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CHARACTERISTICS OF SPODOSOLS DEVELOPED ON A SANDY TOPO-BIOSEQUENCE IN NORTHERN MICHIGAN

By

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ABSTRACT

CHARACTERISTICS OF SPODOSOLS DEVELOPED ON A SANDY TOPO-BIOSEQUENCE IN NORTHERN MICHIGAN

By

Johnnie B. Collins

The study area is located in the northern part of Michigan's lower peninsula in south central Crawford county. It is located in what is known as the "Jack Pine Area" of Michigan. The sandy and gravelly tills and outwash plains of this area are pitted with kettle holes. The study site is located along the edge of one of these kettle holes. Seven pedons, representing five soil series, were sampled in a relatively straight line along a topo-biosequence of Spodosols. The dry end of the transect ends at a well-drained sand ridge and the wet end of the transect terminates in a poorly-drained organic bog. This toposequence of Spodosols includes nearly the whole range of spodic horizon development commonly observed in Michigan.

The characteristics, development and classification of the Spodosols, in relation to the different natural drainage classes, were investigated. In addition, the distribution of the soils was compared with the distribution

of the vegetation groups (after Byer, 1960 and 1965) along the slope of the study site.

These strongly to extremely acid (air-dry pH's in water) soil profiles have developed in heterogeneous, limy, glacial sediments of late pleistocene age. The total sand fractions account for 80-99% of the mechanical composition of the soils, and quartz is the only mineral that accounts for more than 40% of the mineralogical composition of the fine sand fraction. Hence, the soils are classified, at the family level, as having mixed mineralogy (Soil Taxonomy--1970, unedited).

The average depth (mid-June to mid-September of 1969 and 1970) to the water table, in each of the five soil series represented in the toposequence, was 9", 23", 31", 47", and > 65" for Kinross, Saugatuck, AuGres, Croswell, and Graycalm, respectively. The depths of plant roots increase as the depths to the water table and the ortstein layer increase. The site index of jack pine (*Pinus banksiana*) increases as drainage improves from poorly- to well-drained. Certain plant species have their maximum cover on one or more given soil series, and are grouped accordingly. However, the vegetation is best described as a *Pinus banksiana* forest--*Chamaedaphne calyculata* bog transition.

Chemical, physical, and mineralogical data show that the intensity of weathering increases with proximity to the soil surface. These data also show that the somewhat poorly-drained profiles along the edge of the bog, and the poorly-drained profiles in the bog are the most and least weathered, respectively.

The iron and aluminum maxima occur in the same horizon of all profiles, except the two Kinross profiles which do not show iron maxima. The carbon maximum occurs below the aluminum maximum in the Saugatuck and AuGres-Croswell profiles, but in the other five profiles the two occur in the same horizon. The relationships of the carbon maxima to the water table suggest that the water table has played an important role in the occurrence of the carbon maxima in all except the two better drained profiles. The development of the spodic horizon under submerged conditions may not necessarily be dependent upon the occurrence of a water table that descends periodically below the B horizon. But the water table must be below the B horizon for the accumulation of iron. In fact, iron is being lost from the three less well-drained profiles. The maximum spodic horizon development occurs along the edge of the bog in those profiles that are subjected to a combination of alternately wet conditions and flushing moisture regimes. The distribution of the pyrophosphate extractable aluminum values within and among the seven profiles suggest that pyrophosphate extractable aluminum is a good indicator of spodic horizon development.

A revision of the current spodic horizon criteria (Soil Taxonomy--1970, unedited) is proposed. As a second alternative, a return to the earlier spodic horizon criteria as refined by Lietzke (1968) or revision of those criteria is also proposed.

However, by the current spodic horizon criteria, each of the five soil series, represented in the toposequence, qualifies as having a spodic horizon. The placement of these soils in the current classification system is as follows:

Kinross	Histic Haplaquods;[1] sandy, mixed, frigid.
Saugatuck	Aeric Haplaquods; sandy, mixed, frigid ortstein.
AuGres	Entic Haplaquods; sandy, mixed, frigid.
Croswell	Entic Haplorthods; sandy, mixed, frigid.
Graycalm	Entic Haplorthods;[2] sandy, mixed, frigid.

[1]Currently listed as Typic Haplaquods.

[2]Currently listed as Alfic Udipsamments.

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INTRODUCTION AND OBJECTIVES OF THE STUDY

Well-drained soils are characterized by downward leaching of oxygenated water and oxidizing conditions occur throughout the profile for at least the greater part of the year. On the other hand, soils with impeded drainage or a high ground-water level may be subjected in part to reducing conditions for most of the year; however in many soils there is a zone that is subjected alternately to normal oxidizing and reducing conditions during the year. In addition, soil moisture also acts in conjunction with the physical processes and forces involved in soil development, such as eluviation and illuviation. Thus, it is apparent that a gradation in moisture relationships along a slope will materially influence soil profile development along that slope in a manner that is consistent with the moisture regime, whenever parent material, geomorphic age and climate do not change appreciably along the gradient. Such a succession of profile development is recognized in the concept of a toposequence of soils.

Transitions of vegetation groups along such moisture gradients have been generally recognized and accepted. In fact, Warming in 1895 proposed three classes of plants (hydrophytes, xerophytes, and mesophytes) characteristic of wet, dry, and moist habitats, respectively. Byer (1960 and 1965) has described the vegetation of the sandy toposequence used in this study as a *Pinus*-*Chamaedaphne* transition.

The objectives of this study are as follows:

1. To investigate the development of the toposequence of sandy Spodosols in relation to the different natural drainage classes at the study site;
2. To characterize and evaluate the classification of the soils at the study site in relation to natural drainage, and
3. To compare the distribution of the soils with the distribution of the vegetation groups (as reported by Byer, 1960 and 1965) as the two occur along the slope.

LITERATURE REVIEW

With the advent of new knowledge and the need for standard terminology, the system used to classify Spodosols (and soils in general) has undergone several changes and modifications. This is apparent in the review which follows. Hence, the terms, Podzols and Spodosols, are both used in this review where such does not create confusion.

Spodosols and Their Formation

The name, podzol, was first applied by Dokuchaiev to a certain group of soils with a bleached or A2 horizon (Muir, 1961). The bleached horizon was called "bleisand" by Sprengel in 1873 (Muir, 1961). In 1862, Senft described a Podzol in Germany as having an "ortstein" layer beneath the bleached layer (Muir, 1961). In later years the two concepts were taken as equivalents, except that the German concept was limited to sandier soils with an ortstein layer. Thus, our present concept of Spodosols originates in the western European concept of Podzols (bleisand plus ortstein). This concept was brought to the United States by Marbut (Muir, 1961).

Description of Spodosols and Their Formation

Spodosols and their formation have been described by numerous investigators. Franzmeier and Whiteside (1963) have given a very detailed summary of their interpretation of the genesis of the oldest soil in a chronosequence of Podzols in Northern Michigan. The ideas expressed by several investigators are summarized below.

Spodosols have developed under climatic and biologic conditions that have resulted in the accumulation of an organic surface layer (AO) and the formation of acid decomposition products of organic matter. This occurs most readily in moist cool climates under forest or heath vegetation (Stobbe and Wright, 1959; Ponomareva, 1969; Lyford, 1952; Messenger, 1966). However, Spodosols also develop under humid tropical conditions (Andriesse, 1969; Klinge, 1965; Mohr *et al*., 1954; Tan *et al*., 1970). The AO is underlain by a light-colored eluvial horizon (A2) which has lost sesquioxides. The A2 is, in turn, underlain by a darker-colored illuvial B horizon in which the major products of accumulation are sequioxides and organic matter. The solum is acid and the base exchange complex is unsaturated. The accumulation of clay in the B horizon of Podzols is not essential and is generally of little prominence or entirely lacking. In some podzols more clay can be found in the A2 than in the B horizon (Stobbe *et al*., 1959). Significant increases in the clay content of B horizons in podzols have been observed by others (Brown et al., 1958; Gerasimov, 1960; Pawluk, 1960), and these investigators also attributed little importance to the increases. However, the clay content of the B horizon is considered in the classification of Spodosols in the new soil classification system (Soil Taxonomy--1970, unedited).

Spodosols may differ considerably in their morphology depending on local variations in the soil-forming factors (Lyford, 1952; Stobbe et al., 1959). The AO may vary from a trace to 12 inches. The thickness of the A2 and B horizons are also variable and the color of the B varies from brown, yellowish-brown, or reddish-brown depending on the iron and organic matter contents. The accumulations in the B horizon generally consist of organic matter and sesquioxides but may be dominantly organic matter, dominantly iron and aluminum, or dominantly organic matter in the upper B or dominantly organic-sesquioxides in the lower B. The B horizon may vary from loose and friable to hard and irreversibly cemented. The internal drainage may vary from rapid to slow, but it must be sufficient to permit at least seasonal percolation of the soil solution containing the products of eluviation from the upper horizons. The parent materials differ considerably in texture and lithology, but the Podzol profile is most clearly developed on coarse sandy materials rich in quartz sands (Russell, 1961). According to Byers et al. (1938), the typical Podzols in the United States occur only on coarse textured parent materials. The Podzol profiles may be polygenetic or monogenetic, they can form in a few hundred years and their biological destruction can be equally rapid in cultivated soils (Soil Taxonomy--1970, unedited).

Hence, most pedologists agree that the main prerequisites for the formation of Spodosols are as follows:

1. a humid climate (predominance of precipitation over evaporation), and high relative humidity;
2. some degree of through-moistening of the soil system (a flushing moisture regime); and
3. bases must be leached and replaced by hydrogen resulting in unsaturation with respect to bases.

Mobilization, Translocation and Accumulation of Humus, Sesquioxides and Clay

There is no single definition of the process leading to the formation of Spodosols. Most concepts include the following:

1. Mobilization of sesquioxides in the surface horizons;
2. The downward translocation of these sesquioxides and humus;
3. Their immobilization and accumulation in a lower horizon; and
4. Silicate clay may or may not be involved in the

above; but if involved there is no marked clay accumulation in the spodic horizon.

The translocated material (organic matter, clay and iron are partly fractionated and different ingredients are deposited in different horizons of the profile (Byers et al., 1938). Suspended organic matter is deposited just below the bleached layer, together with a considerable quantity of iron to serve as a cementing agent, while clays are carried still deeper by the filtering water. As the acid organic matter slowly decomposes and a part of it dissolves in the presence of iron bearing minerals, solution of the iron in the ferrous state is promoted. As the percolating water carrying compounds in solution or in suspension moves down through the profile it often encounters soil layers less acid than the surface that may flocculate the suspended material and oxidation may take place rendering the ionic iron less soluble. The precipitated or flocculated materials under slightly changed conditions serve as a filter mat to remove more material from the percolating waters. This mat accounts for the high amount of sesquioxides and organic matter in the upper portion of the B horizon in Podzols. The total clay content of this horizon is usually low. Surprisingly large quantities of highly dispersed organic matter are frequently found in C horizons (Byers et al., 1938).

According to Kellogg (1941), the clay or colloidal particles become saturated with hydrogen since the vegetation returns but little bases to counteract the acidity produced by the CO_2 in rain water and the organic acids produced by the decomposing organic matter on the surface. As a result, the clay or colloidal particles are dispersed in water and move with it. Small particles of organic matter also move and seem to assist the dispersion and movement of mineral colloids. Stobbe et al. (1959) have also observed the movement of particles of organic matter with percolating water from the AO horizon to the B horizon where the organic matter is filtered out. Kubiena (1953) pointed out that the droppings of small soil animals could be carried down the profile by percolating water and deposited between the sand grains of the B horizons of humus-iron and humus Podzols.

In addition to movement in suspension, as indicated above, the accumulation of clay in the B horizon of Spodosols may also be due to the formation of clay in this horizon. Pawluk (1960) has postulated the formation of chlorite in the B horizon of Podzols. Bouma et al. (1969) has reported the formation of mixed-layered clay minerals in this horizon.

Since trivalent iron and aluminum are highly insoluble at the pH's that commonly occur in Spodosols, their movement is unlikely. From their studies, McKenzie et al. (1960) concluded that a possible mechanism for iron translocation in Podzols is reduction in the A horizon, translocation of the ferrous iron, and oxidation and precipitation of ferric iron in the B horizon. Deb (1949) pointed out that iron is readily oxidized to the ferric state in Podzols that are subjected to oxidizing conditions. Smith (1934) reported that positive and negative colloids could move down the soil profile independently and flocculate each other.

After much investigation, it was realized that the peaty surface of Podzols is ineffective in causing mobilization of iron and that the peat is relatively inert. So, the investigations were shifted to study the effects of leachates of leaves and of the solutions dripping from the living forest canopy during a rain. Schnitzer et al. (1955) found that both the forest canopy and the forest floor contribute solutions capable of mobilization and transport of iron, aluminum and calcium. DeLong et al. (1955) studied the capacities of leaf extracts and of natural leachates to hold iron in suspension or solution and the capacities of such solutions to dissolve or resuspend the iron or freshly precipitated ferric hydroxide and to extract iron and aluminum from podzolized soils. They found that the amount of iron retained or brought into solution depends on the source of the solution (kind of tree), the nature of the dominant cation present and on the proportion of iron to organic matter in the system. The precipitation of iron and organic matter in the soil profile was found to depend on both the pH and the available iron in the environment. Himes et al. (1963) observed that the water extracts of oak and maple leaves can solubilize iron from freshly precipitated ferric hydroxide. Others (Bloomfield, 1953, 1954; Malcolm et al., 1968; Muir et al., 1964) have also found that canopy drip and leachates of leaves are sources of organic matter for the mobilization of iron and aluminum.

Several investigators (Thorp et al., 1957; Gallagher, 1942; Wright et al., 1963; Atkinson et al., 1957; Hallsworth and Crawford, 1965) have experimentally produced soils in the laboratory that are similar to Podzol and Podzolic soils found in the field. By passing solutions of organic acids and water soluble materials through a column of B2 material from a Miami soil and analyzing the leachate at intervals, Thorp et al. (1957) found that appreciable quantities of calcium, magnesium, iron, and manganese were mobilized. Detectable amounts of fine silicate clays moving in suspension were found. Evidence of redeposition of iron compounds within the soil column was observed. Colored bands which appeared in the columns were suggestive of soil horizons found in the field. Gallagher (1942) was able to produce rapid reorganization in a column filled with material from the B horizon of a Podzol by leaching with 0.1 N oxalic acid. Three centimeters of bleached horizon at the top and a corresponding lower horizon of accumulation of intensely brown material was produced in an hour. Wright et al. (1963) reported that leaching a calcareous soil parent material with a chelating agent

(E.D.T.A.) resulted in the mobilization, transport, and redeposition of iron and aluminum and in the formation of a soil profile, with well-defined horizons, similar to that of certain Podzolic soils.

The products of decomposition of plant residues have a high capacity for combining into complex compounds (apparently chelates with iron and aluminum (Panomareva, 1969)). Mortensen (1967) states that soil organic matter forms complexes with iron and aluminum by ion-exchange, surface adsorption, chelation and complex coagulation and peptization reactions and that the ligands involved are probably hydroxy, carboxyl, and amide groups. Schnitzer and DeLong (1955) proposed two kinds of associations, complex formation and electrostatic bonding, between soil organic matter and sesquioxides. From their electrodialysis study of leaf leachates, they found that most of the iron migrated to the cathode and that the iron at the cathode was in the ferric hydroxide form. That at the anode was ferric hydroxide protected by negatively charged organic matter. Deb (1949) has pointed out that the amount of humus necessary for the full peptization of a sol containing iron oxide is less than 1/3 of the iron present. According to Stobbe et al. (1959), decomposition products of organic matter, particularly organic acids and other complexing substances, bring about the solution of sesquioxides, the reduction of iron, and the formation of soluble metal-organic complexes, some of which may be chelates. These complexes move to the lower horizons and are precipitated under oxidizing conditions, probably by the destruction of the ligand by microorganisms and/or sorption. Wright et al. (1963) have indicated that organic acid on its path down the profile forms water-soluble multidentate chelates with the sesquioxides and that precipitation of these metallo-organic complexes lower in the profile is effected by further reaction with the sesquioxides and by extremely small amounts of ionic calcium and/or magnesium. Martin and Reeve (1960) found no evidence of the formation of coordination compounds in the organic matter of Podzol B horizon. They suggested electrostatic bonding as the type of bond that joins organic matter and sesquioxides. In addition, they indicated that the simultaneous presence of aluminum, iron and organic matter in the B horizon could be solely accounted for by the flocculating properties of aluminum ions.

Other means by which the translocated materials (organic matter, sesquioxides, and clay) may be transferred have been proposed. Bloomfield (1954 and 1957) and Evans et al. (1959) have reported an organic matter-silicate clay association as a possible mechanism of translocation. Mattson (1949) proposed a theory of isoelectric weathering, but it was criticized by Deb (1949) and Stobbe et al. (1959). Deb (1949) and Stobbe et al. (1959) suggested loss of effectiveness of chelating agent, drying of the illuvial horizon and precipitation as basic salts as possible deposition mechanisms. Deb (1949) also criticized the theory of the movement of iron as a silica-protected iron oxide. Bloomfield (1954), Wurman et al. (1959) and Brydon and Sowden (1954) have postulated a silicate clay-sesquioxide-organic matter association. An association of sesquioxide-silicate clay has also been proposed (Byers et al., 1938; Wurman et al., 1959; Jackson et al., 1960).

According to Smith (1965), the illuvial materials of Spodosols are at least partly organic but the key element is most apt to be aluminum, and iron seems to be largely accidental and probably does not contribute to the cation exchange phenomena of the spodic horizon, although it may be an important cementing agent in some ortsteins. In addition, accumulations of free iron oxides are found in many soils and are not restricted to Spodosols. The albic (A2) horizon may be thin and is often incorporated with the spodic horizon by plowing, pasturing or by earthworms. The albic horizon is related to the absence of coatings of free iron (this can be either the results of soil genesis or the accident of the parent material).

Hence, the present concept of Spodosols (Soil Taxonomy--1970, unedited) differ from that of Podzols in two ways--it reduces emphasis on the albic horizons and on the importance of the movement of iron.

Toposequence and Topo-Biosequence of Soils

A gradation in the moisture regime occurs along the slope of a toposequence, and the soils have developed under different natural drainage conditions. In humid areas the well-drained soils of the toposequence are subjected to leaching and oxidizing conditions for the greater part of the year, while the soils with a high water table are subjected to limited leaching and reducing conditions for the greater part of the year (Russell, 1966). Hence, it is conceivable that such a moisture gradient should influence soil profile development as well as the associated vegetation.

Milne (1936) introduced the concept of the soil catena for those soils that have developed from a similar parent material but differing in characteristics of the solum owing to differences in the natural drainage. Referring to soils in a small area and formed on a common parent material, Ellis (1932) introduced the term Oromorphic to describe well drained soils, Hydromorphic for soils severely affected by the ground water table, and Phyto-hydromorphic for soils having impeded drainage.

Glinka (1927) described the characteristics of some Podzol soil profiles developed under different moisture regimes as having differences of considerable magnitude. He attributed the differences to the natural drainage and other features of the topography. Norton and Smith (1930) found that the morphological features of Alfisols used in their study varied directly with the natural drainage of the site on which they occurred. Johnsgard (1938) studied some Ground-Water Podzols and associated soils, and indicated that the various profiles in the association appeared to owe their distinctive morphological characteristics to differences in natural drainage of the site on which they occurred. Hill (1945) described the soils on a hydrologic sequence as ranging from Gray Brown Podzolic, Brown Podzolic, Podzol and Tundra.

There is a close relationship between the vegetation, natural drainage, and type of soil profile that develops at a particular site (Bouma et al., 1969). A gradation in moisture has a marked effect on the vegetation. A high water table and reducing conditions are very inimical to root development of many plants and the two slow up decomposition of organic matter and favor shallow rooting plants and peat formation (Russell, 1961). According to Shantz (1938), native plants may be used as a guide to the nature of the soils under some conditions. In the classification of soils only soil properties are used and in the classification of vegetation only characteristics strictly limited to vegetation should be used. These independent groupings can then be compared. Shantz (1938) further states that vegetation has been used to indicate the moisture condition (e.g., permanently dry soil, permanently moist soils, and flooded soils).

Mattson and Lönnemark (1939) studied a hydrologic Podzol series developed on an acid, fine sandy glacial till in Sweden. The entire sequence of soils occurs within a distance of 15 to 18 feet. The dry end of the sequence ends at a sandy hill that is several yards high (not affected by water table) and the wet end of the series terminates in a wet depression (only completely submerged during the rainy season) covered with water-loving mosses. Starting at the wet end of the series the sequence of soils is as follows: Peat Podzol, Humus Podzol (with dark brownish-gray B horizon marked by accumulation of humus) and Iron Podzols with a yellowish-brown B horizon that is relatively low in humus. The vegetation of the entire sequence of soils consists of pine and spruce forest with a variable ground vegetation. The sequence of ground vegetation from the wet to the dry end is as follows: *Polytrichum commume*, *Ledum palustre*, *Vaccinium uliginosum*, *Empethrum nigrum*, *Vaccinium myrtillus*, *Calluna vulgaris*, *Vaccinium vitis idea*, and *Cladonia*. The acidity of the sequence of soils ranges from pH 3.03 to greater than 4.5. The highest acidity occurs at the foot of the slope, not at the wettest or dryest portion of the series. Higher pH's are found in the B and C horizons of the iron podzols on the higher portions of the transect.

Bouma *et al*. (1969) found that Podzols on well drained sites are indicated by the growth of heather and bilberries. On moderately well or well drained sites, *Calluna* sp. and *Vaccinium* sp. are always dominant. *Picea abies* and at higher altitudes *Pinus cembra* are normally found on these sites. Byer (1960 and 1965) has described the vegetation at the site used in the present study as a *Pinus*-*Chamaedaphne* transition. Spruce-fur (Northern Conifer Forest), according to Shantz (1938), indicates a Podzol soil or a raw material that is gradually being developed into a Podzol profile.

The Podzol profile is the result of leaching under a cover of sour humus (Jenny, 1941). Where the water table is low, a light-gray A2 horizon and a rusty-brown B horizon are developed (Iron Podzol). Where the water table is high enough to influence directly the pedogenic process, the Humus Podzols are formed. In the extreme cases where complete submergence of the mineral horizons occur, nonpodzolized bluish gray bog soils are formed. Ground-Water Podzols are somewhat like the sandy podzols in the appearance of the soil profile (Kellogg, 1941). They are found on imperfectly drained, but not swampy, sandy plains throughout the humid forested region. Where Ground-Water Podzols occur, the roots are shallow and trees easily blow over. Låg (1970) noted that the ground water level must be considerably below the B horizon for the formation of an Iron-Humus Podzol.

Damman (1962) indicated that Hydromorphic Podzols can develop under submerged conditions as a result of internal water movement, and their development is by no means dependent on the occurrence of a water table which descends periodically below the B horizon. The percolating water is rich in humus and has a very low oxygen content. Under these anaerobic conditions, iron goes into solution as ferrous iron and is leached beyond the B horizon. Therefore the humates cannot form complex humate-iron colloids as they do in most Podzol soils, but go into suspension as almost pure humus colloids. Their precipitation results in the formation of a very pronounced humus B horizon.

Johnsgard (1938) observed that the order in which the soils occur, as one proceeds from sites of the poorest natural drainage toward successively better drainage, is as follows: Bog Soil, Bog Transition Phase Ground-Water Podzol, Half-Bog Soil, Normal Phase Ground-Water Podzol, Dry Phase Ground-Water Podzol, and Dry Sandy Podzol. The Half-Bog and Bog soils do not possess an A, B and C type profile because of weak leaching action in the presence of a high water table. The dry sandy podzol has developed under the influence of a rather weak biological cycle and although an A, B and C type profile exist, the observable contrast between horizons is not as marked as in the Normal Ground-Water Podzol which possesses the most strongly developed horizons of eluviation and illuviation of any soils studied. All the Ground-Water Podzols were characterized by horizons of organic matter, sesquioxides, and clay concentrations. An horizon of depletion of these constituents overlies the horizon of concentration. The Half-Bog soils do not possess horizons of depletion and concentration of the above constituents.

Glentworth and Dion (1949) observed that the variations, in the properties of some Brown Podzolic soils developed under different hydrologic conditions, follow definite trends from one major profile to another irrespective of parent material. They sampled six major profiles along the slope and described the drainage at each as follows: I--excessively drained; II--freely drained; III--deep, freely drained; IV--slightly poorly drained; V--poorly drained; VI--very poorly drained. Profiles # I, II, and III occur on the convex portion of the slope, while the other three profiles occur on the concave portion of the slope. Their observations of pertinent soil properties are summarized below:

Organic matter is high, in the upper 7 inches, at both ends of the slope with a minimum at profile V. The content of sesquioxides is higher in the surface layer of profile II than it is at profile V, but in the C horizon the reverse is true. The indurated layer is absent in profiles showing signs of the action of excess ground water (IV, V, VI), but it is an obvious feature of the freely-drained profiles.

Profile I is strongly acid and highly unsaturated throughout (usually 90%, even in C horizon). The cation exchange capacity is closely correlated with organic matter and falls off rapidly with depth. Profiles II and III show the same tendencies but there is a marked increase in pH and base saturation with increasing depth. The C horizons of these profiles is usually 75% unsaturated. Profile V receives drainage water from the surrounding well-drained soils and is subjected to less intense vertical leaching. As a result, it has a higher pH and base status than the freely-drained profiles. The pH, base saturation and exchange capacity of profile IV is intermediate between the freely- and poorly-drained profiles. The peat at profile VI is strongly acid and highly unsaturated (80-90%). The base exchange capacity of this profile is high in the surface organic layer and decreases sharply in the mineral soil below.

Exchangeable calcium is highest in the A horizon of profile II and decreases in the B1 and B2 horizons, and may rise or decrease in the horizon depending on the parent material. At profile V, calcium generally tends to decrease in the G horizon and below this it may rise or decrease depending on parent material. However, the amount of calcium in the G horizon of profile V is higher than that in the B1 or B2 horizons of profile II. Exchangeable magnesium of profile II decreases sharply from the A horizon downward and rises slightly in the C horizon. At profile V magnesium increases sharply with depth to values much higher than those in the lower layer of profile II.

Wicklund *et al*. (1959) studied the soils of the Caribou Catena in the Podzol region of eastern Canada. They found that the profiles of all the soils in the better-drained positions had the same sequence of horizons, but the sola became thinner toward the base of the slope. The A2 horizon in the well-drained positions was replaced by an A1 in the imperfectly and poorly-drained positions. The profiles showed marked gains in organic matter in the A0, A1, and B horizons. Aluminum had accumulated in the B horizons of all profiles. A small net gain in iron occurred in the best-drained profiles, but the associated poorly-drained soil showed a decrease in iron. The surface horizons of all profiles showed the greatest concentration of exchangeable cations.

Mineralogy of Sand Fraction

From his investigation of the frequency of occurrence of a number of mineral species in sedimentary rocks, Pettijohn (1941) proposed the following order of decreasing persistence of 25 minerals: anatase, muscovite, rutile, zircon, tourmaline, monazite, garnet, biotite, apatite, ilmenite, magnetite, staurolite, kyanite, epidote, hornblende, andalucite, topaz, sphene, soisite, augite, stillimanite, hypersthene, diopside, actinolite, and olivine. According to Brewer (1964), this sequence is generally in agreement with those suggested by Weyl (1952), Marel (1953), Graham (1953), Fields and Swindale (1954), Smithson (1941), Dryden and Dryden (1946) and Goldich (1938). Discrepancies occur principally with the accessory and ferromagnesian minerals. The relative stability follows approximately the reverse order of Bowen's reaction series (Goldich, 1938): the last minerals to crystallize from a magma are the most resistant.

The resistance of primary minerals to podzolization has also been investigated. Cady (1940) found a marked decrease in the hornblende and hypersthene content of the A2 horizon of a podzol relative to the C horizon. There was also an increase of magnetite and garnet in the A2 horizon due to the decrease in the more readily weathered minerals. He also found that the light fraction consisted largely of quartz and could be assumed to be resistant to acid weathering, and that the heavy fraction had a high proportion of easily weathered ferromagnesian minerals. Johnsgard (1938) observed that the normal Ground-Water podzols showed a marked depletion of hornblende, augite, actinolite (group of minerals) and feldspars in the following order: A2 > B > G1. On the other hand, he noted that the Half-Bog soil possessed an almost constant content of these minerals throughout the profile.

Franzmeier and Whiteside (1963) observed no weathering of k-feldspars in the light fraction. Plagioclase feldspars were present in small amounts in all horizons except the A2. Weathering of augite, hornblende and hypersthene in the heavy fraction was observed in the A2 horizon of all soils in the chronosequence.

Using the 0.1 to 0.5 mm fraction of some Podzols from Alberta, Pawluk (1960) concluded the following weathering rates: heavy minerals--hematite > hornblende > garnet ≥ magnetite; intermediate minerals--chlorite > biotite > muscovite; and light minerals--feldspars > quartz.

From their study of the fine sand fraction of some Michigan soils, Yassoglou and Whiteside (1960) noted weathering of olivine, epidote and hornblende in all horizons above the Bt, and that the intensity of weathering increases with proximity to the soil surface. They observed a slight decrease in the feldspars of the A2 horizon in bisequal soils, but garnet, tourmaline, magnetite and zircon were considered to be resistant.

Interpretations of weathering intensity within a given soil profile were usually reported to be A2 > B > C. The exceptions were B > A2 > C, and A2 > B = C as observed by Cady (1940).

