo-chemical Podzol development and age.

Concentrations within the illuvial horizons of the C and D profiles show an average increase with age and stage of plant succession but no increase with Podzol development.

Estimates of total exchangeable potassium per illuvial zone, solum and profile (5½ and 8 feet) are given in Table 15.

TABLE 15. ESTIMATED POUNDS PER ACRE OF EXCHANGEABLE POTASSIUM

Profile	# Exch. K/A in Illuvial Zone	# Exch. K/A in Solum	# Exch. K/A in 5½-foot Profile	# Exch. K/A in 8-foot Profile
A1	-	17	266	388
A2	17	63	209	281
A3	23	73	405	687
B1	195	321	556	799
B2	253	460	666	828
C1	144	219	431	633
C2	48	140	205	277
D1	203	308	538	740

These values indicate that exchangeable K in the solum of the young soils increases generally with age and Podzol development. In the B profiles, however, solum values increase directly with the stage of plant succession but inversely with the organo-chemical degree of Podzol development. The high values of exchangeable K in Profile B2 reflect, at least in part, the effect of American beech which has higher foliar contents of potassium than all the other species analyzed in this study (see Table 7).

The C and D profiles have lower quantities of exchangeable K than do the B profiles pointing to the possibility that the older profiles have lost some potassium or that the primary materials were endowed with a lesser amount. While solum values do not consistently increase with the stage of vegetation succession in the C and D profiles, the climax stage (D1) is characterized by having higher amounts of exchangeable K in the solum than the two earlier stages (C1 and C2).

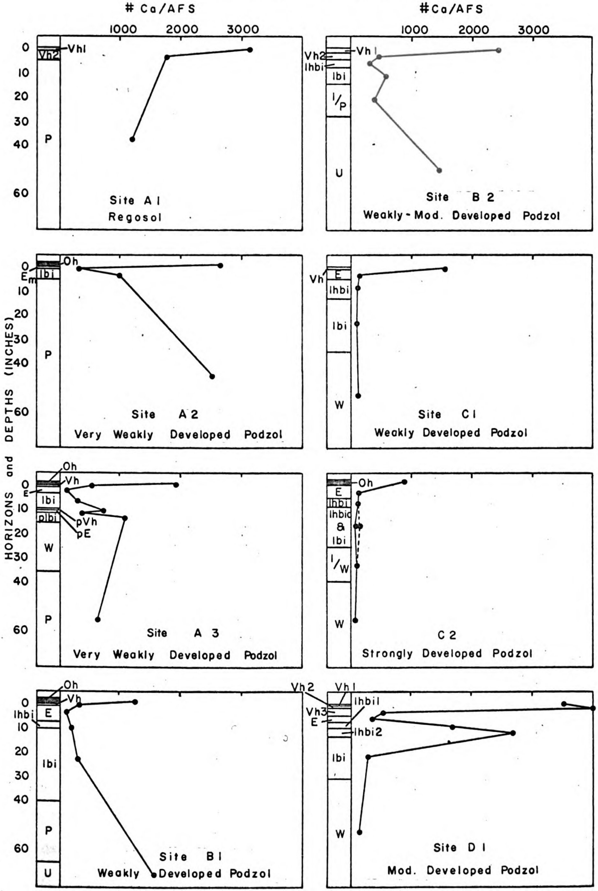
Exchangeable Calcium in Soil Horizons

Profile distributions of exchangeable Ca concentrations are shown in Figure 31.

The Oh or Vh horizons contain the maximum concentration in each of the profiles. In the Podzols occupied by more than 50% hardwoods, a secondary peak occurs in the illuvial horizons. In the Podzols occupied by mostly conifers, no such illuvial zone peak occurs, either as a result of gradually increasing values from the E horizon down to the calcareous sub-solum horizons or because E horizon concentrations are similar to I horizon concentrations (both being low). With increasing age and development, Podzols with mor humus types show gradual calcium desaturation in their Oh horizons while the opposite

FIG. 31

EXCHANGEABLE CALCIUM



is true for the upper humic horizons of hardwood Podzols.

Sub-solum concentrations are less than 110#/AFS in all the C and D profiles despite large differences in solum concentrations between these profiles, indicating that either carbonate calcium has been removed from depths considerably greater than the depth of solum development or that the primary materials contained no carbonates. In the Delta-Alger County area, carbonates in sand soils cannot be found within 5½ feet of the surface unless the soils are younger than 3500 years (unpublished field descriptions made by the author and others during soil survey operations).

Estimations of total exchangeable calcium in the various zones of the profiles are shown in Table 16.

TABLE 16. ESTIMATED POUNDS PER ACRE OF EXCHANGEABLE CALCIUM

Profile	Illuvial Zone	Solum	5½-foot Profile	8-foot Profile
A1	-	1400	12,464	17,888
A2	359	1005	23,744	35,025
A3	234	662	5,090	8,647
B1	1046	1507	8,189	15,101
B2	1435	2397	10,648	17,128
C1	341	748	1,237	1,705
C2	301	558	787	1,108
D1	2744	3756	4,246	4,678

On the youngest surfaces, solum totals tend to decrease with the degree of Podzol development. No such relationship is evident in the older profiles; here, the solum values are higher in the hardwood site

Podzols (B2 and D1) than in profiles beneath dominantly coniferous forests. The exchangeable calcium value is lowest at Site C2 under hemlock and at the B sites it is lower under hemlock (B1) than under red oak (B2).

Exchangeable Magnesium in Soil Horizons

Highest concentrations of exchangeable Mg in each profile are likewise found in the upper humic horizons. The absolute highest concentrations are shared by the upper humic horizons of Profiles A3 and B2.

Secondary peaks occur in the upper illuvial horizons of all the Podzols except Profiles A3, C1 and C2. The most pronounced of these peaks is found in Profile D1.

The highest sub-solum concentrations are found in Profiles A3, B1 and B2 thus indicating that the hardwoods on A3 and B2 have been more effective in adding Mg to the exchange complex of the upper humic horizons (see above) than the conifers on Site B1 have been.

Estimation of total exchangeable Mg per genetic zone (in #/A) and the concentration of exchangeable Mg per upper humic horizon (in #/AFS) are presented in Table 17.

TABLE 17. ESTIMATED POUNDS PER ACRE OF EXCHANGEABLE MAGNESIUM

Profile	Upper Humus Horizons (#/AFS)	Illuvial Zone	Solum	5½-foot Profile	8-foot Profile
A1	108	-	50	419	600
A2	99	12	39	203	284
A3	188	28	86	145	1090
B1	115	104	156	434	722
B2	170	162	246	613	901
C1	114	94	129	242	350
C2	109	1	34	67	68
D1	108	203	250	372	480

In each age group, solum Mg is greatest in the predominantly hardwood soils (A3, B2 and D1). The two sola with the absolute highest values are found in the two profiles under 100% hardwood stands (B2 and D1).

Eight-foot profile maxima correspond to maximum concentrations in the upper humic horizons (A3 and B2). In other cases, however, upper humic horizon concentrations do not reflect sub-solum quantities. In fact, all the other upper humic horizons have essentially equal concentrations while their sola and profiles contain quite variable amounts of exchangeable Mg.

The exchangeable Mg content of Profile C2 is particularly interesting. First of all, 97% of the exchangeable Mg in the solum is located in the Oh horizon despite a relatively high content of illuvial organic matter. Secondly, the sub-solum content is extremely low. Perhaps related to this low content is the fact that with increasing Podzol development under pines and hemlock, E horizon and upper I horizon concentrations decrease despite clay and organic matter increases. The pollen profile of Three Lakes Bog indicates that Profile C2 has been dominated by such forests throughout the course of its development. The pioneer forest of jack and/or red pine indicated by the bog pollen would certainly not have been conducive to the maintenance of high magnesium levels since these species have always been found to have low foliar contents of bases. Succession to white pine would not alter this situation greatly especially if the carbonates were deeply leached prior to the succession.

Reaction of Soil Horizons

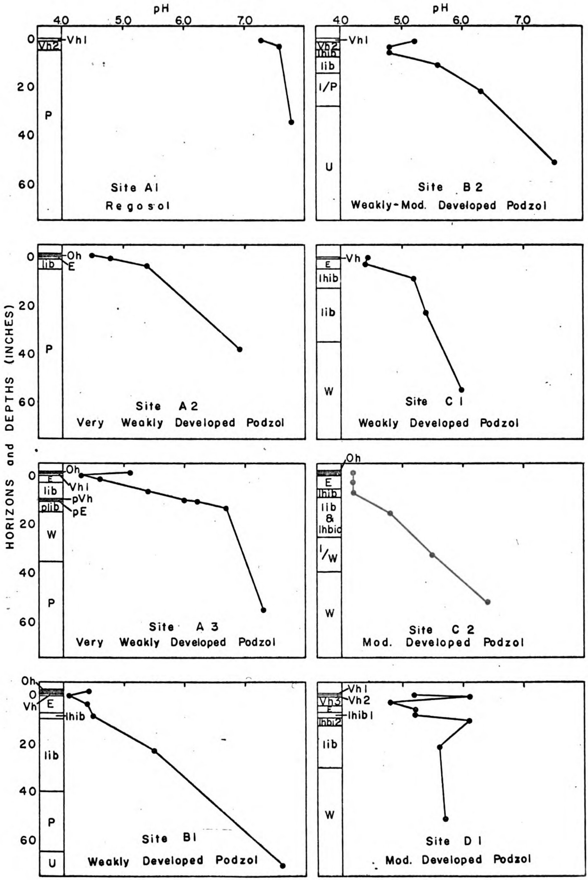
Profiles of pH variations with depths and horizons are illustrated in Figure 32. The low values in the upper humic horizons of Podzols beneath conifer stands (A2, B1, C1 and C2) are quite obvious. In fact, the upper humic horizons fall into three distinct categories: those having a pH of 4.2 to 4.5 (A2, B1, C1 and C2); those having a pH of 5.1 to 5.2 (A3, B2 and D1) and the one with a pH of 7.3 (A1). The pH values of 5.1 and over correlate with relatively high concentrations of exchangeable calcium (A1 and D1) or magnesium (A3 and B2). These high concentrations of exchangeable cations can be traced back to the foliar composition of the trees occupying the sites, high calcium being attributed to the predominance of either balsam fir (A1) or sugar maple and black cherry (D1), and high magnesium being attributed to the predominance of red oak (A3 and B2).

The relationship of pH to nitrate and crenic acid production has already been discussed.

With increasing development, Podzols with mor humus layers exhibit increasing penetrations of very strongly and extremely acid reactions,

FIG. 32

REACTION PROFILES



such reactions reaching down to approximately 25 inches in Profile C2.

The lowest pH in the hardwood mull Podzols (B2 and D1) is 4.8 and this pH occurs in the lowermost Vh horizon of both profiles. In Profile D1, a pH of 6.1 is found in the Vh2 and the Ihbi2 horizons, precisely coinciding with concentration peaks of exchangeable K, Ca and Mg.

In all profiles except D1, a gradient of increasing pH values occurs from the Vh2 or E horizon downward. The steepest gradients are found in the profiles which contain an E horizon and a carbonate-containing P or U horizon.

Mechanical Analyses of Soil Horizons

Distribution of the particle size fractions in the profiles studied are shown in Figures 33 and 34.

The primary material (or slightly weathered W horizons) of all eight profiles is composed of 98-100% sand (see Appendix); however, profiles A1, A2, A3, B1 and D1 contain finer sand in their P or W horizons than do the other profiles and the ortstein tongues in Profile C2 contain finer sand than surrounding horizons.

The uniform distribution and low percentages of clay in Profile A1 indicate the lack of clay formation and movement.

