PHYSICO-CHEMICAL, MINERALOGICAL AND MICROMORPHOLOGICAL STUDIES ON ALFISOL AND SPODOSOL PROFILES FROM SOUTHERN ONTARIO, CANADA

PHYSICO-CHEMICAL, MINERALOGICAL AND MICROMORPHOLOGICAL STUDIES ON ALFISOL AND SPODOSOL PROFILES FROM SOUTHERN ONTARIO, CANADA

by

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SCOPE AND CONTENTS: The relationship between soil properties and micromorphological features was studied in six Alfisol and six Spodosol profiles from Southern Ontario. The total porosity of the soil material was largely related to the size, shape and conformation of the soil voids in thin sections, while the differential development of plasma fabric could be used to discern a sequence of degrees of weathering which was also expressed by various mineralogical and physico-chemical indices. The relative proportions of soil constituents in thin sections was successfully used to indicate the existing textural discontinuities in five of the profiles studied. The elementary structure of soil thin sections is considered the most important micromorphological feature in the investigation of the degree of B horizon development in both Alfisol and Spodosol profiles.

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(*) Each series has four sections : "Site description"; "Horizon (Profile) description"; "Micromorphological description"; and "Discussion and first interpretation".

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CHAPTER I

INTRODUCTION

The object of this study is to establish relationships between various physico-chemical and mineralogical properties of soils and the observed micromorphological features of the $B_{22}t$ and the $B_{22}ir$ horizons in both Alfisols and Spodosols in Southern Ontario. These horizons contain the most important diagnostic pedogenetic features relevant to soil classification. The upper and the very lower horizons of the selected profiles were also studied to serve in the investigation of the pedogenetic features in the B horizon, especially as regards the detection of profile discontinuities and the empirical establishment of sequences of soil development.

The relationship between soil composition and soil micromorphology was early discussed by Kubiena (1938). The connection between the dominant color of the soil fabric and the iron content has recently been studied by Bennema et al (1970). According to Stoops (1968) the position of any soil profile in a weathering sequence is not only connected with the changes in the plasma fabric from soil to soil but also, and to a greater extent to the iron content of the horizon. Such fabrics can originate from the concentration of particular elements as well as from the destruction or alteration of another fabric (Federoff, 1968).

The relationship between optically-measured porosity and clay content in the argillic (B_2t) horizon was studied by Dalrymple (1964), while the relationship between the measured pore space and the percent porosity determined from hydrological data was studied by Gillespie et al (1968). The great differences in porosity in the argillic horizon are not only affected by the differences in granular composition but also partly connected with the depth at which the horizon was sampled (Bennema et al, 1970). Observed soil micromorphological features were also used as important indicators of textural discontinuities in different types of soils from Ontario by Acton (1970) and for the Atlantic Provinces by McKeague in 1969.

In this review, most relationships between soil composition and micromorphological features have been, in general, qualitatively described and studied, using small numbers of soil samples and simpler techniques.

The following are the major characteristics which seemed most relevant to the study of the relationships between soil properties and micromorphological features:-

1) Soil porosity was calculated from specific gravity and volumetric weight determinations related to the size, the shape and conformation of the voids in the B horizons of both Alfisol and Spodosol profiles.
2) Potential degree of chemical weathering in the B horizons of both Alfisol and Spodosol profiles was established by the silica/sesquioxide ratio, which indicates the relative mobility of ferrisilicates in the soil material. The degree of mineral weathering was determined by use of the ratio quartz/chlorite content in Alfisols,

and the ratio tourmaline/pyroxene content in Spodosols. The differences in weathering revealed by this approach were clearly related to differing types of plasmic fabric for the profiles studied. These fabric types were described using the terminology of Brewer (1964).

3) Textural discontinuities were established by the detection of size changes in the particle size analysis of different subhorizons and these in turn were related to the relative proportions of soil constituents -(skeleton, plasma and void)- in thin section.

4) The accumulation of silicate minerals in the B horizon was established by the percent clay gained in Alfisol profiles, and by the ratio of silt to silt plus fine sand content in Spodosol profiles. Such accumulations were in turn related to the differing elementary structural forms which could be described by use of both the terminology of Kubiena (1938) and that of Brewer (1964) and, to a lesser extent, that of Beckman and Geyger (1967). These three classification schemes have all been used to provide adequate description to support the previously-established relationships for the sake of a complete study. It is therefore clear that this study draws from several established approaches in various branches of soil science.

The study of soil physical properties is stressed in the study of soil porosity. Soil porosity may be defined as that percentage of soil volume that is not occupied by soil particles. In a soil containing no moisture, the total pore space will be filled with air; the pores of moist soil are filled with both air and water. The relative amounts of air and water present will largely depend upon the size of the pores (Brewer, 1966).

A soil profile is the complete succession of soil horizons down to the undifferentiated parent material. The development of a soil profile is mainly the consequence of movements of water in the soil. Under humid conditions (Southern Ontario), there is an excess of rainfall over evaporation. There is thus a general tendency toward downward movement of soil moisture and the soil is subjected to a leaching process, whereby certain constituents are carried downward and either deposited in the lower horizons or completely removed in drainage. Thus the properties of the soil material in each horizon are a result of the process of soil formation. The rate and extent of each process can be used to indicate the degree of soil development in each horizon.

Chemical weathering may be defined as the disintegration of the original material through reaction of atmospheric influences and the soil components. The most important reaction by chemical weathering is hydrolysis by which various cations are replaced by hydrogen ions. The degree of soil chemical weathering was indicated by the study of certain chemical properties, especially determination of the silica/sesquioxide ratio. Such a ratio indicates the degree to which desilification of the soil material has occurred. The chemical weathering of minerals in the soil parent material also involves more intense alterations than the desilification of the soil material such as depotassication, hydroxylation and dealumination, (Jackson 1952) and occurs mainly in Spodosols and partially in Alfisols.

In many soils it is essential to determine the degree to which partially or wholly reformed material of secondary origin is developed, which differs markedly from the original parent materials. In this respect, ratios of quartz/chlorite, quartz/mixed layer minerals and quartz/vermiculite were used to indicate the degree of mineral weathering in Alfisol profiles, according to the sequence of chlorite alteration established by Drost et al (1958). The ratio of quartz/feldspar, garnet/pyroxene and tourmaline/pyroxene were used to indicate the degree of mineral weathering in Spodosol profiles. Such ratios serve to establish the degree of non-resistant minerals by relating to successive degrees of removal in sequence as established by Reeder (1961).

A soil profile discontinuity is defined as an abrupt change in the magnitude of a property within a vertical soil section. The origin of the discontinuity may be geologic, pedologic or a combination of geologic-pedologic processes in varying degrees of intensity. Textural discontinuities were observed in five of the twelve profiles studied. The magnitude changes of soil textures in each profile were explained as a result of geological and/or pedological formations associated with the location of the textural discontinuity. Such textural discontinuity, of soil genesis or development, is a result of process of soil formation (Arnold, 1968). It is important to detect profile discontinuities for, if they exist, direct comparison of changes in properties of subhorizons is not possible if the soils in question are to be ordered in a progressive weathering sequence.