The first task in evaluating soil profile development is to establish the degree of uniformity of the parent material of the whole soil profile at the start of soil formation. Toward this end, Marshall (1943) has proposed the following criteria:

1. Throughout the profile the relative proportions of two or more of the highly resistant sand size

minerals should be the same. Zircon, tourmaline, garnet, rutile, and anatase are the minerals cited for use. To this list, Barshad (1955) added quartz, albite, microcline or a combination of several resistant minerals.

2. Throughout the profile the particle size distribution of a given resistant mineral should remain the same.

Other criteria that may be used for establishing the uniformity of soil parent materials have been summarized by Barshad (1955) as follows:

1. Total mineralogical analysis, with particular attention to the heavy mineral suite.
2. Nature of particle size distribution of the resistant mineral, either heavy or light, of non-clay fraction.
3. Nature of the ratio of two resistant mineral in any one fraction of non-clay fraction, preferably the fine sand or coarse silt.
4. Particle size distribution of the whole non-clay fraction.
5. Nature of clay distribution with depth.
6. Nature of the change in chemical composition of the non-clay fraction.

Mineralogy of Clay Fraction

Zvereva (1968) studied some soils that ranged from Rendzina to Podzol, and he investigated the clay mineralogy at various stages in their pedological evolution. He summarized his results as follows:

Illite predominates in the rocks which produce the soils. This mineral is transformed into chlorite, into the intermediary minerals chlorite-vermiculite, and into vermiculite when a large carbonate content prevents podsolization (rendzina stage). Soil development is accompanied by a lowering of pH, leaching of calcium and magnesium ions from the exchange complex and substitution of these by hydrogen ions. Under these conditions, illite loses potassium ions and is changed into vermiculite, which is distinguishable from rendzina vermiculite. In Podzolic soils, the mobile sesquioxides cause the vermiculite to change into chloritizable vermiculite. Podzols are characterized by much leaching of potassium ions from the illite lattice which is followed by the formation of montmorillonite and possibly kaolinite. Montmorillonite, in Podzols, also results from the transformation of chlorite.

Franzmeier and Whiteside (1963) also noted that the pattern of clay mineral distribution in Podzol profiles suggested a weathering sequence from illite and chlorite, possibly through intergradient vermiculite to montmorillonite. Ross (1965) studied the montmorillonite of a podzol in northern Michigan and concluded that illite, chlorite, interstratified chlorite-vermiculite and chlorite-montmorillonite have weathered in situ through a vermiculite stage to montmorillonite. Bouma et al. (1969) found that the clay minerals present in the Podzols, used in their study, were the results of degradation of the original muscovites and chlorites, probably through an extraction of potassium and iron. They suggested that such reactions would produce mixed-layered minerals. The purest swelling-clay mineral was found in the A2 horizon of a profile in a wet pinewood.

Johnson and Jeffries (1957) concluded that poor drainage could inhibit the formation of vermiculite in the lower horizons. However, they observed that in both the poorly and well drained members of the Allenwood catena the weathering sequence was as follows: mica (illite) →, mica intermediate →, vermiculite →, chlorite-like. They further concluded that drainage controls the degree of expression of the above sequence. If any clay is formed under the influence of a high water table, it is of the montmorillonite type (Russell, 1966).

Brydon et al. (1968) have also studied the clay mineralogy of some Podzols. They found that clays of the C horizons ranged from well-ordered mica and chlorite mixtures to a mixture of amorphous and poorly crystallized "14 A°" mineral. Smectite was not a common constituent of the C horizons. The results of their examination of the Ae horizons show that:

1. The major mineral was a well-crystallized smectite with varying degrees and kinds of mica interstratification;
2. Orthochlorites had completely disappeared from the Ae, yet were present in the lower horizons. (They suggested that this is due to protection by the sesquioxides in the B horizons.);
3. In the majority of the soils, there was a decrease in mica from the C horizon to the Ae horizon; and
4. There was no evidence of major kaolinite formation in the Ae horizons.

Jackson et al. (1948) proposed the following sequence for clay mineral weathering in Podzols: illite →, hydrous mica intermediates →, montmorillonite →, kaolinite → gibbsite. In 1952, Jackson et al. attributed weathering of mica and similar layer silicates to the following: depotassication, hydroxylation, dealumination, and desilication.

Pawluk (1960) found that the A and C horizons of some Podzols from Northern Alberta contained illite, montmorillonite, interstratified illite-montmorillonite and kaolinite, while the B horizons were primarily chlorite-like with lesser amounts of kaolinite. He explains these results by synthesis of chlorite in the B horizon.

On the contrary, several investigators have reported that Podzols developed on sandy parent materials sometimes show a greater percentage of montmorillonite in the A2 than in the deeper horizons (Brown and Jackson, 1958; Wurman *et al.*, 1959; and Franzmeier *et al.*, 1963).

DESCRIPTION OF THE STUDY AREA AND OF THE PEDONS SAMPLED

The study area is located in the northern part of Michigan's lower peninsula on State Forest land, in south central Crawford County. This county is located in what is known as the "Jack Pine Area" of Michigan. The soil parent materials are extensive areas of sandy and gravelly tills and outwash plains of late pleistocene age. These plains are pitted with glacial kettle holes. Soils with weak spodic horizon development (Graycalm and Croswell) are located on the better-drained sites, and soils with varying degrees of spodic horizon development (AuGres, Saugatuck, and Kinross) are located on the less well-drained sites.

Various types of bog and marsh vegetation have developed in the kettle holes. It is along the border of one such depressional area that the study site is located. This kettle is occupied by a poorly-drained, acid bog of the type known as "leatherleaf" for the dominant shrub cover.

The area selected for study extends from out in the bog to the well-drained soil on a sand ridge. Hence, the study area is a Jack Pine-Leatherleaf bog transition, a sandy topo-biosequence, and it includes the whole range of spodic horizon development commonly observed in Michigan (from a Brown Podzolic Graycalm to the Ground Water Podzol, Saugatuck with an ortstein subsoil).

Seven pedons were described and sampled in a relatively straight line along the slope gradient, and the resulting soil profile descriptions are shown below. (Pedons and profiles are used interchangeably.) Figure 1 shows the location of the study area, and Plate 1 shows the soil profiles samples. (The author expresses his appreciation to Dr. R. L. Donahue and Dave Lietzke who photographed the soil profiles.)

Graycalm Sand, Site No. 7

Horizon	Depth (inches) Site No./ Sample No.	Description
A1	0 - 1" 7/01	Medium sand mixed with litter and decomposed organic matter; 10YR2/1; weak, medium granular structure; friable; very strongly acid (pH 4.6); abrupt, wavy boundary.
A2	1 - 3" 7/02	Medium sand; 10YR6/2; single grain (structureless); loose; extremely acid (pH 4.4); abrupt, wave boundary.
B21hir	3 - 11" 7/03 upper part 7/04 lower part	Loamy sand to medium sand; 7.5YR5/6; moderate, coarse granular to weak, fine, subangular blocky structure; firm; strongly acid (pH 5.2); clear, wavy boundary.
B22hir	11 - 23" 7/05	Loamy sand to medium sand; 10YR6/6-6/8; moderate, coarse granular to weak, fine, subangular block structure; friable to firm; strongly acid (pH 5.3); clear, wavy boundary.

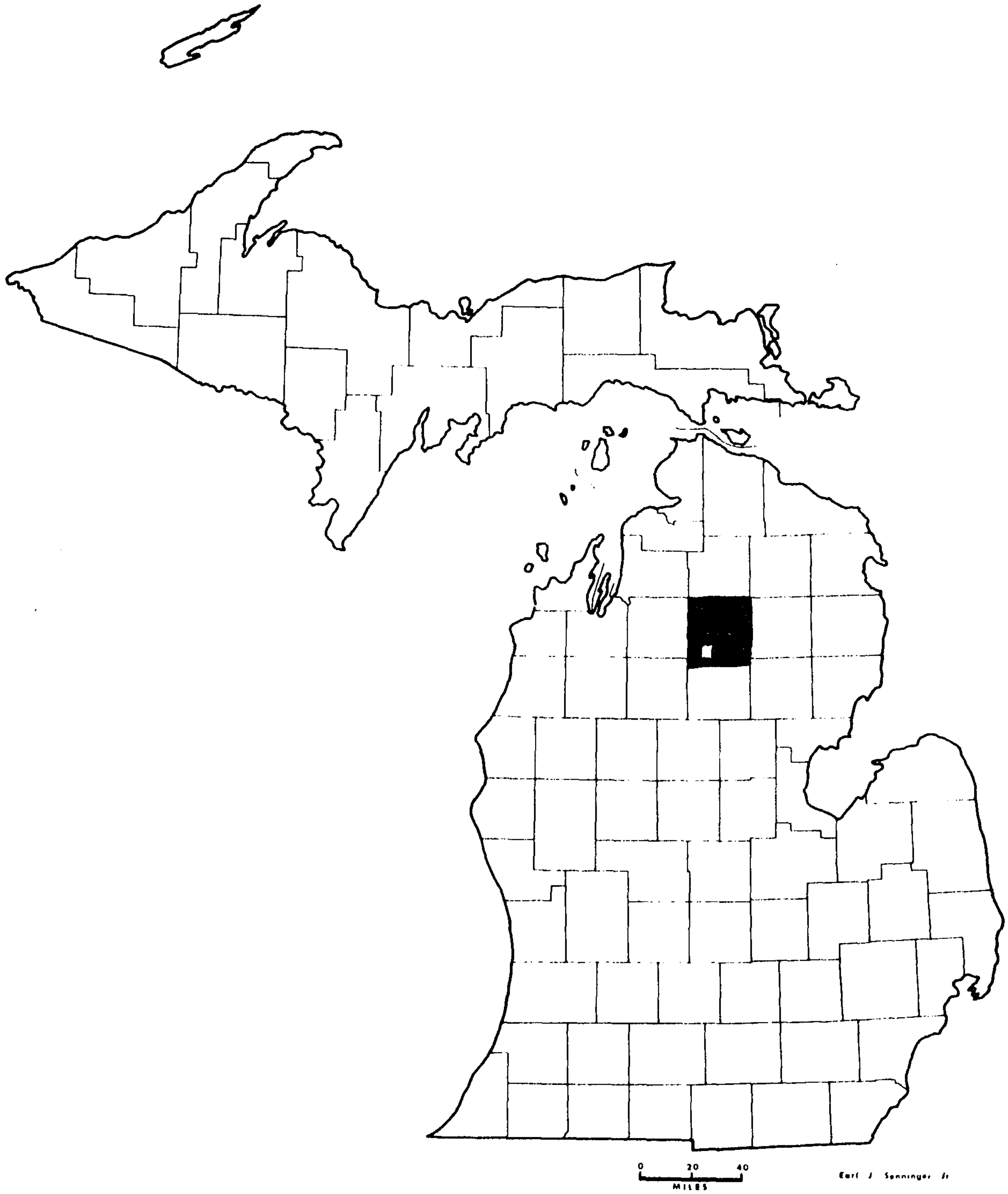


Figure 1.--Location of the study area. Shaded area shows Crawford Co. and part of Roscommon Co. Enclosed unshaded area shows the study site.

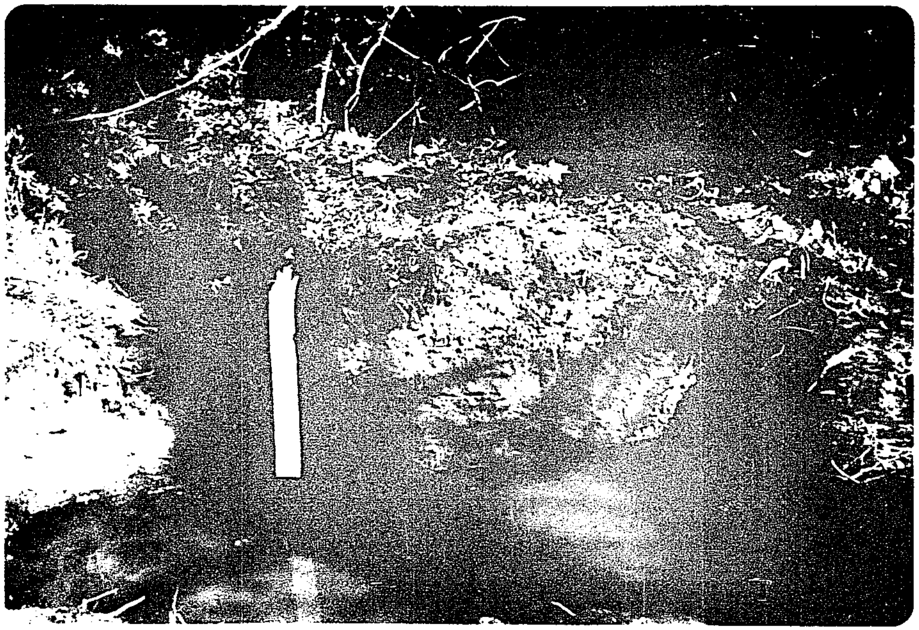
No. 7, Graycalm

PLATE 1.--Color photographs of four better-drained profiles, the edge of the bog, and the bog.

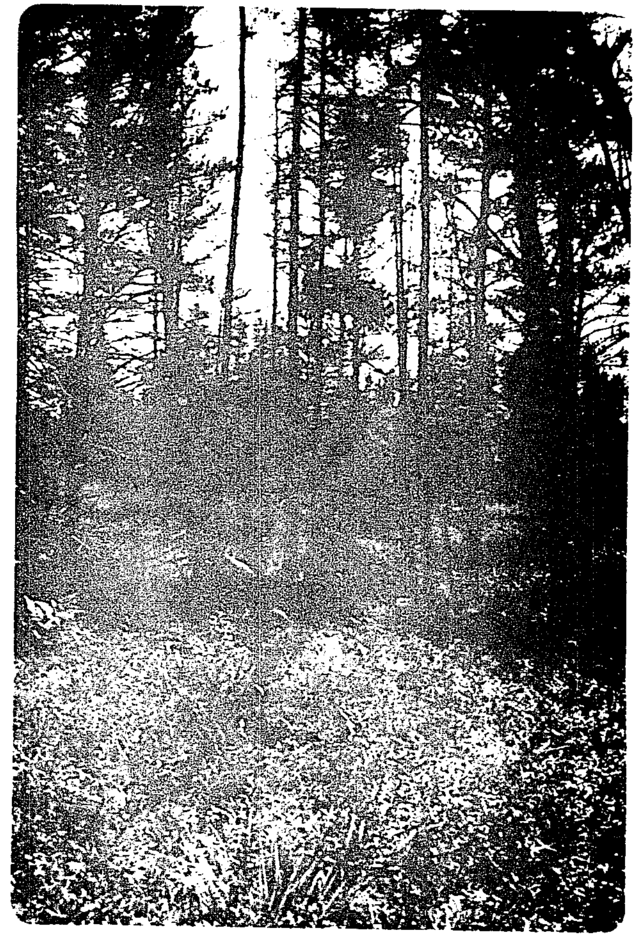
No. 5, AuGres-Croswell

No. 4, Saugatuck-AuGres

PLATE 1.--Continued



No. 3, Saugatuck



Edge of Bog

PLATE 1.--Continued

Organic Bog

PLATE 1.--Continued

A2'	23 - 30" 7/06	Loamy sand to medium sand; 10YR7/4 to 10YR6/4; weak, medium granular structure; loose to soft; strongly acid (pH 5.4); clear, wavy boundary.
A2' & B2t'1	30 - 55" 7/07	Loamy sand to medium sand; 10YR7/4 to 10YR6/4 for A2, and 7.5YR5/6 for B2t; weak, fine granular for A2 and moderate, medium granular to weak, fine subangular blocky structure for B2t; loose to soft for A2 and slightly hard for B2t; strongly acid (pH 5.4); clear, wavy boundary.
A2' & B2t'2	55 - 60" 7/08	Medium sand; 10YR7/3 for A2 and 7.5YR5/6 for B2t; weak, fine granular for A2 and moderate, medium granular to weak, fine subangular blocky structure for B2t; loose to soft for A2 and slightly hard for B2t; strongly acid (pH 5.5).

Dominant Vegetation:*

Jack pine, oak, blueberries, ferns (see discussion of vegetation).

Relief and Physiography:

Gently rolling to sloping relief with southern exposure. Well drained with water table below 60". The soil pit was located at 154 ft. north of bog's edge.

Additional Notes:

1. Many roots in A and upper B horizons, but present at 60" ±.
2. Dry below 23".
3. Stratified at $\approx$ 55".
4. The B21hir horizon was described as one, but samples were taken from the upper and lower portions of the horizon.

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*In this study A0, A00, Hemic (H), Sapric (S) and Fibric (F) are equivalent to the 01, 02, Oe, Oa and Oi horizon, respectively.

Croswell-Graycalm Sand, Site No. 6

Horizon	Depth (inches) Site No./ Sample No.	Description
A0	.5 - 0" 6/01	Partly decomposed litter; 10YR3/2 to 10YR2/2; moderate, fine to medium granular and weak, fine to medium subangular blocky structure; friable; very strongly acid (pH 4.6); abrupt, smooth boundary.
A1	0 - 1" 6/02	Medium sand; 10YR2/1; weak, fine to medium granular structure; friable; extremely acid (pH 4.2); abrupt, smooth boundary.
A2	1 - 3" 6/03	Medium sand; 10YR6/2 to 10YR5/2; weak, fine to medium granular structure; loose; extremely acid (pH 4.3) abrupt, wavy boundary.
(Upper) B21hir	3 - 5" 6/04	Loamy sand; 5YR3/3 to 7.5YR4/4; weak, coarse granular to weak, fine subangular blocky structure; firm to friable; very strongly acid (pH 4.9); abrupt, wavy boundary.
(Lower) B21hir	5 - 7" 6/05	Same description as for upper portion, except that reaction is strongly acid (pH 5.1).
B22hir	7 - 18" 6/06	Medium sand; 7.5YR4/4 to 7.5YR5/4; weak, coarse granular to weak, fine subangular blocky structure; very friable to nearly loose; strongly acid (pH 5.4); clear, smooth boundary.
B3	18 - 23" 6/07	Medium sand; 7.5YR5/4 to 10YR5/6; structureless to weak, fine subangular blocky structure; friable to loose; strongly acid (pH 5.4); clear, smooth boundary.

A2'	23 - 28" 6/08	Medium sand; 10YR6/3 with few, fine, faint to distinct 10YR6/3 mottles; single grain; loose; weak, discontinuous, slightly brittle fragipan; strongly acid (pH 5.5); abrupt, wavy boundary.
A2' & B2t'1	28 - 39" 6/09	Medium sand; 10YR6/3 to 10YR7/3 for the A2, and 7.5YR5/4 for the B2t with few to many, fine to coarse, distinct to prominent 7.5YR5/8 and 5YR5/8 to 5YR6/8 mottles; single grain (structureless) for A2 and massive for the B2t; loose for the A2 and slightly plastic for the B2t; strongly acid (pH 5.4); clear, wavy boundary.
A2' & B2t'2	39 - 49" 6/10	Medium sand; 10YR7/3 with many, fine to coarse, distinct to prominent, 10YR6/4 to 10YR6/6 mottles; single grain (structureless) for the A2 and massive for the B2t; loose for the A2 and slightly plastic for the B2t; strongly acid (pH 5.5); clear, wavy boundary.
	6/11	(Bt bands sampled separately, loamy sand.)
C1	49 - 60" 6/12	Medium sand; 10YR7/3; single grain (structureless); loose; strongly acid (pH 5.4).

Dominant Vegetation:

Jack pine, oaks, blueberries, ferns (see discussion on vegetation).

Relief and Physiography:

The site is gently rolling with a southern exposure. Moderately well to well drained, with the water table at 58". This site is 84 ft. north of the bog's edge.

Additional Notes:

1. Many roots in the A and upper B horizons but present to 50".

2. Weak fragipan at the 23 - 28" depth.

3. The bands are discontinuous and occur more or less as chunks.

4. In the A2 & B2t horizons, the A2 is sand and the B2t is loamy sand but the two together make a sand, which means that the A2s are dominant.

AuGres-Croswell Sand, Site No. 5

Horizon	Depth (inches) Site No./ Sample No.	Description
A0	1 - 0" 5/01	Partly decomposed litter; 10YR3/2 to 10YR2/2; moderate, fine to medium granular and weak, fine to medium subangular blocky structure; friable; extremely acid (pH 4.4); abrupt, smooth boundary.
A1	0 - 6" 5/02	Medium sand; 7.5YRN2/0; weak, fine granular structure; friable; extremely acid (pH 4.2); clear, wavy boundary.
A2	6 - 10" 5/03	Medium sand; 10YR6/1 to 10YR6/2; single grain (structureless); loose; extremely acid (pH 4.4); gradual, irregular boundary.
B21hir	10 - 14" 5/04	Loamy sand; 5YR4/6 with few, fine, faint 10YR6/6 mottles; moderate, fine granular and weak, fine subangular blocky structure; friable; very strongly acid (pH 4.7); clear, wavy boundary.
B22hir	14 - 21" 5/05	Loamy sand; 10YR6/4 with common, medium, distinct 7.5YR6/6 to 7.5YR6/8 mottles; single grain (structureless) and weak, fine, subangular blocky structure; loose to friable; very strongly acid (pH 4.7); clear, wavy boundary.

B23h	21 - 28" 5/06	Medium sand; 10YR5/4 with common, medium, distinct 7.5YR7/8 mottles; single grain and weak, fine granular structure; loose to friable; very strongly acid (pH 4.6); clear, wavy boundary.
B31	28 - 39" 5/07	Medium sand; 10YR6/4 with common to many, medium to coarse, distinct to prominent 7.5YR7/8 mottles; single grain (structureless); loose; very strongly acid (pH 4.9); clear, wavy boundary.
B32	39 - 50" 5/08	Medium sand; 10YR6/4 with common to many, medium to coarse, distinct to prominent 7.5YR7/8 mottles; single grain (structureless); loose; strongly acid (pH 5.1); clear, wavy boundary.
C1	50 - 60" 5/09	Medium sand; 10YR6/1 to 10YR6/2; single grain; loose; strongly acid (pH 5.2).

Dominant Vegetation:

Jack pine, oak, blueberries, ferns (see discussion on vegetation).

Relief and Physiography:

This soil site has a southern exposure with a gently sloping relief. Drainage is imperfect to moderately well with the water table at 36". This site is located 49 ft. north of the bog's edge.

Additional Notes:

1. Few to many roots to a depth of $\cong$ 30".
2. As the name suggests, this is a border case with respect to drainage and spodic horizon development.

Saugatuck-AuGres Sand, Site No. 4

Horizon	Depth (inches) Site No./ Sample No.	Description
AO(H)	3.5 - 1.0" 4/01	Partly decomposed litter with many roots; 7.5YR3/2; weak, coarse granular structure; loose to very friable; extremely acid (pH 4.3); abrupt; smooth boundary.
AOO(S)	1.0 - 0.0" 4/02	Well decomposed organic matter (mucky) with some charcoal; 7.5YR2/0; weak, fine granular structure; very friable; extremely acid (pH 4.2); abrupt; smooth boundary.
A1	0.0 - 1.5" 4/03	Loamy sand; 10YR2/1; weak, fine to medium, granular structure; very friable; extremely acid (pH 4.1); abrupt; smooth boundary.
A2	1.5 - 3" 4/04	Loamy sand; 10YR5/2; structureless to weak, fine granular structure; loose; extremely acid (pH 4.2); abrupt; smooth boundary.
B21hir	3 - 7" 4/05	Loamy sand; 5YR3/3 with common, medium, distinct 7.5YR5/3 mottles; weak to moderate, fine to medium granular structure; very firm; very strongly acid (pH 4.8); clear, smooth boundary.
B22hir	7 - 11" 4/06	Loamy sand; 5YR3/3; with many (40%), common, distinct, 7.5YR5/3 mottles; weak, fine to medium granular to weak, fine subangular blocky structure; very firm; very strongly acid (pH 4.8); clear, smooth boundary.
A2'	11 - 16" 4/07	Loamy sand; common, medium, distinct mottles of 10YR5/3 and 7.5YR4/4; structureless to weak, medium subangular

		blocky structure; massive; slightly firm; very strongly acid (pH 4.6); abrupt, wavy boundary.
II B21hir'	16 - 23" 4/08	Medium sand; mottled--many, medium, faint 5YR3/4 and 7.5YR4/4 to 7.5YR5/3 mottles; weak, medium to coarse subangular blocky structure to massive; firm to friable; very strongly acid (pH 4.9); clear smooth boundary.
II $Bhir_m$'	23 - 33" 4/09	Medium sand; 5YR3/2 to 5YR3/3; massive chunks, very firm to weakly cemented; very strongly acid (pH 5.0); clear, smooth boundary.
II B3'	33 - 48" 4/10	Medium sand; 5YR3/3 to 5YR4/3; massive chunks; very firm to firm; strongly acid (pH 5.0); clear, smooth boundary.
II C1	48 - 58+" 4/11	Medium sand; 7.5YR4/3 to 7.5YR5/3; single grain (structureless); very friable to loose; strongly acid (pH 5.1).

Dominant Vegetation:

Jack pine, aspen, cherry, oak, blueberries, ferns, wintergreens (see discussion on vegetation).

Relief and Physiography:

This site has a southern exposure with a gently rolling relief. Drainage is imperfect with the water table at 28". The site is located 14 ft. north of the edge of the bog.

Additional Notes:

1. Saugatuck occurs in the downhill side of the pit.
2. Many roots in the upper 14" with few in the next 12".
3. This profile has two sequences of Spodic development.
4. The upper part of this profile is finer in texture (ls) than the other six profiles.
5. Traces of charcoal in the Al horizon.

Saugatuck Sand, Site No. 3

Horizon	Depth (inches) Site No./ Sample No.	Description
A0	4 - 0" 3/01	Partly decomposed litter; 10YR3/2 to 10YR2/2--rubbed; moderate, fine to medium granular and weak, fine to medium subangular blocky structure; friable; extremely acid (pH 4.1); clear, wavy boundary.
A1	0 - 1" 3/02	Medium sand, slightly mixed with organic matter in various stages of decomposition; N2/0; weak, fine to medium granular to subangular blocky structure; friable; extremely acid (pH 4.0); abrupt, smooth boundary.
A2	1 - 11" 3/03	Medium sand; 10YR6/3 to 10YR5/3; single grain (structureless); loose; extremely acid (pH 4.2); abrupt, smooth boundary.
$B21hir_m$	11 - 17" 3/04	Medium sand; 5YR2/2; strong, medium to coarse and very coarse, subangular blocky structure plus some chunks; strongly cemented; very strongly acid (pH 4.5).
$B22hir_m$	17 - 24" 3/05	Medium sand; 5YR2/2 - 2/3; moderate to strong, medium subangular blocky structure plus some chunks; extremely firm to weakly cemented; very strongly acid (pH 4.6).
B23hir	24 - 33" 3/06	Medium sand; 5YR3/3 to 7.5YR3/2; moderate, medium to coarse subangular blocky structure; firm; very strongly acid (pH 4.8).

C1	33 - 43" 3/07	Medium sand; 7.5YR4/2 to 7.5YR4/3; single grain (structureless); loose; very strongly acid (pH 4.8).
C2	43 - 61" 3/08	Medium sand; 10YR4/3; single grain; loose; strongly acid (pH 5.1).

Dominant Vegetation:

Jack pine, Spruce, Oaks (see discussion on vegetation).

Physiography and Relief:

This site is located 8 ft. north of the bog's edge. Relief is nearly level to gently sloping with a southern exposure. Drainage is imperfect with the water table at 20" below the surface.

Additional Notes:

1. Most of the roots are above 15".
2. Ortstein appeared to be softer at H_2O table.
3. Sand grains in the spodic horizons are well coated and they are angular to rounded and of various shapes and sizes. The cemented masses appeared to have disconnected pores but there are a few root channels.
4. Sand grains in A2 are similar to those in the B horizons, except that many of them are clear and reflective.
5. In the C horizons, the number of rock fragments, and the sizes, shapes, and angularity of sand grains increase.

Kinross Sand (better drained), Site No. 2

Horizon	Depth (inches) Site No./ Sample No.	Description
Hemic	2 - 1 1/2" 2/01	Moderately decomposed organic matter with fine roots and conifer needles; 10YR2/2 to 10YR2/1; weak, coarse granular to subangular blocky structure; friable; extremely acid (pH 4.1); abrupt, wavy boundary.

Sapric	1 1/2 - 0" 2/02	Mat of decomposed organic matter with a few fine roots; N2/0; weak to moderate, coarse platty structure; friable; extremely acid (pH 4.2); clear, smooth boundary.
A1	0 - 1 1/2" not sampled	Medium sand; N/0; weak, fine granular structure; friable; extremely acid (pH 4.2); clear, smooth boundary.
A2	1 1/2 - 15" 2/03	Medium sand; 10YR5/2 to 10YR6/2; single grain (structureless); loose; extremely acid (pH 4.3); clear, smooth boundary.
B21h	15 - 25" 2/04	Medium sand; 5YR2/2; weak, medium, granular to subangular blocky structure; friable; very strongly acid (pH 4.5).
B22hir	25 - 35" 2/05	Medium sand; 5YR3/2 to 5YR2/2; weak to moderate, medium to coarse, subangular blocky structure; firm; very strongly acid (pH 4.6).
B23	35 - 54" 2/06	Medium sand; 5YR3/3 to 7.5YR4/3; weak to moderate, medium to coarse, subangular blocky structure; firm; strongly acid (pH 5.2).

Dominant Vegetation:

Jack pine, spruce and a ground cover of sphagnum (see discussion on vegetation).

Physiography and Relief:

This site is located two feet south of the edge of the bog. The exposure is southern and the slope is nearly level. Drainage is poor and the water table occurs at 7 1/2" below the surface.