Profiles A2 and A3 show some indications of silt having weathered to clay with the subsequent movement of this fraction into the Ibi horizons. In the B site profiles, clay maxima are more marked than in the younger profiles. Higher concentrations of silt in the Vh2 and Em horizons indicate the possibility that sand is being weathered to silt faster than silt is being weathered to clay. Clay concentrations in Profile B2 (weakly to moderately developed Podzol with mull humus) are considerably higher than those in Profile B1 (weakly developed Podzol

FIG. 33

PARTICLE SIZE DISTRIBUTION PROFILES

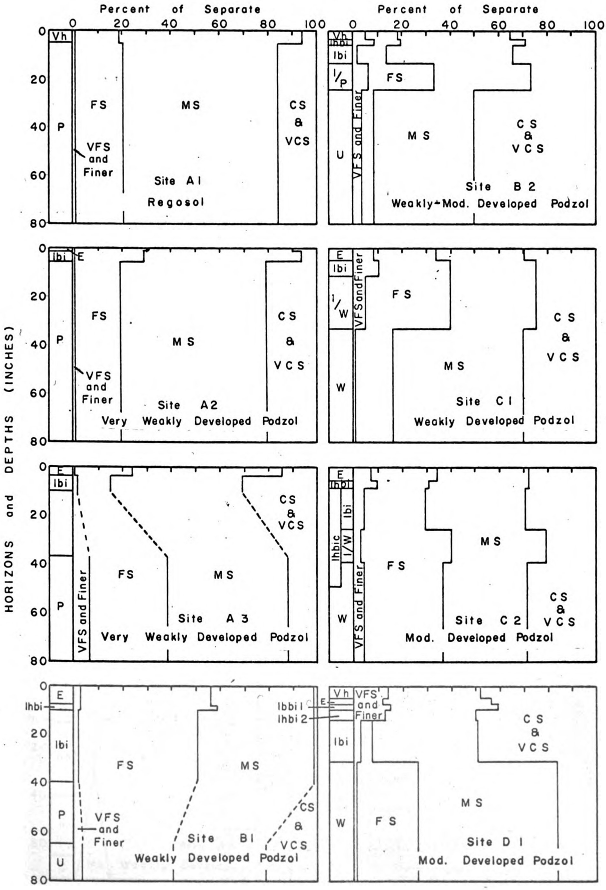
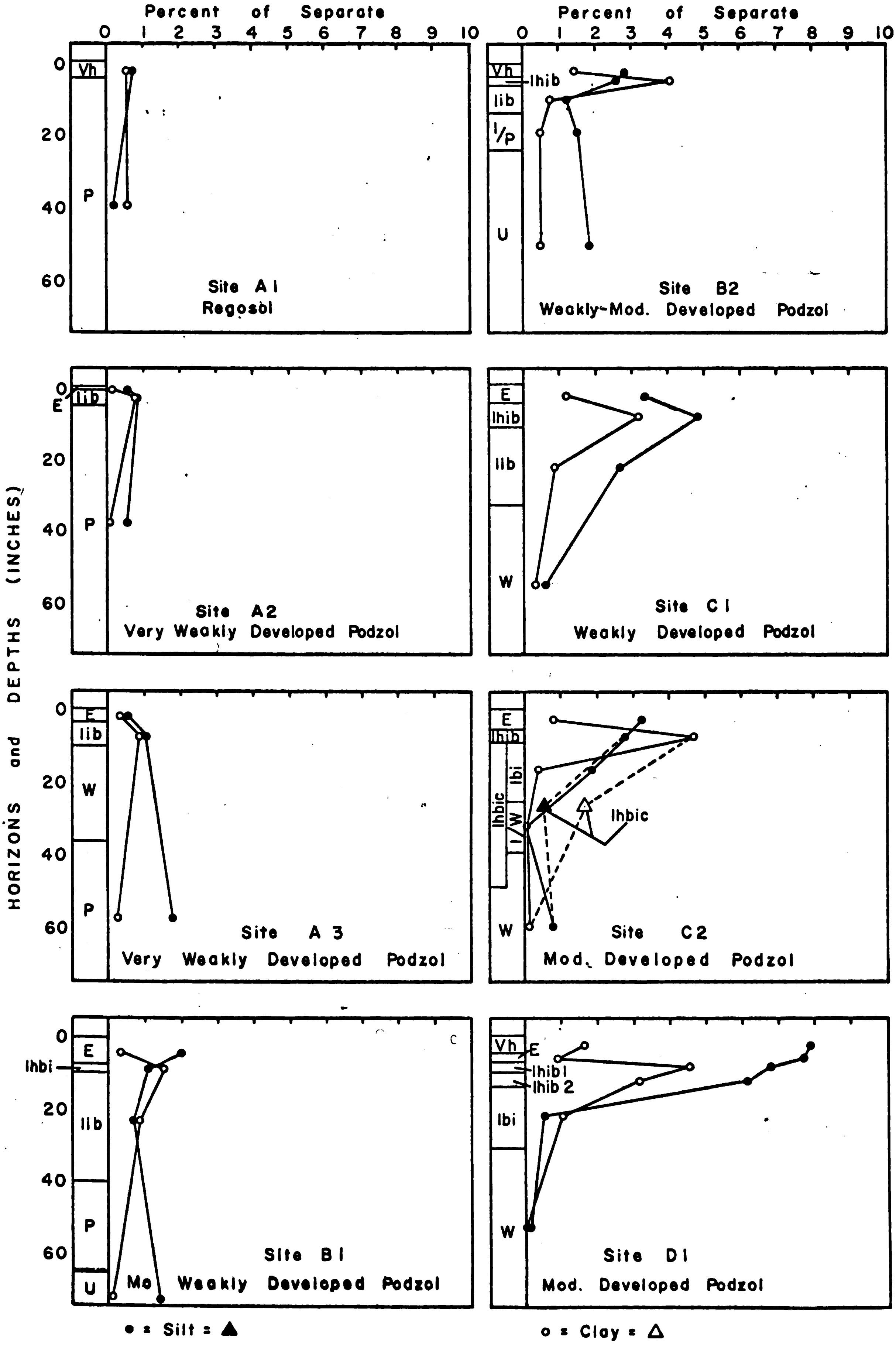


FIG. 34
SILT AND CLAY DISTRIBUTION



with mor humus). In the C Site profiles, the gap between silt and clay concentrations in the Em horizons continues to widen with the magnitude being similar in both profiles. Clay concentrations in the I horizons are marked but the C1 profile has a lower maximum than the B2 profile which is chronologically much younger. The C2 profile has a maximum clay concentration which is not exceeded by any other profile in the group studied. The D1 profile exhibits the widest gap between silt and clay concentrations in the Vh and Em horizons. The maximum concentration of clay is almost identical to that in the C2 profile, however. Silt concentrations in the D1 profile are high in the horizons above the Ibi horizon, the lowest of these being higher than the highest in any of the other profiles.

Clay maxima, where present, always occurred in the I horizons. Where more than one I horizon was present, the maximum occurred in the uppermost one of these. This distribution is somewhat at variance with the findings of Franzmeier (1962), inasmuch as the chronologically younger soils in his study showed low maxima or co-maxima of clay concentrations in the Vh horizons.

Estimated amounts of clay (method of estimation outlined in Chapter 9) in the illuvial zones of each profile are shown in Table 18. These values indicate that I horizon clay increases with age with the outstanding exception of Profile C2. Since conditions are extremely favorable for crenic acid production (thick, extremely acid mor humus) but unfavorable for complex immobilization by Ca and Mg, clay-crenic acid complexes may have been leached completely out of the profile. Studies made by Wicklund and Whiteside (1959) indicate that clay destruction or eluviation may be more active than clay formation and

illuviation in some mor humus Podzols in New Brunswick. Although the New Brunswick soils were silt loams, their solum morphology and pH values were similar to those of Profile C2. The sub-solum material was also carbonate-free as in Profile C2.

TABLE 18. ESTIMATED POUNDS PER ACRE OF CLAY IN ILLUVIAL ZONES

Profile	Clay(lb/A)
A1	-
A2	6,035
A3	13,709
B1	71,299
B2	65,863
C1	117,815
C2	52,177
D1	122,059

The physical property which is most consistently related to chronological age in both Franzmeier's and the present study is the percent sand (of the < 2mm particles) in the uppermost mineral horizon in each profile. When these data from both studies are combined, the percentages of sand for the 2500 year old and younger soils are 99.1, 99.0, 99.4 and 99.2. The percentages for the Lake Nipissing-aged soil (approximately 3500) of Franzmeier's study and the Upper Algoma-aged soils (approximately 3000) of this study are very similar, being 97.4, 97.7 and 96.9. The C profiles (assumed to be of Sub-Duluth age) in this study contain 95.6 and 94.4% while the Lake Algonquin-aged profile (in Franzmeier's study) has a value of 92.5%. These figures suggest a continuation of the same age-percent sand trend since the Sub-Duluth deluge is assumed to have occurred following the highest stage of Lake Algonquin. The D1 profile contains 90.5% sand which may indicate that the D1 moraine was deposited before the highest stage of Lake Algonquin subsided. The sand percentages for the Blue Lake profiles in Franzmeier's study were 84.1% and 79.3%. These profiles should be the oldest chronologically since they occur in moraines (either Valders or Port Huron) which lie about 50 miles south of the D1 moraine. The low percentages of silt in the sub-solum horizons of the older profiles and the general decrease of silt downwards in the solum may reflect the relative intensity of physical weathering with depth as suggested by Franzmeier (1962) or they may represent additions of aeolian silt to the surface with subsequent down-drifting as suggested by Olson (1958). Plotting the percent silt of the uppermost mineral horizons against time produces a sigmoid curve with a plateau between 2500 years and 10,000 years (writer's estimate of the age of the Sub-Duluth surface based on Broecker and Farrand's chronology), a result that might be expected if hydrolysis and other moisture-dependent weathering processes were less prevalent during Lake Chippewa to Lake Nipissing times. A similar curve is shown in Olson's paper. Additional research especially designed to elucidate these relationships is needed since weathering of sand to silt and clay as well as loess depositions may be involved.

Soil Differences Associated With Cliseral and Successional Trends on Each Site

Profile A1 (Regosol) reflects the short time and slow rate of weathering taking place under neutral to alkaline conditions maintained

by the presence of calcium-rich balsam fir foliage and free lime. Although low in fertility, Profile A1 shows evidence of increasing fertility in the Vh horizons except for available P. The mull humus characteristic of the juniper thickets in the dune heath zone* is somewhat more shallow in Profile A1, pointing to the possibility that gradual destruction of the Vh horizon is taking place. No illuvial horizon is present in the currently developing solum above the pVh.

Profile A2 (very weakly developed Podzol) reflects a more rapid rate of weathering taking place beneath a strongly acid mor humus which releases crenic acid upon being incubated and leached with water in the laboratory. The dominance of calcium-poor pine foliage (which also has a low foliar Ca/Al ratio) is related to the occurrence of this humus type apparently at the expense of the entire upper part of the former dune heath Vh horizon which may have contributed humus, by eluviation and illuviation, to the horizons below. In this profile, silt and clay maxima are definitely present in the illuvial horizon along with a peak in extractable iron and aluminum, available P, exchangeable Mg and K, and organic matter. The simultaneous occurrence of these maxima in the illuvial horizon along with the occurrence of crenic acid production in the Oh horizon strongly suggests that crenic acid is at least partially responsible for this profile development.