Soil development is defined as the rate and extent of the process of soil formation in each horizon. Hence the properties of the soil material in each horizon are a result of the process of soil formation. Genetic development of the soil is evaluated in terms of the magnitude of pedogenic changes that occur in soil properties as a function of the stage of soil formation (such as the accumulation of silica and silicate clay). Such horizon development may be promoted or retarded according to the intensity of the silicate accumulation. High silicate accumulation with a lower degree of weathering will retard further development.

The study of the micromorphological features was mainly aimed at determining the major features of descriptive micromorphology, namely the type of feature, but in addition particular attention was paid to the size and the form of microvoids, plasma fabric, the relative proportion of soil constituents and the elementary structure.

Soil microvoids were defined by Brewer (1964) as individual separate units forming a connected system linked with each other by intergranular spaces. Such spaces are very important for the investigation of storage and movement of water. The voids are also indirectly responsible for the progression of pedogenetic changes that occur in soils and the accompanying changes of properties such as clay skins, resulting from clay translocation through pores and channels.

Plasmic fabric was also defined by Brewer (1964) as the physical constituents of a soil material as expressed by the spatial arrangement of the soil particles and associated voids. Such plasma fabrics were found to be very important in the investigation of differing soil compositions (Bennema et al, 1970), clay translocation (Dalrymple, 1964), and the degree of swell-shrink potential of the soil material (Nettleton et al, 1969). The plasmic fabric has also indirect relationships with the soil microvoids.

Elementary structure was defined by Kubiena (1938) as the natural arrangement of the elementary particles (plasma and skeleton grains) in relation to each other. Such elementary structure can be useful for the investigation of macrostructure which includes most micromorphological features.

The analysis described in this thesis used six Alfisol and six Spodosol profiles representative of Southern Ontario. The six Alfisol profiles were developed upon gray calcareous clay till from Wentworth, Huron, Lincoln and Middlesex Counties. The six Spodosol profiles were developed upon outwash sand from Simcoe and Renfrew Counties and upon sandy till from the Parry Sound district. These soils were classified according to both the American and Canadian systems of soil classification (the 7th Approximation, 1967 and the C.D.A., 1970), currently used in order to provide adequate comparative information and to indicate the appropriate degree of pedological development of the different units of the classification.

CHAPTER II

LITERATURE REVIEW

2.1. THE SIGNIFICANCE OF SOIL ANALYSIS IN THE STUDY OF SOIL GENESIS AND DEVELOPMENT

In Southern Ontario the mineralogical composition of many parent materials is not directly related to the underlying bedrock. The parent materials were transported from other localities during and immediately following glaciation. The study of soil formation in Southern Ontario is complicated by this relationship between the parent material and underlying bedrock.

Soil formation may be divided into two stages:

(a) The accumulation of soil parent material by geomorphic agents. In Southern Ontario the principal geomorphic agents were related to the Pleistocene glaciation and subsequent deglaciation.

(b) The differentiation of the parent materials into soil horizons or layers, by additions, removals, transfers and translocations within the soil profile. These four processes affect the organic and mineral fractions of the soil as well as many forms of soil life.

2.1.1. The characteristics of the Alfisol order

The Alfisols are mineral soils that are usually moist and have no mollic epipedon, or oxic or spodic horizon but, an argillic or natric horizon and a base saturation value of more than 35%. The argillic horizon, which was found to be common in Alfisols from Southern Ontario, is defined as an horizon that contains illuvial layer-lattice-clays below an eluvial horizon, but which may be at the surface if the soil has been partially truncated (U.S.D.A., 1960).

In Southern Ontario the Alfisols have developed under a deciduous and/or mixed vegetation with a climate that is warmer than that associated with the Spodosols. Leaf litter seldom accumulates. The formation of a mineral organic layer appears to be related to a significant change in the activity of micro-organisms. Earthworms are common and contribute to the mixing of soil layers. The soil materials are slightly alkaline in reaction. Clay minerals may have accumulated through transformation or by weathering in situ from the primary minerals, such as mica and feldspars.

Alfisols are dominant on well and/or imperfectly-drained sites throughout Southern Ontario. Alfisols do not occupy significantly large areas in the Precambrian shield or the northern part of Ontario. In general, the distribution of the Alfisols is dominantly controlled by higher precipitation, warmer temperature and a longer period of formation - about 2,000 years or more (Martini, 1971). (Fig. 3).

2.1.2. The characteristics of the Spodosol order

The Spodosols are mineral soils that are usually dry and have a spodic horizon. A spodic horizon is defined as an horizon that contains active amorphous material, composed of organic matter and sesquioxide aluminium, with or without iron, that are precipitated below an eluvial horizon (U.S.D.A., 1960).

In Southern Ontario, Spodosols have developed under a forest where leaf litter has accumulated and forms an organic layer. The decomposition products of the organic matter have a strong leaching effect which results in an eluvial grayish horizon (the albic epipedon) near to the surface. Under cultivation, the upper horizons of Spodosols are mixed and only remnants of the upper eluvial horizons are usually discernible. The parent materials are normally non-calcareous or else very low in lime though some sandy parent materials in Ontario are calcareous. The partial breakdown of the surface organic matter results in acidic conditions, which results in the general absence of earthworms and retardation of bacterial decomposition of the organic matter. Spodosols are usually found in three areas in Southern Ontario:

(a) In Precambrian shield and Northern Ontario,

(b) In central Ontario, including parts of Simcoe, Dufferin and Grey Counties,

(c) In eastern Ontario, including parts of Carleton, Russell and Prescott Counties.

The major soil characteristics such as soil porosity, soil weathering, soil development and soil discontinuities will now be discussed in the argillic horizon of the Alfisol profiles as well as for the spodic horizon of the Spodosol profiles. These characteristics were deemed to be the most relevant in the study of the relationship between soil properties and micromorphological features such as the voids, the plasma fabric, the soil constituents and the elementary structure.

The argillic and spodic horizons of Alfisol and Spodosol orders were examined to study the magnitude of changes in soil properties above mentioned, as a function of soil formation.

2.1.3. Soil porosity as related to soil genesis

Soil porosity may be defined as that percentage of soil volume that is not occupied by soil particles. In a soil containing no moisture, the total pore space will be filled with air. The pores of moist soil are filled with both air and water. The relative amounts of air and water present will largely depend upon the size of the pores (Brewer, 1966). The porosity of the soil is calculated by volumetric weight and specific gravity determination (Emerson, 1936). This method however is not suitable for soils containing a higher percent of organic matter, since the presence of organic matter decreases the real value of particle density (specific gravity).