Additional Notes:

1. A few burned wood fragments or charcoal in the sapric horizon.

2. Most sand grains in the B horizons are well coated to only slightly stained. These coatings are thickest in the B21h horizon and decrease in thickness with depth.

3. Most of the recognizable plant remains (roots, twigs, bark, woody fragments, etc.) occur in the upper 5 horizons of the profile.

4. The sand grains are angular to rounded and of various sizes and shapes. Many of those in the A1 and A2 horizons are also clear and reflective.

Kinross Sand (with Organic Surface), Site No. 1

Horizon	Depth (inches) Site No./ Sample No.	Description
Fibric	13 - 7" 1/01	10YR7/2--after squeezing; relatively undecomposed mat of sphagnum peat; extremely acid (pH 4.0); abrupt smooth boundary.
Hemic	7 - 3" 1/02	5YR3/2--after squeezing, 5YR2/2--rubbed; moderately decomposed organic matter, 65% fibers but 30% fibers after rubbing; weak, coarse mat of organic matter; extremely acid (pH 4.3); abrupt, smooth boundary.
Sapric	3 - 0" 1/03	N2/0; mucky, well decomposed organic matter; weak, fine to medium, granular to subangular blocky structure; friable; extremely acid (pH 4.4); abrupt, smooth boundary.
A1	0 - 1" not sampled	10YR2/2; medium sand; single grain (structureless); friable; extremely acid (pH 4.3); clear smooth boundary.
A2	1 - 11" 1/04	Medium sand; 10YR4/2; weak, fine granular structure; loose; very strongly acid (pH 4.5); clear, wavy boundary.

B21h	11 - 21" 1/05	Medium sand; 5YR3/3; weak, medium granular to subangular blocky structure; friable; very strongly acid (pH 4.5).
B22hir	21 - 27" 1/06	Medium sand; 5YR4/3; moderate, medium to coarse, subangular blocky structure; firm to very firm; very strongly acid (pH 4.7).
B23	27 - 37" 1/07	Medium sand; 7.5YR4/3; weak to moderate, medium to coarse, subangular blocky structure; firm; very strongly acid (pH 4.7).
C1	37 - 50" 1/08	Medium sand; 10YR4/3; single grain (structureless); loose; very strongly acid (pH 4.9).

Dominant Vegetation:

Jack Pine, Spruce, Tamarack, Leatherleaf (see discussion on vegetation).

Physiography and Relief:

The site described is 20 ft. out into the bog on a nearly level area. Its drainage is poor with the water table at 6" below the surface.

Additional Notes:

1. Few clear to slightly stained, angular to rounded sand grans are randomly distributed throughout the hemic, sapric, and A1 horizons. Sand grains in the A2 horizon are similar, except that more of them are clear and reflective. In the C horizon, there is an increase in the number of different shapes, sizes, and color of sand grains--angularity increases also.

2. Most of the plant roots occur in the hemic, sapric, A1, A2, and upper B21h horizons.

3. Aggregates in the organic and A horizons are held together by plant roots, clay, and organic matter (dark in color). On the other hand, aggregates in the Spodic B horizons are apparently held together by the reddish-brown humus-sesquioxides as well as clay.

4. Sand grains in the B horizons are well coated to only slightly stained. The thickest coatings occur on those sand grains in the Bh horizon.

5. There appeared to be some charcoal in the Sapric horizon.

METHODS OF ANALYSIS

All analyses were made on air dry samples that had been crushed and sieved through a two millimeter screen, except where otherwise indicated.

Chemical

Soil Reaction

The hydrogen ion activity was determined on air dry samples with a Beckman Zeromatic pH meter and with the Hellige-Truog colorimetric kit. The glass electrode pH's were measured by using the following soil-liquid ratio (on a weight basis): 1:1 soil-H_2O, 1:2 soil-0.01 M $CaCl_2$, and 1:2 soil-1.0 N KCl. The suspensions were each allowed to equilibrate for fifteen minutes with several intermittent stirrings (Agronomy No. 9, Part 2, 1965).

Cation Exchange Capacity

Cation Exchange Capacity (C.E.C.) was determined by saturating the exchange complex with sodium ions (1.0 N NaAc at pH 8.2) and replacing the sodium ions with ammonium ions (1.0 N NH_4Ac). The sodium in dilute solution was measured with a Coleman Flame Photometer, and expressed as m.e./100 grams of soil (Soil Survey Investigation Report No. 1, 1967).

Exchangeable Bases

Calcium, magnesium, potassium, and sodium were extracted by use of a 1.0 N NH_4Ac solution. The leachate was analyzed for potassium and sodium by use of a Coleman Flame Photometer, and for calcium and magnesium by use of a 303 Model Perkins-Elmer Atomic Absorption Spectrophotometer (Jackson, 1964), and the results expressed as m.e./100 grams of soil.

Extractable Acidity

This soil property was measured by using the barium chloride-triethanolamine method (Soil Survey Investigations Report No. 1, 1967). The results were expressed as m.e./100 grams of soil.

Total Carbon

A Leco carbon analyzer, Model 598-500, with digital readout was used to determine the total carbon content of a 0.1 gram sample (personal communication with staff of soil testing laboratory), and the results are expressed as per cent total carbon.

Extractable Iron and Aluminum

A 200 ml amount of 0.1 M $Na_4P_2O_7$ was added to 2.0 grams of soil in a 250 ml centrifuge bottle, and the bottle was capped and shaken overnight. Then, 10 drops of 0.4%

superfloc was added and the bottle was shaken again for 5 minutes. After this, the samples were centrifuged at 2,000 rpm for 15 minutes or until the supernatant liquid was clear in reflected light.

In addition, iron and aluminum were also extracted by use of the dithionite-citrate method (Soil Survey Investigation Report No. 1, 1967).

The extract was analyzed for iron and aluminum by use of a 303 Model Perkins-Elmer Atomic Absorption Spectrophotometer, and the results are expressed as per cent elemental iron and aluminum.

Physical

Mechanical Analyses

The pipette method was used for the mechanical analysis of the <2 mm soil material. H_2O_2 with several drops of glacial acetic acid was used for the removal of organic matter, and a 0.1 N solution of HCl was used for the removal of any carbonates and exchangeable base that may have been present. The excess acid was washed out with distilled water, and the samples were saturated with sodium by titration with 0.1 N NaOH to pH 8.4. After 24 hours of shaking, the samples were sieved though a 300 mesh screen and transferred to 1000 ml sedimentation cylinders. Using Stokes Law, a 25 ml aliquot was taken at the proper depth and time to give the total clay, fine silt, and total silt plus clay. The sands were placed at the top of a nest of sieves and shaken with a mechanical shaker for 15 minutes. The fractions separated were as follows: 2.0 - 1.0, 1.0 - 0.5, 0.5 - 0.25, 0.25 - 0.10, and 0.10 - 0.053 mm. The per cent of each size fraction and the solution losses were calculated on an oven dry, acid insoluble basis (Kilmer et al., 1949).

The <2μ clay was separated by several siphonings of the samples in suspension after allowing sufficient time for the silt particles to settle out.

Water Retention

Since it was impossible to obtain undisturbed core samples from below the high water table at the less well-drained sites, the bucket auger was employed to obtain bulk samples. From these bulk samples, disturbed core samples were prepared by filling the metal cylinders (3" diameter and 3" high) with the bulk material and alternatively soaking and draining for several times. Then these cores were soaked in water and drained on a tension table for 24 hours. Hence, water retention at 60 cm tension was measured by the blotter paper-tension table method of Leamer and Shaw (1941), except that disturbed core samples were used.

Moisture equivalent was measured by the method of Briggs and McLane (1907).

Maximum water holding capacity was determined as follows: place 30 gms of air dry soil in a moisture equivalent box, saturate in 1 cm of water for 24 hours, and drain for 30 minutes on a paper towel while covered with a damp cloth.

Per cent water retained at each of the above moisture conditions was expressed on an oven-dry basis.

Bulk Density

This soil parameter was calculated by dividing the oven dry weight of the core samples used for the water retention determinations at 60 cm by the volume of the metal cylinders.

Mineralogical

Qualitative Identification of Clay Minerals

The clay minerals in the samples were identified by standard X-ray diffraction techniques (Agronomy No. 9, Part I). The following four treatments were employed: Mg-saturated, glycerol-solvated and air-dried; K-saturated and air-dried; K-saturated and heated to 300°C; K-saturated and heated to 550°C.

Sand Mineralogy

The fine sand fraction (0.25 - 0.10 mm) that was saved from the particle size analysis of the soil samples was employed in the study of the mineralogy of the sand fraction. Enough of the uniformly mixed sample was placed on a well slide, with epoxy, to uniformly cover an area about 22 mm square. Then, another layer of epoxy was placed on the top of the grains. After this, the slides were placed in an oven for one hour. Next, the slides were cooled and ground with successively finer abrasives to a thickness of 0.030 mm or until the interference colors of quartz were of the first order. After thorough washing and drying, an immersion oil was applied and a temporary cover slide set.

The minerals were identified by standard mineralogical procedures and the relative abundance was estimated by counting on regularly spaced traverses with the aid of an automatic recorder (Heinrich, 1965; Kerr, 1959).

Biological

Site index measurements for Jack Pine (*Pinus banksiana*) were made using the method of Gevorkiantz (1956).

The distribution of the vegetation along the soil moisture gradient was investigated by Byer (1960 and 1965) by analyzing the data collected from quadrats (1 x 1 meter) that were randomly located in the study area (100 x 100 meters).

RESULTS AND DISCUSSION

Variations in the Depths to the Water Table and in the Depths to Which Most Roots Occur

Figure 2 and Table 1 show that the depths to the water table not only vary from month to month during a given year but that they also vary from one year to the next.

Depths to the water table at each of the sites were somewhat irregular but generally tended to increase from June to mid-September in a similar manner in both 1969 and 1970. However, the measurements for 1969 are more variable than those for 1970 (Table 1). It is interesting to note that the measurements made on September 26, 1968 and September 22, 1970 are very similar (differences do not exceed 3.0 inches). The relative heights of the water table at all the sites are consistent throughout the observations.

Variations in the water table measurements made during this study are summarized in Table 1. This table also shows the horizons that were subjected to fluctuations of the water table. Except for sites #6 and #7, each of the profiles have horizons that are subjected to a permanent water table, and except for #7 each of the profiles have horizons that are subjected to a water table for a considerable part of the year.

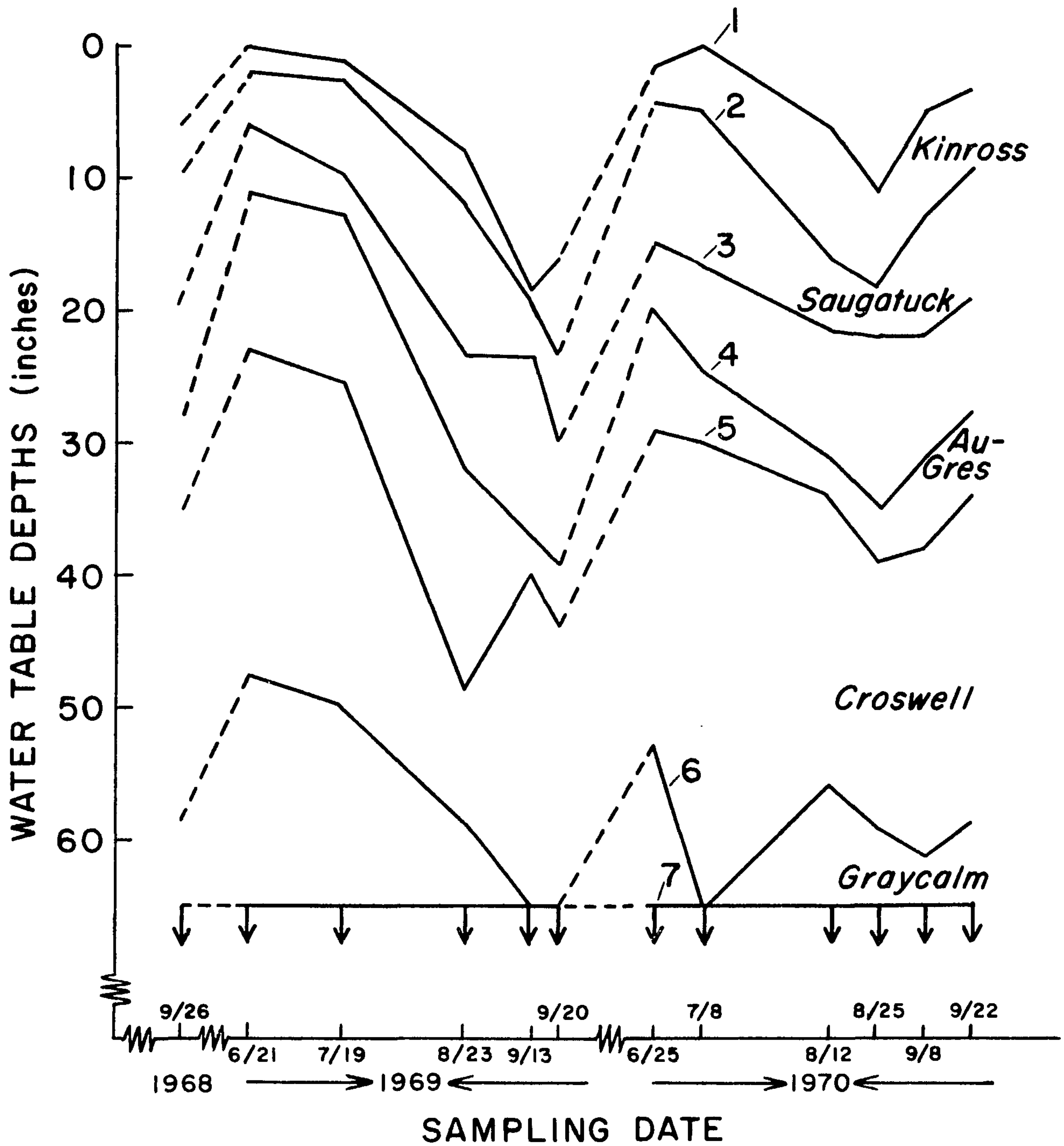


Figure 2.--Seasonal variations of water table depths.

TABLE 1.--Depths (inches) of water table and plant roots in each of the seven pedons.

Site #	Average Depths to Water Table	Range in Depths to Water Table		Maximum Variations in Depths to Water Table		Horizons Subjected to Water Table Fluctuations	Depths to Which Roots Occur	Horizons in Which Roots Occur
		1969	1970	1969	1970			
#1, Kinross (organic surface)	6.0	0.0-18.5	0.0-11.0	18.5	11.0	F,H,S,A1, upper A2	25	F,H,S,A1,A2, upper B21h
#2, Kinross (better drained)	11.0	2.0-23.5	4.5-18.0	21.5	13.5	A1,A2, lower B21h	27	H,S,A1,A2,B21h
#3, Saugatuck	19.0	6.0-30.0	15.0-22.0	25.0	7.0	Lower A2 B21hir$_m$, B22hir$_m$, upper B23hir	15	A0,A1,A2 (not observed in B22hir$_m$ or below)
#4, Saugatuck-AuGres	27.0	11.0-39.0	20.0-35.0	28.0	15.0	A2', IIB21hir', IIBhir$_m$', IIB3'	26	A0, A00, A1, A2 B21hir, B22hir, A2' IIB21hir', IIBhir$_m$' (end in this horizon)
#5, AuGres-Croswell	35.0	23.0-48.5	29.0-39.0	25.5	9.0	B23h, B31,B32	30	A0,A1,A2,B21hir, B22hir, B23
#6, Croswell-Graycalm	58.0	47.5->65.0	53.0->65.0	17.5	12.0	C2	55	All except C2
#7, Graycalm	>65.0	>65.0	>65.0	>65.0	>65.0	None	65	Throughout the profile

Table 1 also shows the depths to which roots occur. From these data, it is apparent that:

1. The plant roots do not extend very much, 3 to 6 inches, into the permanent water table of the Kinross soils in the bog.
2. The roots do not extend very deep, 3 to 4 inches, into the ortstein layer of Saugatuck and Saugatuck-AuGres (see profile description).
3. The plant roots stop in the zone of fluctuation of the water table in AuGres-Croswell and Croswell-Graycalm.
4. Except for site #'s 1 and 2, maximum depths to the water table are below the depths to which most roots occur.

These observations are in agreement with those of Joffe (1941), Russell (1956), and Lunt (1939). From his studies, Joffe (1941) concluded that the dodging of the ortstein layer by the roots of forest and fruit trees is not merely a mechanical problem but is also one of aeration. Russell (1966) indicated that the reducing conditions created by impeded drainage and a high water table are very inimical to root development. Lunt (1939) pointed out that physical soil factors are more important in root growth than are the chemical factors. Kellogg (1941) has observed that the roots of trees growing on Ground-Water Podzols are shallow and easily blow over. In the present study, the author also observed blown-over trees on those Ground-Water Podzols with an ortstein layer.

Due to the manner in which the soils were sampled along the slope, five individual soil series (Kinross, Saugatuck, AuGres, Croswell, Graycalm) are represented in the seven pedons sampled. Hence, the ranges in the observed and measured properties of each horizon or of the entire profiles of these five soil series can be obtained. This idea of the range in the soil series will be considered at various stages of this discussion.

Thus, Table 1 shows that the average variations in the depths to the water table for the individual soil series of the toposequence are as follows: Kinross, 6-15"; Saugatuck, 15-27"; AuGres, 27-35"; Croswell, 35-58"; and Graycalm, 58"+.

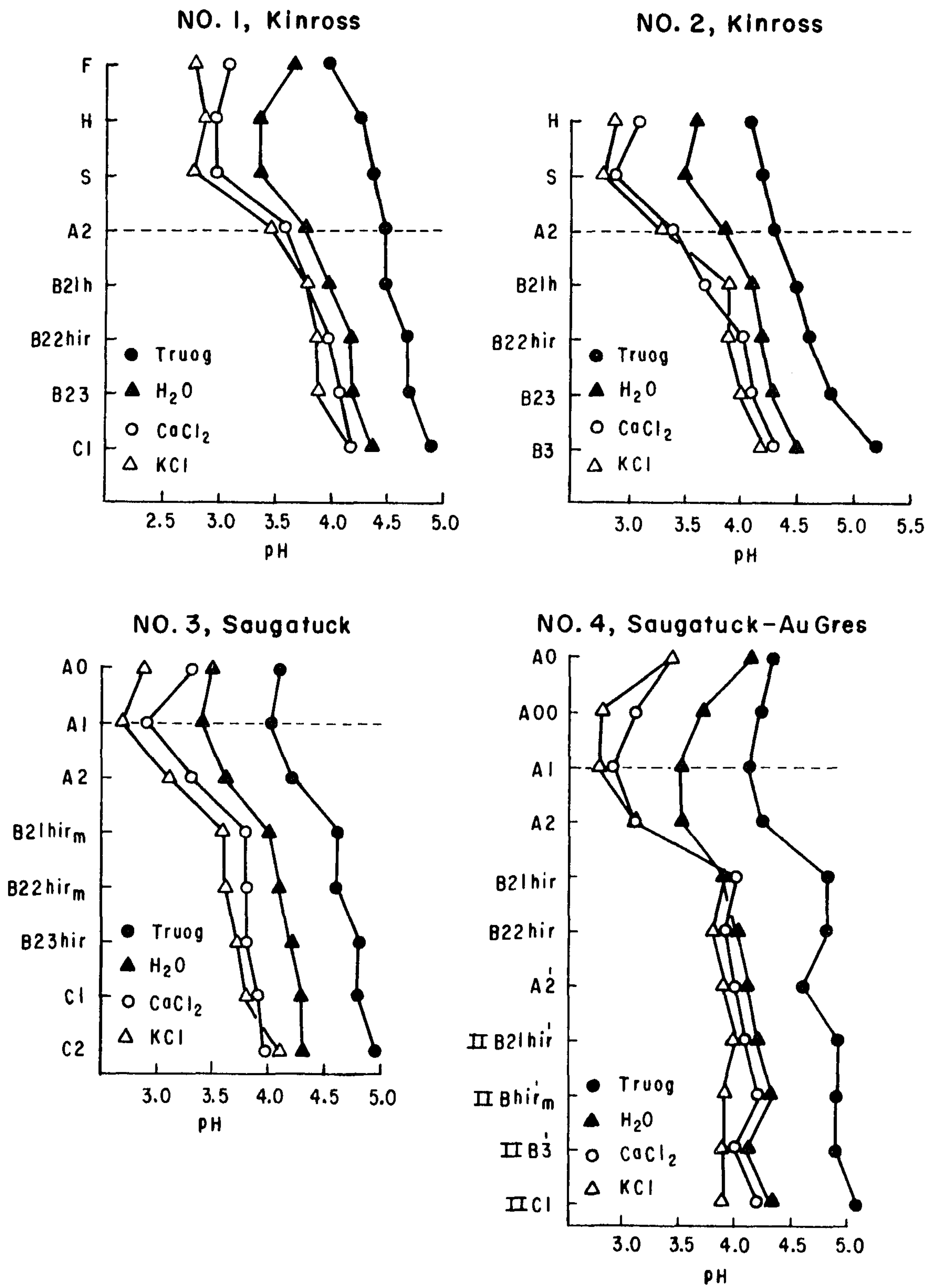
Much of the variation in the depths to the water table can be accounted for by the amount and frequency of precipitation. However, the fact that some of the sites varied considerably more than others, means that soil properties and vegetation are also important. The relatively high silt content of the upper part of the AuGres-Saugatuck profile helps to explain the variations at this site, since the capillary rise of silt is quite high. Accumulation of run off and seepage water in the bog accounts for some of the variation at the two Kinross sites: the soil slope-water table relationship is important here. Some of the variation is due to the consumption rate of moisture by the plants, since plant activity was at a high level during the daylight period that the measurements were made.

From Table 1 it is apparent that the horizons, of the five individual soil series, which were subjected to fluctuations of the water table are as follows: Kinross--organic surface horizons, A1, A2, and upper B horizons; Saugatuck--lower A2 and upper B horizons; AuGres--lower B horizons; Croswell--lower B and C horizons; and Graycalm--C horizon and below 65".

Soil Reaction

These coarse-textured soils have developed in limy sandy parent materials, and they have been subjected to considerable leaching during their formation. The pH's, measured in water with the glass electrode, show that these soils are strongly to extremely acid (Figure 3) throughout their profiles. (Data not cited in text appear in Appendix, es. Table A-1 is soil pH's.)

Regardless of suspending media, the pH's generally increase from the lowest values in the organic surface or upper A horizons to higher values in the A2 horizons and then continue to increase to the highest values in the C or B horizons (Figure 3). These differences in soil pH with depth vary from 1.0 to 1.6 pH unit in each profile. This general trend reveals itself in each of the seven profiles.


NO. 1, Kinross
F
H
S
A2
B21h
B22hir
B23
C1
Truog
H_2O
$CaCl_2$
KCl
2.5 3.0 3.5 4.0 4.5 5.0
pH
NO. 2, Kinross
H
S
A2
B21h
B22hir
B23
B3
Truog
H_2O
$CaCl_2$
KCl
3.0 3.5 4.0 4.5 5.0 5.5
pH
NO. 3, Saugatuck
A0
A1
A2
$B21hir_m$
$B22hir_m$
B23hir
C1
C2
Truog
H_2O
$CaCl_2$
KCl
3.0 3.5 4.0 4.5 5.0
pH
NO. 4, Saugatuck-Au Gres
A0
A00
A1
A2
B21hir
B22hir
A2'
II B21hir'
II $Bhir'_m$
II B3'
II C1
Truog
H_2O
$CaCl_2$
KCl
3.0 3.5 4.0 4.5 5.0
pH

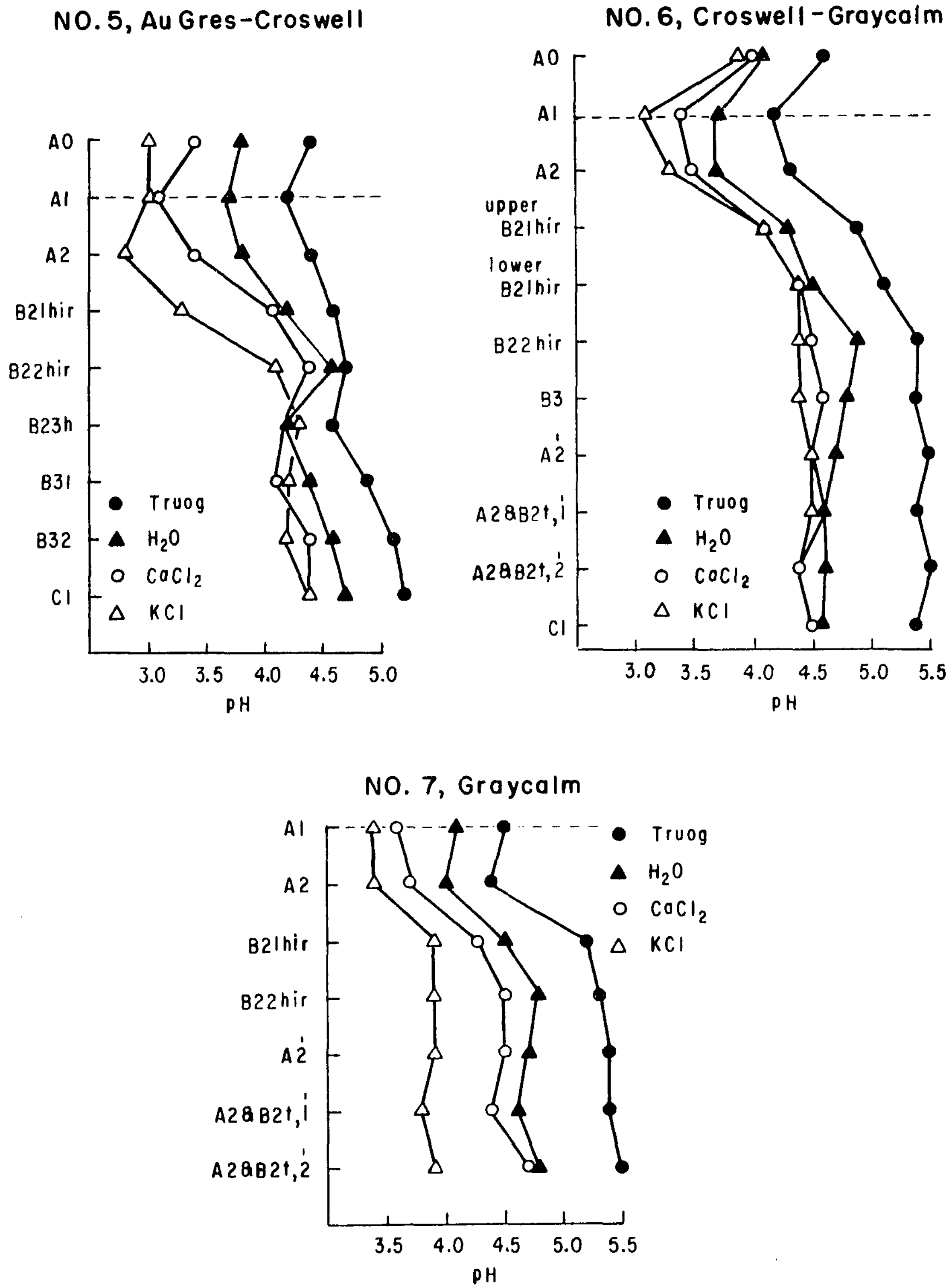


Figure 3.--Comparison of pH profiles by different methods of determination. (Dashed line is at mineral soil surface.)

There is an irregular, but definite net increase in pH as the drainage improves from poor to well. This is to say that the lowest pH does not occur out in the bog at the Kinross sites, but along the edge of the bog at the Saugatuck site. From the Saugatuck site, soil pH increases to its highest values at the well-drained, Graycalm site or the Croswell-Graycalm site. This general trend is more pronounced in the A2, C, and lower B horizons than it is in the other horizons. These differences in pH, with drainage, amount to approximately 0.5 pH unit.

The above general trends are in agreement with those of Mattson and Lönnemark (1939) and Glentworth and Dion (1949).

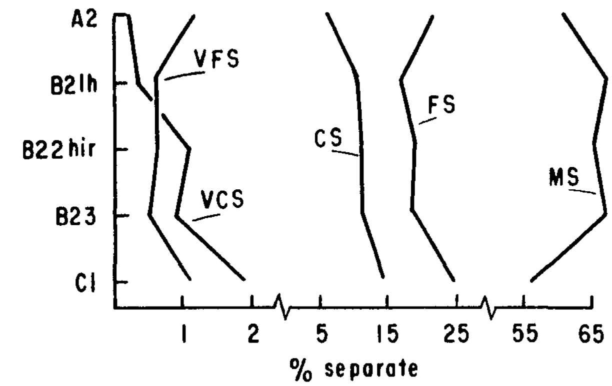
The pH's measured in water, 0.01 M $CaCl_2$ in 1.0 N KCl with the glass electrode are on the average 0.6, 0.9, and 1.2 pH units lower than those measured with the Truog Kit, respectively. However, there are little differences in the pH's as measured in the three suspending media with the glass electrode. In fact, using water as the standard, the $CaCl_2$ and KCl pH's are on the average only 0.25 and 0.35 pH units lower, respectively. However, these differences are greater in the upper parts (organic and A horizons) of all but the well-drained Graycalm and the Croswell-Graycalm profiles.