Profile A3 is a very weakly developed Podzol which is, however, somewhat more strongly developed than Profile A2 (on the basis of illuvial zone totals of organic matter and extractable sesquoxides). The composition and age stratification of the stand at Site A3 (red oak,

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*Terminology used by Cowles and Gates (vide Olson, 1958).

pioneer sugar maple and relict white pine) suggests that red oak invaded a former pine stand (since white pine can be found on unaltered calcareous beach sand in this area while northern red oak cannot be) and paved the way for northern hardwood encroachment by altering the nature of the humus type; characteristics of foliage and humus-containing horizons indicate that the alterations were in the form of increases in the content of calcium, magnesium and nitrogen with a related increase in pH. In turn, these alterations are related to a decrease in crenic acid production and an increase in nitrate production (as compared to Profile A2).

Profile B1 is a weakly developed Podzol (with respect to color of the upper illuvial horizon) which apparently has always been occupied by dominantly coniferous forests following the dune heath stage. The structure of the present forest indicates that it has developed from a seral stage similar to that at Site A2 (i.e. a change from white and red pine dominants to white pine, hemlock and yellow birch dominants). The invasion of hemlock introduces foliage which contains relatively high concentrations of aluminum and has the lowest Ca/Al ratios of any foliage in this study which was collected from trees growing on soils having carbonates within 3½ feet of the surface. In addition hemlock foliage contains higher concentrations of all the major nutrient elements than the foliage of the pines on Site A2. The encroachment of yellow birch introduces foliage having comparatively very high concentrations of calcium and iron. However, the dominance of pine and hemlock foliage plus sustained production of crenic acid probably has precluded any rapid build-up of bases in the surface horizons. The high concentrations of extractable iron in the Ihib horizon, though, may be in part a reflection of biologically circulated iron.

Profile B2 is a weakly to moderately developed Podzol which has undergone a more rapid build-up of solum fertility and upon which forest succession has proceeded more rapidly than in the case of Profile B1. Scattered relict yellow birches (none on plot itself) and huge old red oaks (up to 36 inches, DBH) suggest that these two species invaded the former coniferous stands and paved the way for succession to the present forest of red oak and mixed northern hardwoods. The flood of bases brought into the surface horizons by these species has certainly been instrumental in forming a well-developed mull humus which has all but completely concealed the Em horizon (which is only present in small disjunct spots or patches just above the Ihib horizon). As a consequence, the concentration of all the major plant nutrients is much higher in the surface horizons of this profile than in those of Profile B1; crenic acid production is less and nitrification is much greater in B2 than in B1. The degree of Podzol development, based on the sum of illuvial totals of extractable sesquioxides and organic matter is less in Profile B2 than in Profile B1. The factors that could have been responsible for these different rates of ecosystem succession are: (1) the shallower U horizon and coarser texture of Profile B2 (2) the more humid climate but possibly warmer micro-climate at Site B2 and (3) the greater availability of hardwood species able to encroach on and succeed earlier seral stages at Site B2.

Profile C1 is a weakly developed Podzol which has evidently supported pines for about 10,000 years (based on pollen analysis stratigraphy in a peat bog near Site C2). This simple regime (jack to red and white pines) has not resulted in the conservation of much of the

calcium supply that is assumed to have been originally present. While fertility has not been favored, the illuviation of extractable sesquioxides and organic matter has been. Foliar analysis indicates that large amounts of aluminum are being circulated in this ecosystem; possibly related to this is the strong acidity of the profile and the large quantity of extractable aluminum in the illuvial horizons. Carbonates are not present within 14 feet of the surface which means that any recent illuviation of sesquioxides and organic matter did not occur as a result of the presence of carbonate Ca and Mg.

Profile C2 is a moderately developed Podzol which apparently supported pines for an estimated 6500 years (Sub-Duluth stage in Lake Superior basin to Lake Nipissing times), then became occupied by gradually increasing amounts of hemlock and yellow birch along with smaller amounts of red maple and beech. The more advanced stage of plant succession on Site C2 as compared with Site C1 is associated with a greater amount of solum organic matter and total nitrogen. The profile also differs from that of Site C1 by having a thick mor humus and an illuvial zone which is darker, contains more organic matter and has a higher extractable aluminum content than extractable iron. The thick mor humus is related to the dominance of hemlock; the high amount of illuvial organic matter is related to the more favorable conditions for crenic acid production (i.e. mor humus with high organic matter and total nitrogen content); the darker color of the upper two illuvial horizons is related to the increase in organic matter content but may be just as dependent on the manganese content (as suggested by the studies of Pol'skiy, 1961) resulting from an increase in the biological circulation of that element by red maple and beech. The high amount of extractable aluminum is correlated with (1) the high acidity of the upper solum which increases aluminum solubility and availability and (2) the fact that pine and hemlock foliages contain $1\frac{1}{2}$ to $3\frac{1}{2}$ times more aluminum than iron thus relatively high amounts of aluminum may be retained in the ecosystem and become concentrated in the illuvial horizons by cheluviation and precipitation or other means. Using the foliar composition of the pines from Site C1 and for hemlock and yellow birch from Site B1 the amount of aluminum phyllocycled by these species during profile C2 development can be estimated. On these sandy sites 2000 pounds per acre is a reasonable estimate of annual leaf fall for pines (vide Scott, 1955). If red and white pine are assumed to have been present in equal proportions during the first 6500 years, the figure of 120 ppm of Al can be used for the calculation; this is equivalent to 0.24 pounds per acre per year and would amount to 1560 pounds per acre for a 5000-year period. If the forests for the remaining 3500 years are assumed to have had fairly equal proportions of white pine, hemlock and yellow birch, the average value of 139 ppm of Al can be used for the foliar content; this would amount to about 0.28 pounds per acre per year and in 3500 years, about 980 pounds would have been cycled onto the soil surface. For the entire period of soil formation, the estimated amount of Al phyllocycled is 2540 pounds per acre, about 11% of the extractable aluminum per acre in the illuvial zone. If the average longevity of the trees which formerly occupied this site was 200 years and the aluminum in the rest of the trees was three times as great as that in the foliage, an average of around .4 pound per acre per 100 years would be added from this source, amounting to a 10,000 year total of only 40 pounds per acre.

Much of the phytocycled aluminum in the estimated 2540 pounds was probably cycled more than once, thus the actual addition of aluminum by the vegetation to the solum has probably been small. The same would be true for iron since the present data indicate that a long history of pines would result in the cycling of even lesser amounts of this element. Intra-solum translocation, however, may be of some consequence. For instance, the predominance of pine and hemlock for 7500 years could result in the translocation of enough aluminum from the Ibi to account for that found in the Ihib. In the case of the pines, the ratio of foliar aluminum to foliar iron seems to increase as solum acidity increases; if this is true of hemlock and yellow birch as well it would increase the foliar aluminum values that should be used in the above calculations. Yellow birch and beech trees have high foliar concentrations of iron and their invasion into a pine forest may result in the translocation of relatively large amounts of this element to other parts of the profile thus leaving extractable aluminum dominant in horizons having high concentrations of birch and beech roots.

Profile D1 is a moderately developed but more highly base-saturated Podzol than the others. It evidently supported spruce and fir during the first 1000-2000 years or more of its development. Because of the shade intolerance of jack and red pine (Kramer and Koslowski, 1960) and the fertility status of the soil, a warming climate very likely favored the invasion of the more shade tolerant white pine. Subsequent succession from white pine forests to hemlock and yellow birch forests to sugar maple, beech and black cherry forests has evidently taken place. The maintenance of a high soil calcium content by spruce and fir may have been influential in determining the course of cliseral and successional changes and soil development. Hardwood encroachment, however, may have begun before the carbonates were leached beyond the reach of their roots. In this event, yellow birch could saturate the surface horizons with calcium and magnesium thereby bringing the humus layer pH within the optimum range of sugar maple and black cherry seedlings (see Wilde, 1958). Continued increases in the percent base saturation of the solum has evidently resulted in the cessation of crenic acid production and promoted the formation of a well-developed mull humus.

Nutrient Pool Relationships

When the soil profile data are compared and combined with an estimate of the standing tree crop on each site (Table 19) it is readily seen that the site sequence A1, A2 and A3, is characterized by tree crops having rapidly increasing amounts of calcium, magnesium and potassium with more slowly increasing amounts of phosphorus. These tree crop increases are accompanied by rapid solum decreases in exchangeable Ca and fairly rapid increases in exchangeable potassium. Tree crop magnesium continues to consistently increase directly with the stage of plant succession on the B sites despite a decrease in basal area per acre.

On the older sites, tree crop calcium, magnesium, potassium and phosphorus all increase directly with the stage of plant succession but with no consistent increase in individual available solum nutrients.

More available P is present in the solum of each Podzol than is estimated to be in the respective tree crop. Exchangeable K in the solum, however, is less than tree crop K in all the A site profiles and in two of the older profiles (C2 and D1). A heavy cutting or two

TABLE 19. NUTRIENT POOL ESTIMATES*

Site, Vegetation and Soil	Ecosystem Components	#Ca/A	#Mg/A	#K/A	#P/A	Est. Dry Weight of Stand (#/A)
Site A1:	Standing Crop	183	23	76	21	99,090
Balsam Fir—	Solum (17½")	1400	50	17	8	
Regosol	5½' Profile	12,464	419	266	128	
sand	Crop&Profile	12,647	442	342	149	
Site A2:	Standing Crop	289	36	122	29	131,890
Pine—	Solum (12¼")	1005	39	63	57	
Eastport	5½' Profile	23,744	203	209	84	
sand	Crop&Profile	24,033	239	331	113	
Site A3:	Standing Crop	380	63	198	36	165,000
Red Oak—	Solum (38")	662	86	73	50	
Eastport	5½' Profile	5090	145	405	131	
sand	Crop&Profile	5470	208	603	167	
Site B1:	Standing Crop	489	65	263	54	223,850
Hemlock—	Solum (40")	1,507	156	321	163	
Rubicon -	5½' Profile	8,189	434	556	193	
Eastport	Crop&Profile	8,678	499	819	247	
sand						
Site B2:	Standing Crop	484	78	241	54	190,900
Red Oak—	Solum (26")	2397	246	460	245	
East Lake	5½' Profile	10,648	613	666	302	
sand	Crop&Profile	11,132	691	907	356	
Site C1:	Standing Crop	245	29	115	29	144,000
Red Pine—	Solum (35")	748	129	219	242	
Rubicon	5½' Profile	1237	242	431	350	
sand	Crop&Profile	1482	271	546	379	
Site C2:	Standing Crop	324	43	179	36	156,830
Hemlock—	Solum (38")	558	34	140	282	
Kalkaska	5½' Profile	787	67	205	334	
sand	Crop&Profile	1111	110	384	375	
Site D1:	Standing Crop	735	117	327	108	270,000
SugarMaple—	Solum (31½")	3756	250	308	224	
Kalkaska	5½' Profile	4246	372	538	331	
sand	Crop&Profile	4981	489	865	439	

*See Appendix IV for calculations.

in the stands on the older soils might result in a drastic lowering of exchangeable K such as has occurred in Wisconsin (Wilde, 1958). A similar reduction of exchangeable Mg in Ecosystem C2 might also be expected should such a practice be pursued without artificial replenishment.

Relationships Between Podzol Development, Time, Plant Succession and Solum Fertility

If degree of Podzol development is based on totals of illuvial organic matter and extractable sesquioxides, Table 20 shows relationships between these criteria, morphological degree of development (based on color profile development), age, successional stages and solum fertility.