The total porosity is not as important for characterizing the structural properties of soils as the relative distribution of the pore sizes. Clay material, for example in Alfisol profiles, tends to have higher total porosities than sand material from Spodosol profiles. Clay soils possess a large number of small pores which contribute to a high water-holding capacity and slow permeability. Sand materials have a small number of large pores which are associated with rapid drainage and low moisture holding capacity. The ideal soil should have the pore space about equally divided between large and small pores. Such a soil would have sufficient aeration, permeability and water-holding properties to stimulate the growth of the plant root system.

Soil porosity, in general, is affected by all the factors varying the volumetric weight of the soil, such as the water-holding capacity, the particle density, the organic matter, the clay content, the swelling tendency and others. For example, Dalrymple (1964) working with Alfisol profiles from Great Britain and New Zealand found that the process of translocation of clay size material dominantly influenced the pore space percentage. The same result was found by Gillespie (1968) in Alfisol profiles from Southern Ontario. This process of translocation of clay size material was shown by Rowell et al (1969) and Nettleton et al (1969) in Alfisol profiles from North America to be a function of the swell-shrink potential of soil material in the B horizon. Gillespie et al (1968) have found a positive relationship between the process of translocation of clay size material (physical transportation) and the weathering of carbonates accompanied by structural change and biological activity.

2.1.4. Chemical weathering as related to soil genesis

Chemical weathering results from a change in chemical environment. Minerals that have formed under magmatic, hydrothermal, metamorphic or sedimentary conditions are considered potentially unstable when exposed to the atmosphere. They are likely to be attacked by water, oxygen and carbon dioxide and the reactions, which are exothermic, tend to proceed naturally. Water penetrates through pores, cleavages and other micro-openings in the minerals and dissolves the more soluble constituents. As these processes intensify, the residue becomes progressively enriched in the less soluble constituents as well as in oxygen and hydroxyl groups. Ultimately crystallization of the residue results in the development of new mineral phases which are in more stable equilibrium with the prevailing atmospheric condition.

The process of chemical weathering followed by the changes in the original composition of the soil material, which in turn affects the relative distribution of soil elements, is considered a very important process in soil formation. The intensity and degree of chemical weathering can be determined by using the following ratios: silica/sesquioxide, silica/aluminum and silica/iron oxide content. These ratios were used by Robinson (1937), Zonn (1950), Rode (1955) and Tatarinova (1966) to identify varying degrees of weathering in both Alfisol and Spodosol profiles.

The weathering activity of clay minerals, in terms of intensity or degree of chemical weathering, was determined by using the effective cation exchange capacity in Alfisol profiles from Wisconsin (Krebs and Tedrow, 1957). However, a better method to indicate the intensity of weathering in loose soil was suggested by Ameryckx and Springer (1967) who applied the ratio of silica/calcium content in Alfisol profiles from Belgium.

The study of the potential degree of chemical weathering in both Alfisol and Spodosol profiles, as related to soil genesis, will now be discussed in detail.

The degree of chemical weathering in terms of silica/sesquioxide ratio in argillic horizons (Bt horizons) was found to be the same as that of the A and C horizon (7th Approximation, 1960, page 38) in Alfisol profiles. The same result was found by Kremer (1969) in Alfisol profiles from Russia. On the other hand, a different result was found by Krebs and Tedrow (1957) in Wisconsin. Yassoglou and Whiteside (1960), working in Northern Michigan, found a lower silica/sesquioxide ratio in the B horizon, relative to the overlying and underlying horizon in Alfisol profiles. This ratio was also applied to the spodic horizons of the Spodosol profile by soil survey staff (1960), Kodama and Brydon (1968), and Stevens and Wilson (1970). They found that the silica/sesquioxide ratio in B horizon is lower than the overlying and the underlying horizon. However, the lower silica/sesquioxide ratio is largely related to higher iron and aluminium accumulation and a higher degree of weathering, while the higher silica/sesquioxide ratio is related to higher silica accumulation and a lower degree of chemical weathering.

The relative distribution of exchanged cations is defined as the effective cation exchange capacity in association with the weathering activity of clay minerals. The relationship between the effective cation exchange capacity and the degree of chemical weathering was studied by McCracken et al (1964) and by Harradine (1963) who found that the exchangeable cations (Ca, Mg, K, Na) can be used to show the degree of soil weathering, since the relative distribution of exchangeable cations is largely affected by the weathering activity of clay minerals.

2.1.5. Soil discontinuities as related to soil genesis

A discontinuity is defined as an abrupt change in the magnitude of a property within a vertical soil section. Generally, the origin of the discontinuity may be geologic, pedologic or a combination of geologic-pedologic process in varying degrees of intensity.

Geologic discontinuities occur in materials of different origin, time of deposition and degree of weathering. For example, the development of the Spodosol profiles in thin sandy layers upon clay tills, exhibits geologic discontinuities. However, pedological discontinuities result from the combined processes of additions, losses, transformations and translocations of fine material. This may be applied to the argillic horizons in Alfisol profiles.

Establishing the presence and location of discontinuities in a profile is important in the study of soil genesis. This subject has been discussed recently by Lea (1967), Arnold (1968),Asamoa (1969), Raad (1969) and Acton (1970). They have shown that an abrupt change in the magnitude of particle sizes at similar depths is most useful for the identification of textural discontinuities.

McKeague and Cann (1969) in Alfisol profiles from the Atlantic Provinces found that a bisequa soil development was apparently superimposed on discontinuities in the material, as abrupt changes in texture occurred at the boundary between the sequa. The accumulation of clay in the upper sequim of Alfisol profiles has been associated with pedological discontinuities in terms of the formation of a superficial layer of fine material.

McKeague et al (1967) in Alfisol profiles from Cape Breton Island, found that the particle size distribution of bisequal profiles showed an abrupt increase of clay in the Bt horizon followed by no significant change in the texture of the CK horizon. The accumulation of clay in the CK horizon of Alfisol profiles have been associated with pedological-geological discontinuity. It may thus be hypothesized that the tendency to clay accumulation and maximum clay values in the Bt horizon of such soils is most marked over carbonate-rich fine parent materials.

2.1.6. Soil development through the accumulation of sesquioxides, silicate clay and other materials in the Bir and Bt horizons

In Alfisol profiles, the accumulation of silicate clay, the decalcification of soil by removal of carbonates and the accumulation of sesquioxide and silica in the B horizons are used as the major factors promoting soil development in this horizon. Allen (1959) in Alfisol profiles from Illinois found that the addition of clay minerals in the B horizon can be used to determine the degree of argillic horizon development. The same result was found by Brewer (1968) in Red-Brown Earths from South Australia. He also indicated three sources of the clay mineral (added) in the B horizon. These are, the clay translocated from the A horizon, the formation of clay in situ by weathering and the existence of a sedimentary layer of clay in a stratigraphic sequence.