Particle Size Distribution

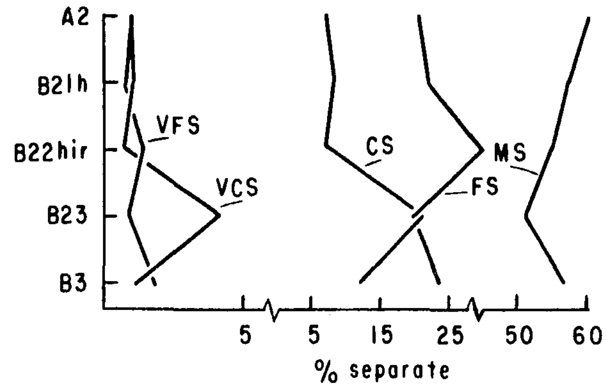
The total sand percentages of these soils range from approximately 80 to 99%, and these values generally attain their maxima in the C or lower B horizons (Figure 4). The total sand percentages in the better-drained soils, are higher in the A horizons than in the upper B horizons, and they increase to values in the C or lower B horizons that are higher than those in the A or upper B horizons. This is not true for the two Kinross soils, in the bog, where the total sand percentages increase with depth. In each horizon of the seven profiles, three sand fractions are dominant: medium sand (68 - 43%) > fine sand (39 - 16%) > coarse sand (21 - 5%) (Figure 4).

Total silt percentages are usually highest in the A and upper B horizons and tend to drop off rather sharply to low values in the lower part of the profiles (Figure 5). The Graycalm profile differs from the others in that the higher silt content continues down to 55 inches. The silt is about equally divided between coarse silt (50 - 20μ) and fine silt (20 - 2μ) (Figure 5). The distributions of these two silt fractions with depth is similar to that for the total silt.

Much of the silt may have weathered from the sand fraction, since its distribution in the profile follows the pattern of increasing intensity of physical weathering, i.e., increasing with proximity to soil surface. St. Arnaud



NO. 1, Kinross



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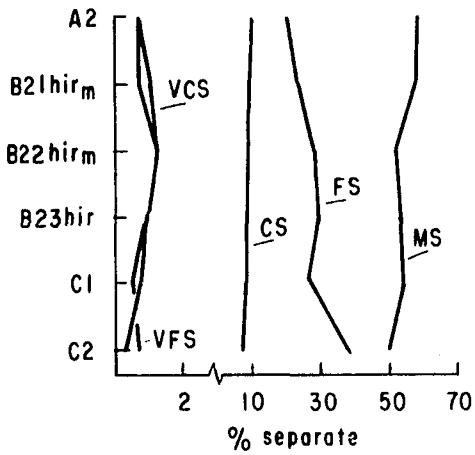
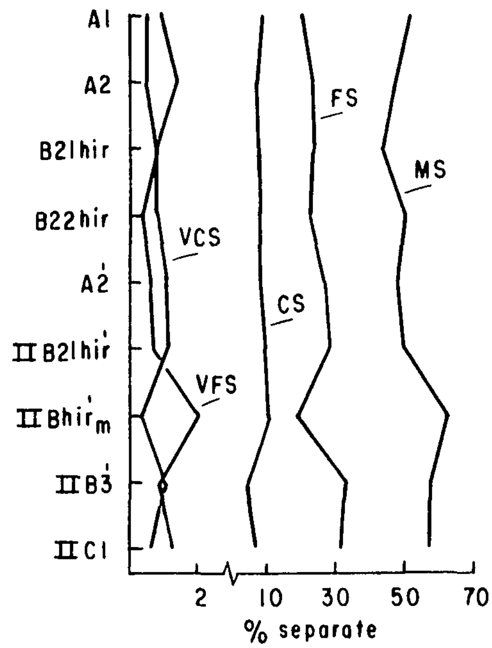


NO. 3, Saugatuck



NO. 4, Saugatuck – Au Gres

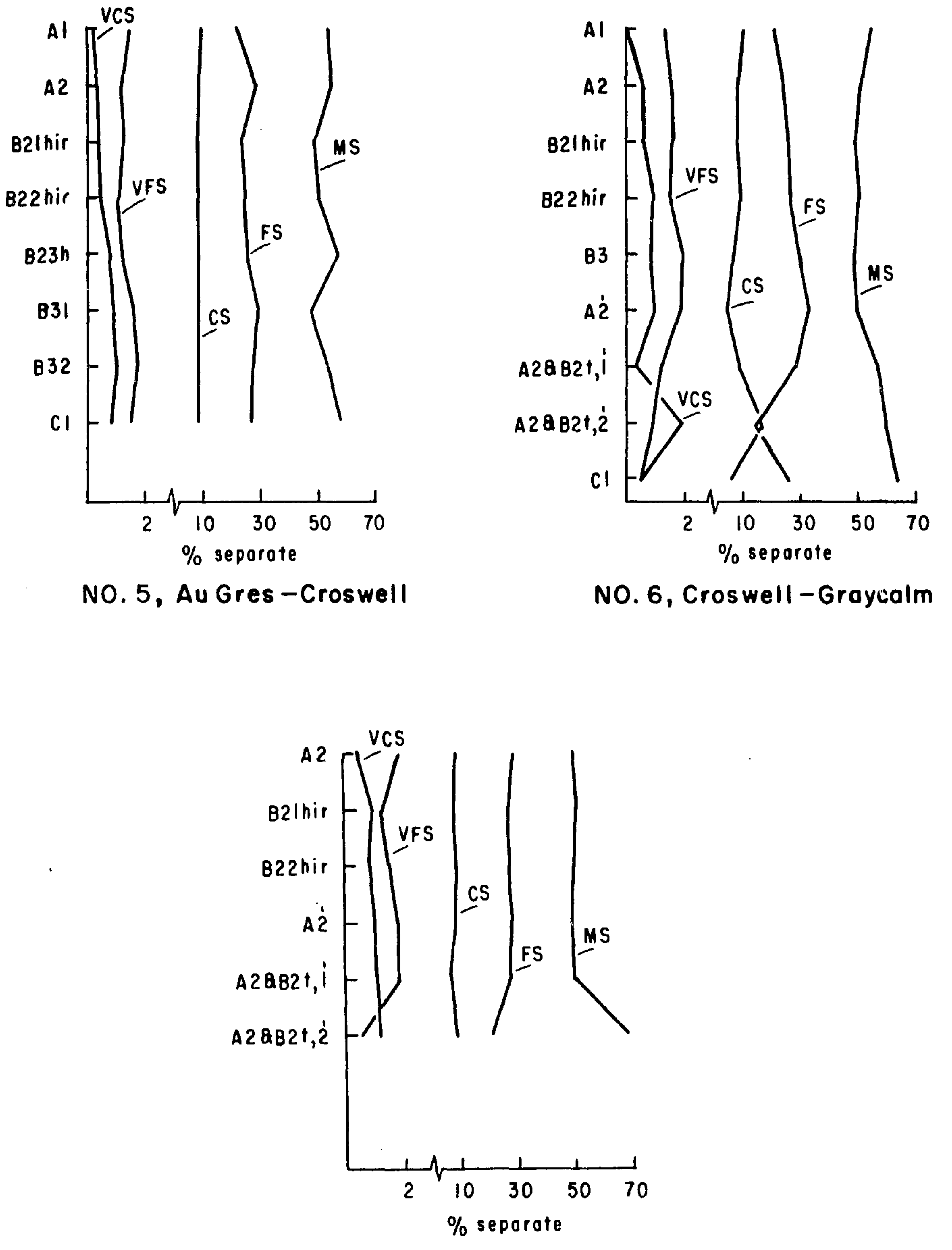
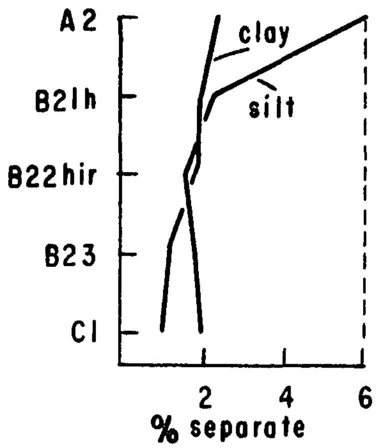
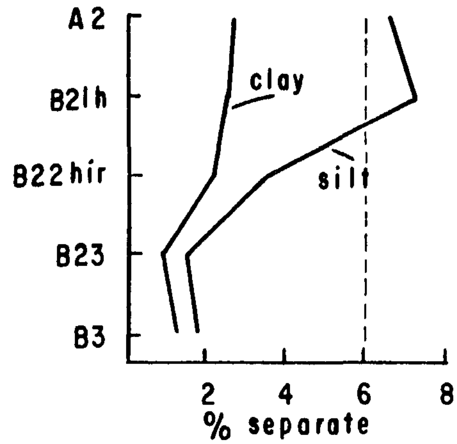


Figure 4.--Sand fraction profiles for each of the seven pedons.



NO. 1, Kinross



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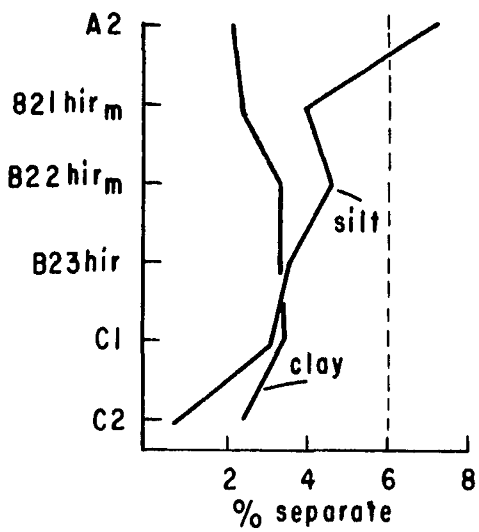
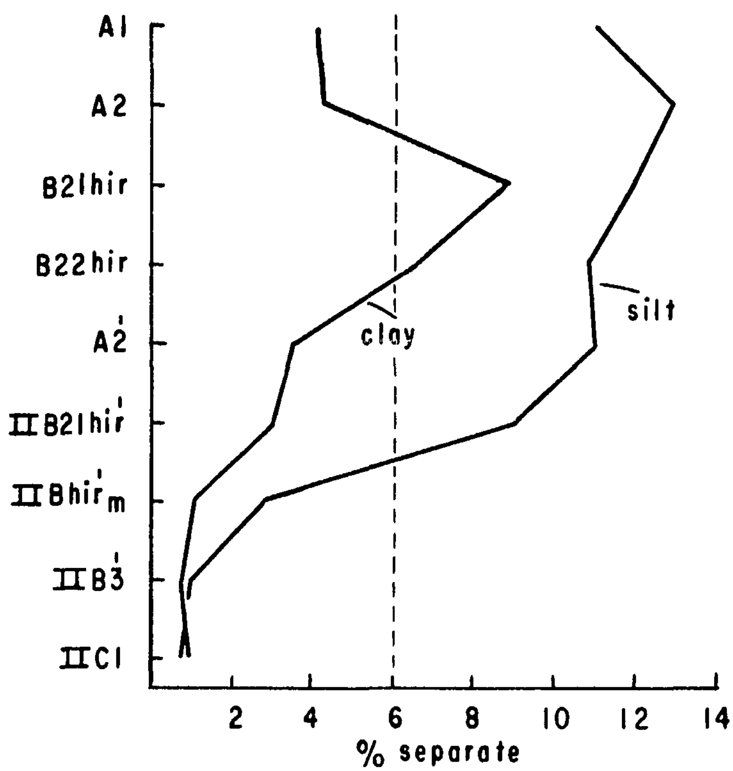


NO. 3, Saugatuck



NO. 4, Saugatuck-Au Gres

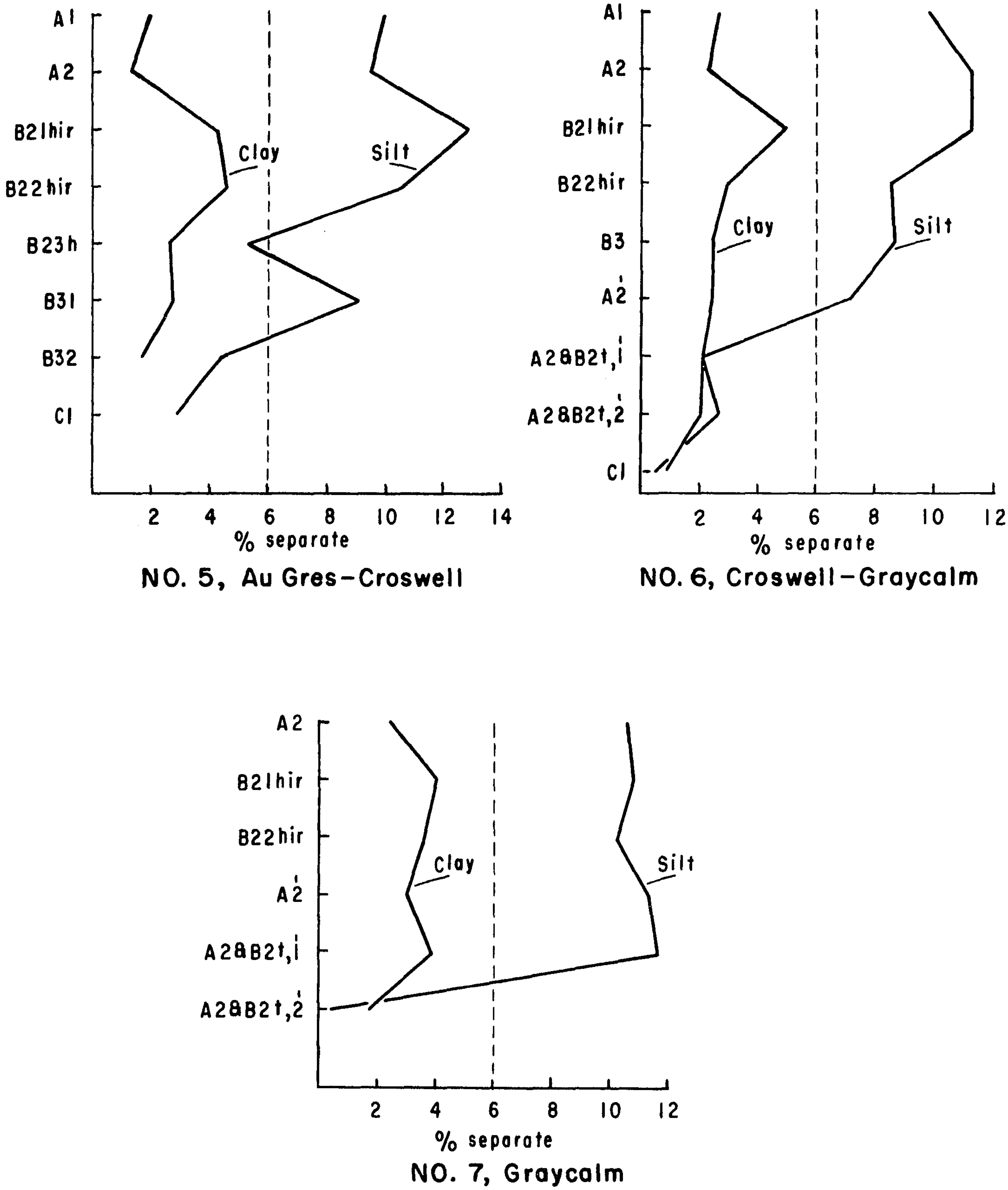


Figure 5.--Silt and clay fraction profiles for each of the seven pedons. (Note differences in scale.)

(1961) demonstrated that significant amounts of sand were lost from the coarse sand fraction of the Ae and C1 horizons of a Grey Wooded soil when they were subjected to 200 cycles of freezing and thawing. However, the distribution of the silt and the greater than 2 mm fractions in the lower profiles of Site #'s 6 and 7, suggest some stratification (Table A-2, Figure 5).

Except for the two Kinross soils, where the maximum clay occurs in the A2 horizons, there are slight clay accumulations in the upper B horizons (Figure 5). The clay percentages for the seven profiles range from approximately 1 to 9%. Only the upper B horizons of the Saugatuck-AuGres profile contain more than 5% clay. The high water table in the two Kinross soils has reduced the accumulation of clay in the upper B horizons, and as a result the clay has remained in the uppermost part of the mineral profile where maximum weathering is occurring. The accumulation of clay in the B horizons of the other five profiles is probably due, in part at least, to translocation of clay from the overlying A horizons.

Using the totals of the fine materials (silt plus clay) in the profiles the following sequence is apparent: Saugatuck-AuGres > AuGres-Croswell ≃ Croswell-Graycalm ≃ Graycalm > Saugatuck > Kinross (better drained) ≃ Kinross (organic surface). This suggests the following:

1. Excess of moisture at the wet end of the transect has severely reduced weathering.

2. Deficiency of moisture at the dry end of the transect has slightly reduced weathering.
3. Conditions favoring formation and accumulation of clay and silt occur along that portion of the transect where the water table is somewhat to moderately deep and subjected to considerable seasonal fluctuations.
4. The organic mat on the Kinross soils may have reduced frost action.

Bulk Density, Moisture Retention, and Porosity

Bulk density, except for the Kinross (organic surface) site where it remains about the same throughout the profile, generally increases with depth (Table A-3). These values for the Saugatuck-AuGres and Kinross (organic surface) sites show the most and least variation with depth, respectively.

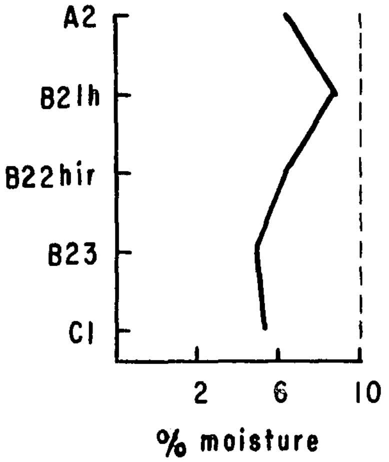
Bulk densities of the C or lower B horizons tend to increase in an irregular manner, while those of the A2 horizons tend to decrease in a similar manner as drainage improves from poor- to well-drained. This can be explained by the fact that the high water table at the less well-drained sites reduces the movement of fine materials and organic matter from the upper to lower portions of the profile, while at the better-drained sites the opposite is true.

These bulk density values for the upper B horizons generally decrease from the Kinross soils to a low value at the Saugatuck-AuGres site and then gradually increase along the transect toward the well-drained site. This reflects the degree of aggregation in the upper B horizons, since the measurements were made on disturbed samples. The fact that the measurements were made on disturbed samples also accounts for the low and high values in those horizons with a firm to cemented and a loose to firm consistency, respectively. These bulk density measurements made on disturbed samples and the variation in these measurements with depth and with natural drainage are similar to those for undisturbed samples from other coarse-textured soils (sand, loamy sand) in Michigan (Franzmeier, et al., 1963; Erickson, et al., 1965).

Sandy soils (sands and loamy sands) with moisture equivalent values (average of control section weighted for thickness) of 2% or more and less than 2% indicates that the sand grains are coated and uncoated, respectively (Soil Taxonomy--1970, unedited). By this criteria, the sands in each horizon of the seven profiles used in this study are coated and/or associated with silt, clay, and organic matter. Hand lens, binocular and microscopic examinations show that the sand grains in the upper B horizons are coated, and the moisture equivalent, mechanical analysis, and organic matter content data in Tables A-2, A-3, and A-5 show that the sands in the A2, lower B, and C horizons are associated with clay, silt, and organic matter. Hence, the sand grains in the upper B horizons are coated.

All profiles showed a trend toward greater moisture retention percentages and non-capillary porosity with proximity to the soil surface (Figures 6 and 7). The content of organic matter accounts for the relatively high moisture percentages in the A1 horizons (indicated with an arrow in Figure 6). The 60 cm moisture retention percentage values are highest and most variable at the Saugatuck-AuGres site and least variable at the Graycalm site.

The maximum water holding capacity percentage values are approximately two to five times larger than the 60 cm moisture retention percentage values, and the smaller and larger differences occur in the A1 and lower B or C horizons, respectively. These differences are more variable, with increasing depth, at the wet end than at the dry end of the transect (Table A-3). These trends and variations in moisture retention and porosity can be explained by the nature and distribution of the fine earth (especially silt) within and among the seven profiles as discussed earlier. However, the organic matter contents (especially of the A1 horizons) and the fact that the bulk densities were determined on disturbed samples also help to explain the above.



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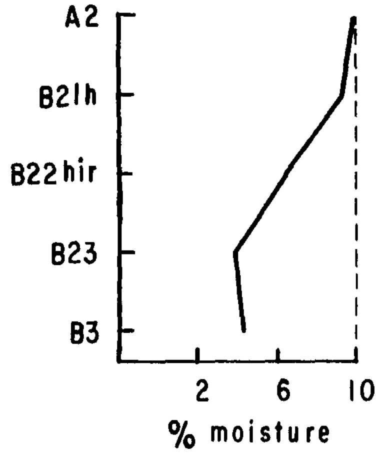

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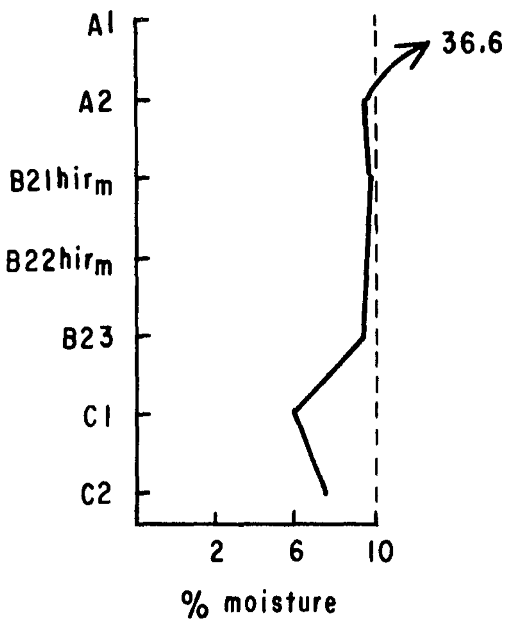
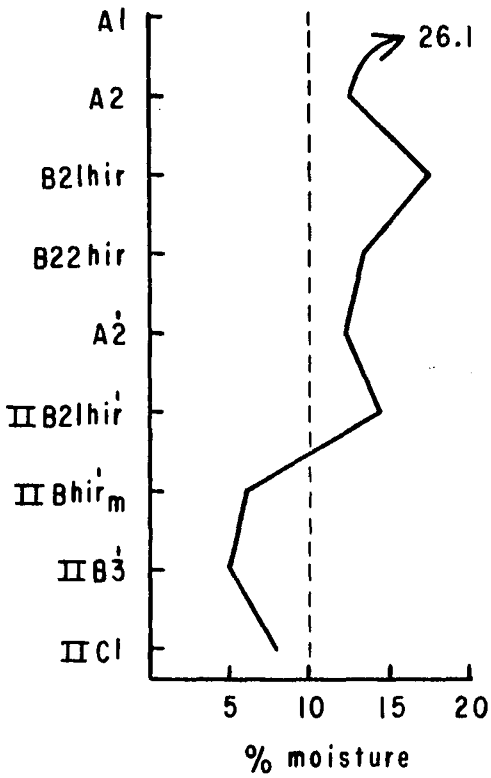


NO. 3, Saugatuck



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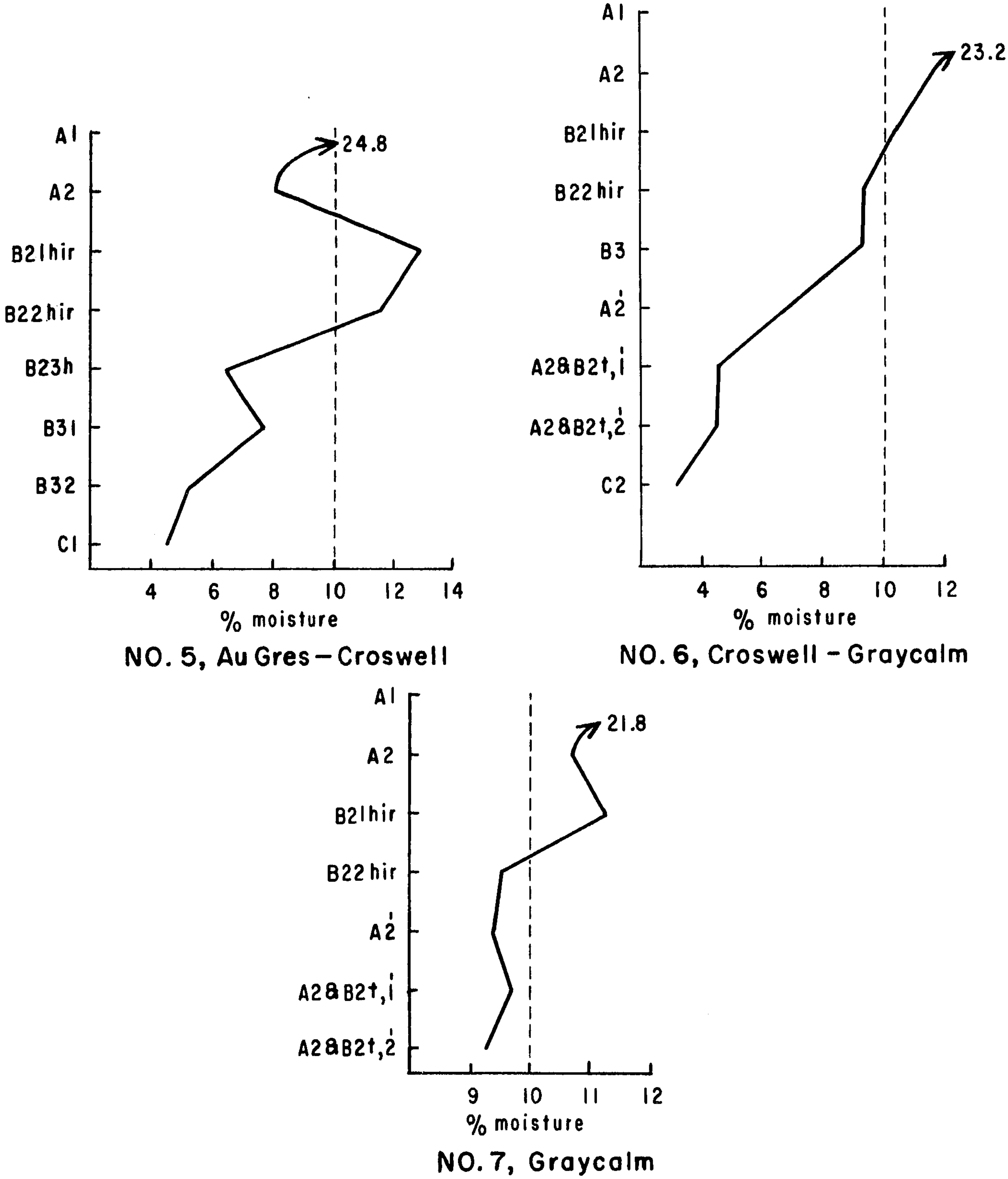
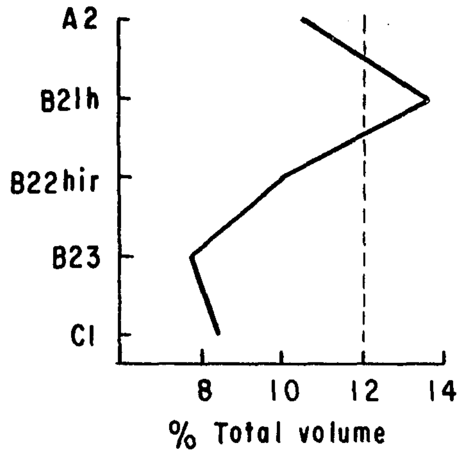
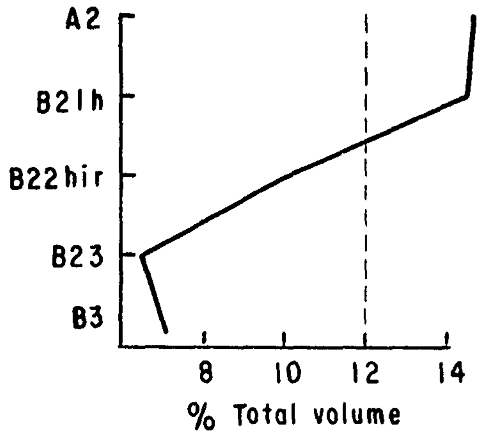


Figure 6.--Moisture retention profiles, at 60 cm tension, for each of the seven pedons. (Note differences in scale.)