TABLE 20. RELATIONSHIP BETWEEN AGE, SUCCESSIONAL STAGE, MORPHOLOGICAL DEGREE OF PODZOL DEVELOPMENT, ILLUVIAL TOTALS OF ORGANIC MATTER AND EXTRACTABLE SESQUIOXIDES AND SOLUM FERTILITY

Site	Approx. Soil Age	Successional Stage and Major Dominants	Morph. Devel.	Illuv. O.M.	#/A Extr.Ill. R_2O_3	Ill. Totals	Solum Fertility*
A1	2500	I-Balsam Fir	0	0	0	0	2127
A2	2500	I-W&R Pines	V.Weak	5548	3914	9450	2704
A3	2500	II-R.Oak&W.Pine	V.Weak	6364	6450	12,814	2510
B1	3000	III-E.H.,Y.B.&W.P.	Weak	42,120	56,010	98,130	4794
B2	3000	IV-R.O., SM.	W-M	19,628	26,808	46,436	6650
C1	10,000	II-Red Pine	Weak	41,762	56,245	98,007	3056
C2	10,000	IV-E.H.,Y.B.,R.M.	Mod.	54,356	43,856	98,212	5733
D1	10,500	V-S.M., B.C.	Mod.	57,753	44,233	101,986	8433

*Sum of total N, available P, exchangeable K, Ca and Mg in #/A.

These data show that Podzols which are moderately or weakly to moderately developed morphologically are associated with advanced stages of succession which involve the presence of maple. These advanced stages of succession are, in turn, related to a high state of solum fertility. The morphologically moderately developed Podzols are assumed to have been dominated by pine for at least 4500 years during the earlier stages of their development. The later vegetational sequences are related to the fact that these soils have the highest illuvial organic matter contents of all the soils studied. Extractable sesquioxides in the illuvial zones, however, are greatest in Podzols which are weakly developed morphologically (as at Site C1) and support dominantly coniferous stands which contain no maple or beech. In the case of Profile B1, this illuvial development and the beginning of the later stages of vegetational succession has taken place in only 3000 years. If the sum of the illuvial organic matter and the extractable illuvial sesquioxides is used to determine the degree of Podzol development, it becomes apparent that there are 4 moderately developed, one weakly developed and 2 very weakly developed Podzols in the group. Three of these moderately developed Podzols are presently occupied by pine and/or hemlock and the fourth (D1) must have been similarly occupied between the end of the spruce-fir period and the assumption of dominance by northern hardwoods within the last two to four thousand years.

CHAPTER 11. SUMMARY AND CONCLUSIONS

A chronoclimobiosequence study was made of eight relatively undisturbed sand soil sites in Delta and Alger Counties in the Upper Peninsula of Michigan. The ages of the geomorphic surfaces on which these sites are located range from about 10,000 to less than 2500 years.

The climate of the Upper Peninsula of Michigan was analyzed by means of water balance computations. Climatic comparisons were made between the Podzol Region and the Gray-Brown Podzolic Soil Region of Michigan and between zones within the Podzol Region. The Gray-Brown Podzolic Soil Region is characterized by spring maxima of precipitation while the Podzol Region has summer maxima or maxima which include the month of September. Within the Podzol Region of the Lower Peninsula, the zone of most strongly developed Podzols closely coincides with the area having a mean fall precipitation of 9 inches or more and a mean annual snowfall of greater than 60 inches. The latter characteristic applies to all of the Upper Peninsula except for the area west of Green Bay. Computations indicate that in almost all of the areas having these characteristics, fall precipitation exceeds fall potential evapotranspiration by a considerable amount resulting in the attainment of field capacity in sand soils by the end of November in an average year.

It is suggested that the increased abundance of white pine in the Podzol Region is favored by increases in soil moisture late in the growing season. The relatively large precipitation to evapotranspiration ratios from September through November are also thought to be partly responsible for some fall leaching in all soils and a particularly deep

leaching of sand soils. It is concluded that the insulation provided by an early and persistent snow cover significantly retards or prevents soil freezing (many chemical, physical and biological processes could thus continue even during the winter when the average air temperature is below freezing).

To gain some information concerning the vegetation present throughout the formation of a well-developed, well-drained sand Podzol, a peat bog surrounded by Kalkaska sand was sampled for pollen analysis. Pine pollen constitutes over 60% of the total tree pollen in the lower three-fourths of the peat bog column. The lack of a spruce-fir maximum at the bottom of the column is attributed to the late emergence of the surrounding land areas from beneath the spillway waters of glacial Lake Duluth. The upper one-fourth of the column is characterized by increasing amounts of hemlock and birch pollen, a substantially higher percentage of spruce and fir pollen and a somewhat higher percentage of beech and maple pollen.

Percentages of pollen grains alone do not give the true percentage composition of the successive floras here but when these data are combined with the analysis of current forest composition in the surrounding area, they indicate that early soil development in the area took place beneath forests dominated by pine. Thus forest succession from pine to the present hemlock-northern hardwood forest in the surrounding area apparently took place during the time of deposition of the upper one-fourth of the peat column. The pollen percentages in the upper one-fourth of the peat column also indicate that the climate during the deposition of this part of the peat was cooler and/or more moist than during the accumulation of the lower portions

of the peat, especially the middle one-third. These lines of evidence imply that both cliseral and successional changes in vegetation have occurred during the development of the surrounding soil body of Kalkaska sand. Since pine forests are usually associated with less well-developed Podzols, it is suggested that the well-developed character of this Kalkaska sand was formed under the conditions of the late post-glacial climate and vegetation.

A composite foliage sample was collected from one tree of one or more representative species on each of five plots. Although the lack of replication and the collection of current conifer needles limit interpretations, chemical analyses and corroborative evidence from the literature indicate: (1) that the pines contain less foliar calcium than any of the other species sampled, (2) that the order of decreasing foliar calcium concentrations for some other important species is yellow birch, sugar maple, American beech and eastern hemlock, (3) that the pines contain lower concentrations of foliar N than sugar maple and yellow birch and (4) that maple foliage contains comparatively high concentrations of manganese.

Results from the present study alone also indicate that red pine contains similar amounts of foliar calcium, magnesium and phosphorus when growing on sand soils having a considerable range of exchangeable and/or available forms of these elements. A single composite sample of balsam fir foliage from one tree contained a concentration of calcium which was about four times as great as those of single samples of red and white pine foliage when all three species were growing on young soils developed in calcareous sand. A yellow birch foliage sample contained much higher concentrations of Ca and Mg than any other sample and a sugar maple foliage sample was outstanding with respect

to high phosphorus concentrations. A hemlock sample contained a much higher concentration of aluminum than any other sample. The relatively great aluminum cycling ability of hemlock is corroborated by the consistently high extractable Al concentrations in the Oh horizons of soils under stands containing hemlock.

Based on the evidence, it is concluded that the presence of red and white pines is not as conducive to the retention of ecosystem calcium supplies as is the presence of balsam fir, white spruce or northern hardwoods (with the doubtful exclusion of northern red oak). Based on the present study alone, it is suggested that these pines also are not as conducive to the retention of ecosystem magnesium supplies as are the hardwoods sampled in this study.

Both species of pine contained significantly more foliar manganese and aluminum when growing on a well-developed acid Podzol than when growing on a weakly developed Podzol containing carbonates within a foot of the soil surface.

Soils at the study sites were described and profile samples were taken for laboratory analyses of physical, chemical, microbiological and biochemical properties.

Direct microscopic counts of bacterial cells did not reveal a cells-per-gram-of-sample maximum in the Vhl (mull humus) horizon studied when compared with an Oh (mor humus) horizon. However, there were twice as many cells per gram of organic matter in the Vhl horizon as in the Oh horizon. The Vh horizon contained vastly greater amounts of actinomycete filaments than did the Oh horizon even when expressed on a per-gram-of-sample basis. Amounts of stained and unstained fungal hyphae per gram of organic matter were greater in the Vhl horizon than

in the Oh horizon, but on a per-gram-of-sample basis, fungal hyphae were more prevalent in the Oh horizon. The occurrence of higher quantities of micro-organisms per gram of organic matter in the Vhl horizon was associated with the higher calcium and nitrogen content of the organic matter and its apparently greater susceptibility to microbial attack.

Organic matter determinations indicated the presence of illuvial maxima in all profiles having an eluvial (E) horizon. However, darker colors of illuvial horizons were not always indicative of higher organic matter contents but were in some cases more closely related to the presence of a considerable proportion of maple in the surrounding vegetation. The calculated weight of illuvial organic matter increases generally with age but other factors were evidently responsible for rather large variations from this pattern.

Total nitrogen varied directly but not always proportionately with organic matter content. When converted to percent N in the organic matter, the resultant values were distinctly higher for the profiles under hardwood-dominated forest types. Judging from the literature, hemlock contains lower foliar nitrogen concentrations than associated hardwoods. Hemlock and northern hardwoods (exclusive of beech) in this study have distinctly higher foliar N values than the pines. Thus it is concluded that total nitrogen percentages in the upper humic (Oh or Vhl) horizons is dependent both on foliar nitrogen concentrations and on the organic matter content.

Fulvic acid could be extracted from all Oh, Vh and illuvial horizons but no quantitative determinations on this fraction were made. Guaiacol and phenols were present in the humic acid fraction from both Oh and Vh horizons. The humic acid fraction from an illuvial horizon

of one of the well-developed Podzols contained no identified organic compounds like those found in the same fraction of the Oh and Vh horizons when subjected to the same thermo-decomposition and chromatographic identification technique.

When Oh horizons (from mor and duff-mull humus layers) were alternately incubated and leached with distilled water, crenic acid* production was profuse and sustained. The length of time of profuse production was directly related to the organic matter content. Production of crenic acid by Vh horizons was either not profuse or not sustained. Vh horizons containing more than 3000 # Ca/AFS produced no crenic acid. Nitrate production was nil when crenic acid production was profuse. Logarithmic decreases in crenic acid production were accompanied by logarithmic increases in nitrate production and acidity of the leachates.

It is suggested that some components of crenic acid end up in the fulvic acid-containing illuvial horizons as a part of a flocculated organo-mineral complex. Based partly on the studies of other authors, it is concluded that most of the phenols present in the high calcium horizons have been polymerized and rendered incapable of tanning protein. The degree of Oh horizon development is believed to reflect the amount of tanned protein present which, in turn, restricts the numbers and kinds of micro-organisms and soil fauna present. It is further believed that fungi are the primary attackers of the tanned proteins and that until such time as the concentrations of these tanning agents are considerably reduced, crenic acid production is

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*Crenic acid as used herein refers to the yellow, water-soluble leachate produced by alternately incubating and leaching Oh and Vh horizons in the laboratory.

profuse and ammonia oxidation by bacteria is inhibited.

Illuvial maxima of extractable sesquioxides apparently form in originally calcareous sand in less than 2500 years under Oh horizons which produce crenic acid on incubating and leaching in the laboratory. Extractable iron is greater than extractable aluminum in every horizon in every profile that is younger than 3500 years in this study. Extractable aluminum is nil in calcareous P and U horizons whereas extractable iron is present in concentrations up to 0.25%. Estimated total extractable sesquioxides in the illuvial zones is greater in one approximately 3000 year old profile than in two of the older (between 10,000 and 10,500 years old) profiles. Extractable aluminum exceeds extractable iron in the lower part of the solum in two of the three older profiles and in the ortstein of one of these.

Distinct maxima of available phosphorus occur in all the illuvial zones. Horizons containing high concentrations of calcium contain extremely low concentrations of available P.

In seven of eight profiles, the upper humic horizons contain the highest concentrations of exchangeable potassium. In three of these cases, it is estimated that the Oh horizon contains over 50% of the total exchangeable K in the solum.

Either a Vh or an Oh horizon contains the maximum concentration of exchangeable calcium and magnesium in each solum. In four sola, over one-third of the total exchangeable calcium is estimated to be in the uppermost humic horizon. In one of these, 97% of the exchangeable magnesium in the solum is estimated to be in the Oh horizon.