Khalifa and Buol (1968) in Alfisol profiles from North Carolina indicated that the addition of clay mineral in the B horizon is mainly by the transportation of clay mineral from the A horizon through physical transportation. This result was accepted by Harradine (1963) for a non-calcareous brown soil from California. Smech et al (1968) and Allan (1968) found that leaching of carbonate minerals (decalcification) leads to the production of voids which are subsequently occupied by clay, translocated from the upper horizon. Most authors agree that though there is little alteration of clay, mainly the fine clay is moved into the Bt horizon.

In Spodosols the accumulation of sesquioxide and silica and of humified organic matter in the B horizon and the presence of carbonate and coarse textured material in the parent material are used to indicate the differential development of podzol B horizons. McKeague et al (1969) in reddish-brown soils from the Atlantic Provinces, found that the differences in texture and properties such as pH and base saturation are related to the presence or absence of carbonate in the C horizon which had an effect upon podzol B horizon development. The same result was found by Mackney (1961) in a study of a Brown Earth-Podzol sequence in central England.

De Coninck et al (1968) in Spodosol profiles from Belgium, established three stages of podzol development. Translocation with local accumulation of clay occurs in the first stage; weathering of clay minerals in the second stage and further weathering of clay minerals under the influence of very acid organic matter was the third stage of B horizon development. However, Mackney (1961) in England has proposed the gradual degradation sequence of the initial soil to a podzol B horizon development, characterized in four stages:

1. translocation of clay (first stage),
2. chemical weathering of the Ae horizon (second stage),
3. strong iron illuviation (third stage),
4. eluviation of organic matter (fourth stage) to form an illuvial Bh horizon.

These results show that the second stage of podzol B horizon development by De Coninck et al (1968) in Belgium is largely associated with the second and the third stages of degradation sequence of podzol B development outlined by Mackney(1961) in England.

2.2. THE SIGNIFICANCE OF SOIL MICROMORPHOLOGY IN THE STUDY OF SOIL GENESIS AND DEVELOPMENT

Soil material is composed of a certain number of constituents, having different properties. Soil micromorphology studies are concerned with the identification of these constituents in thin section, the description of their size, shape and arrangement. It is an important part of the petrographic study of soil. As soil is an alteration product of rock, a study of the rock and its alteration stages becomes a necessary step to the complete understanding of soil and its formation. Soil micromorphology thus, to a certain extent, tries to decrease the gap between petrography and pedology. To Kubiena (1938) is granted the honour of having provided the initial study of this new field and Brewer (1964) has recently attempted to systematize the more purely morphological aspects.

The study of micromorphological features as related to soil genesis has been discussed by different authors in different countries. Concerning the soil voids, Rutherford (1967), in a Gray-Brown Podzolic profile from Southern Ontario, found that the increase in clay content with depth gives less room for expansion and contraction or wetting and drying that the voids are finer and the pattern less complicated. The part of the soil material which is capable of being moved, re-organized and/or concentrated by the process of soil formation is called the plasma fabric. Such fabric was found in connection with the position of the soil in a weathering sequence for a suite of argillic horizons from soils in South Brazil by Bennema et al (1970). The type of elementary structure of soil material was considered by Geyger and Beckman (1967) to be the result of the capacity of the soil to form voids and/or aggregations which in turn influenced the degree of clay illuviation.

The major soil micromorphological features which were deemed most relevant in the study of the relationship between soil properties and micromorphological features will be discussed in detail.

2.2.1. Soil voids as related to soil genesis

The voids between the soil materials are considered to be individual and/or in connection with each other. The smallest voids are mostly beyond the resolving power of the polarizing microscope. The most important characteristic of visible voids is that they can be described in terms of their size, shape, arrangement and morphology in thin sections.

Brewer (1964) was able to classify the voids satisfactorily in six categories. These are packing voids, vughs, vesicles, channels, chambers and planar types. Packing voids were associated principally with sandy soils (Spodosols), whilst planar voids occurred in the clay soils (Alfisols).

Beckman and Geyger (1967) reduced the classification of voids to two essentially different types. These are "fissures" and "cavities". Fissures are simply voids resulting from the shrinkage of the soil material (due to drying out). They correspond with Brewer's (1964) planar voids. Cavities are simple voids whose opposite walls do not accomodate each other. They correspond essentially to Brewer's vughs, but also vesicles, channels and chambers seem to be included. A grouping of channels and chambers, on the same level as fissures and cavities, would have been useful. Simple packing voids (Brewer, 1964) are not considered as an element for morphological characterization of structure, since their size, shape and orientation is supposed to be purely accidental (Beckman and Geyger, 1967).

Two major factors can affect the size, shape and distribution of soil voids, the translocation of clay minerals from the upper layer and the degree of swelling and shrinking or wetting and drying of the soil material. However, the second factor affecting the soil voids was neglected in this thesis, because the soil material was tested in dry condition.

Dalrymple (1964) in Alfisol profiles from Great Britain and New Zealand found that the translocation of clay material is influenced by the size, shape and the pattern of the distribution of the voids. Sleeman

(1963) in Alfisols from South East Australia and Czeratizki and Frese (1958) in Alfisol profiles from North America, found that the increase in clay content by translocation processes in the Bt horizon gives less room for expansion and contraction on wetting and drying and hence the voids become finer and the pattern less complicated. The same result was found also by Rutherford (1967) in Alfisol profiles from Southern Ontario.

2.2.2. Plasma fabric as related to soil genesis

Plasma is that part of a soil material that is capable of being moved or has been moved, re-organized and/or concentrated by soil forming processes (Brewer, 1964). Kubiena (1938) defined the plasma fabric as that part of the soil material moved easily, changed in composition and shape and redeposited. It is generally regarded as being coincident with the finely-dispersed and highly-active, newly-formed compounds in soils. Kubiena was able to present the plasma in thin section in two flocculated states; these are a peptized and a pectized flocculated state.

Brewer (1964) classified plasma fabrics into five major types, according to the kind and degree of development of plasma separation and the presence of opaque, isotropic and anisotropic components. These are asepic, sepic, undulic, isotic and crystic plasmic fabrics. According to the degree of orientation of the plasma grain and the degree of preferred orientation of domain, sepic plasmic fabric was divided into seven subtypes; these are insepic, masepic, mosepic, vosepic, skelsepic, lattisepic and omnisepic fabrics. According to the presence of visible crystals of plasma, asepic plasmic fabric was divided into argillasepic and silasepic fabrics. Masepic and mosepic plasmic fabrics are associated principally with clay material (Alfisol) whilst skelsepic and vosepic plasmic fabrics occurred in the sandy soils (Spodosol).