NO. 1, Kinross



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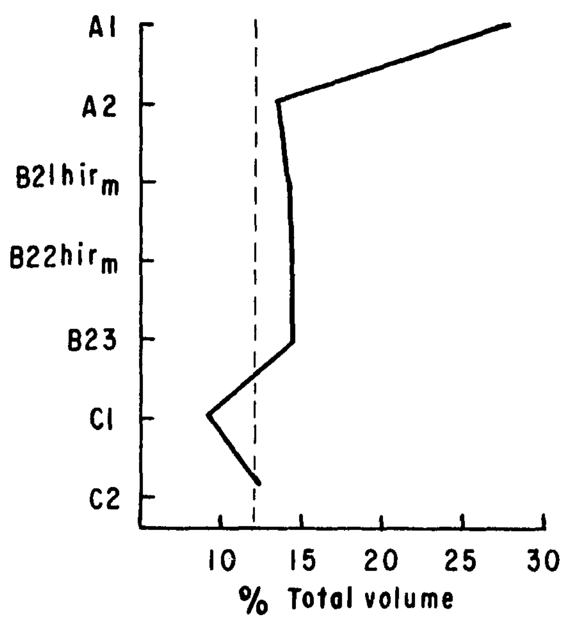

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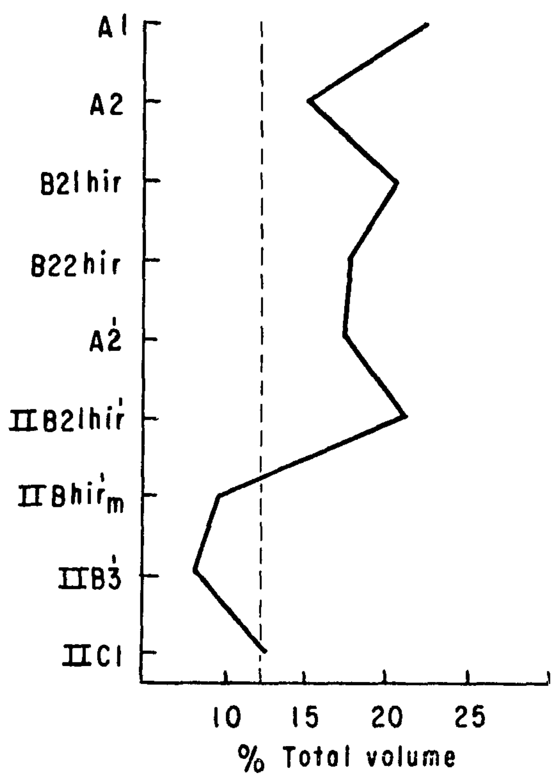


NO. 4, Saugatuck - Au Gres

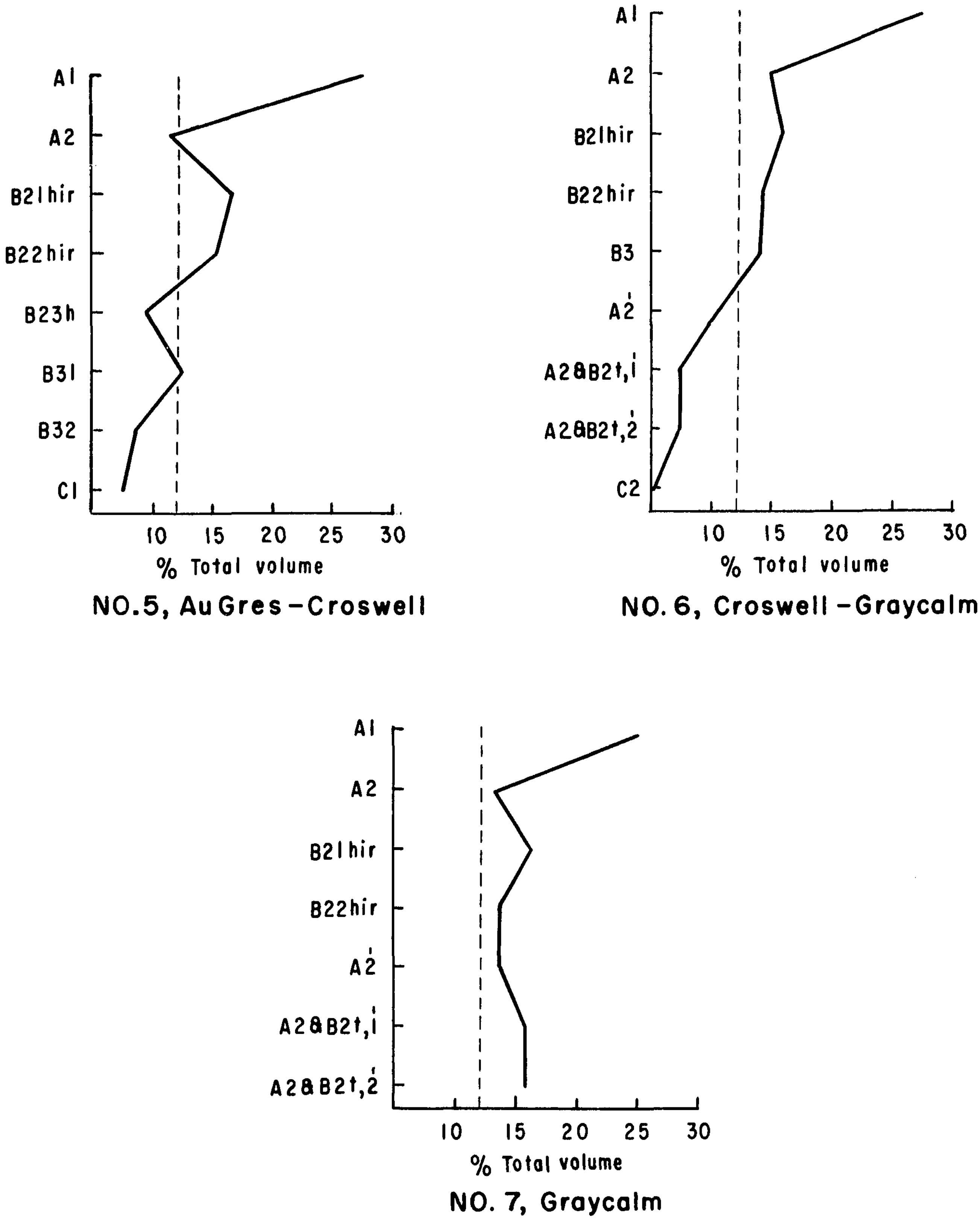


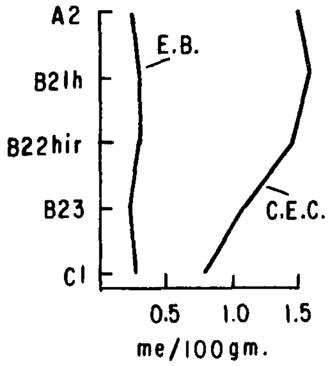
Figure 7.--Non-capillary porosity profiles for each of the seven pedons. (Note differences in scale.)

Cation Exchange Capacity, Exchance Acidity, Exchangeable Bases and Base Saturation

Cation exchange capacity, exchange acidity, and exchangeable bases are always highest in the organic matter-rich A1 horizons (Figure 8 and Table A-4). Exchangeable bases (sum of Ca, K, Mg, Na) remain about the same or tend to decrease with increasing depth from the A1 horizons (Figure 8). Cation exchange capacity (sum of bases plus $BaCl_2$-TEA extractable acidity), for the five less well-drained profiles, show a maximum in the upper B horizons and then decrease to lower values in the C or lower B horizons. For the two best-drained profiles (#'s 6 and 7), cation exchange capacity values show a continuous decrease from the highest values in the A1 horizons to the lowest values in the C1 horizons, with an increase being exhibited by the A2 & B2t horizons.

In each of the seven profiles, the exchangeable bases are predominantly calcium. Exchangeable base contents are highest along the edge of the bog in the Saugatuck profile and lowest in the two Kinross soils in the bog.

These data suggest that the amount and distribution of bases in the soils are related to the movement of water through the profile which is at a minimum in the Kinross soils. Bases are highest along the edge of the bog, in the Saugatuck profile, probably as a result of enrichment by drainage water from the surrounding better-drained soils. In addition, the data also show evidence of nutrient cycling



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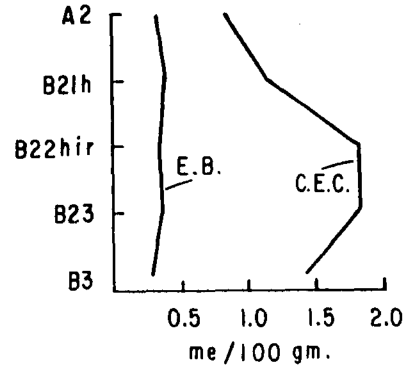

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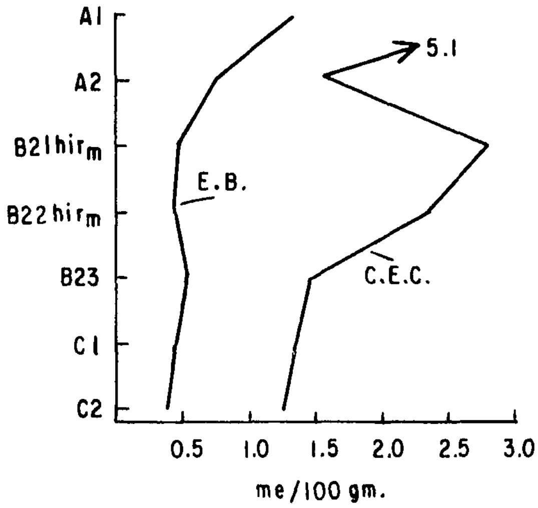

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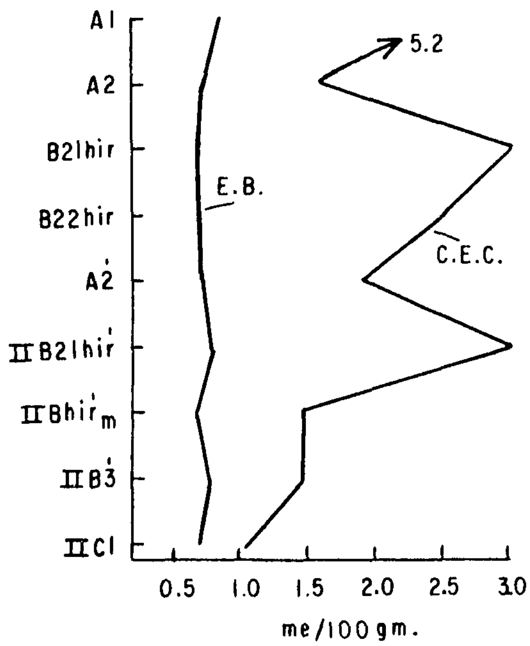


NO. 4, Saugatuck – Au Gres

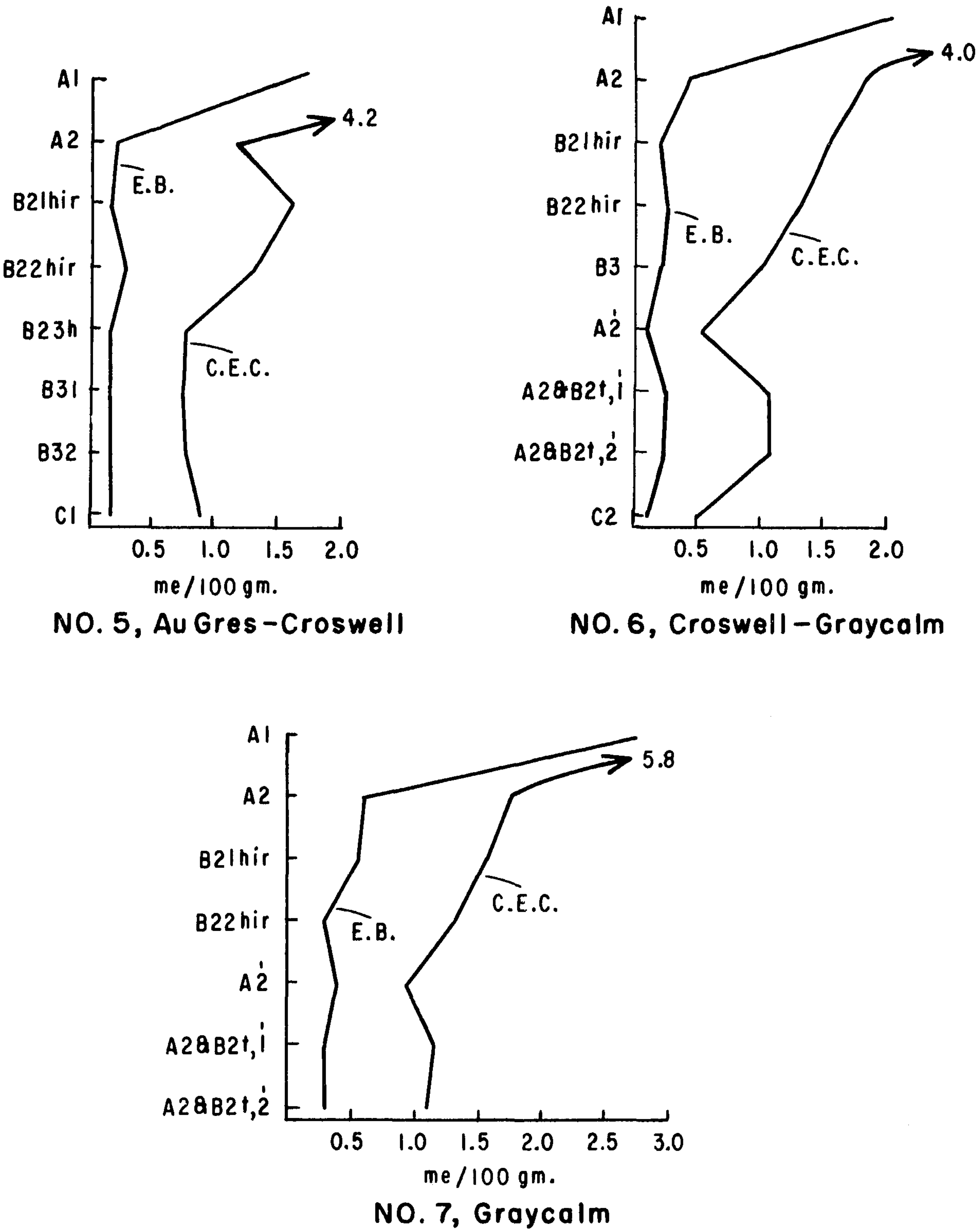


Figure 8.--Base exchange and cation exchange capacity profiles for each of the seven pedons.

where bases are returned to the soil surface by the vegetation, enriching the A1 horizons and the A2 horizons of the better-drained soils.

Cation exchange capacity (sum of cations) is much lower (as much as 6 times) than that determined with NaOac at pH 8.2 (Table A-4). In a recent study of similar soils in Michigan, Pailoor (1969) has made similar observations and he concludes that these variations in cation exchange capacity are not well understood and deserve further study. The results of this study are in agreement with this conclusion.

Mineralogy of Sand Fraction

The largest percentage of the feldspars were identified as orthoclase and albite which are more resistant to weathering than the calcium feldspars. The garnets were dark in color such as melanite and grossularite, and hence contain no iron (Heinrich, 1965). Thus, quartz, feldspars and garnets, and pyroxenes plus amphiboles are suitable for use as resistant and weatherable primary minerals, respectively.

The materials in which these seven soil profiles have developed are heterogeneous, as indicated by the variations in the mineral percentages and the mineral ratios within and among the profiles (Table 2). However, the mineral suite is the same for all profiles, which indicates similarity in the original parent materials. The

TABLE 2.--Mineralogical composition and mineral ratios of the fine sand fractions of the seven pedons.

	Kinross, #1				Kinross, #2			Saugatuck, #3		
Materials	A	A	A	A	A	A	A	A	A	A
Horizons Depths	A2 1-11"	B21h 11-21"	B22hir 21-27"	C1 37-50"	A2 1.5-15"	B22hir 25-35"	B3 54-63"	A2 1-11"	B22hir$_m$ 17-24"	C2 43-61"
Minerals										
Quartz	75.49	70.59	73.12	66.08	61.19	72.13	66.27	72.60	70.15	68.12
Feldspars	7.84	13.07	12.90	15.09	15.05	12.29	10.84	10.96	13.43	13.04
Pyroxene, Amphiboles	1.96	3.28	2.15	3.78	3.22	3.26	4.82	1.37	2.99	2.89
Garnet	1.96	1.31	2.15	1.89	2.15	2.45	2.40	2.74	2.99	2.89
Others	12.74	13.08	9.68	13.23	13.98	9.81	15.66	12.32	10.45	13.03
Number Counted	306	306	279	318	279	244	249	292	268	276
Garnet/ Quartz + Feldspars	.0235	.0196	.0249	.0232	.0282	.0290	.0311	.0328	.0358	.0356
Garnet/ Pyroxenes + Amphi- boles	1.0000	.3994	1.0000	.5000	.6677	.7515	.4979	2.0000	1.0000	1.0000
Quartz + Feldspars/ Pyroxenes + Amphi- boles	45.52	25.51	40.01	21.47	23.68	25.89	15.99	60.99	27.95	28.08

TABLE 2.--Continued

	Saugatuck-AuGres, #4						AuGres-Croswell, #5			
Materials	B	B	B	B	A	A	A	A	A	A
Horizons	A1	A2	B22hir	IIA2'	IIBhir$_m$'	IIC1	A1	A2	B21hir	C1
Depths	0-1½"	1½-3"	7-11"	11-16"	23-33'	48-58"	0-6"	6-10"	10-14"	50-60"
Minerals										
Quartz	57.89	59.34	64.52	72.32	77.50	66.36	70.83	69.33	66.67	58.21
Feldspars	16.84	12.09	14.52	12.50	8.75	16.36	13.33	17.33	19.35	19.40
Pyroxene, Amphiboles	4.21	4.39	1.62	1.78	2.50	4.55	2.49	1.34	2.15	2.99
Garnet	3.16	3.29	3.23	2.68	2.50	2.73	2.50	2.67	2.15	2.23
Others	17.90	20.87	14.52	10.71	8.75	9.99	10.84	9.33	5.38	6.72
Number Counted	285	273	310	336	320	330	240	300	279	268
Garnet/ Quartz + Feldspars	.0423	.0461	.0409	.0316	.0289	.0303	.0297	.0308	.0250	.0287
Garnet/ Pyroxenes + Amphi-boles	.7506	.7494	1.9938	1.5056	1.0000	.6000	1.0040	1.9925	1.0000	.7458
Quartz + Feldspars/ Pyroxenes + Amphi-boles	17.75	16.27	48.79	47.65	34.50	18.18	33.79	61.69	40.01	25.96

TABLE 2.--Continued

Materials	Croswell-Graycalm, #6						Graycalm, #7				LSD$_{.05}$
	A	A	A	A	A	C	A	A	A	C	
Horizons	A1	A2	B21hir	B3	A2'	A2'&B2t'2	A2	B21hir	A2'	A2'&B2t'2	
Depths	0-1"	1-3"	3-7"?	18-23"	23-28"	39-49"	1-3"	3-11"?	23-30"	55-60"	
Minerals											
Quartz	60.83	62.11	69.83	67.69	51.69	70.18	72.09	61.78	63.64	72.82	16.67
Feldspars	25.00	16.77	16.38	10.77	20.32	14.91	13.18	16.56	14.39	10.68	7.35
Pyroxene, Amphiboles	1.67	1.86	1.72	3.08	5.62	1.75	1.55	1.91	3.03	1.94	2.03
Garnet	1.67	1.86	1.72	3.08	3.37	2.63	1.55	1.91	1.52	2.91	1.19
Others	10.83	17.39	12.07	15.39	19.10	10.53	11.63	17.83	17.42	11.65	7.13
Number Counted	240	322	348	260	267	342	248	314	264	309	
Garnet/ Quartz + Feldspars	.0195	.0236	.0199	.0393	.0469	.0309	.0182	.0244	.0195	.0349	.0933
Garnet/ Pyroxenes + Amphiboles	1.0000	1.0000	1.0000	1.0000	.5996	1.5029	1.0000	1.0000	.5017	1.5000	.7759
Quartz + Feldspars/ Pyroxenes + Amphiboles	51.39	42.41	50.12	25.47	12.79	48.62	55.01	41.01	25.75	43.04	25.16

weatherable mineral percentages (pyroxenes, amphiboles) suggest that these glacial sediments are young and of late pleistocene age.

The ratios of resistant mineral/weatherable mineral generally tend to decrease with increasing depth, which means that the intensity of weathering decreases with increasing depth. These ratios also show that the soils in the bog and the soils along the edge of the bog are the least and most weathered, respectively.

Both the particle size distribution data (Table A-2) and the garnet/quartz plus feldspars ratio (Table 2) suggest slight differences in parent material. The two soils along the edge of the bog (Saugatuck and Saugatuck-AuGres) have developed in similar materials (A), but the lower part of the Saugatuck-AuGres profile has developed in a material (A) that is similar to that in which the Kinross profiles, AuGres-Croswell profiles, and the upper part of the Croswell-Graycalm and Graycalm profiles have developed. The A2'& B2t' horizons of the latter two profiles have developed in similar materials, but this material (C) is slightly different from that in which the upper portions of these two profiles have developed. Hence, some stratification of the original glacial sediments is apparent.

Quartz is the only mineral that accounts for more than 40% but less than 90% of the mineralogical composition of these soils. Thus, these soils are classified as having mixed and not siliceous mineralogy at the family level of the new soil classification system (Soil Taxonomy--1970, unedited).

Mineralogy of Clay Fraction

The clay fractions of all horizons contain kaolinite and quartz. The clay of the lower B or C horizons or least altered horizons of the seven pedons used in this study all contain the following clay minerals: illite, chlorite and chlorite-vermiculite intergrade (Table 3). Each of the spodic horizons in the seven profiles contain chlorite-vermiculite intergrade.

Discrete illite occurs in the C or lower B horizons of all profiles and in small amounts in the A horizons (A1 or A2) of the Croswell-Graycalm and Graycalm profiles, but it does not occur in the A2 horizon of the other five profiles. In addition, discrete illite does not occur in the spodic horizons of the three better-drained profiles. This suggests that illite is being weathered out of the upper portions of the profiles. The contents of pyroxenes and amphiboles further indicate that the high water table has reduced the intensity of weathering at the less well-drained sites. The fact that the illite peaks generally tend to increase in height and symmetry with increasing depth is further evidence of the decrease in alteration of illite with depth. The chlorite and kaolinite peaks also tend to increase in height and symmetry with increasing

TABLE 3.--Summary of X-ray diffraction data for clays of selected horizons of each of the seven pedons.

Clay Minerals	Kinross (C.S.)			Kinross (B.C.)			Saugatuck			Saugatuck-AuGres						AuGres-Croswell				Croswell-Graycalm							Graycalm			
	A2	B22 hir	B23	A2	B22 hir	B3	A2	B22 hir$_m$	C2	A1	A2	B22 hir	II A2'	II Bhir$_m$'	II C1	A1	A2	B21 hir	C1	A1	A2	B21 hir	B3	A2'	A2'& B2t;2	C1	A2	B21 hir	A2'	A2'& B2t;2
Illite	--	XVl 2a	Xm 1s	-	Xl 1a	Xm 1s	--	XVl 2a	Xh 1s	--	--	--	--	XVl 2a	Xm 2a	--	--	--	Xl 2a	XVl 2a	--	--	XVl 2a	XVl 2a	Xh 2a	Xm 2a	XVl 1s	--	XVl 2a	Xh 2s
Kaolinite	XVl 1a	Xm 1s	Xm 1s	Xm 1s	Xm 1a	Xm 1s	Xl 1a	Xm 1a	Xh 1s	Xl 1a	Xl 1a	Xl 1a	Xm 1a	Xm 1a	Xh 1s	XVl 2s	Xl 2a	Xl 2a	Xh 2a	XVl 2a	Xl 2a	Xm 2a	Xm 1a	Xm 2a	Xh 2a	Xm 2a	Xl 1s	Xl 1a	Xm 2a	Xh 1s
Chlorite	--	Xl 1a	Xm 1a	--	Xl 1a	Xm 1a	--	Xl 2a	Xm 2a	--	XVl 2a	--	Xl 2a	Xm 2a	Xm 1a	--	--	--	Xl 2a	--	--	Xl 2a	--	Xl 2a	Xl 2a	XVl 2a	--	--	--	XVl 2a
Vermiculite	--	--	Xl 1a	--	--	--	Xm 1a	--	--	--	--	--	--	--	--	--	XVl 2a	--		Xl 2a	--	--	Xl 2a	XVl 2a	--	--	--	--	--	Xl 1a
Montmorillonite	--	--	--	--	--	--	--	--	--	Xm 2a	--	--	--	--	--	Xl 2s	Xm 2a	--		Xl 2a	Xl 2a	--	--	--	--	--	Xl 2a	--	--	--
Chlorite-Vermiculite Intergrade	--	Xl 2a	Xl 2a	--	Xl 2a	Xl 2a	Xm 2a	Xm 2a	Xm 2a	--	--	Xm 2a	Xm 2a	Xm 2a	Xm 2a	--	--	Xm 2a	Xm 2a	--	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xm 2a	Xl 1a
Vermiculite-Montmorillonite Interstratified	XVl 2a	--	--	Xm 2a	--	--	--	--	--	Xm 2a	--	--	--	--	--	--	Xm 2a	--		Xl 2a	--	--	--	--	--	--	--	--	--	--
Chlorite-Vermiculite-Montmorillonite Interstratified	--	--	--	--	--	--	--	--	--	--	Xm 2a	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Quartz	Xh 1s	Xm 1s	Xm 1s	Xh 1s	Xm 1s	Xm 1s	Xh 1s	Xm 1s	Xm 1s	Xh 2s	Xh 1s	Xl 1s	Xl 1s	Xh 1s	Xh 1s	Xh 1s	Xh 1s	Xl 1s	Xh 1s	Xh 1s	Xh 1s	Xh 1s	Xm 1s	Xh 1s	Xh 1s	Xh 1s	Xh 1s	Xm 1s	Xm 1s	Xm 1s

Notes:

X = present
-- = absent

h = high peak intensity
m = medium peak intensity
l = low peak intensity
Vl = very low peak intensity

1 = sharp peak
2 = broad peak

s = symmetrical peak
a = asymmetrical peak

depth, which means that these two-layered silicates are also being altered, probably by the loss of interlayered aluminum and desilication, respectively (Franzmeier et al., 1963, and Ross, 1965; Jackson et al., 1952).

Montmorillonite occurs only in the A1 or A2 horizons. As pointed out by Beavers (1965), the presence of montmorillonite in these horizons could be due to deposition by wind. However, Franzmeier et al. (1963) and Ross (1965) concluded from their study of podzols in northern Michigan that this clay mineral has formed in situ from illite, chlorite, and chlorite-vermiculite intergrade, through vermiculite. These data are in agreement with the latter.

Relationship Between the Soils and the Vegetation Groups

Due to the short distance between them, the two Kinross profiles (#'s 1 and 2) and the Saugatuck and Saugatuck-AuGres profiles (#'s 3 and 4) were combined for the site index portion of this study. (The author expresses his appreciation to Lyle Linsemier and Massoud Hakimian who assisted in the site index measurements.)

Figure 9 shows that the site index (average of three stem measurements) of jack pine (*Pinus banksiana*) increases as natural drainage improves from poorly to well-drained. The relatively low site index at the wet end of the transect (Kinross profiles, #'s 1 and 2) can be explained by the presence of the high water table and the associated poor aeration in these soils. The relatively high index at the dry end of the transect (Graycalm, #7) can best be explained by the absence of a high water table and the presence of the thin Bt bands which serve to increase the available water and nutrient supplies within the reach of plant roots. Apparently, the effects of the ortstein layer in the Saugatuck and Saugatuck-AuGres profiles are counteracted by the supply of available moisture in these profiles that can apparently move through this layer by capillarity or fluctuations in the water table. In addition, the roots may move laterally to uncemented subsoil areas.

These conclusions are in agreement with those of van Eck (1958) and Shetron (1970), who conducted site index studies of red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana*) in Michigan, respectively.

From Figure 9, it is apparent that the range in the site index for each of the five soil series is as follows: Kinross, 35 - 40; Saugatuck, 40 - 43; AuGres, 43 - 46; Croswell, 46 - 50; and Graycalm, 50 - 55.

Byer (1960 and 1965) has studied the vegetation along the moisture and slope gradient used in this study. The discussion which follows is based on his investigations.

Figure 10 shows the general distribution of the vegetation and the soils along the moisture gradient, and Figures 11 and 12 show the species area curves for the

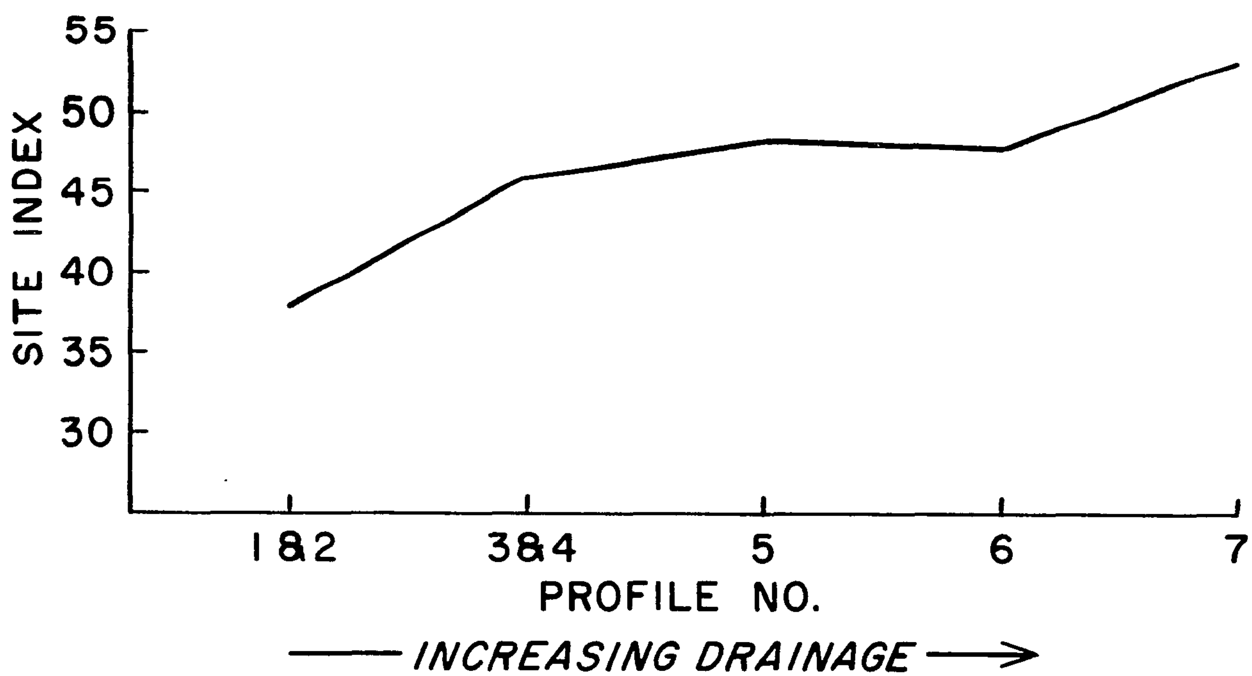


Figure 9.--Site index for Jack pine as a function of position along the slope.