Rough estimates, based on an 8-foot soil profile, indicate that

up to 39% of the "available"* potassium and magnesium in the ecosystems studied may be in the standing crop. For available calcium and phosphorus, estimates indicate that up to 23% may be so distributed.

Upper humic horizons of Podzols beneath conifer-dominated stands ranged in pH from 4.2 to 4.5 which was more acid than those of Podzols beneath other forest stands. With increasing development, Podzols with Oh horizons exhibit increasing penetrations of very strongly and extremely acid reactions. This trend is also exhibited by estimated totals of extractable aluminum in the sola and the concentration of extractable aluminum in the Oh horizons.

Mechanical analyses of the profiles revealed that all the sub-solum horizons contained 98-100% sand although some sub-solum horizons contained finer sand than others. The percent sand in the uppermost mineral soil horizons decreased with chronological age of the soil regardless of the degree of Podzol development. Illuvial horizon clay increased generally with age but the most acid of the older profiles contained only half as much as the other two similarly-aged profiles. Further investigations are necessary for adequate explanations of some of the apparent anomalies regarding clay and silt content and distribution.

The fertility data indicate that succession from pine to pine-hemlock to hemlock-yellow birch forests is associated with increasing total contents of N and available P in the solum along with increasing concentrations of N in the Oh horizon. Increasing proportions of

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*"available", as used here, refers to total elements within the trees and exchangeable or available amounts in the soil.

sugar maple are associated with increasing total solum fertility*, increasing total content of exchangeable calcium in the sola and increasing concentrations of exchangeable calcium in the uppermost humic horizons.

Conclusions Regarding the Sequence of Events in the Development of Podzols in the Study Area

Initial profile development in limy well-drained sands in the study area involves the formation of a Vh horizon only. This type of profile can be found under some types of pioneer shrub vegetation and under balsam fir, white spruce and paper birch stands which may succeed the shrub thickets. Under the dune heath shrubs and the succeeding boreal forest type, carbonates are not rapidly leached out of the surface because of the high foliar calcium contents of the component species and the aeolian transfer of unweathered sand grains from nearby unstabilized beach sand areas. At biologically favorable temperatures, solutions moving through the Vh horizon tend to remain clear and nearly neutral in reaction.

If, however, pioneer shrubs have been succeeded by an overstory of red and white pines and the distance from unstabilized sand is several hundred feet, an acid Oh horizon begins to develop which apparently contains substances (probably tannins) that inhibit nitrification. Under favorable environmental conditions, crenic acid is then rapidly formed in these Oh horizons and is later leached by rainwater or melting snow into the mineral horizons below.

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*Sum of total N, available P, exchangeable K, Ca and Mg in #/A

Crenates of iron, aluminum, calcium, magnesium, manganese, ammonium and potassium may be formed within the Oh horizon, in the mineral horizon below, or in both. The VH horizon is thus destroyed, a reduction in exchangeable Ca and Mg occurs below the Oh horizon and a bleached, acid E horizon forms as crenic acid and/or water soluble crenates such as those of Fe, Al, Ca and Mg move downward from the developing Oh horizon.

An illuvial horizon forms within the upper part of the subsiding zone of carbonates or above it. The illuvial horizon is characterized by maxima of extractable iron and aluminum, clay, available P, exchangeable Mg, exchangeable K and organic matter. Because of the initially restricted zone of low pH values, aluminum solubility is limited. The fact that all young profiles developing in calcareous parent materials contain more extractable iron than aluminum is either dependent upon the low solubility of aluminum, a greater affinity of the organic matter for iron, easier flocculation of organo-iron complexes than organo-aluminum complexes or a combination of these factors.

The fact that some studies indicate that organo-iron complexes can also be flocculated by relatively small amounts of aluminum suggests that this mechanism could become increasingly important as the profiles become more acid and as forest succession proceeds toward a higher proportion of vegetation which has the ability to cycle relatively large quantities of aluminum. The relative amounts of phytocycled Al, Ca and Mg are thought to be of some consequence since other studies indicate that the depth of penetration of some organo-metal complexes are not only controlled by the concentration of flocculating agents

in the illuvial horizons but also by how "sensitized" with polyvalent cations the complexes are upon their arrival in these horizons. The evidence at hand suggests that the prevalence of white pine and hemlock promotes a relatively high rate of aluminum cycling, the persistence of a thick, extremely acid, aluminum-rich Oh horizon and a high rate of crenic acid production. A sustained dominance of these species, in association with a much smaller percentage of hardwoods such as red maple and yellow birch on deep-to-carbonate sites, apparently initiates the evolution of very strongly to extremely acid illuvial horizons which contain as much or more extractable aluminum as extractable iron and sometimes contain ortstein. Continued increases in maple and yellow birch with the encroachment of beech coincides with the formation of a dark upper illuvial horizon dominated by extractable iron.

The data further indicate that a more advanced stage of forest succession to northern hardwoods involves an increase in the cycling of Ca and Mg and a decrease in the production of crenic acid. These factors suggest an increase in Ca and Mg sensitization of any subsequent organo-mineral complexes formed and consequently a reduced depth of their penetration. Upper illuvial horizons formed in this manner contain prominent amounts of exchangeable Ca and Mg as well as extractable Fe. Persistence of a climax hardwood forest containing considerably more sugar maple than beech increases the susceptibility of the forest litter to decomposition by both micro-organisms and soil fauna. The resulting change in the soil organism population is responsible for the conversion of what was an extremely acid mor humus (Oh + Of horizons) into a more base-saturated mull humus (Vh horizons

only). The production of crenic acid apparently ceases when the exchangeable calcium content exceeds 3000 lb/AFS. At this stage, nitrification is favored and soil solutions moving downward out of the Vh horizons are clear and have near neutral reactions when temperatures are favorable for biochemical activity.

<u>The Projection of the Study Area Relationships to the Podzol Region</u>

The extrapolation of the study area relationships to the entire Podzol Region of Michigan suggests that Podzol Zone III is a zone of relatively strong Podzol development (development of dark upper illuvial horizons) as a result of: (1) an early and mid-post-glacial vegetation characterized by the prevalence of species conducive to the formation of mor humus layers; (2) a current climate characterized by relatively mild droughts, relatively great amounts of fall precipitation and the accumulation of a thick and seasonally persistent snow cover which begins to form early enough to retard soil freezing; and (3) a late post-glacial increase in the prevalence of hemlock, maple and beech on some very sandy soils. The older, sandier sites now supporting northern hardwoods or mixed stands of hemlock, white pine and northern hardwoods, are characterized by well-developed Podzols having dark upper illuvial horizons as in the study area. Based on current soil-vegetation relationships, it is suggested that these well-developed Podzols were only weakly or moderately developed (i.e. minimal Podzols according to Michigan nomenclature) prior to hardwood encroachment if the previous vegetation was predominantly pine. Limited observations in the study area indicate that dark upper illuvial horizons can ~~only~~ also develop in white spruce stands.

Therefore, it cannot be stated that in all cases, dark upper illuvial horizons begin to form only as the proportions of maple and beech increase.

Podzol Zone II, despite the prevalence of older land surfaces, is a zone of less strongly developed Podzols (lacking dark upper illuvial horizons) as a consequence of less snowfall, drier soils in fall and beneath the snow cover, higher proportions of pines on the sandier sites and a greater proportion of oaks during post-glacial times than in Zone III.

Podzol Zone I is a zone of weak or no Podzol development as a result of relatively dry soils in fall and certain climatic conditions which have been responsible for this area being a vegetation tension zone throughout much of post-glacial time. Hemlock, for instance, is represented to a much lesser extent in pollen profiles in Zone I than in Zone II or III. Considerable proportions of oaks are (and probably have been for the latter part of post-glacial time) almost invariably associated with pines and some of the sand soils recently supported mainly grass (Newaygo prairies). It is suggested that the weak Podzols that are present owe their existence to the former prevalence of pine and spruce and to the persistence of white pine up to the present time on some of the sandier soil materials.

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A P P E N D I C E S

APPENDIX I. CLASSIFICATION OF THE SOILS STUDIED

Michigan Classification System

The lack of rigorous, quantitative standards in the classification system used in the United States to date, by the National Cooperative Soil Survey, makes it difficult to classify several of the soils in this study according to that scheme. The distinction between Regosols and Brown Forest soils is not quantitatively defined; the same is true between Podzols and Brown Podzolic soils, and between Brown Podzolic sands and Gray-Brown Podzolic sands. The Podzol subgroups minimal, medial and maximal likewise are not defined by quantitative criteria and some important but easily measured properties such as depth and color of the Vh horizons or color and thickness of the illuvial horizons may not have been taken into account.

The following suggested taxonomic key is based on the soil morphology-soil chemistry relationships found in this study and that of Franzmeier:

1.1. color value of E horizon 5, 6 or 7 and color chroma 1 or 2; I horizon has a redder hue and/or a higher chroma than the P or W horizon...Podzol

1.11. single I horizon with a color value not more than one unit lower than that of the P horizon; illuvial zone less than 18 inches thick............Sub-minimal Podzol

1.12. same as 1.11 except illuvial zone is thicker than 18 inches....................................Minimal Podzol

1.13. either: (1) more than one distinct illuvial horizon, the upper one of which has a lower color value than that of the P or W horizon or (2) only one distinct illuvial horizon having a redder hue plus a color chroma at least 2 units higher than those of the P or W horizon; illuvial zone less than 18 inches thick...................................Sub-medial Podzol

1.131. color values in illuvial zone not more than 2 units lower than that of P or W horizon ....Yellowish Sub-medial Podzol

1.1311. hues in lower illuvial horizon redder than those in P or W horizon......... .<u>Yellowish</u> <u>Ferro-aluminic</u> <u>Sub-medial</u> <u>Podzol</u>

1.1312. hues in lower illuvial horizon not redder than those in P or W horizon.. .<u>Yellowish</u> <u>Alumino-ferric</u> <u>Sub-medial</u> <u>Podzol</u>

1.132. color values of upper illuvial horizon more than 2 units lower than that of P or W horizon.......................<u>Dark</u> <u>Sub-medial</u> <u>Podzol</u>

1.1321. hues in lower illuvial horizon redder than those in P or W horizon and/or little or no ortstein in illuvial zone; pH above 5.5 in lower illuvial horizon ......<u>Dark</u> <u>Ferro-aluminic</u> <u>Sub-medial</u> <u>Podzol</u>

1.1322. hues in lower illuvial horizon not redder than those in P or W horizon; pH below 5.5 in entire illuvial zone; mor humus and ortstein chunks commonly present under relatively undisturbed conditions ......<u>Dark</u> <u>Alumino-ferric</u> <u>Sub-medial</u> <u>Podzol</u>

1.14. same as 1.13 except that illuvial zone is thicker than 18 inches......................................<u>Medial</u> <u>Podzol</u>

1.141. ....<u>Yellowish</u> <u>Medial</u> <u>Podzol</u>

1.1411. .....<u>Yellowish</u> <u>Ferro-aluminic</u> <u>Medial</u> <u>Podzol</u>

1.1412. .....<u>Yellowish</u> <u>Alumino-ferric</u> <u>Medial</u> <u>Podzol</u>

1.142. ....<u>Dark</u> <u>Medial</u> <u>Podzol</u>

1.1421. ....<u>Dark</u> <u>Ferro-aluminic</u> <u>Medial</u> <u>Podzol</u>

1.1422. ....<u>Dark</u> <u>Alumino-ferric</u> <u>Medial</u> <u>Podzol</u>

1.15. same as 1.14 except that a continuous ortstein zone is present..<u>Maximal</u> <u>Podzol</u>

1.2 no E horizon; Vh zone at least 3 inches thick, slightly acid to alkaline and overlying a slightly acid to neutral W or I horizon.......................................<u>Brown</u> <u>Forest</u> <u>Soil</u>

The terms <u>minimal</u>, <u>medial</u> and <u>maximal</u> relate to <u>concentrations</u> of illuvial components, which, of course, only tells part of the story.