The type of plasmic fabric is associated with other soil properties such as the moisture content (precipitation), the pressure and tension effects produced by soil wetting and drying and the weathering of clay minerals. For example, Blockhuis et al (1970) in Vertisol profiles from the Sudan found that the fraction of masepic plasmic fabric of the total plasma is larger in the higher than in the lower rainfall profile area. Greene-Kelly et al (1970) in artificial soils, have shown experimentally that omnisepic, lattisepic and masepic fabrics are caused by pressure, especially shear stresses, while Brewer (1964) proposed that the pressure and tension produced by soil wetting and drying and mineral clay illuviation promoted the development of complicated plasma fabrics (Sepic fabrics).

The type of plasma fabrics relatable to soil weathering was also studied by McCracken et al (1964) in South America, Federoff (1968) in France and Jongerius (1970) in the Netherlands. They proved that lattisepic fabrics resulted from clay mineral formation in situ. Other authors (Federoff 1968, Stoops 1968 and Jongerius 1970) have shown that the vosepic fabric in an argillic horizon was the result of destruction of ferri-argillans in various types of soils, the so-called "B dynamic" horizon formation process.

2.2.3. The cutan as related to soil genesis

The cutan was defined by Brewer (1964) as a modification of the texture, structure or fabric at natural surfaces in soil material, due to the concentration of particular soil constituents or in situ modification of the plasma. It can be composed of any of the component substances of the soil material. Brewer (1964) was able to recognize five types of cutan, according to the surface effects, these are: ped cutans, grain, natural void, channel and plane cutans. Grain and void cutans are largely associated with sandy soil (Spodosols) while ped and plane cutans are associated with voids in clays (Alfisols). According to the layering features, simple and compound cutans were distinguished by Brewer. Each of them was genetically subdivided into illuvial, diffusion, stress and complex cutans.

The study of cutanic features as related to soil genesis is discussed by many different authors; Kubiena (1938), Brewer (1956), Jongerius (1957), Dalrymple (1964), Acton (1963), Altemüller (1962), Federoff (1965) McKeague (1969) and many others in Russia. All these authors considered the presence of optically-oriented clay (described as illuvial cutans) in the B horizon as convincing evidence of illuviation in the soil. The origin of diffuse cutans in the Bt horizon from Wisconsin was related by Buol and Hole (1961) to the effect of seasonal water movement in the soil material, associated with the frequent presence of large pores. The origin of stress cutans in soil from Australia was suggested by Lafeber (1962) to be the result of skeleton grains moving under pressure in the Bt horizon, due to differential forces in the soil material such as shearing forces. Such stress cutans are frequent in clay soils and their detection in some clayey parent materials in Southern Ontario is important.

2.2.4. The glaebules feature as related to soil genesis

The glaebule was defined by Brewer (1964) as a three dimensional unit within the soil matrix, and usually approximately prolate to equant in shape. According to the internal fabric, varying in shape and composition glaebules were divided by Brewer (1964) into six types. These are nodules, concretions (ortstein) septaria, pedodes, glaebular haloes and papules.

Raslikova and Kononova(1961) and Ogleznev (1968) found that the ~~maximum~~ ortstein development occurs where there is a marked fluctuation in the moisture content, generally in the A_2 horizons. McCracken et al (1964) found that in Alfisol soils, iron-manganese nodules are related to the seasonal percolation of water from a saturated zone above a B_2t horizon. Absence of concretions and normal nodules is a result of a much lower content of iron and manganese in the original sedimentary parent material. Ogleznev (1968) indicated that an increasing degree of wetness in a Red Podzolic soil is accompanied by progressive accumulation of humus, iron, phosphorus and magnesium in the ortstein and a corresponding decrease in the content of manganese.

Sokolova and Paltova (1968), found that the iron and humus content of concretions decreased with depth in the profiles, whereas the manganese content increased. Concretions occurring in the upper horizons were more rounded, harder, more strongly magnetic and lighter in colour.

Brewer (1964) and Ogleznev (1968) contend that the more sharply defined the interchange between oxidizing and reducing conditions throughout the seasons, the more regular is the shape of the concretion, and the sharper its boundaries are with the surrounding soils. Hence from previous work, one would surmise that glaebules will be most frequently encountered in Southern Ontario soils in alternating wet and dry soils in fine textured horizons, especially in parent materials rich in iron and manganese.

2.2.5. The elementary structure as related to soil genesis

Elementary structure was defined by Kubiena (1938) as the natural arrangement of elementary particles (plasma and skeleton grains), in relation to each other. Eight types of elementary structure were distinguished by Kubiena (1938), according to the qualitative and quantitative differences in the various arrangements of plasma and skeleton. These are porphyropeptic, pectic, intertextic, chlamedomorphic, plectoamictic, agglomeratic, bleached sand and mortar fabric. Chlamedomorphic and plectoamictic fabrics are associated principally with Spodosols whilst porphyropeptic-pectic fabrics occur in Alfisols. Kubiena gave examples of the same elementary structure occurring in different soils. He also noted that there was a developmental sequence for one fabric to another.

Elementary structure was defined by Brewer (1964) as the characteristic size, shape and arrangement of specific pedological features with regard to the basic structure of the soil material. He proposed (1957) that the clay illuviation associated with oriented clay in thin sections can be used to indicate the degree of soil development within the Alfisol profiles. Elementary structure recently was also defined by Beckman and Geyger (1967) as the tendency of a soil to form voids and/or aggregations. They considered that a soil material without aggregation or voids is thus structureless (does not have elementary structure). This assumption was avoided by using terms from either Kubiena's (1938) or Brewer's (1964) schemes. According to the dominant types of voids, fissures and cavities, the elementary structure was divided by Beckman and Geyger into seven major types; these are cracked, regular-jointed, irregular-jointed, fragmented, porous, spongy, and crumby structures.

These three classification schemes will all be used in this thesis to provide adequate information supporting the established description and also relationship of fabric to other properties, for the sake of a complete study and to facilitate comparison with work in different countries. The relationship between the elementary structure and the degree of soil development has been most recently studied by Eswaran (1967) in Belgium, who found that the terminology of Kubiena (1938) is most relevant to indicate the degree of development of the Spodosol profiles, while the terminology of Brewer (1964) can be used to evaluate the degree of development in the Alfisol profiles.

2.3. THE SIGNIFICANCE OF SOIL MINERALOGY IN THE STUDY OF SOIL GENESIS AND DEVELOPMENT

2.3.1. Light and heavy minerals associated with Soil Genesis

The light and heavy mineral associations in a soil usually indicate the source rocks. For example, tourmaline is a mineral derived from granitic pegmatites, pneumatolytic veins and some granites. The minerals of the parametamorphic group vary in their genesis and as a result, their sources. The kyanites originate from pelitic rocks subjected to regional metamorphism. Andalusite on the other hand is found typically in the argillaceous rock of contact aureoles around igneous intrusions. Hypersthene, a mineral common in basic and ultrabasic rocks, is rare in acid igneous rocks but may occur in some highly-differentiated rocks. Zircon and titaniferous minerals are usually found as accessory minerals of igneous rocks, particularly in plutonic rocks.