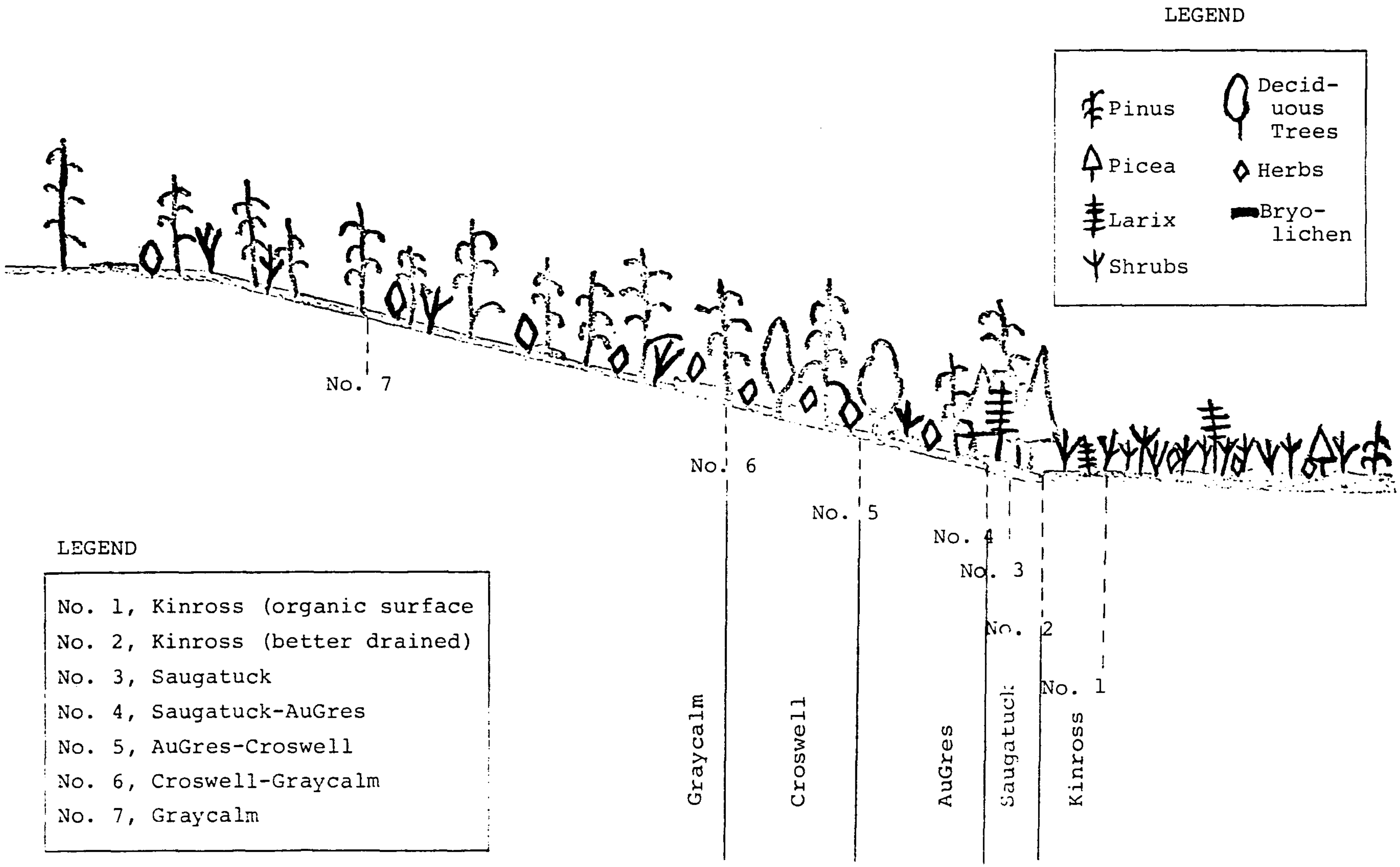


Figure 10.--General distribution of the vegetation and the soils along the slope (1 cm = 14 ft.).

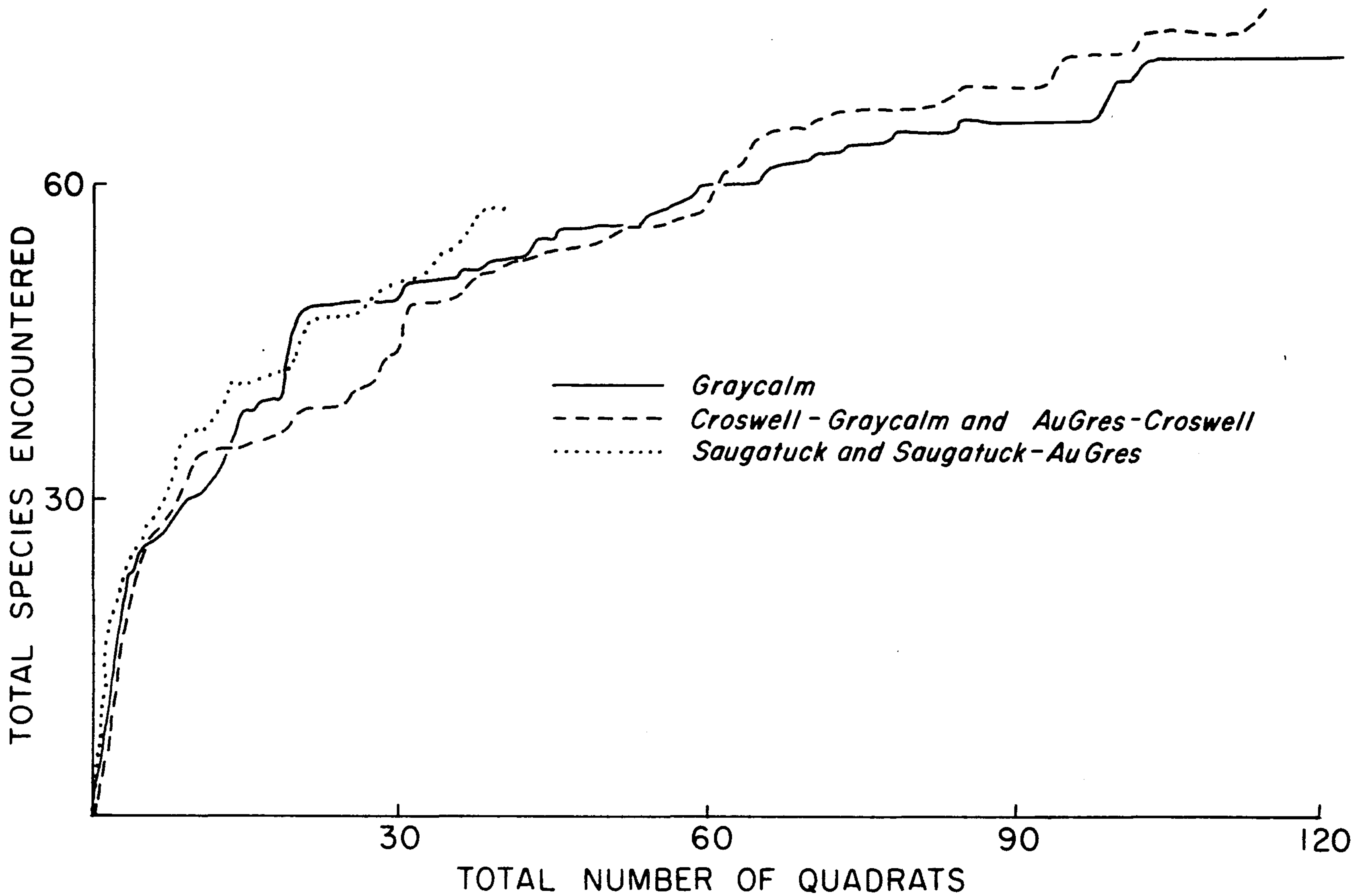


Figure 11.--Species-area curves for the five better drained soils.

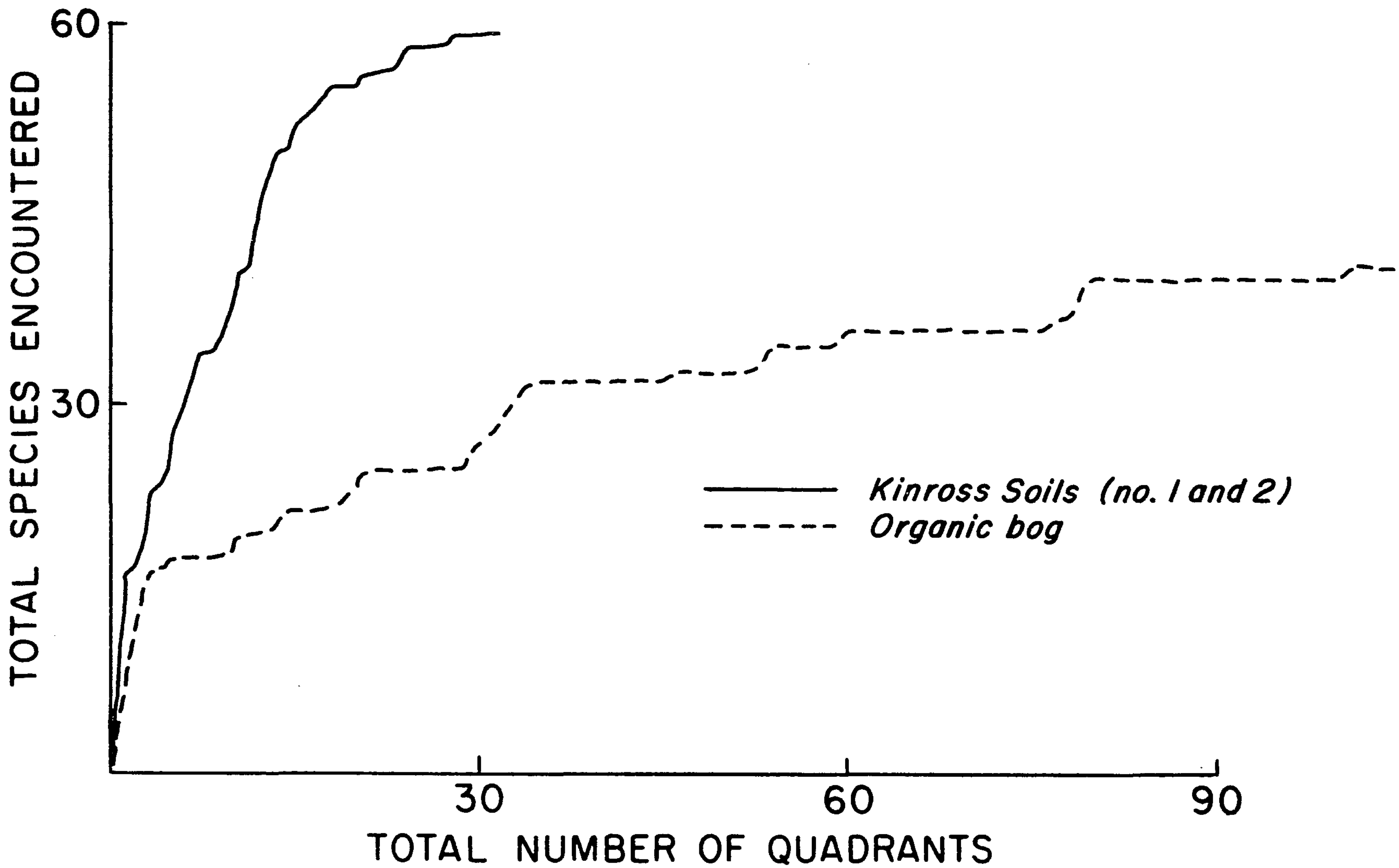


Figure 12.--Species-area curves for the Kinross soils and the organic soils in the bog.

soils. The species area curves show that the flora of the Kinross soils is the richest in species, and that of the organic bog is the poorest. Graycalm is intermediate between the two, and the total flora increases as the depth to the water table decreases from the well-drained Graycalm soil to the less well-drained Saugatuck soil along the edge of the bog. This strongly suggests that the organic bog is the most unfavorable habitat for the plants that occur in the area, more so even than the well-drained sandy soil. The site indexes of jack pine (Pinus banksiana) also suggest that the organic bog is the most unsuitable habitat for plants in general.

Both the lichen and moss covers decrease sharply from the Graycalm soil to the Croswell-Graycalm soil, and then increase again between the Croswell-Graycalm soil and the Kinross soils. This is explained by the fact that mosses are probably not so much restricted by moisture conditions as they are by accumulation of deep leaf litter.

Tree cover is much greater on the dry end of the gradient than it is in the bog. This is due to the variation in the depths to the water table along the gradient. Shrub cover increases steadily from the well-drained Graycalm soil to the organic soils in the bog. The high shrub cover on the organic soils in the bog is at least partially a consequence of the low tree cover and partially as a result of the peculiar adaptation of Chamaedaphne to occupation of, and reproduction by rhizomes on the *Sphagnum* mat. Herb cover decreases sharply on Saugatuck and continues to decrease on the Kinross soil and the organic soils. This indicates that each layer of the vegetation inhibits the one below it.

Based on the part of the gradient where they have their maximum cover, the plant species have been placed into several groupings that are discussed below.

A. Small Solitaries. This is a rather heterogeneous assemblage of small, mostly non-clonal and non-tussock forming species whose areal extent is not great and whose presence does not constitute a conspicuous part of the vegetation. This group occurs on the Graycalm or Croswell soil series, and the species included are as follows:

Amelanchier oblongifolia
Amelanchier sanguinea
Anemane quinquefolia
Arctostaphylos uva-ursi
Aster "hairy ovate"
Aster laevis
Rubus canadensis
Solidago "lanceolate long petiole"
Oryzopsis pungens
Oryzopsis asperifolia
Prunus serotina
Viola adunca

B. Clonal Xerophytes. These are the more common species having xerophytic microdistributions, generally more abundant, more clone-forming and more conspicuous than the Small Solitaries. This group occurs on one of the three better-drained soils (Graycalm, Croswell, AuGres soil series), and the included species are as follows:

Carex pedunculata
Carex pensylvanica
Comptonia peregrina
Danthonia spicata
Pteridium aquilinum

C. Margin Dry. The six taxa in this group are markedly clonal and they are a dominant or conspicuous component of the vegetation. Their cover maxima occur on the Croswell and AuGres soil series. The following species are included:

Epigaea repens
Gaultheria procumbens
Maianthemum canadense
Melampyrum lineare
Vaccinium angustifolium var. *nigrum*
Vaccinium boreale

D. Margin Wet. The characteristics of the species in this group are similar to those of the Margin Dry group, except that they are more dominant or conspicuous. The maximum cover occurs on the Saugatuck soil series. The species that follow are included in this group:

Coptis groenlandica
Cornus canadensis
Ilex verticillate
Lycopodium obscurum
Nemopanthus mucronata
Rubus hispidus var. *obovalis*
Trientalis borealis
Vaccinium myrtilloides
Viburnum cassinoides

E. Bog Series. As the name implies, this grouping attains its maximum cover on the Kinross soil series and on the organic soils in the bog. The following species are included in this grouping:

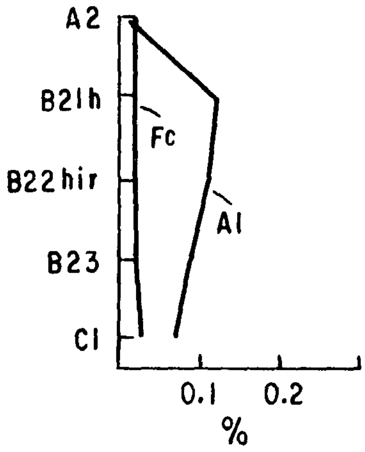
Chamaedaphne calyculata
Eriophorum spissum
Kalmia polifolia
Kalmia angustifolia
Ledum groenlandicum
Polytrichum strictum
Sphagnum plumosum
Sphagnum spp., other than S. plumosum
Vaccinium angustifolium var. nigrum
Vaccinium oxycoccus
Vaccinium boreale

The demarcations between the above groupings are by no means very sharp. In fact, several species, such as Pinus banksiana and Vaccinium angustifolium span the entire moisture gradient. Hence, the vegetation is best described as a Pinus banksiana forest--Chamaedaphne calyculata bog transition.

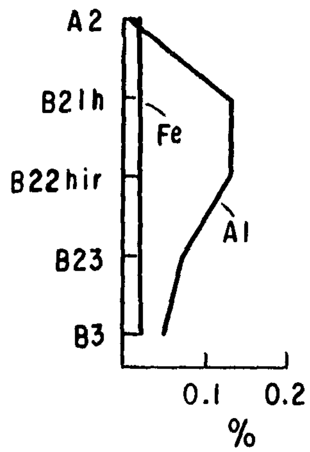
As pointed out by Byer (1960 and 1965), the distribution of the vegetation along the surface gradient is due to complex interactions within the vegetation itself, between the vegetation and the environment (including man and fire) including the moisture regime, soil acidity, soil structure, and plant nutrients supplies as the most important soil factors (Table 1 and Figures 2, 3, and 8).

Total Carbon and Extractable Iron and Aluminum (Per Cent Elemental)

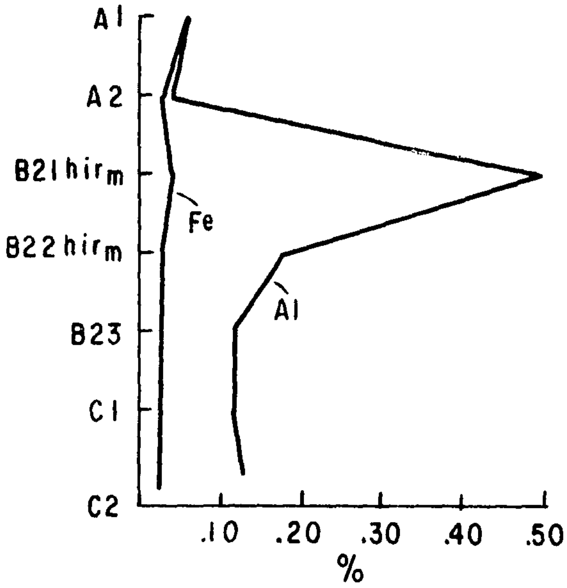
All profiles show a subsurface maximum of carbon and aluminum and each profile, except for the two Kinross soils, shows a subsurface maximum of iron (Figures 13 and 14). The iron and aluminum maxima always occur in the same



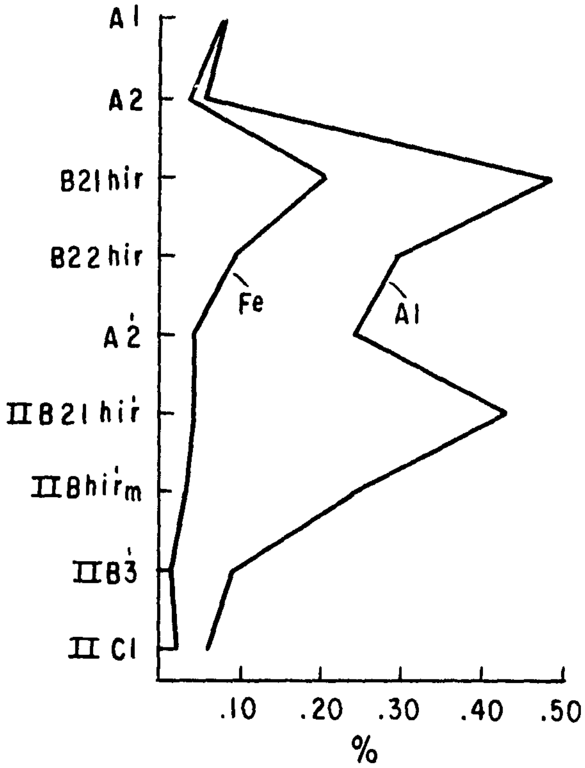
NO. 1, Kinross



NO. 2, Kinross



NO. 3, Saugatuck



NO. 4, Saugatuck - Au Gres

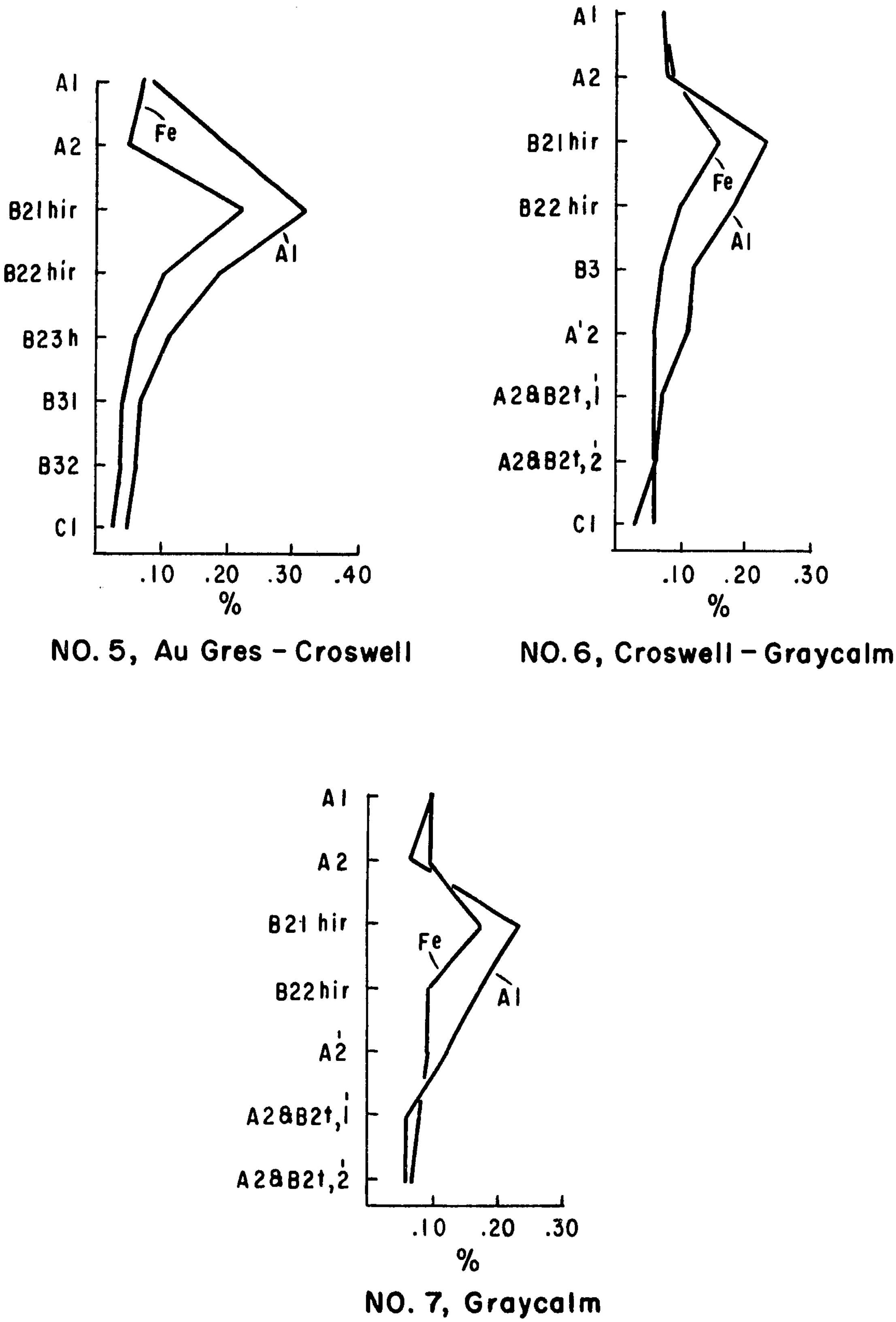
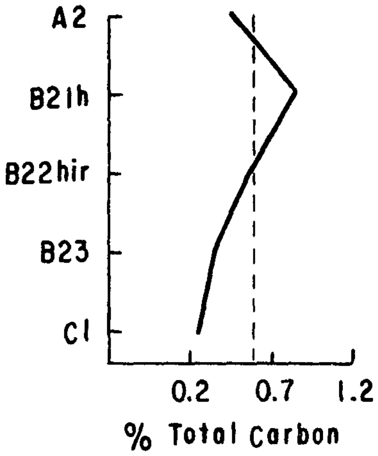
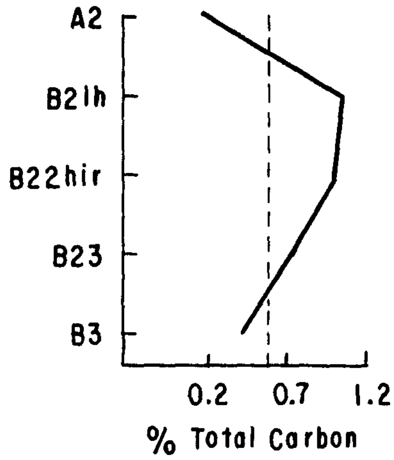


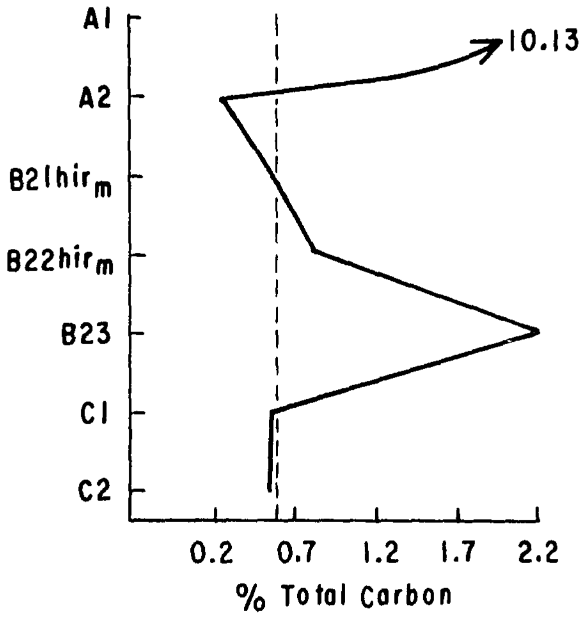
Figure 13.--Pyrophosphate extractable iron and aluminum profiles for each of the seven pedons.



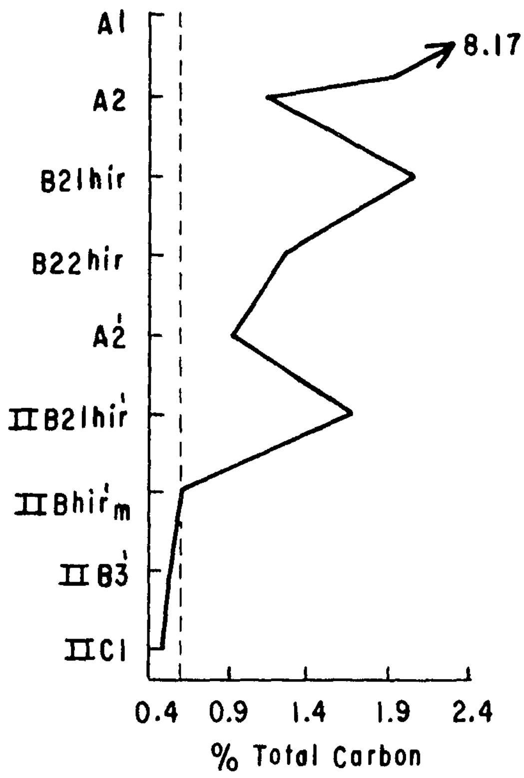
NO. 1, Kinross



NO. 2, Kinross



NO. 3, Saugatuck



NO. 4, Saugatuck - Au Gres

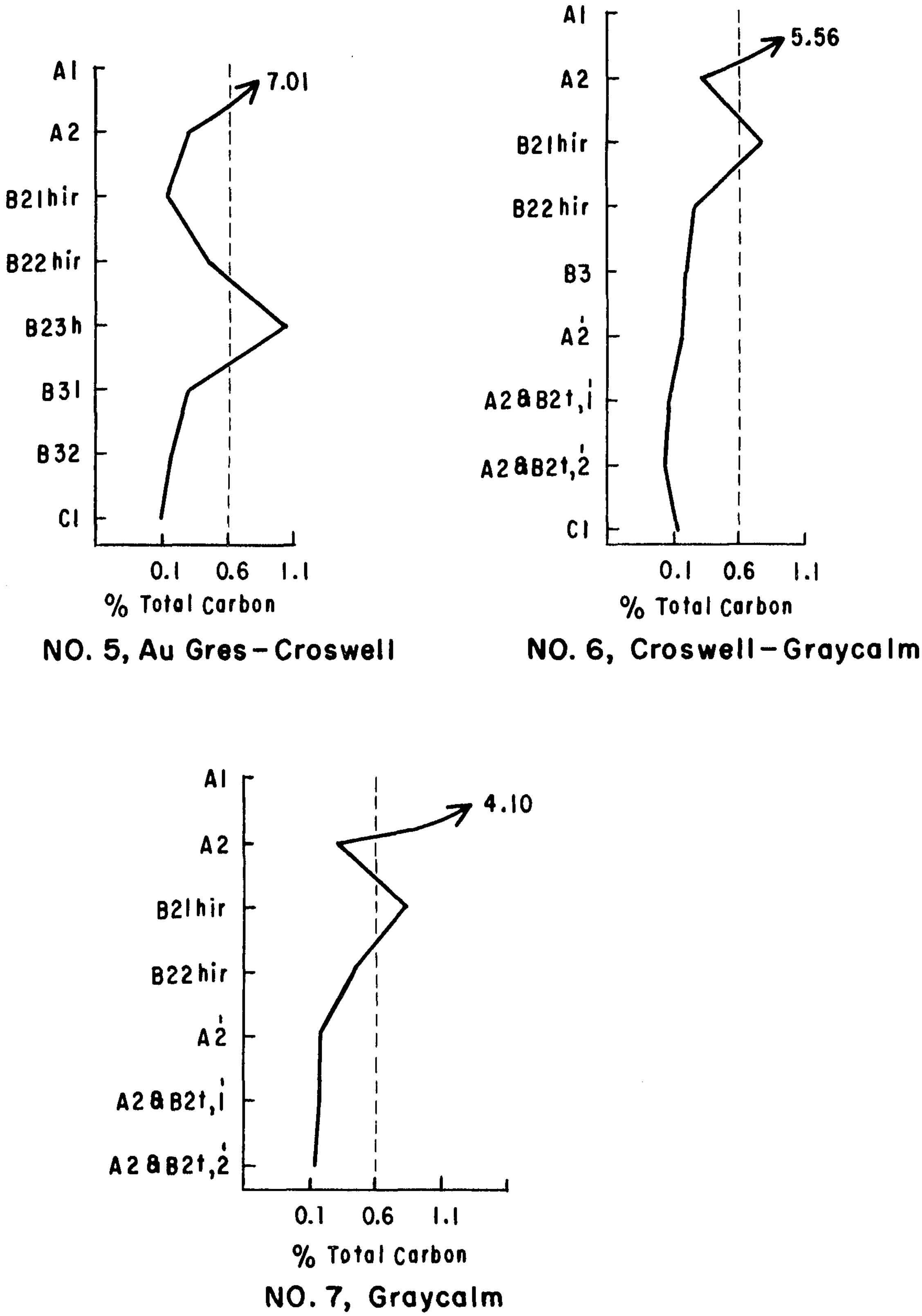


Figure 14.--Total carbon profiles for each of the seven pedons. (Note differences in scale.)

horizon of the five better-drained profiles. The occurrence of the iron, aluminum, and carbon maxima and the relationship of these maxima to the water table in each of the seven pedons are further summarized as follows:

#1, Kinross (organic surface)--The aluminum and carbon maxima occur in the same horizon which is below the maximum observed depth to the water table.