By using the prefix "sub" in conjunction with the above terms, the factor of thickness is at least partially evaluated. The terms "yellowish", "dark", "alumino-ferric" and "ferro-aluminic" are related to base status, induration, content of extractable aluminum, organic matter and color. "Yellowish" indicates that the illuvial horizon(s) is(are) yellowish or orangish in color and low in organic matter. "Dark" indicates that the upper illuvial horizon has a color value 3 or 4 units lower than the underlying P or W horizon. "Alumino-ferric" indicates that the upper illuvial horizon contains more than 0.4% extractable aluminum and when used in conjunction with "dark" further denotes that the illuvial zone is low in bases and may contain chunks of ortstein. "Ferro-aluminic" indicates that the upper illuvial horizon contains less than 0.4% extractable aluminum, that little or no ortstein is present and when used in conjunction with "dark" and "medial" further denotes a relatively high supply of bases in the illuvial zone; in the present study, the highest nitrification rates took place in the Vhl horizons of the Ferro-aluminic Dark Medial Podzol and the Ferro-aluminic Dark Sub-medial Podzol.

The classification scheme suggested above has some practical significance since thickness and organic matter contents of illuvial zones have pedogenic, hydrologic and fertility implications. The terms ferro-aluminic and alumino-ferric have pedogenic and fertility implications. Aluminum toxicity could be a fertility factor since some plants such as lettuce, onions and spinach are adversely affected when soluble aluminum is present at concentrations higher than 10-20 ppm (Bear, 1957) and Wilde (1958) states that high concentrations of soluble aluminum and manganese in the accumulative layers of Podzol soils appear to arrest

the downward penetration of roots. The classification of the soils in this and Franzmeier's (F) study would be as follows:

Sub-minimal Podzol - Eastport (A-2 and A-3)
Minimal Podzol - Eastport (F)
Yellowish Ferro-aluminic Medial Podzol - Rubicon (B-1), Rubicon (F)
Yellowish Alumino-ferric Medial Podzol - Rubicon (C-1), Kalkaska (F)
Dark Ferro-aluminic Sub-medial Podzol - East Lake (B-2)
Dark Ferro-aluminic Medial Podzol - Kalkaska (D-1), Blue Lake I (F)
Dark Alumino-ferric Medial Podzol - Kalkaska (C-2), Blue Lake II (F)

The Dark Ferro-aluminic Medial Podzols and the Dark Ferro-aluminic Sub-medial Podzol all supported pure northern hardwood forests. Dark Alumino-ferric Medial Podzols are currently being separated from the Dark Ferro-aluminic Medial Podzols in the U.S. Forest Service soil survey of Hiawatha National Forest. Soils mapped in Delta County as Rubicon sand but which have a shallow solum commonly supported mainly jack pine as the natural vegetation. Data is probably available which will indicate that rate of growth differences will also occur between soils having thinner sola and those having thicker ones, especially where the profiles have most of their cation exchange capacity and water-holding capacity concentrated in the solum.

The European Classification System

The terms "Humus Podzol", "Iron Podzol" and "Iron-Humus Podzol" do not bring out important differences with respect to degree of Podzol development and fertility. Thus, profiles A2, A3, B1, and C1 would all fall into the category of Iron Podzols whereas the remainder would be classified as Iron-Humus Podzols (see Kubiena, 1953).

The Seventh Approximation

The E horizons of all profiles have moist color chromas of 3 or less than 3 and all but that of Profile A2 have moist color values greater than their respective underlying spodic (or spodic-like) horizons; in all likelihood, the *dry* value of the E horizon of Profile A2 would be higher than that of the underlying Ibi horizon. Thus, all the Podzols in this study can be said to have an "albic" horizon although it is discontinuous in Profile B2.

The illuvial zone of each profile except A3 contains a horizon having at least 0.5% organic matter; profiles C1, C2 and D1 contain horizons having more than 0.58% carbon and are the only ones which qualify as Spodosols. Profile C1 qualifies for the subgroup Entic Normorthod. Profile C2 falls into the Typic Normorthod subgroup. Profile D1 is also classified as a Typic Normorthod.

Profile A1 qualifies for the subgroup Cumulic Normipsamment and the remaining profiles qualify for the subgroup Spodic Normipsamment.

The following table gives a ready comparison of the profiles as classified by: (1) the former system of the National Cooperative Soil Survey, (2) the author's suggested classification outlined previously and (3) the 7th Approximation.

Profile	Former Classification	Suggested Classification	7th Approximation
A1	Regosol	Brown Forest Soil	Cumulic Normipsamment
A2	Minimal Podzol	Sub-minimal Podzol	Spodic Normipsamment
A3	Minimal Podzol	Sub-minimal Podzol	Spodic Normipsamment
B1	Minimal Podzol	Yellowish Ferro-aluminic Medial Podzol	Spodic Normipsamment
B2	Minimal to Medial Podzol	Dark Ferro-aluminic Sub-medial Podzol	Spodic Normipsamment
C1	Minimal Podzol	Yellowish Alumino-ferric Medial Podzol	Entic Normorthod
C2	Medial Podzol	Dark Alumino-ferric Medial Podzol	Typic Normorthod
D1	Medial Podzol	Dark Ferro-aluminic Medial Podzol	Typic Normorthod

If the spodic horizon were defined as having an extractable sesquioxide percentage twice that of the P or W horizon, all the profiles but A1 in this study would have spodic horizons. The writer wholeheartedly supports Franzmeier who suggested this amendment previously. Concerning field characteristics, the writer believes more emphasis should be put on chromas and horizon thicknesses. Comparisons of color characteristics between illuvial horizons and their respective P or W horizons seems just as realistic as between E horizons and their subjacent I horizons. With moderately well-drained soils and imperfectly drained soils, this procedure would probably not be satisfactory, however.

For field use, the author feels that a classification system should be used which is based on quantitative characteristics measurable in the field so that the individual soil mapper can be objective in making his identifications. Such quantitative separations should be based on

edaphological, hydrological or other practical considerations. The suggested classification is merely an attempt to fulfill these qualifications. Additional field studies are needed for testing and refinements of such a scheme. Classification according to 7th Approximation standards cannot as yet be accomplished in the field.

APPENDIX II. FUTURE RESEARCH NEEDS

Climatic Studies

The effects of snowcover and fall rains need to be studied in relation to their effect on soil temperature, moisture and oxidation-reduction conditions during the winter. These studies should be made both on mull humus sites and mor humus sites. Concurrent studies of the physiological activity of evergreen conifers and hardwoods might also be enlightening, both edaphologically and pedogenically. Concurrent studies of microorganism populations and activities under a snowcover might also yield valuable information which might throw light on the relations between climate, higher plants and soil chemical processes.

Pollen Analysis

Several more pollen analyses should be made; these should be on different age surfaces and different textured surfaces, particularly where different great soil groups are involved such as Brown Forest soils on till and Brown Podzolic soils on sand. Pollen stratigraphy should be strengthened with radiocarbon dates of the key peat layers.

Foliar Analysis

High priority should be given to a study designed to bring out between species differences in foliar composition by studying a series of neighboring trees of different species and to determine within species differences attributable to soil conditions. The data to date indicate that some species respond to increased supplies of certain available chemical elements while other species do not.

Soil Biochemistry Studies

High priority should also be given to further studies on the composition of crenic acid, its ability to form water soluble complexes with metals, its susceptibility to flocculation or precipitation and the range of conditions under which it forms including vegetation types as well as soil nitrogen forms.

Soil Chemistry Studies

Determination of extractable manganese in the illuvial horizons and in the surface horizons is needed to elucidate the relation between plant foliage, dark horizon colors, organic matter and manganese oxides.

Total calcium determinations for all the horizons of profiles C1 and D1 might indicate whether or not the solum calcium in D1 came from cycling of calcium from the free carbonates before they were leached below the root zone. These determinations might also indicate whether or not it is possible for C1 to reach the stage of fertility exhibited by D1 at the present time.

The acetylacetone method of soil extraction used by Martin (1960) should be compared with the sodium dithionite-citrate-bicarbonate method used in this study. Martin found that the amounts of Al extractable from acetylacetone dispersions of Podzols greatly exceeded extractable iron. Extractable Al in this study never greatly exceeded extractable iron although somewhat greater amounts were found in the lower horizons of the illuvial zones in Profiles C2 and D1.

APPENDIX III. PROFILE DATA TABLES

TABLE 21. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE A1

Property	Horizon: Depth(in.):	Vh1 0-1	Vh2 1-4½	P 17½+
Particle size dist. (%)				
Gravel: 2 mm		-	0.0	0.0
Very coarse sand: 2-1 mm		-	0.0	0.1
Coarse sand: 1-0.5 mm		-	6.7	16.6
Medium sand: 0.5-0.25 mm		-	73.0	62.6
Fine sand: 0.25-0.1 mm		-	19.1	20.0
Very fine sand: 0.1-0.05		-	0.2	0.2
Total sand		-	99.0	99.3
Silt: 0.05-0.002 mm		-	0.5	0.2
Clay: 0.002 mm		-	0.6	0.5
USDA textural class		-	ms	ms
Concentration (%)				
Extractable Al_2O_3		0.025	0.010	0.005
Extractable Fe_2O_3		0.250	0.205	0.185
Total Nitrogen		0.141	0.028	-
Organic carbon		2.827	1.025	-
Organic matter		4.87	1.77	-
C:N		20	37	-
N in organic matter		2.90	1.58	-
Concentration (#/AFS)				
Available P		10	12	13
Exchangeable K		54	18	27
Exchangeable Ca		3106	1776	1200
Exchangeable Mg		108	64	40
pH		7.3	7.6	7.8
Cation exchange capacity (me/100g)		8.5	4.6	3.1
Percent base saturation		100	100	100

TABLE 22. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE A2

Property	Horizon: Depth(in.):	Oh 1½–0	Em 0–1¼	IIb 1¼–6¼	P 12¼–
Particle size dist. (%)					
Gravel: 2 mm		—	0.00	0.00	1.70
Very coarse sand: 2–1 mm		—	0.09	0.12	0.40
Coarse sand: 1–0.5 mm		—	7.72	5.81	22.33
Medium sand: 0.5–0.25 mm		—	61.21	65.02	59.24
Fine sand: 0.25–0.1 mm		—	29.82	27.08	17.07
Very fine sand: 0.1–0.05 mm		—	0.56	0.43	0.40
Total sand		—	99.38	98.45	99.43
Silt: 0.05–0.002 mm		—	0.52	0.80	0.58
Clay: 0.002 mm		—	0.10	0.76	0.00
USDA textural class		—	ms	ms	ms
Concentration (%)					
Extractable Al_2O_3		0.100	0.020	0.070	0.015
Extractable Fe_2O_3		0.315	0.255	0.445	0.240
Total nitrogen		0.750	—	0.021	—
Organic carbon		18.207	—	0.422	—
Organic matter		31.39	—	0.73	—
C:N		24	—	20	—
N in organic matter		2.39	—	2.88	—
Concentration (#/AFS)					
Available P		29	24	120	3
Exchangeable K		182	27	45	16
Exchangeable Ca		2620	296	958	2496
Exchangeable Mg		99	24	32	18
pH		4.5	4.8	5.4	6.9
Cation exchange capacity (m.e./100g)		26.7	0.8	4.4	—
Percent base saturation		25.0	100	54.5	100