The distribution and relative accumulation of light and heavy minerals with depth in the soil profiles were used by Jackson (1953), Brydon (1965) and Wilson (1967), to indicate the extent of mineral weathering. It was avoided by Yassoglou (1960) because of the very slight differences in the data with depth in the profiles studies by him.

The weathering of light minerals was considered by Wilson (1967) in Aberdeenshire and Yassoglou and Whiteside (1960) in Northern Michigan, who proved that quartz minerals are the most resistant minerals to weathering, while muscovite and plagioclase feldspar and amphibole are the least stable minerals. McKeague and Brydon (1970) in the Atlantic Provinces, Wall (1969) in Alberta and Reeder et al (1961) in Eastern New Brunswick, found that the quartz/feldspar ratio in the 250-500 u fraction decreases with depth in the profile and hence reasoned that the degree of mineral weathering decreased with depth in the profile.

The relative resistance of the several heavy minerals has been a subject of continuous study. Significant contributions have been made by Gravenar (1954), Ruhe (1956), Brophy (1959) and Reeder et al (1961). The zircon + tourmaline to tourmaline + pyroxene ratio was used by Ruhe (1956) while the tourmaline + zircon to hornblende and to garnet ratios were used by Brophy (1959). The ratio of zircon + tourmaline + garnet + epidote to amphibole + pyroxene + iron oxide was used by Reeder (1961). These ratios are commonly used to determine the degree of mineral weathering in Spodosol profiles. Earlier studies by Van der Marel (1949) in Holland, showed that the amount of heavy minerals increased with depth in Spodosol profiles. However, Eswaran (1967) in Belgium, has shown that the amount of heavy minerals does not vary with depth in the Spodosol profile.

2.3.2. Clay minerals produced by soil genesis

The study of clay minerals by X-ray diffraction and/or electron microscopy and their relation to soil genesis has been discussed in detail by several workers. The identification of clay minerals and the degree of clay alteration have been the aim of most workers investigating soil genesis. Mica, especially hydrous mica (illite) has been found to be the predominent clay mineral by nearly all investigations in areas analogous to Southern Ontario. Krebs and Tedrow (1957) found that hydrous micas are the most abundant minerals in all clay samples extracted from Alfisols from Wisconsin. The same result was found by Brydon (1968) in clay minerals from the Ottawa and St. Lawrence Valleys. Kaolinite was reported by McKeague (1970) in Alfisols from Canada, but since it was not confirmed by others, the possibility must be recognized that a chlorite second-order reflection from X-ray diffraction may have been interpreted as kaolinite (Reeder, 1961). Chlorite was found in all samples by Karrow (1957) in soil from Quebec and in a single sample by Allen and Johns (1960) in soil from New England and Eastern Canada. Brydon's (1961) works show that chlorite was present in some cases and not in others, The hydrated layer clay minerals -montmorillonite, vermiculite and mixed layer minerals- were reported in a number of cases by Karrow (1957), Allen and Jones (1960) and Brydon and Patry (1961).

The origin of the chlorite, vermiculite, montmorillonite and mixed layer minerals in Alfisols of Southern Ontario is unknown. They may all have been inherited and have remained unchanged or they may have been formed in situ. It is possible that these minerals have been formed by the removal of inter-layer K or Mg in mica or chlorite, respectively

(Jackson 1968).

The degree of weathering of clay minerals is expressed in the present study largely by the alteration process of the chlorite clay minerals. It represents one of the least weatherable of the clay minerals.

Vermiculite, vermiculite-chlorite, mixed lattice clay minerals and expandable vermiculite were referred to by Frye et al (1960) as a transitional series of alteration products, derived primarily from chlorite. Drost and Thoren (1958) indicated that chlorite alters first to vermiculite-chlorite, then to the partially expandable vermiculite stage. Frye et al (1960) in Alfisol profiles from Illinois found that the oxidation and initial alteration of chlorite to vermiculite-chlorite and vermiculite appear to be the earliest weathering effects. These effects were present at the greatest depths below the surface in presently existing soils.

Khalifa and Buol (1968) revealed through electron microscope studies that the individual fine clay particles ($< 0.2u$) from the clay skin of a $B_{22}t$ horizon as well as these from the A_2 horizon were mainly poor crystalline kaolinite, resulting from a higher degree of weathering in the A_2 horizon while in contrast, the fine clay particles of both the bulk $B_{22}t$ horizon and the clay skins of the C_1 horizon samples had sharp and well defined edges, indicating a lesser degree of weathering. Gradusov and Dyazdevich (1960) in a study of clay minerals of the Bt horizon found a considerable quantity of particles of colloidal dimensions and some fairly compact mineral fragments. Such examination seems to indicate that the clay minerals have suffered severe weathering. Hence one can assume that differing degrees of clay minerals alteration and a succession of weathering may be indicated by the sequence: chlorite → vermiculite-

CHAPTER III

GENERAL ASPECTS OF THE ENVIRONMENT

3. 1. Location of the sites.

Southern Ontario includes that portion of the Province lying between 75° and 83° W. longitude and 42° and 46° N. latitude. As a geographical entity Southern Ontario, or Peninsular Ontario, has been defined as the area "bounded by the shores of Georgian Bay, Lake Huron, Lake Erie, Lake Ontario and the short connecting links between the longer water bodies" (Putman, 1955). The land area is approximately 51,000 square miles (32,656,000 acres), over 13 million acres being part of the Canadian Shield. Approximately 55% is occupied farm land, most of which occurs south of the shield (Richards, 1968). The distribution of moraines, drumlins, eskers and shorelines may be used to delineate 52 minor physiographic regions which were formed during the late Pleistocene. These glacial and lacustrine deposits produced the present topography. The elevation ranges from 1,600 feet a.s.l. in the South Central part to 400 - 600 feet close to the present lake shores.

For more than forty years, Soil Surveys have been conducted in Ontario. The surveys were co-operative projects between personnel of the Ontario and Canada Departments of Agriculture (Richards, 1968). These surveys show that soil distribution in Southern Ontario is related to climatic influence, effect of parent material, geomorphology, age of land form, previous vegetation and use by man (Martini, 1970). For the sites sampled see Fig. 1.