#2, Kinross (better drained)--The aluminum and carbon maxima occur in the same horizon, and this horizon is within the observed zone of fluctuation of the water table.

#3, Saugatuck--The carbon maximum is below the aluminum maximum. The former occurs at about the maximum observed depth to the water table, and the latter occurs within the observed zone of fluctuation of the water table.

#4, Saugatuck-AuGres--The first maxima of iron, aluminum, and carbon occur in the same horizon, and the lower part of this horizon occurs at about the minimum observed depth to the water table. The second carbon and aluminum maxima occur in the same horizon and the lower part of this horizon occurs at about the average observed depth to the water table.

#5, AuGres-Croswell--The carbon maximum occurs below the iron and aluminum maxima. The former occurs within the zone of fluctuation of the water table and the latter occur above the zone of fluctuation of the water table.

#6, Croswell-Graycalm--The iron, aluminum and carbon maxima occur in the same horizon and above the zone of fluctuation of the water table.

#7, Graycalm--The iron, aluminum and carbon maxima occur in the same horizon and above the zone of fluctuation of the water table.

These data suggest that iron, aluminum, and carbon may move independently or in association with each other. However, the exact mechanism of the movement of these three constituents deserve very detailed investigations (Atkinson et al., 1957; Bloomfield, 1953 and 1955; Schnitzer et al., 1970). According to Byers et al. (1938) dispersed organic matter may move deeply into the soil profile and may also occur in large amounts even in the C horizons of podzols. Martin (1960) observed that small amounts of aluminum can cause flocculation of humus. The relationship of the water table to the carbon maxima appears to suggest that the water table has played an important and active role in the occurrence of the carbon maxima in profiles #'s 1, 2, 3, 4, and 5.

The content of iron in the two Kinross profiles and in the Saugatuck profile is relatively low and shows little or no variation with increasing depth. This is probably due to the loss of iron from the profile in the ferrous state with reducing conditions caused by the high water table in these profiles. This conclusion is in agreement with those of Damman (1962), Byers et al. (1938), and Russell (1966). This low content of iron probably explains why no mottles were observed in these profiles as they were described in the field.

The highest content of iron, aluminum, and carbon occurs along the edge of the bog in the Saugatuck and Saugatuck-AuGres profiles. Carbon is higher at the wettest end (Kinross) than it is at the driest end (profiles #'s 6 and 7) of the transect, but for iron and aluminum the reverse is true. In each profile, there is more extractable aluminum than iron (with pyrophosphate) in the B and C horizons. The dithionite citrate extractable iron and aluminum show greater amounts of iron than aluminum in the B horizons of the two better-drained profiles (Croswell-Graycalm and Graycalm) (Table A-5).

The ranges in per cent total carbon and per cent elemental iron and aluminum in the B horizons (possibly spodic) of the five soil series are as follows:

	Total Carbon	Pyrophosphate Extractable		Dithionite Citrate Extractable	
		Iron	Aluminum	Iron	Aluminum
Kinross	.34-1.05	.02	.07-.13	.02-.04	.14-.26
Saugatuck	.56-2.53	.03-.20	.12-.50	.08-.30	.23-.63
AuGres	.21-1.67	.03-.22	.24-.32	.30-.51	.26-.88
Croswell	.16-1.08	.06-.22	.11-.24	.28-.55	.22-.59
Graycalm	.21- .89	.09-.19	.17-.24	.52-.56	.31-.47

Field observations and the section on classification which follows show that the maximum spodic horizon development does not occur in the Kinross soils in the bog nor in the well-drained Graycalm soil at the dry end of the transect, but along the edge of the bog in the Saugatuck and Saugatuck-AuGres profiles. Table 1 shows the horizons of each profile that were subjected to fluctuations of the water table. From this table, Figures 13 and 14 and other data collected in this study, it is apparent that:

1. The development of the spodic horizon under submerged conditions may not necessarily be dependent upon the occurrence of a water table which descends periodically below the B horizon.
2. The water table must be considerably below the B horizon for the accumulation of iron in the B horizon.
3. The maximum spodic horizon development occurs in those profiles that are subjected to a combination of humid conditions and flushing moisture regimes.
4. Pyrophosphate extractable aluminum appears to be a good indicator of spodic horizon development, since its maximum values were obtained from the ortstein layer of the Saugatuck profile and similar values were obtained from the B horizons of both the well and poorly drained soils.

Classification of the Soils

Munsell color values of 7 or lower and chromas of 3 or higher, obtained from a saturated sodium pyrophosphate quick test, may qualify any particular B horizon as having sufficient iron, aluminum, and carbon to meet the spodic horizon requirement (Lietzke, 1968). By this criterion, each of the profiles used in this study has horizons that qualify as spodic horizons (Table 4). However, the test results do not confirm the field observations that the maximum spodic development is along the edge of the bog. Actually, the quick test results show that the extracts become progressively darker as the depth to the water table decreases along the slope from site No. 7 to site No. 2. Hence, the darkest and lightest colored extracts were obtained from the Kinross soils in the bog, and from Graycalm on the ridge, respectively.

Soil Taxonomy (1970, unedited) states that spodic horizons must meet one or more of the following:

1. Have a subhorizon that is more than 2.5 cm thick and that is continuously cemented by some combination of organic matter with iron or aluminum or both.
2. Have a particle size distribution that is sandy or coarse loamy and sand grains are covered with cracked coating or there are distinct dark pellets of coarse silt size, or both.

TABLE 4.--Saturated sodium pyrophosphate quick test colors.

Site	Horizon	Color	Spodic Horizon
#1, Kinross (organic surface)	B21h	5yR3/2	yes
	B22hir	5yR3/3	yes
	B23	7.5yR5/4	yes
#2, Kinross (better drained)	B21h	7.5yR3/2	yes
	B22hir	5yR3/2	yes
	B23	7.5yR4/4	yes
	B3	10yR5/4	yes
#3, Saugatuck	$B21hir_m$	5yR3/4	yes
	$B22hir_m$	5yR3/4	yes
	B23hir	5yR3/4	yes
#4, Saugatuck-AuGres	B21hir	7.5yR4/2	yes
	B22hir	5yR4/4	yes
	IIB21hir'	5yR3/4	yes
	$IIBhir_m'$	5yR4/4	yes
	IIB3'	7.5yR5/4	yes
#5, AuGres-Croswell	B21hir	7.5yR4/4	yes
	B22hir	10yR7/3	yes
	B23h	10yR8/3	no
	B31	10yR8/2	no
	B32	10yR8/2	no
#6, Croswell-Graycalm	B21hir	7.5yR5/4	yes
	B22hir	10yR7/3	yes
	B3	10yR8/3	no
#7, Graycalm	B21hir	10yR5/4	yes
	B22hir	10yR8/3	no

3. Have one or more subhorizons in which:
   a. % pyrophosphate extractable (pH 10) Fe + Al (elemental)/% clay $\geq$ 0.15, and
   b. % pyrophosphate extractable Fe + Al / % dithionite - citrate extractable Fe + Al $\geq$ 0.45, and
   c. loses 25% or more of its exchange capacity (at pH 8.2) upon shaking overnight in a dithionite-citrate solution, and
   d. is thick and developed enough that the index of accumulation of amorphous material (CEC(pH 8.2) - 1/2% clay) X thickness in cm, in the horizons that meet the preceding requirements, is equal to or greater than 65 (as revised).

Only two of the seven pedons studied, Saugatuck and Saugatuck-AuGres, meet the first of the three criteria listed above (Table 5). Each of the seven pedons has a subhorizon that meets the second criteria (Table 5). The Saugatuck and the Saugatuck-AuGres profiles, and each of the seven pedons meet criterion 3a and 3b, respectively (Table 5). Except for the two better-drained sites, Croswell-Graycalm and Graycalm, each of the profiles has a subhorizon that meets criterion 3d. Criterion 3c was not tested since the data is sufficient to indicate that the horizons of these profiles are not cambic.

TABLE 5.--Application of spodic horizon criteria (Soil Taxonomy--1970, unedited) to the soils used in this study.

Soil Site Number	Horizons	3a % pPO$_4$ Fe+Al / % Clay	3b % pPO$_4$ Fe+Al / % Dith.-cit. Fe+Al	3d (CEC(pH 8.2)-1/2% Clay) X Thickness in cm)	Spodic Horizon Current	Spodic Horizon Revised
1. Kinross (organic surface)	B21h	.07	.48	181.4	no	yes
	B22hir √	.07	.62	79.6	yes	yes
	B23	.09	.65	135.6	no	yes
				Total 396.6		
2. Kinross (better drained)	B21h	.06	.60	163.8	no	yes
	B22hir √	.07	.71	179.6	yes	yes
	B23	.10	.50	184.4	no	yes
				Total 527.8		
3. Saugatuck	B21hir$_m$ √	.23	.76	333.1	yes	yes
	B22hir$_m$ √	.06	.54	132.6	yes	yes
				Total 465.7		
	B23 √	.04	.48	122.1	yes	no
4. Saugatuck-AuGres	B21hir √	.07	.49	65.3	yes	yes
	B22hir √	.06	.86	109.1	yes	yes
	IIB21hir √	.15	.65	227.1	yes	yes
	IIBhir$_m$ √	.25	.44	135.1	yes	yes
				Total 536.6		
5. AuGres Croswell	B21hir √	.13	.48	64.7	yes	yes
	B22hir √	.06	.30	44.8	yes	yes
	B23	.06	.30	12.1	no	yes
				Total 112.6		

TABLE 5.--Continued

Soil Site Number	Horizons	3a % pPO_4 Fe+Al / % Clay	3b % pPO_4 Fe+Al / % Dith.-cit. Fe+Al	3d (CEC(pH 8.2)-1/2% Clay) X Thickness in cm)	Spodic Horizon Current	Spodic Horizon Revised
6. Croswell-Graycalm	upper B21hir	.12	.34	6.0	no	yes
	lower B21hir	.12	.62	32.5	no	yes
	B22hir√	.10	.37	45.5	yes	yes
	B3	.08	.38	16.3	no	yes
				Total 100.3		
7. Graycalm	upper B21hir√	.11	.47	26.4	yes	yes
	lower B21hir√	.09	.38	26.5	yes	yes
	B22hir	.07	.31	50.9	no	yes
				Total 103.8		

Notes:

m--continuously cemented horizon > 2.5 cm thick.

√--sand grains covered with cracked coatings.

yes--meet criteria 1 or 2 and 3a + 3b + 3d; totals = based on 3a and 3b as revised.

Thus, by these criteria all the profiles in this study qualify as having spodic horizons. But three of the profiles (representing the range of the Graycalm and Croswell series) do not meet the 3d criterion, and only profiles 3 and 4 (representing the range of the Saugatuck series) meet criteria 1 and 3a. One of the two horizons of Saugatuck that meets both criteria 1 and 2 does meet criterion 3a.

The ranges in the values of criteria 3a, 3b, and 3d for the B horizons of the seven profiles can be obtained from Table 5. The ranges in these values for the five individual soil series are shown below:

	3a	3b	3d
Kinross	.06-.10	.48-.71	0
Saugatuck	.15-.25	.44-.86	333-362
AuGres	.06-.14	.30-.64	362-0
Croswell	.06-.12	.30-.62	0
Graycalm	.07-.11	.31-.47	0

The accumulation indexes calculated by using both the current criteria and the proposed revisions (totals for 3d-Table 5) suggest that the order for the degree of spodic horizon development is as follows: Saugatuck > Kinross > AuGres > Croswell > Graycalm. Field observations are in agreement with this order. As pointed out in Soil Taxonomy (1970), the accumulation index reflects the amount of amorphous material. Hence, there are many soils that have an index greater than the lower limit (65), but do not have spodic horizons.

Considering the above discussion and other data collected in this study, the seven profiles were placed in the new soil classification system (Soil Taxonomy--1970, unedited) as follows:

#1, Kinross (organic surface)--Histic Haplaquod; sandy, mixed, frigid

#2, Kinross (better drained)--Typic Haplaquod; sandy, mixed, frigid

#3, Saugatuck--Aeric Haplaquod; sandy, mixed, frigid, ortstein

#4, Saugatuck-AuGres--Aeric Haplaquod; sandy, mixed, frigid, ortstein

#5, AuGres-Croswell--Entic Sideraquod; sandy, mixed, frigid

#6, Croswell-Graycalm--Entic Haplorthod; sandy, mixed, frigid

#7, Graycalm--Entic Haplorthod; sandy, mixed, frigid

Thus, the placement of the five soil series of the toposequence is as follows:

Kinross--Histic Haplaquod; sandy, mixed, frigid

Saugatuck--Aeric Haplaquod; sandy, mixed, frigid, ortstein

AuGres--Entic Haplaquod; sandy, mixed, frigid

Croswell--Entic Haplorthod; sandy, mixed, frigid

Graycalm--Entic Haplorthod; sandy, mixed, frigid

Except for the Kinross and Graycalm series, the above is in agreement with the present official placement (Soil Classification, Placement of Michigan Series into the Soil Classification System--March, 1971). The present official placement of these two series is as follows:

Kinross--Typic Haplaquod; sandy, mixed, frigid

Graycalm--Alfic Udipsamments; mixed, frigid

Hence, these two series deserve further investigation in order to determine the placement of most pedons as they occur in Michigan.

Lietzke (1968) proposed the following refinements of the then current criteria for spodic horizons:

1. Total % C + dithionite-citrate extractable Fe + Al / % Clay $\geqq$ .12.
2. Total % C + dithionite--citrate extractable Fe + Al $\geqq$ 0.8.
3. The spodic horizon or some subhorizon should have less than 0.31% dithionite-citrate extractable iron if sand or loamy sand or less than 0.80% iron if sandy loam or loam to qualify as Humod and equal or greater amounts in order to qualify as an Orthod.

By criteria 1 and 2 above, each of the seven profiles has a subhorizon that qualifies as spodic (Table 6). By criterion 3, Kinross and Saugatuck would be Humods and the remaining soils would be Orthods.

Based on the data collected in this study and the discrepancy between the two sets of spodic horizon criteria (Lietzke's refinements, 1968 Vs. Soil Taxonomy--1970, unedited), the following possible revisions are proposed:

TABLE 6.--Application of spodic horizon criteria as refined by Lietzke (1968).

Soil Site Number	Horizons	Tot. % C + Dith.-cit. Fe+Al / % Clay	Tot. C % + Dith.-cit. Fe+Al	Spodic Horizon	
				Lietzke	Revised
1. Kinross	B21h	.55	1.15	yes	yes
(organic	B22hir	.42	.75	no	yes
surface)	B23	.43	.51	no	yes
2. Kinross	B21h	.52	1.30	yes	yes
(better	B22hir	.55	1.22	yes	yes
drained)	B23	1.01	.91	yes	yes
3. Sauga-	B21hir$_m$	.53	1.27	yes	yes
tuck	B22hir$_m$	.36	1.21	yes	yes
	B23	.74	2.52	yes	yes
4. Sauga-	B21hir	.45	3.92	yes	yes
tuck-Au	B22hir	.25	1.69	yes	no
Gres	IIB21hir'	.77	2.39	yes	yes
	IIBhir$_m$'	1.12	1.23	yes	yes
5. AuGres-	B21hir	.30	1.29	yes	yes
Croswell	B22hir	.32	1.46	yes	yes
	B23h	.61	1.64	yes	yes
6. Croswell-	Upper				
Graycalm	B21hir	.35	1.76	yes	yes
	Lower				
	B21hir	.41	1.47	yes	yes
	B22hir	.36	1.03	yes	yes
	B3	.28	.71	no	no
7. Graycalm	Upper				
	B21hir	.46	1.61	yes	yes
	Lower				
	B21hir	.44	1.92	yes	yes
	B22hir	.35	1.28	yes	yes

a. Reduce criteria 3a and 3b of Soil Taxonomy (1970) to $\geqq$ .06 and $\geqq$ .30, respectively. This would include the range of the horizons in Table 5.

b. A less preferable alternative is to return to the earlier criteria as refined by Lietzke (1968), or revision of those criteria so that: 1 is raised to $\geqq$ .30, and 2 is reduced to $\geqq$ .7.

The major advantage of the present criteria (Soil Taxonomy, 1970) is that the high water table in the three less well-drained soil series is recognized at the suborder level. On the other hand, the criteria as refined by Lietzke (1968) recognize the relatively high per cent of carbon in the Kinross and Saugatuck soil series at the suborder level.

SUMMARY AND CONCLUSION

Seven pedons, representing five soil series, were sampled in a relatively straight line along a sandy, topo-biosequence of Spodosols in northern Michigan. The wet end of the transect ends in a poorly-drained organic bog, and the dry end of the transect terminates on a well-drained sand ridge. The characteristics, development, and classification of the Spodosols, in relation to the different natural drainage classes, were investigated. In addition, the distribution of the soils was compared with the distribution of the vegetation groups (after Byer, 1960 and 1965) as the two occur along the slope.

The results of this study are summarized as follows:

1. The average depth (mid-June to mid-September of 1969 and 1970) to the water table in each of the five soil series was observed to be 9", 23", 31", 47", and >65", for Kinross, Saugatuck, AuGres, Croswell, and Graycalm, respectively. Plant roots do not extend very deep (3-6") into the permanent water table of the poorly-drained soil nor do they extend very deep (3-4") into the ortstein layer of the somewhat poorly-drained soils, and they stop in the zone of fluctuation of the water table in the moderately

well-drained soil. They occur throughout the profile of the well-drained soil. Hence, the depth of plant root distribution increases as the depths to the water table and the ortstein layer increases. In addition, the maximum observed seasonal depths to the water table are below the depths to which most roots occur, except for the poorly-drained Kinross soil. This suggests that the high water table and the associated poor aeration and the cemented layer are inimical to the development and downward extension of some plant roots.

The site index of jack pine (Pinus banksiana) increases as natural drainage improves from poorly- to well-drained. The relatively low index (38) for the Kinross soil can be explained by the high water table and the associated poor aeration in this soil. The relatively high index (53) for the well-drained Graycalm soil is best explained by the absence of a high water table and the presence of the textural bands which serve to increase the available water and nutrient supplies within the reach of plant roots.

Certain plant species have their maximum cover on one or more given soil series, and were grouped accordingly. However, several species span the entire soil moisture gradient, and demarcations between the groupings are by no means very sharp. Thus, the vegetation is best described as a Pinus banksiana forest-Chamaedaphne calyculata bog transition (Byer, 1960 and 1965).

2. The pH's of air-dried samples measured in water with the glass electrode, show that the soils used in this study are strongly to extremely acid throughout their profiles. However, soil pH generally increases with increasing depth, in a given profile. The lowest pH occurs along the edge of the bog in the Saugatuck profile, and from this profile pH increases to it's highest value in the well-drained Graycalm soil. The pH's of air-dry samples measured in water, in 0.01 M $CaCl_2$, and in 1.0 N KCl with the glass electrode are on the average 0.6, 0.9, and 1.2 pH units lower than those measured with the Truog kit, respectively. Using the pH's measured in water as the standard, the $CaCl_2$ and KCl pH's are only 0.25 and 0.35 pH units lower, respectively.

3. The texture of these soils is sand, and the total sand percentages range from 80 to 99% in the horizons studied. The medium sand, fine sand, and coarse sand make up 68 - 43%, 39 - 16%, and 21 - 5% of the total sand fraction, respectively. The finest-textured profile (Saugatuck-AuGres, #4) occurs along the edge of the bog, and the coarsest-textured profile (Kinross, #1) occurs in the bog. The total silt ranges from 1 - 13%, and much of it may have weathered from the sand fraction, since it's distribution in the profile follows the pattern of increasing intensity of physical weathering, i.e., increasing with proximity to the soil surface. Except for the Saugatuck-AuGres profile (#4), the total clay ranges from 1 - 5% and

the five better-drained profiles show slight clay accumulations in the upper B horizons. Apparently, the high water table has reduced the accumulation of clay in the B horizons of the poorly-drained Kinross soils.

The seven profiles have developed in sandy, limy and heterogeneous glacial sediments of late Pleistocene age. The five soil series are classified as having mixed mineralogy, since quartz is the only mineral that accounts for more than 40% but less than 90% of the mineralogical composition. The ratios of resistant mineral/weatherable mineral tend to decrease with increasing depth, which indicates that the intensity of weathering decreases with increasing depth. These ratios also show that the poorly-drained Kinross soils in the bog are the least weathered, and the Saugatuck profile along the edge of the bog is the most weathered.

The clay fractions of all horizons contain kaolinite and quartz. The clay of the C or least-altered horizons contains illite, chlorite, and chlorite-vermiculite intergrade. Each of the spodic horizons contain chlorite-vermiculite intergrade. Discrete illite does not occur in the A2 horizons, which seems to suggest that it is being weathered out of the upper portions of the profiles. Montmorillonite occurs only in the A1 or A2 horizons of the four better-drained profiles, which probably means that it has formed in situ from illite, chlorite, and chlorite-vermiculite intergrade, through vermiculite.

4. Cation exchange capacity, exchange acidity, and exchangeable bases are always highest in the organic matter-rich A1 horizons. Exchangeable bases are predominantly calcium. Bases are lowest in the Kinross soil in the bog and highest along the edge of the bog in the Saugatuck profile, probably as a result of enrichment by drainage water from the surrounding better-drained soils. The data show evidence of nutrient cycling where bases are added to the soil surface by the vegetation, enriching the A1 horizons and the A2 horizons of the better-drained soil profiles.

5. Bulk density, except for the Kinross profile (organic surface) where it remains about the same throughout the mineral portion, generally increases with increasing depth. This is further evidence that the high water table at the poorly-drained sites has reduced soil profile development. All profiles showed a trend toward greater moisture retention percentages and non-capillary porosity with proximity to the soil surface. The trends and variations in these three soil properties is explained by the nature and distribution of the fine earth (especially silt) and organic matter within and among the seven profiles.

6. All profiles exhibit subsurface maxima of carbon and aluminum and each profile, except for the two Kinross soils, shows a subsurface maximum of iron. The iron and aluminum maxima occur in the same horizon of all profiles, except the Kinross soils which do not show an iron maximum.

The carbon maximum occurs below the aluminum maximum in profiles #'s 3 and 5, but in the other profiles the two occur in the same horizon.

This suggests that the water table has played an important role in the occurrence of the carbon maxima in all except the two better-drained profiles. In addition, it appears that the development of the spodic horizon under submerged conditions may not necessarily be dependent upon the occurrence of a water table which descends periodically below the B horizon. But, the water table must be below the B horizon for the accumulation of iron. In fact, the results of this study suggest that iron is being lost from the profiles of Kinross and Saugatuck in the ferrous state with reducing conditions caused by the high water table. The maximum spodic horizon development occurs in the profiles (#3 and #4), along the edge of the bog, that have been subjected to a combination of alternating wet conditions and flushing moisture regimes.

Pyrophosphate extracts more aluminum than iron from the B horizons of all profiles. In addition, pyrophosphate-extractable aluminum appears to be a good indicator of spodic horizon development, since its maximum values were obtained from the ortstein layer of the Saugatuck profile and slightly higher values were obtained from the well than from the poorly-drained soils.

7. The particle size distribution of the soils used in this study is sandy, and each profile has an horizon in

which sand grains are covered with cracked coatings. Thus, by the second spodic horizon criteria listed in Soil Taxonomy (1970, unedited), all of the profiles qualify as having spodic horizons. However, only the Saugatuck and Saugatuck-AuGres profiles (representing the range of the Saugatuck series) meet criterion 1 (cemented horizon > 2.5 cm thick), criterion 2, and the combination of criteria under number 3.

According to the results of the saturated sodium pyrophosphate quick test developed by Lietzke (1968), each of the seven profiles has an horizon that qualifies as spodic. Each of the profiles has a subhorizon that qualifies as spodic, according to the then current spodic horizon criteria as refined by Lietzke (1968).

Using Lietzke's (1968) refinement, Kinross and Saugatuck would be Humods and the other soils would be Orthods. Placement of the soils in the new classification system (Soil Taxonomy--1970, unedited) reveals that the two better-drained soil series (Croswell and Graycalm) are Orthods and the other three less well-drained soil series are Aquods. At the family level, the placement is sandy, mixed, frigid, except for Saugatuck which also includes an ortstein layer.

The present criteria (Soil Taxonomy, 1970) recognizes the high water table in the less well-drained soils at the suborder level, while the criteria as refined by Lietzke (1968) recognizes the relatively high per cent of carbon in these same soils at the same level (suborder) of the classification system. However, the latter separates Saugatuck and AuGres at the suborder level. This may be desirable, since the results of this study show that AuGres tends to develop under better drained conditions than Saugatuck.

In view of the above and other data collected in this study, the following revisions are proposed:

a. Reduce criterion 3a (% pPO_4 Fe + Al / % clay) of Soil Taxonomy (1970) from $\geqq$ .15 to $\geqq$ .06; and, reduce criterion 3b (% pPO_4 Fe + Al / % dith.-cit Fe + Al) of Soil Taxonomy (1970) from $\geqq$ .45 to $\geqq$ .30.

   These proposed revisions of the current spodic horizon criteria would include the range of the soils used in this study.

b. A less preferable alternative is to return to the earlier spodic horizon criteria as refined by Lietzke (1968), or revision of those criteria so that No. 1 (% Tot. C + % dith.-cit. Fe + Al / % clay) is raised from $\geqq$ .12 to $\geqq$ .30, and No. 2 (% dith.-cit. Fe + Al) is reduced from $\geqq$ .8 to $\geqq$ .7.

8. In conclusion, the soils of the toposequence used in this study appear to owe their distinctive characteristics and associated vegetation to the differences in the natural drainage of the site on which they occur.

NEED FOR FURTHER RESEARCH

1. Similar studies need to be conducted in other areas where it is possible to ascertain the role played by any one or combination of the five soil-forming factors. This should make it possible to more accurately characterize, classify, and define a given soil series as it occurs in Michigan.

2. Further study is needed to fully understand the exact mechanism involved in the mobilization, translocation, and accumulation of the humus and sesquioxides.

3. The proposed revisions of spodic horizon criteria, based on this study, would make Lietzke's (1968) quick test more useful. However, the development of a quick test to be used in the field by soil surveyors for spodic horizon recognition and for the determination of the degree of spodic horizon development deserves further investigation. In addition, more research is needed to determine the best and most useful morphological, chemical, mineralogical, and physical properties to be used in the laboratory as spodic horizon criteria.

4. The results of this study clearly illustrate the need for further investigation of how Spodosols differ,

why they differ, and how these differences are related to use and management of the soils.

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APPENDIX

TABLE A-1.--Soil pH's, determined by different methods, for each of the seven pedons.