TABLE 23. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE A3

Property	Horizon: Depth(in.):	Oh 0-1	Vh 1-2¼	Em 2¼-4½	IIb 4½-10¼	pVh 10¼-11-3/4	pEm 11-3/4-12-3/4	pIIb 12-3/4-16-3/4	W 16-3/4-38	P 38-66-
Particle size dist. (%)										
Gravel: 2 mm		-	-	0.00	1.25	-	-	-	-	3.73
Very coarse sand: 2-1 mm		-	-	0.29	3.47	-	-	-	-	1.16
Coarse sand: 1-0.5 mm		-	-	11.92	25.75	-	-	-	-	10.90
Medium sand: 0.5-0.25 mm		-	-	62.19	54.28	-	-	-	-	48.76
Fine sand: 0.25-0.1 mm		-	-	24.06	14.24	-	-	-	-	32.06
Very fine sand: 0.1-0.5 mm		-	-	0.78	0.49	-	-	-	-	5.14
Total sand		-	-	99.23	98.23	-	-	-	-	98.01
Silt: 0.05-0.002 mm		-	-	0.47	1.01	-	-	-	-	1.77
Clay: 0.002 mm		-	-	0.31	0.78	-	-	-	-	0.22
USDA textural class				ms	cs					ms
Concentration (%)										
Extractable Al_2O_3		0.155	0.055	0.015	0.060	0.085	0.025	0.030	-	0.015
Extractable Fe_2O_3		0.335	0.215	0.170	0.315	0.285	0.285	0.270	-	0.160
Total nitrogen		0.957	0.078	-	0.014	0.035	-	0.019	-	-
Organic carbon		16.665	1.606	-	0.217	0.545	-	0.295	-	-
Organic matter		28.73	2.77	-	0.37	0.94	-	0.51	-	-
C:N		17	21	-	16	16	-	16	-	-
N in organic matter		3.33	3.55	-	3.78	3.72	-	3.73	-	-
Concentration (#/AFS)										
Available P		24	15	7	48	45	26	26	-	11
Exchangeable K		192	54	18	27	27	27	27	-	45
Exchangeable Ca		1881	496	96	272	720	352	1056	-	600
Exchangeable Mg		188	72	32	32	72	48	48	-	80
pH		5.1	4.3	4.6	5.4	6.0	6.2	6.7	-	7.3
Cation exchange capacity (m.e./100g)		23.0	9.5	0.4	0.7	4.1	2.5	3.3	-	1.8
Percent base saturation		26.0	15.7	97.5	100	51.2	40.0	84.8	-	100

TABLE 24. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE B1

Property	Horizon: Depth(in.):	Oh 2–0	Vh 0–½	Em ½–7½	Ihib 7½–9½	Iib 9½–40	P 40–66	U 66–
Particle size dist. (%)								
Gravel: 2 mm				0.0	0.0	0.0		6.6
Very coarse sand: 2–1 mm				0.0	0.1	0.0		5.3
Coarse sand: 1–0.5 mm				1.3	1.4	2.3		18.1
Medium sand: 0.5–0.25 mm				41.7	39.0	47.0		35.8
Fine sand: 0.25–0.1 mm				53.5	55.8	49.0		36.6
Very fine sand: 0.1–0.05 mm				1.3	1.2	0.9		2.8
Total sand				97.7	97.4	98.5		98.6
Silt: 0.05–0.002 mm				2.0	1.1	0.7		1.3
Clay: 0.002 mm				0.3	1.5	0.8		0.2
USDA textural class				fs	fs	ms		ms
Concentration (%)								
Extractable Al_2O_3		0.165	0.020	0.005	0.070	0.180		0.015
Extractable Fe_2O_3		0.335	0.180	0.150	0.685	0.480		0.270
Total Nitrogen		0.923	0.063	-	0.023	0.014		-
Organic carbon		18.989	1.254	-	0.452	0.278		-
Organic matter		32.72	2.16	-	0.78	0.48		-
C:N		20	20	-	20	20		-
N in organic matter		2.82	2.92	-	2.95	2.92		-
Concentration (#/AFS)								
Available P		30	6	3	23	37		7
Exchangeable K		282	80	36	63	45		54
Exchangeable Ca		1210	280	80	160	246		1536
Exchangeable Mg		115	16	16	32	24		64
pH		4.4	4.1	4.4	4.5	5.5		7.6
Cation exchange capacity		27.5	6.8	0.32	4.5	1.7		4.0
Percent base saturation		20.0	11.7	100	11.1	41.1		100

TABLE 25. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE B2

Property	Horizon: Depth(in.):	Vh1 0–2	Vh2 2–5½	Em 5½–6(spots)	Ihib 5½–8¼	Iib 8¼–15¼	I/P 15¼–26	U 26–
Particle size dist. (%)								
Gravel: 2 mm		–	1.08	–	1.54	0.72	1.54	18.70
Very coarse sand: 2-1 mm		–	1.75	–	1.49	1.39	2.66	7.42
Coarse sand: 1–0.5 mm		–	34.64	–	26.17	31.42	25.01	42.79
Medium sand: 0.5–0.25 mm		–	46.65	–	52.24	54.02	40.28	42.36
Fine sand: 0.25–0.10 mm		–	12.93	–	12.22	10.95	25.66	3.71
Very fine sand: 0.1–0.05 mm		–	1.05	–	1.35	0.33	4.47	1.49
Total sand		–	96.86	–	93.46	98.09	98.07	97.76
Silt: 0.05–0.002 mm		–	2.76	–	2.54	1.20	1.49	1.77
Clay: 0.002 mm		–	1.40	–	4.01	0.71	0.45	0.48
USDA textural class		–	cs	–	cs	cs	cs	gr.cs
Concentration (%)								
Extractable Al_2O_3		0.060	0.040	–	0.145	0.070	0.055	0.015
Extractable Fe_2O_3		0.315	0.270	–	0.710	0.285	0.275	0.120
Total nitrogen		0.482	0.079	–	0.033	0.012	0.009	–
Organic carbon		6.909	1.501	–	0.458	0.158	0.115	–
Organic matter		11.91	2.59	–	0.79	0.27	0.20	–
C:N		14	19	–	14	13	13	–
N in organic matter		4.05	3.05	–	4.18	4.44	4.50	–
Concentration (#/AFS)								
Available P		49	15	–	110	115	30	10
Exchangeable K		511	104	–	104	88	63	36
Exchangeable Ca		2444	440	–	296	568	384	1440
Exchangeable Mg		170	64	–	72	40	48	64
pH		5.2	4.8	–	4.8	5.6	6.3	7.5
Cation exchange capacity (m.e./100g)		17.2	5.4	–	5.1	1.6	2.6	3.8
Percent base saturation		36.0	25.9	–	21.5	100	42.3	100

TABLE 26. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE C1

Property	Horizon: Depth(in.):	Vh 0-1¼	Em 1¼-6	Ihib 6-13	Iib 13-35	W 35-156
Particle size dist. (%)						
Gravel: 2 mm		-	0.47	2.02	1.59	0.80
Very coarse sand: 2-1 mm		-	1.66	2.09	5.10	3.31
Coarse sand: 1-0.5 mm		-	26.55	21.99	19.48	26.32
Medium sand: 0.5-0.25 mm		-	37.75	36.08	35.39	53.89
Fine sand: 0.25-0.1 mm		-	25.90	28.99	34.16	14.93
Very fine sand: 0.1-0.05 mm		-	3.64	2.91	2.47	0.71
Total sand		-	95.55	92.06	96.59	99.16
Silt: 0.05-0.002 mm		-	3.33	4.77	2.66	0.54
Clay: 0.002 mm		-	1.18	3.17	0.76	0.31
USDA textural class		-	cs	ms	ms	cs
Concentration (%)						
Extractable Al_2O_3		0.090	0.020	0.535	0.235	0.060
Extractable Fe_2O_3		0.210	0.135	0.610	0.265	0.170
Total nitrogen		0.139	-	0.030	0.010	-
Organic carbon		4.173	-	0.655	0.163	-
Organic matter		7.19	-	1.13	0.28	-
C:N		30	-	22	16	-
N in organic matter		1.96	-	2.65	3.57	-
Concentration (#/AFS)						
Available P		15	21	85	42	23
Exchangeable K		231	36	54	27	45
Exchangeable Ca		1534	120	104	72	104
Exchangeable Mg		114	16	16	24	24
pH		4.5	4.4	5.2	5.4	6.0
Cation exchange capacity (m.e./100g)		19.7	0.52	6.4	0.5	2.4
Percent base saturation		10.9	80.7	6.1	53.6	17.4

TABLE 27. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE C2

Property	Horizon: Depth(in.):	Oh 2-0	Em 0-6	Ihib 6-8	Ihbic 8-44	Ibi 8-26	I/W 26-38	W 39-96-
Particle size dist. (%)								
Gravel: 2 mm		-	0.42	1.68	-	1.01	1.79	2.58
Very coarse sand: 2-1 mm		-	1.55	2.32	1.77	3.66	2.08	4.73
Coarse sand: 1-0.5 mm		-	26.40	21.57	12.09	24.99	19.35	23.00
Medium sand: 0.5-0.25 mm		-	37.72	40.63	40.99	42.35	38.06	34.73
Fine sand: 0.25-0.1 mm		-	26.17	25.90	41.72	25.06	37.31	33.38
Very fine sand: 0.1-0.05 mm		-	2.61	2.18	2.51	1.76	3.08	3.25
Total sand		-	94.43	92.59	97.75	97.82	99.88	99.14
Silt: 0.05-0.002 mm		-	3.25	2.74	0.59	1.81	0.13	0.77
Clay: 0.002		-	0.77	4.68	1.66	0.38	0.00	0.15
USDA textural class		-	cs	ms	ms	cs	ms	cs
Concentration (%)								
Extractable Al_2O_3		0.250	0.020	0.470	0.440	0.285	0.140	0.050
Extractable Fe_2O_3		0.505	0.135	0.840	0.360	0.215	0.120	0.095
Total nitrogen		1.521	-	0.092	0.047	0.012	0.006	-
Organic carbon		29.605	-	1.957	1.158	0.232	0.106	-
Organic matter		51.04	-	3.37	2.00	0.40	0.18	-
C:N		19	-	21	25	19	18	-
N in Organic matter		2.98	-	2.73	2.35	3.00	3.33	-
Concentration (#/AFS)								
Available P		65	3	72	108	51	52	18
Exchangeable K		232	24	32	24	8	8	16
Exchangeable Ca		823	112	104	112	56	64	64
Exchangeable Mg		109	0	3	0	0	0	4
pH		4.2	4.2	4.2	4.6	4.8	5.5	6.3
Cation exchange capacity(m.e./100g)		2.7	2.2	-	17.2	7.1	3.1	-
% base saturation		99.9	9.0	-	1.1	1.4	3.2	-