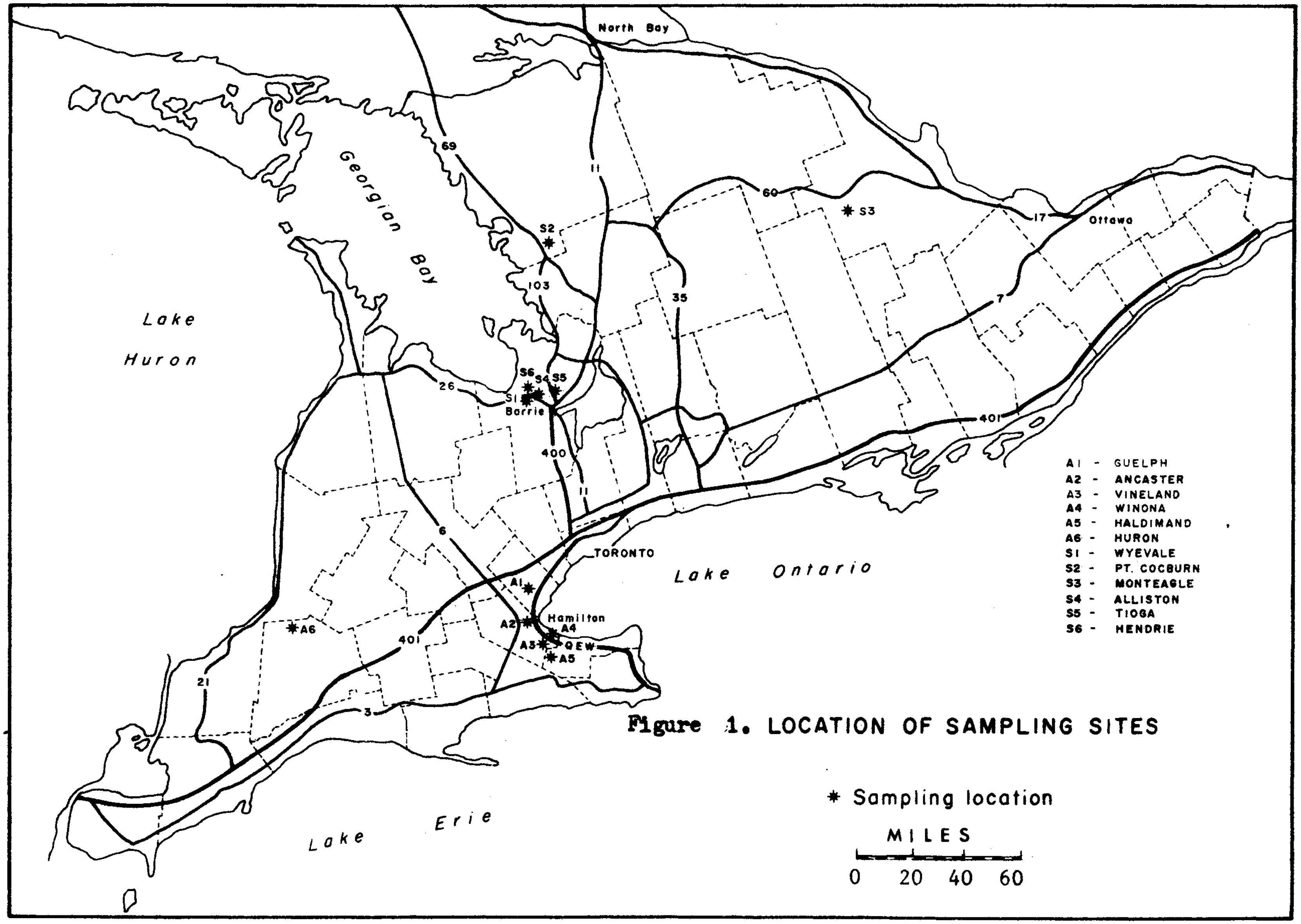


Figure 1. LOCATION OF SAMPLING SITES

3. 2. Climate of Southern Ontario.

Within the Köppen classification, Alfisol profiles occur in a Dfa climate having a relatively warm summer with maximum mean monthly temperature of 71°F. The Spodosol profiles have developed under a Dfb climate, relatively cool summer and maximum temperature under 71°F (see Fig. 2 and 3).

Under Thornthwaite's classification (1948), the climatic type is more complicated than under Köppen's with four climate figures in each type. These figures are largely related to geographical position, moisture index, thermal efficiency, seasonal rainfall variation and its summer concentration, which will be discussed for the locations of the twelve profiles. The six Alfisols are located in the South-East (Wenthworth, Huron and Lincoln Counties) and South-West part (Middlesex County) of Southern Ontario. The six Spodosols are located in the North-West (Simcoe and Parry Sound Districts) of Southern Ontario.

Moisture index in terms of the relationship between potential evapotranspiration and precipitation ranges in Alfisol sites between 15.29 % and 58.79 % (Winona and Huron Sites respectively), while in Spodosol sites it ranges between 23.83 % and 49.79 % (Monteagle and Port-Cockburn sites). Higher moisture indices prevail in the west part of Southern Ontario, while a lower index is found in the east. Thermal efficiency in terms of potential evapotranspiration is related to day-length and average daily temperature, which factors affect the water necessary for plant growth. Values range between 55.01 mm and 58.2 mm at Guelph and Vineland sites (Alfisols) and 52.2 mm and 54.6 mm (Monteagle and Port-Cockburn sites, Spodosols).