Depth (inches)	Horizon	Lab. No.	pH			
			Truog	H_2O	$CaCl_2$	KCl
No. 1, Kinross (organic surface)						
13-7"	F	01	4.0	3.7	3.1	2.8
7-3	H	02	4.3	3.4	3.0	2.9
3-0	S	03	4.4	3.4	3.0	2.8
1-11	A2	04	4.5	3.8	3.6	3.5
11-21	B21h	05	4.5	4.0	3.8	3.8
21-27	B22hir	06	4.7	4.2	4.0	3.9
27-37	B23	07	4.7	4.2	4.1	3.9
37-50	C1	77	4.9	4.4	4.2	4.2
No. 2, Kinross (better drained)						
2-1 1/2	H	08	4.1	3.6	3.1	2.9
1 1/2-0	S	09	4.2	3.5	2.9	2.8
1 1/2-15	A2	10	4.3	3.9	3.4	3.3
15-25	B21h	11	4.5	4.1	3.7	3.9
25-35	B22hir	12	4.6	4.2	4.0	3.9
35-54	B23	13	4.8	4.3	4.1	4.0
54-63	B3	14	5.2	4.5	4.3	4.2
No. 3, Saugatuck						
4-0	A0	15	4.1	3.5	3.3	2.9
0-1	A1	16	4.0	3.4	2.9	2.6
1-11	A2	17	4.2	3.6	3.3	3.1
11-17	$B21hir_m$	18	4.6	4.0	3.8	3.6
17-24	$B22hir_m$	19	4.6	4.1	3.8	3.6
24-33	B23hir	20	4.8	4.2	3.8	3.7
33-43	C1	21	4.8	4.3	3.9	3.8
43-61	C2	22	5.1	4.3	4.0	4.1

TABLE A-1.--Continued

Depth (inches)	Horizon	Lab. No.	pH			
			Truog	H_2O	$CaCl_2$	KCl
			No. 4, Saugatuck-AuGres			
3 1/2-1	A0	23	4.3	4.1	3.4	3.4
1-0	A00	24	4.2	3.7	3.1	2.8
0-1 1/2	A1	25	4.1	3.5	2.9	2.8
1 1/2-3	A2	26	4.2	3.5	3.1	3.1
3-7	B21hir	27	4.8	3.9	4.0	3.9
7-11	B22hir	28	4.8	4.0	3.9	3.8
11-16	IIA2'	29	4.6	4.1	4.0	3.9
16-23	IIB21hir'	30	4.9	4.2	4.1	4.0
23-33	$IIBhir_m$'	31	4.9	4.3	4.2	3.9
33-48	IIB3'	32	5.0	4.1	4.0	3.9
48-58	IIC1	33	5.1	4.3	4.2	4.0
			No. 5, AuGres-Croswell			
1-0	A0	34	4.4	3.8	3.4	3.0
0-6	A1	35	4.2	3.7	3.1	2.8
6-10	A2	36	4.4	3.8	3.4	3.3
10-14	B21hir	37	4.6	4.2	4.1	4.1
14-21	B22hir	38	4.7	4.6	4.4	4.3
21-28	B23	39	4.6	4.2	4.2	4.1
28-39	B31	40	4.9	4.4	4.1	4.2
39-50	B32	41	5.1	4.6	4.4	4.4
50-60	C1	42	5.2	4.7	4.4	4.4

TABLE A-1.--Continued

Depth (inches)	Horizon	Lab. No.	pH			
			Truog	H_2O	$CaCl_2$	KCl
		No. 6, Croswell-Graycalm				
1/2-0	A0	43	4.6	4.1	4.0	3.9
0-1	A1	44	4.2	3.7	3.4	3.1
1-3	A2	45	4.3	3.7	3.5	3.3
3-5	Upper B21hir	46	4.9	4.3	4.1	4.1
5-7	Lower B21hir	47	5.1	4.5	4.4	4.4
7-18	B22hir	48	5.4	4.9	4.5	4.4
18-23	B3	49	5.4	4.8	4.6	4.4
23-28	A2'	50	5.5	4.7	4.5	4.5
28-39	A2&B2t,'1	51	5.4	4.6	4.6	4.5
39-49	A2&B2t,'2	52	5.5	4.6	4.4	4.4
49-60	C2	54	5.4	4.6	4.5	4.5
		No. 7, Graycalm				
0-1	A1	55	4.5	4.1	3.6	3.4
1-3	A2	56	4.4	4.0	3.7	3.4
3-8	Upper B21hir	57	5.2	4.4	4.3	4.3
8-11	Lower B21hir	58	5.3	4.7	4.5	4.5
11-23	B22hir	59	5.3	4.8	4.5	4.4
23-30	A2'	60	5.4	4.7	4.5	4.4
30-55	A2'&B2t'1	61	5.4	4.6	4.4	4.3
55-60	A2'&B2t'2	62	5.5	4.8	4.7	4.4

TABLE A-2.--Particle size analysis for each of the seven pedons.

Depth (inches)	Horizon	Lab. No.	Total: Gravel %	Total: Sand %	Total: Silt %	Total: Clay %	Sand: VCS %	Sand: CS %	Sand: MS %	Sand: FS %	Sand: VFS %	Silt: CSI %	Silt: FSI %
No. 1, Kinross (organic surface)													
1-11	A2	04	0.2	91.1	6.4	2.5	0.2	6.0	62.4	21.4	1.2	2.8	3.5
11-21	B21h	05	0.7	95.4	2.5	2.1	0.3	10.2	67.0	17.2	0.6	1.6	0.9
21-27	B22hir	06	1.2	96.7	1.6	1.8	1.1	10.8	65.4	18.9	0.6	0.8	0.8
27-37	B23	07	3.3	97.0	1.9	1.2	0.9	11.0	66.9	18.3	0.5	1.8	0.1
37-50	C1	77	9.1	97.0	2.0	1.0	1.9	14.0	56.0	24.0	1.1	0.0	2.0
No. 2, Kinross (better drained)													
1 1/2-15	A2	10	2.1	90.9	6.5	2.6	0.9	7.2	60.5	21.4	1.0	3.1	3.5
15-25	B21h	11	3.7	90.3	7.2	2.5	1.0	8.8	57.7	22.0	0.8	2.9	4.3
25-35	B22hir	12	5.1	94.4	3.4	2.2	0.7	7.3	55.4	29.6	1.4	2.3	1.1
35-54	B23	13	8.7	97.6	1.5	0.9	4.3	21.0	51.4	20.1	0.8	0.9	0.6
54-63	B3	14	3.5	96.9	1.8	1.3	1.1	12.6	57.2	24.1	1.8	1.1	0.6
No. 3, Saugatuck													
1-11	A2	17	4.5	90.5	7.3	2.2	0.7	9.4	58.2	21.4	0.9	2.5	4.8
11-17	B21hir$_m$	18	2.7	93.6	4.0	2.4	1.1	9.3	58.1	24.3	0.9	2.9	1.1
17-24	B22hir$_m$	19	2.9	92.0	4.6	3.4	1.3	7.9	52.0	29.6	1.2	3.0	1.1
24-33	B23hir	20	3.8	92.9	3.6	3.4	1.0	7.8	53.1	20.1	1.0	2.1	1.5
33-43	C1	21	1.1	93.3	3.2	3.5	0.8	8.2	55.6	28.0	0.7	2.1	1.2
43-61	C2	22	9.8	96.7	0.8	2.5	0.3	6.5	50.4	38.7	0.8	0.6	0.2

TABLE A-2.--Continued

Depth (inches)	Horizon	Lab. No.	Total: Gravel %	Total: Sand %	Total: Silt %	Total: Clay %	Sand: VCS %	Sand: CS %	Sand: MS %	Sand: FS %	Sand: VFS	Silt: CSI %	Silt: FSI %
No. 4, Saugatuck-AuGres													
0-1 1/2	A1	25	1.3	84.7	11.1	4.1	0.6	9.3	52.4	21.4	1.0	5.1	6.0
1 1/2-3	A2	26	0.6	82.8	13.0	4.2	0.6	7.1	48.6	24.9	1.5	6.9	6.1
3-7	B21hir	27	1.8	79.1	12.1	8.8	0.9	8.0	43.7	25.5	0.9	5.2	6.9
7-11	B22hir	28	2.6	82.2	11.0	6.7	0.4	6.5	51.0	23.5	0.8	4.7	6.3
11-16	IIA2'	29	4.5	85.1	11.4	3.6	0.6	6.6	49.6	27.5	1.1	5.1	6.3
16-23	IIB21hir'	30	5.7	87.9	9.1	3.1	0.7	8.0	50.5	28.1	1.1	4.8	4.3
23-33	IIBhir$_m$'	31	5.7	96.1	2.8	1.1	2.0	11.5	62.9	19.2	0.4	1.4	1.4
33-48	IIB3'	32	2.1	98.1	1.0	0.9	0.9	4.9	57.9	33.3	1.0	0.6	0.4
48-58	IIC1	33	6.9	98.1	0.8	1.1	1.3	6.8	57.1	32.3	0.6	0.6	0.2
No. 5, AuGres-Croswell													
0-6	A1	35	--	87.9	10.0	2.1	0.3	9.9	53.9	22.3	1.5	4.8	5.2
6-10	A2	36	0.2	89.0	9.6	1.5	0.4	9.4	55.0	29.9	1.2	5.0	4.6
10-14	B21hir	37	1.2	82.8	12.9	4.3	0.5	7.8	49.8	23.5	1.3	5.8	7.4
14-21	B22hir	38	2.0	84.8	10.6	4.6	0.5	7.8	50.8	24.6	1.1	5.3	5.3
21-28	B23h	39	2.2	91.9	5.4	2.7	0.8	7.8	7.1	25.1	1.2	3.2	2.2
28-39	B31	40	1.4	88.0	9.2	2.8	0.9	7.6	48.2	29.8	1.6	6.1	3.1
39-50	B32	41	4.3	93.7	4.5	1.8	1.0	8.0	54.3	28.6	1.8	3.0	1.6
50-60	C1	42	5.3	95.3	3.0	1.8	0.9	7.9	58.3	26.8	1.5	1.5	1.4

TABLE A-2.--Continued

Depth (inches)	Horizon	Lab. No.	Total Gravel %	Total Sand %	Total Silt %	Total Clay %	Sand VCS %	Sand CS %	Sand MS %	Sand FS %	Sand VFS %	Silt CSI	Silt FSI
						No. 6, Croswell-Graycalm							
0-1	A1	44	--	87.4	9.9	2.7	0.1	10.1	54.2	21.7	1.4	4.9	5.0
1-3	A2	45	2.0	86.5	11.3	2.3	0.6	8.5	51.5	24.3	1.6	4.8	6.5
3-5	Upper B21hir	46	5.0	84.7	10.3	5.0	0.4	7.0	49.0	26.7	1.6	5.2	5.2
5-7	Lower B21hir	47	1.0	85.0	11.4	3.6	0.7	8.6	49.4	24.9	1.5	4.9	6.5
7-18	B22hir	48	3.8	88.6	8.5	2.9	0.9	8.2	51.1	26.8	1.5	4.4	4.1
18-23	B3	49	5.8	88.8	8.6	2.5	0.8	7.0	49.7	29.3	1.9	5.9	2.8
23-28	A2'	50	4.1	90.4	7.2	2.5	0.9	5.8	49.7	32.0	1.9	4.2	2.9
28-39	A2'&B2t¦1	51	1.4	96.2	2.1	2.1	0.3	8.2	57.4	29.1	1.2	1.2	0.5
39-49	A2'&B2t¦2	52	8.8	95.4	2.6	2.1	1.9	16.6	60.4	15.7	0.9	1.1	1.4
49-60	C2	54	2.2	98.5	0.5	0.9	0.5	6.6	64.6	26.4	0.5	0.2	0.3
						No. 7, Graycalm							
1-3	A2	56	0.8	87.0	10.6	2.4	0.4	7.9	48.8	28.1	1.8	5.6	5.0
3-8	Upper B21hir	57	2.3	86.3	10.3	3.5	0.9	7.0	50.7	26.4	1.4	4.6	5.6
8-11	Lower B21hir	58	3.9	84.2	11.4	4.4	0.9	7.3	48.1	26.9	1.0	5.7	5.7
11-23	B22hir	59	2.4	86.0	10.3	3.7	0.8	8.5	48.5	26.7	1.5	4.8	5.5
23-30	A2'	60	2.5	85.6	11.4	3.0	0.9	7.5	47.9	27.6	1.8	6.0	5.4
30-55	A2'&B2t¦1	61	3.9	84.5	11.7	3.9	1.0	6.5	48.1	27.0	1.9	6.7	4.9
55-60	A2'&B2t¦2	62	11.3	97.9	0.5	1.7	1.1	8.1	67.0	21.2	0.5	0.3	0.3

TABLE A-3.--Bulk density (B.D.), non-capillary porosity (N.C.P.), and moisture retention (maximum water holding capacity--M.W.H.C., 60 cm tension, moisture equivalent--M.E. and air dry--A.D.) for each of the seven pedons.

Depth (inches)	Horizon	Lab. No.	B.D. gm/cc	N.C.P. %	Moisture Retention (%)			
					M.W.H.C.	60 cm	M.E.	A.D.
			No. 1, Kinross (organic surface)					
1-11	A2	04	1.59	10.49	25.98	6.60	4.68	0.58
11-21	B21h	05	1.50	13.68	28.37	9.12	6.03	0.83
21-27	B22hir	06	1.58	10.13	26.65	6.41	4.75	0.62
27-37	B23	07	1.59	7.81	25.93	4.91	3.49	0.71
37-50	C1	77	1.57	8.42	24.98	5.36	3.00	1.11
			No. 2 Kinross (better drained)					
1 1/2-15	A2	10	1.53	14.70	28.07	9.61	6.12	1.54
15-25	B21h	11	1.55	14.60	28.75	9.42	5.92	0.94
25-35	B22hir	12	1.57	10.09	28.60	6.43	5.83	1.11
35-54	B23	13	1.72	6.69	22.49	3.89	3.49	0.70
54-63	B3	14	1.68	7.11	26.11	4.23	3.25	1.08
			No. 3, Saugatuck					
0-1	A1	16	0.76	27.84	77.35	36.63	22.33	2.30
1-11	A2	17	1.47	13.82	28.78	9.40	5.62	0.89
11-17	$B21hir_m$	18	1.49	14.47	37.29	9.71	8.68	1.59
17-24	$B22hir_m$	19	1.50	14.49	29.82	9.66	5.88	0.98
24-33	B23	20	1.57	14.66	27.99	9.34	5.88	1.30
33-43	C1	21	1.63	9.63	26.58	5.91	4.28	0.72
43-61	C2	22	1.64	12.10	26.39	7.38	5.76	1.17

TABLE A-3.--Continued

Depth (inches)	Horizon	Lab. No.	B.D. gm/cc	N.C.P. %	Moisture Retention (%)			
					M.W.H.C.	60 cm	M.E.	A.D.
				No. 4, Saugatuck-AuGres				
0-1 1/2	A1	25	0.87	22.73	58.46	26.13	15.61	1.75
1 1/2-3	A2	26	1.19	15.17	36.12	12.75	9.00	1.17
3-7	B21hir	27	1.17	20.45	45.93	17.48	9.13	1.49
7-11	B22hir	28	1.33	17.96	36.36	13.50	9.14	1.31
11-16	IIA2'	29	1.42	17.59	32.44	12.39	8.60	1.15
16-23	IIB21hir'	30	1.43	21.28	34.60	14.88	9.72	1.52
23-33	IIBhir'$_m$	31	1.61	9.68	28.58	6.01	5.16	0.93
33-48	IIB3'	32	1.61	8.24	26.32	5.12	3.42	0.88
48-58	IIC1	33	1.60	12.86	26.34	8.04	2.73	0.39
				No. 5, AuGres-Croswell				
0-6	A1	35	1.12	27.78	47.35	24.80	13.72	1.71
6-10	A2	36	1.43	11.61	24.57	8.12	6.43	0.88
10-14	B21hir	37	1.32	16.96	34.70	12.85	9.09	1.09
14-21	B22hir	38	1.33	15.51	32.40	11.66	8.20	0.89
21-28	B23	39	1.52	9.82	25.18	6.46	4.28	0.67
28-39	B31	40	1.64	12.87	25.15	7.85	5.09	0.57
39-50	B32	41	1.65	8.68	25.62	5.26	2.71	0.56
50-60	C1	42	1.67	7.72	25.37	4.62	2.45	0.27

TABLE A-3.--Continued

Depth (inches)	Horizon	Lab. No.	B.D. gm/cc	N.C.P. %	Moisture Retention (%)			
					M.W.H.C.	60 cm	M.E.	A.D.
				No. 6, Croswell-Graycalm				
0-1	A1	44	1.19	27.57	49.65	23.17	12.18	1.10
1-3	A2	45	1.28	15.00	33.11	11.72	8.01	0.75
3-5	Upper B21hir	46	1.45	17.07	32.08	11.77	8.55	2.04
5-7	Lower B21hir	47	1.47	14.92	30.43	10.15	7.03	0.83
7-18	B22hir	48	1.53	14.41	27.11	9.42	5.87	0.64
18-23	B3	49	1.51	14.21	28.27	9.41	4.26	0.50
23-28	A2'	50	1.56	10.73	26.91	6.88	4.75	0.47
28-39	A2'&B2t'1	51	1.63	7.48	25.79	4.59	2.02	0.62
39-40	A2'&B2t'2	52	1.65	7.57	26.94	4.59	2.84	0.61
49-60	C2	54	1.67	5.36	25.27	3.21	2.20	0.16
				No. 7, Graycalm				
0-1	A1	55	1.20	26.20	51.54	21.83	11.45	1.99
1-3	A2	56	1.27	13.55	36.82	10.67	7.10	0.50
3-8	Upper B21hir	57	1.42	16.07	37.05	11.32	7.11	0.96
8-11	Lower B21hir	58	1.44	16.08	34.23	11.17	7.03	0.70
11-23	B22hir	59	1.45	13.82	31.77	9.53	6.03	0.78
23-30	A2'	60	1.45	13.60	28.23	9.38	5.39	0.65
30-55	A2'&B2t'1	61	1.61	15.62	29.65	9.70	5.76	0.66
55-60	A2'&B2t'2	62	1.70	15.79	27.74	9.29	5.35	0.39

TABLE A-4.--Exchangeable bases (E.B.), exchange acidity (E.A.), cation exchange capacity (C.E.C.), and base saturation (B.S.) for each of the seven pedons.

Depth (inches)	Horizon	Lab. No.	E.B.-me/100 gm					E.A. me/100 gm	C.E.C.-me/ 100 gm		% B.S.
			Ca	Mg	Na	K	Sum	$BaCl_2$-TEA	Na Oac	Sum	Sum
					No. 1, Kinross (organic surface)						
1-11	A2	04	.20	.02	tr.	.02	.24	1.26	3.35	1.50	16.00
11-21	B21h	05	.24	.02	tr.	.05	.31	1.26	8.19	1.57	19.77
21-27	B22hir	06	.24	.03	tr.	.04	.31	1.16	6.12	1.47	21.09
27-37	B23	07	.17	.02	tr.	.04	.23	0.84	5.94	1.07	21.49
37-50	C1	77	.19	.02	tr.	.04	.25	0.53	3.57	.78	32.05
					No. 2, Kinross (better drained)						
1 1/2-15	A2	10	.24	.04	tr.	.03	.32	0.53	2.38	.85	37.65
15-25	B21h	11	.31	.04	tr.	.05	.40	0.74	7.70	1.14	35.09
25-35	B22hir	12	.28	.03	tr.	.04	.35	1.47	8.17	1.82	19.23
35-54	B23	13	.24	.03	tr.	.09	.36	1.47	4.27	1.83	19.67
54-63	B3	14	.20	.06	tr.	.03	.29	1.16	3.35	1.45	20.00
					No. 3, Saugatuck						
0-1	A1	16	.88	.36	tr.	.15	1.39	3.68	35.22	5.07	27.62
1-11	A2	17	.63	.06	tr.	.05	.74	0.84	4.80	1.58	46.84
11-17	$B21hir_m$	18	.35	.08	tr.	.06	.49	2.31	23.06	2.80	17.50
17-24	$B22hir_m$	19	.34	.08	tr.	.03	.45	1.89	9.16	2.34	19.23

TABLE A-4.--Continued

Depth (inches)	Horizon	Lab. No.	E.B.-me/100 gm					E.A. me/ 100 gm	C.E.C.-mg/ 100 gm		% B.S.
			Ca	Mg	Na	K	Sum	$BaCl_2$-TEA	N_aO_{ac}	Sum	Sum
No. 3, Saugatuck											
24-33	B23	20	.40	.10	tr.	.03	.53	0.95	7.04	1.48	35.81
33-43	C1	21	.33	.07	tr.	.04	.44	0.89	6.29	1.33	33.09
43-61	C2	22	.27	.06	tr.	.05	.38	0.87	6.29	1.25	30.40
No. 4, Saugatuck-AuGres											
0-1 1/2	A1	25	.50	.24	tr.	.15	.89	4.31	28.53	5.20	17.11
1 1/2-3	A2	26	.15	.05	tr.	.06	.26	1.37	7.18	1.63	15.95
3-7	B21hir	27	.11	.02	tr.	.10	.23	2.84	17.26	3.07	7.49
7-11	B22hir	28	.18	.02	tr.	.05	.25	2.31	14.09	2.56	9.77
11-16	IIA2'	29	.18	.02	tr.	.05	.25	1.68	8.28	1.93	12.95
16-23	IIB21hir'	30	.24	.02	tr.	.05	.31	2.73	14.32	3.04	11.36
23-33	$IIBhir'_m$	31	.15	.02	tr.	.03	.20	1.26	6.87	1.46	13.69
33-48	IIB3'	32	.17	.02	tr.	.10	.29	1.16	5.37	1.45	20.00
48-58	IIC1	33	.14	.02	tr.	.05	.21	0.84	2.64	1.05	25.00
No. 5, AuGres-Croswell											
0-6	A1	35	1.05	.29	tr.	.17	1.51	2.73	31.44	4.24	35.61
6-10	A2	36	.17	.02	tr.	.03	.22	0.95	3.26	1.17	18.80
10-14	B21hir	37	.09	.01	tr.	.05	.15	1.47	8.52	1.62	9.26
14-21	B22hir	38	.22	.01	tr.	.03	.26	1.05	4.82	1.31	19.85

TABLE A-4.--Continued

Depth (inches)	Horizon	Lab. No.	E.B.-me/100 gm					E.A. me/ 100 gm	C.E.C.-mg/ 100 gm		% B.S.
			Ca	Mg	Na	K	Sum	$BaCl_2$-TEA	Na O_{ac}	Sum	Sum
					No. 5, AuGres-Croswell						
21-28	B23	39	.11	.01	tr.	.03	.15	0.63	2.03	.78	19.23
28-39	B31	40	.10	.02	tr.	.03	.15	0.61	1.89	.76	19.72
39-50	B32	41	.09	.02	tr.	.03	.14	0.64	1.01	.78	13.86
50-60	C1	42	.10	.02	tr.	.03	.15	0.74	.84	.89	16.85
					No. 6, Croswell-Graycalm						
0-1	A1	44	1.44	.39	tr.	.21	2.04	2.00	23.95	4.04	50.49
1-3	A2	45	.31	.08	tr.	.09	.48	1.37	3.23	1.85	25.95
3-5	Upper B21hir	46	.14	.01	tr.	.04	.19	1.37	4.87	1.56	12.18
5-7	Lower B21hir	47	.16	.02	tr.	.05	.23	1.37	8.19	1.60	14.38
7-18	B22hir	48	.21	.03	tr.	.04	.28	1.05	3.08	1.33	21.05
18-23	B3	49	.19	.02	tr.	.03	.24	0.78	2.53	1.02	23.53
23-28	A2'	50	.10	.01	tr.	.03	.14	0.42	2.25	.56	25.00
28-39	A2'&B2t'1	51	.20	.06	tr.	.03	.29	0.80	1.69	1.09	26.61
39-49	A2'&B2t'2	52	.19	.05	tr.	.03	.27	0.84	1.74	1.11	24.32
49-60	C1	54	.08	.01	0.00	.02	.11	0.42	0.97	.53	20.75

TABLE A-4.--Continued

Depth (inches)	Horizon	Lab. No.	E.B.-me/100 gm					E.A. me/ 100 gm	C.E.C.-mg/ 100 gm		% B.S.
			Ca	Mg	Na	K	Sum	$BaCl_2$-TEA	Na O_{ac}	Sum	Sum
					No. 7, Graycalm						
0-1	A1	55	1.79	.50	tr.	.47	2.76	3.05	27.82	5.81	47.50
1-3	A2	56	.45	.08	tr.	.05	.58	1.16	2.98	1.74	33.33
3-8	Upper B21hir	57	.37	.05	tr.	.08	.50	1.05	5.22	1.55	32.26
8-11	Lower B21hir	58	.40	.06	tr.	.06	.52	1.05	5.68	1.57	33.12
11-23	B22hir	59	.24	.02	tr.	.03	.29	1.05	3.52	1.34	21.64
23-30	A2'	60	.29	.05	tr.	.05	.39	0.53	3.69	.92	42.39
30-55	A2'&B2t'1	61	.21	.03	tr.	.06	.30	0.84	3.19	1.14	26.32
55-60	A2'&B2t'2	62	.18	.05	tr.	.06	.29	0.81	3.20	1.10	26.36

TABLE A-5.--Total carbon, organic matter, and extractable iron and aluminum percentages for each of the seven pedons.

Depth (inches)	Horizon	Lab. No.	Tot. C. %	O.M. %	Ext. Fe - %		Ext. Al - %	
					Pyro. PO_4	Dith.-Cit.	Pyro. PO_4	Dith.-Cit.
No. 1, Kinross (organic surface)								
1-11	A2	04	0.44	0.76	.02	--	.01	--
11-21	B21h	05	0.86	1.48	.02	.03	.12	.26
21-27	B22hir	06	0.54	0.93	.02	.03	.11	.18
27-37	B23	07	0.34	0.57	.02	.03	.09	.14
37-50	C1	77	0.29	0.50	.03	--	.07	--
No. 2, Kinross (better drained)								
1 1/2-15	A2	10	0.20	0.34	.02	--	.01	--
15-25	B21h	11	1.05	1.81	.02	.02	.13	.23
25-35	B22hir	12	1.01	1.74	.02	.03	.13	.18
35-54	B23	13	0.73	1.26	.02	.04	.07	.14
54-63	B3	14	0.45	0.78	.02	.04	.05	.09
No. 3, Saugatuck								
0-1	A1	16	10.13	17.46	.06	--	.06	--
1-11	A2	17	0.24	0.41	.03	--	.04	--
11-17	$B21hir_m$	18	0.56	0.96	.04	.08	.50	.63
17-24	$B22hir_m$	19	0.82	1.41	.03	.08	.18	.31
24-33	B23hir	20	2.21	3.81	.03	.08	.12	.23
33-43	C1	21	0.56	0.97	.03	--	.12	--
43-61	C2	22	0.54	0.93	.03	--	.13	--

TABLE A-5.--Continued

Depth (inches)	Horizon	Lab. No.	Tot. C. %	O.M. %	Ext. Fe - %		Ext. Al - %	
					Pyro. PO_4	Dith.-Cit.	Pyro. PO_4	Dith.-Cit.
				No. 4, Saugatuck-AuGres				
0-1 1/2	A1	25	8.17	14.09	.07	--	.08	--
1 1/2-3	A2	26	1.15	1.98	.03	--	.05	--
3-7	B21hir	27	2.53	4.36	.20	.51	.48	.88
7-11	B22hir	28	1.24	2.14	.09	.14	.29	.31
11-16	IIA2'	29	0.91	1.57	.04	--	.24	--
16-23	IIB21hir'	30	1.67	2.88	.04	.09	.43	.63
23-33	IIBhir'$_m$	31	0.61	1.05	.03	.18	.24	.44
33-48	IIB3'	32	0.53	0.91	.01	.04	.09	.13
48-58	IIC1	33	0.49	0.84	.02	--	.06	--
				No. 5, AuGres-Croswell				
0-6	A1	35	7.01	12.09	.07	--	.09	--
6-10	A2	36	0.33	0.57	.05	--	.06	--
10-14	B21hir	37	0.16	0.28	.22	.54	.32	.59
14-21	B22hir	38	0.48	0.83	.10	.55	.19	.43
21-28	B23	39	1.08	1.86	.06	.30	.11	.26
28-39	B31	40	0.21	0.36	.04	--	.07	--
39-50	B32	41	0.19	0.33	.04	--	.06	--
50-60	C1	42	0.10	0.17	.03	--	.05	--

TABLE A-5.--Continued

Depth (inches)	Horizon	Lab. No.	Tot. C. %	O.M. %	Ext. Fe - %		Ext. Al - %	
					Pyro. PO_4	Dith.-Cit.	Pyro. PO_4	Dith.-Cit.
No. 6, Croswell-Graycalm								
0-1	A1	44	5.56	9.59	.07	--	.07	--
1-3	A2	45	0.31	0.53	.09	--	.08	--
3-5	Upper B21hir	46	0.78	1.34	.12	.52	.21	.46
5-7	Lower B21hir	47	0.78	1.34	.19	.43	.24	.26
7-18	B22hir	48	0.28	0.48	.10	.43	.18	.32
18-23	B3	49	0.21	0.36	.07	.28	.12	.22
23-28	A2'	50	0.17	0.29	.06	--	.11	--
28-39	A2'&B2t'1	51	0.08	0.14	.06	--	.07	--
39-40	A2'&B2t'2	52	0.05	0.09	.06	--	.06	--
49-60	C1	54	0.13	0.22	.06	--	.03	--
No. 7, Graycalm								
0-1	A1	55	4.10	7.07	.09	--	.09	--
1-3	A2	56	0.30	0.52	.09	--	.06	--
3-8	Upper B21hir	57	0.76	1.31	.19	.54	.21	.31
8-11	Lower B21hir	58	0.89	1.53	.15	.56	.24	.47
11-23	B22hir	59	0.42	0.72	.09	.54	.17	.32
23-30	A2'	60	0.17	0.28	.09	--	.12	--
30-55	A2'&B2t'1	61	0.16	0.28	.08	--	.06	--
55-60	A2'&B2t'2	62	0.15	0.27	.07	--	.06	--