TABLE 28. CHEMICAL AND PHYSICAL PROPERTIES OF PROFILE D1

Property	Horizon: Depth(in.):	Vh1 0–½	Vh2 ½–1	Vh3 1–5	Em 5–7½	Ihib1 7½–10	Ihib2 10–14	Ibi 14–31½	W1 31½–144
Particle size dist. (%)									
Gravel: 2 mm		-	-	-	2.51	0.68	2.36	-	0.34
Very coarse sand: 2–1 mm		-	-	3.45	3.24	2.39	6.12	2.32	1.19
Coarse sand: 1–0.5 mm		-	-	44.11	38.85	38.92	43.19	45.97	16.68
Medium sand: 0.5–0.25 mm		-	-	29.57	36.37	33.16	29.18	44.34	56.58
Fine sand: 0.25–0.1 mm		-	-	9.25	9.20	10.63	8.67	5.16	23.57
Very fine sand: 0.1–0.05 mm		-	-	4.13	3.84	3.67	3.62	1.05	1.85
Total sand		-	-	90.50	91.49	88.78	90.77	98.83	99.86
Silt: 0.05–0.002 mm		-	-	7.88	7.61	6.75	6.11	0.51	0.14
Clay: 0.002 mm		-	-	1.63	0.90	4.49	3.12	1.02	0.00
USDA textural class		-	-	cs	cs	cs	cs	cs	ms
Concentration (%)									
Extractable Al_2O_3		0.065	0.040	0.020	0.015	0.160	0.455	0.210	0.065
Extractable Fe_2O_3		0.235	0.195	0.170	0.155	0.765	0.965	0.175	0.090
Total nitrogen		0.603	0.353	0.046	-	0.052	0.088	0.015	-
Organic carbon		7.635	4.741	0.500	-	0.673	1.406	0.219	-
Organic matter		13.16	8.17	0.86	-	1.16	2.42	0.38	-
C:N		13	13	11	-	13	16	15	-
N in organic matter		4.58	4.32	5.35	-	4.48	3.64	3.95	-
Concentration (#/AFS)									
Available P		10	10	10	4	17	22	74	21
Exchangeable K		63	128	104	54	96	120	36	45
Exchangeable Ca		3482	4170	480	304	1630	2640	208	96
Exchangeable Mg		108	144	32	16	104	64	48	24
pH		5.2	6.1	4.8	5.2	5.2	6.1	5.6	5.7
Cation exchange capacity		21.6	11.1	1.4	0.9	4.5	6.9	0.8	0.4
Percent base saturation		53.8	100	100	99.8	100	100	96.3	100

APPENDIX IV. CALCULATION OF NUTRIENT POOL ESTIMATES

Calculation of total stand weight per acre was based on: (1) the regression analysis relation between total tree weight and tree DBH (Shanks et al. 1961b) and (2) the relation between average tree DBH and basal area per acre.* Total tree weights were estimated by interpolation and extrapolation for those species for which no tree weight data was available, using relative oven-dry specific weights of the wood as a basis (vide Brown et al., 1949).

Calculations of crop nutrients per acre was made on the basis of the percent composition per species with interpolations and extrapolations being made for species for which no total tree percent composition data was available. The interpolations and extrapolations were made by comparing published data on foliar composition of the species involved with those for which total tree composition data were available.

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*An average DBH of 13.5 inches was used since the basal area of that diameter is approximately 1 square foot. Thus, if the basal area per acre of a species is 80 square feet the total weight of a 13.5 inch DBH tree can be multiplied by 80 to arrive at the stand weight per acre of that species.

APPENDIX V. SOIL SERIES DESCRIPTIONS

... Park series consists of well drained weakly developed Podzol soils in... ...zolic soils which developed in acid fine sands and sands on dunes near the Great ...s. They have faint A_2 horizons and usually have thin B_2ir horizons of slightly ...her chroma than either the A2 or the underlying C horizon. They have less distinct ...rizonation and lighter colored B2ir horizons than the Rubicon and Vilas soils, and ...re formed in finer sands. The Deer Park soils differ from the Grayling and Omega soils ...n having more distinct A2 horizons. Deer Park soils are developed in sands in the ...er end of the medium sand size and in fine sands; while Grayling and Omega are ...eloped in sands in the coarse end of the medium sand size and in coarse sands. Deer ...rk soils include profiles with B2ir horizons comparable to those of Grayling and ...a at the most strongly developed end of their range. Deer Park soils also ...lude soils without identifiable B2ir horizons, which the Grayling and Omega soils ...not. They have less distinct horizonation than the Eastport soils and are medium ... depths of several feet, while Eastport soils are slightly acid to mildly alkaline ...the sola and overlie calcareous or moderately alkaline sands at depths of 25 ...s or less. Deer Park soils have much more weakly developed Podzol horizons tha... ...soils and are coarser in texture. Deer Park soils are more acid, have less ..., and lack the stratification of the Abscota and Mascota soils. Deer Park ...nly extensive in the dune areas along the Great Lakes but are used largely for ...tional purposes.

...Profile: Deer Park sand.

0-1" Very dark brown (10YR2/2) to very dark gray (10YR3/1); sand; single g... structure; loose; contains considerable organic matter; 1/4-inch ma... of forest litter on surface; medium to strongly acid; clear smooth boundary. 1 to 3 inches thick.

1-4" Light brownish gray (10YR6/2); sand; single grain structure; loose; many fine roots; medium to strongly acid; clear wavy boundary. 2 to 6 inches thick.

4-20" Yellowish brown (10YR5/4) to light yellowish brown (10YR6/4); sand; single grain structure; loose; common fine roots; medium to strongly acid; gradual wavy boundary. 12 to 25 inches thick.

20-60"+ Pale brown (10YR6/3); sand; single grain structure; loose; few fine roots extend to 60 inches; medium acid; many feet thick.

...e in Characteristics: Sand and fine sand types are recognized. The A2 horizon ...times is as bright as brown (10YR5/3). Where the A2 horizons are thickest, the ...orizon is only slightly lower in chroma than the B2ir horizon below it, commonly ...r. The B2ir horizon is usually present, and may range up to 25 inches in thick... ...B2ir horizon is never well expressed, and usually has values of 5 or greater. The ...m usually ranges in thickness from 18 to 36 inches. Fine sand textures often ... ...in the upper 30 inches with the content of medium sands sometimes increasing wi... ...ors refer to moist conditions.

...graphy: Gentle to steep sand dunes.

...age and Permeability: Well drained. Surface runoff is slow to medium. ...ability is rapid.

[illegible] red oaks, white birch, and [illegible] ... ground cover.

[illegible] second growth forest and recreation.

[illegible] Northern Great Lakes in Michigan and possibly adjoining states.

[illegible] County, Michigan. SW, of NE, of Sec. 2[illegible]; T[illegible]

[illegible] County, Michigan, 19[illegible].

[illegible] Village in [illegible] County, Michigan.

National Cooperative Soil Survey - U.S.A.

[illegible] Grayling soils differ from [illegible] Pauka soils have a loam [illegible] inches. Montcalm soils have a loam to [illegible] inches.

Grayling soil.

Forest litter of leaves, needles, and twigs, [illegible] 1/2 to 3 inches thick.

[illegible] very dark grayish brown (10YR 3/2) sand; [illegible] held together loosely by fine roots, very [illegible] abrupt wavy boundary. 1/2 to [illegible]

[illegible] brown [illegible] or light brownish gray [illegible] single grain; loose; medium to strongly acid [illegible] 3 inches thick.

[illegible] brown (10YR 5/4 - 5/8) sand; single [illegible] medium acid; gradual wavy boundary. [illegible]

[illegible] brown (10YR 5/6) or brownish yellow [illegible] single grain; loose; medium to very strongly acid [illegible] boundary. [illegible] to 36 inches thick.

[illegible] brownish yellow [illegible] or light yellowish brown [illegible] single grain; loose; medium acid; [illegible] to 40 inches thick.

[illegible] brown (10YR 5/3) sand; single grain; [illegible] slightly acid.

[illegible]

[illegible]

[illegible] cover of predominantly [illegible] cultivation.

[illegible], Michigan.

[illegible] Section 26, T23N, R4W, Cheboygan County [illegible]

[illegible] County, Michigan, 1929.

[illegible] Survey of Crawford County, Michigan.

[illegible] the soils formerly mapped and correlated [illegible] with Grayling soils. [illegible]

National Cooperative Soil Survey [illegible]

SPARTA SERIES

The Sparta series comprises somewhat excessively drained Regosols intergrading to the Brunizem group. They have developed in acid sandy parent material on level to gently sloping outwash plains and stream terraces under a grass cover. The parent material consists almost entirely of quartz sand and contains very few other minerals. Sparta soils occur in close association with the Plainfield and Gotham series. They differ from Plainfield soils in having a thicker and darker colored A horizon. Gotham soils have a slightly lighter colored A horizon, a thicker solum, and a B horizon with slight clay accumulation, lacking in the Sparta series. Sparta soils have developed in coarse textured parent material, lack the B horizon and have a thinner solum than the Dakota soils. Hubbard soils have a B horizon, thicker sola, and have developed from mixed lithologic material. Although Sparta soils are rather widely distributed, their total acreage is relatively small and they make little contribution to agriculture.

Soil Profile: Sparta loamy fine sand - meadow

A_1 0-9" Very dark gray (10YR 3/1) to very dark brown (10YR 2/2) loamy fine sand; weak fine granular structure; very friable; fibrous grass roots plentiful; neutral; clear wavy boundary. 7 to 10 inches thick.

A_3 9-18" Dark brown (10YR 3/3) to very dark grayish brown (10YR 3/2) loamy fine sand; very fine weak granular structure; very friable; roots plentiful; strongly to medium acid; clear wavy boundary. 8 to 12 inches thick.

C_1 18-26" Yellowish brown (10YR 4/4) fine sand; single grain; loose; few plant roots; very strongly to strongly acid; indistinct boundary. 8 to 12 inches thick.

C_2 26"+ Yellowish brown (10YR 5/6) to brownish yellow (10YR 6/6) fine sand; single grain; loose; weakly stratified; strongly to medium acid becoming more nearly neutral with depth. Several feet thick.

Range in Characteristics: Color of A_1 horizon ranges from black (10YR 2/1) to very dark grayish brown (10YR 3/2). The A_1 ranges in thickness from 8 to 20 inches. Thin noncontinuous lenses or clayey spots may occur in substratum below 36 inches. Colors are for moist soils; dry soil colors commonly are one or more units of value higher.

Topography: Level to gently undulating stream terraces and outwash plains. Wind erosion has resulted in a hummocky surface (dunes) in some areas.

Drainage and Permeability: Somewhat excessive; surface drainage is slow but internal drainage is rapid. Very rapid permeability.

Vegetation: Mixed prairie grasses and scattered oak and hickory.

[illegible]: Much of this land is under cultivation. Corn, small grains and forage crops produce fair yields when the soils are managed properly. Drouth and wind erosion are serious hazards. Severely eroded areas are being planted to trees or used as pasture for livestock.

[illegible]: Prairie border region of Wisconsin and adjoining states.

[illegible]: NE 1/4 NW 1/4 Sec. 13, T.23N, R.1 W. Buffalo County, Wisconsin.

[illegible]: Monroe County, Wisconsin, 1923.

[illegible]: Name of city in Monroe County, Wisconsin.

[illegible] consists and a [illegible] [illegible] [illegible]

[illegible] sand

[illegible] [illegible] and [illegible]

[illegible] 0 to [illegible] inches thick

[illegible] sand, pinkish white [illegible] very [illegible] structure, very [illegible]; [illegible] 4 to 24 inches thick

[illegible] 12 inches [illegible] (10YR/4 dry); weakly [illegible] structure; very [illegible] 12 inches thick

[illegible] sand to loamy sand [illegible] 8 to 24 inches thick

[illegible], very pale brown (10YR [illegible]) [illegible] grain structure [illegible]

[illegible] The A_2 and B_2 horizons [illegible] The A_1 horizon may be very [illegible]

[illegible] to steep [illegible] and [illegible]

[illegible] Surface [illegible] low, [illegible]

[illegible] White pine and red pine. [illegible] cherry and white birch [illegible]

[illegible] [illegible] coarse [illegible] [illegible]

[illegible] northern Michigan and [illegible] Wisconsin

[illegible] County, Michigan.

[illegible] County, Michigan, [illegible]

[illegible] in southern [illegible] County, Mich [illegible]

[illegible] in series file