Study of seasonal variation of effective moisture shows that variable

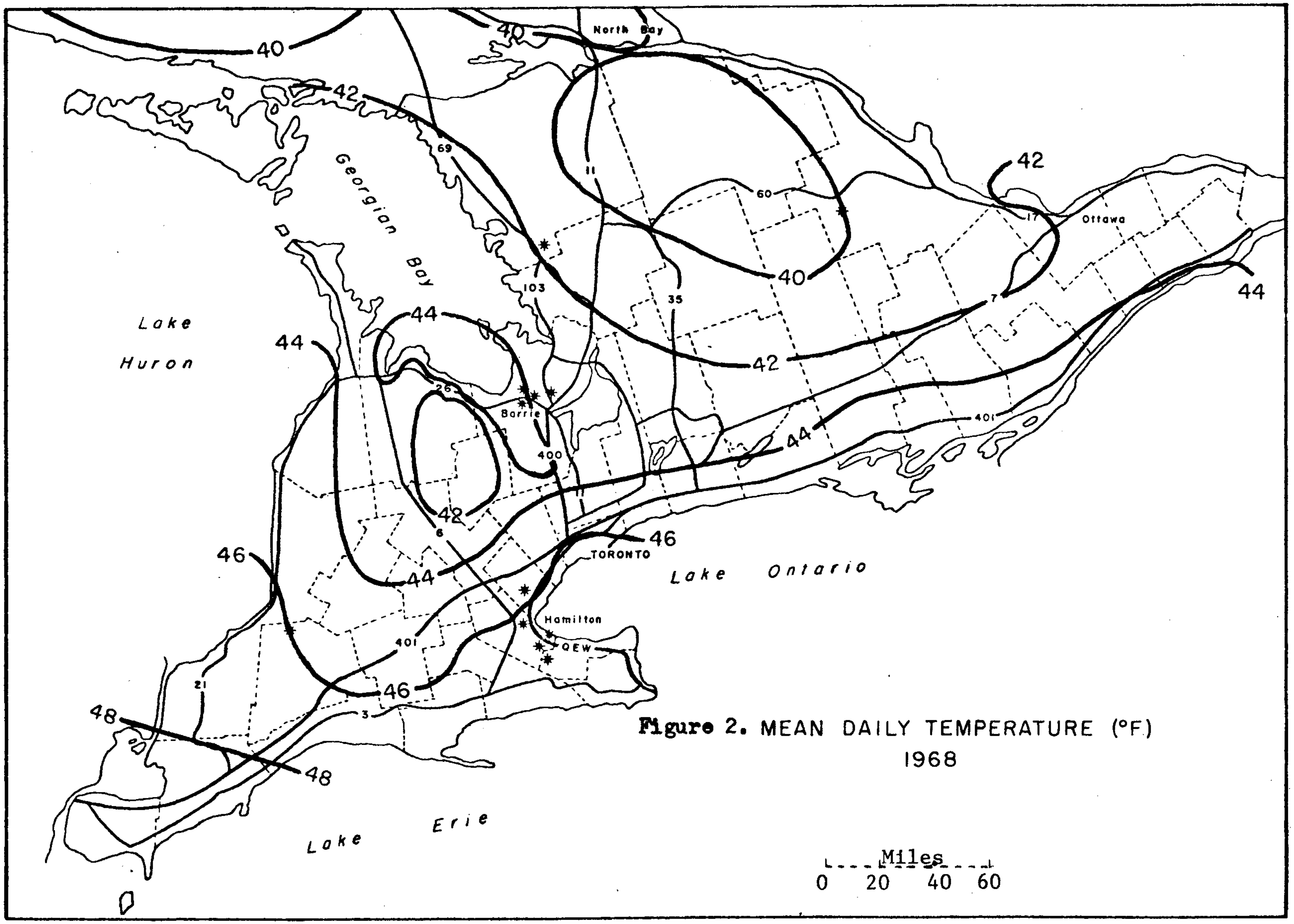


Figure 2. MEAN DAILY TEMPERATURE (°F)
1968

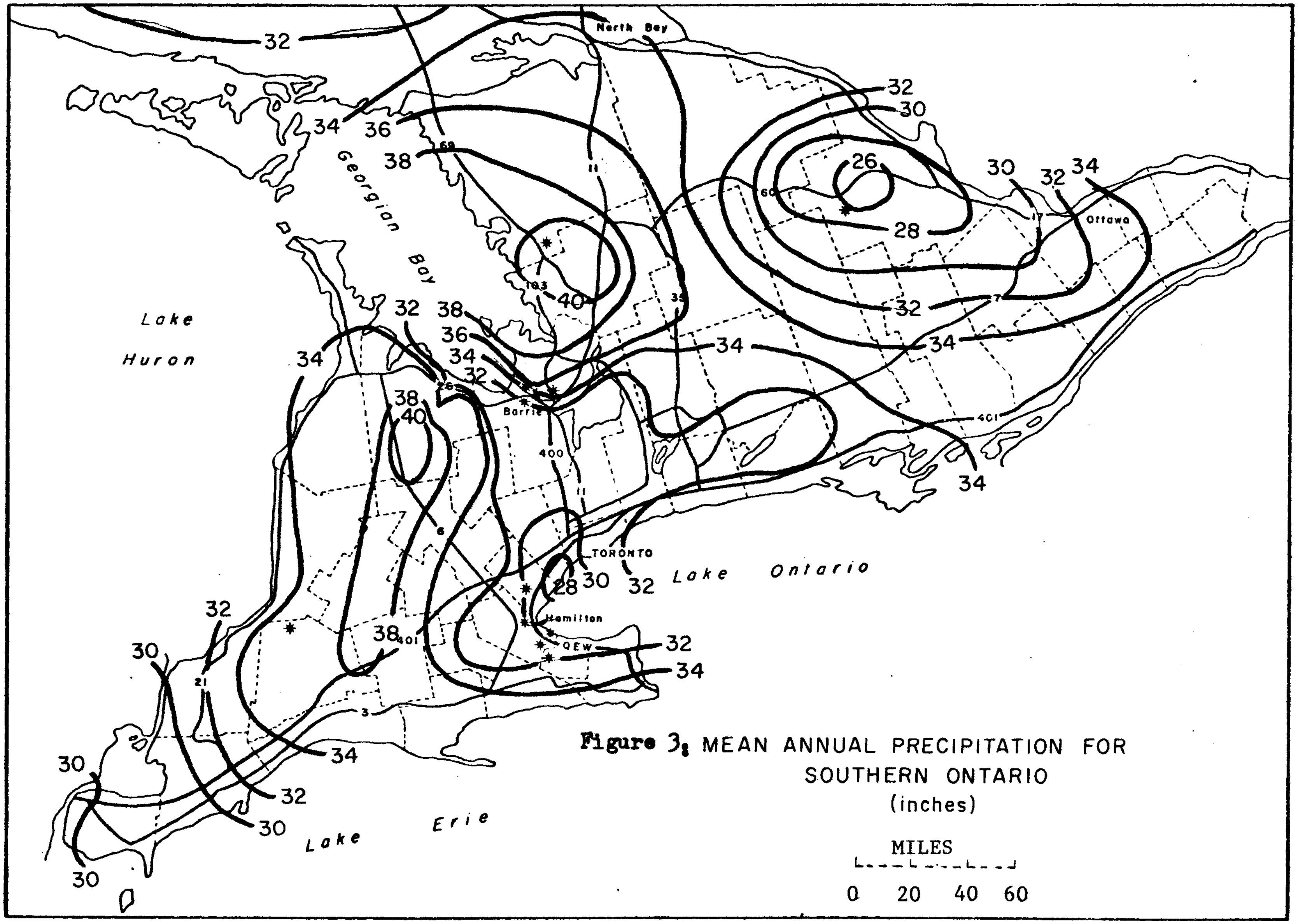


Figure 3: MEAN ANNUAL PRECIPITATION FOR SOUTHERN ONTARIO (inches)

amounts of water deficiency are found in Southern Ontario. Such deficiency ranges between 5.04% and 12.32% in Huron and Winona (Alfisol) sites, while in Spodosol locations it ranges between 4.99% and 8.81% (Port-Cockburn and Monteagle). Seasonal water deficiency increases from east to west in Southern Ontario, while moisture index and thermal efficiency decrease from east to west.

The following are some possibilities which may involve the effect of climatic parameters on the processes of soil formation in both Alfisols and Spodosols : 1) The range in the moisture index may influence the degree of summer drying of the upper soil and could be related to argilluviation depth in Alfisol profiles (Soil Survey Staff, 1967, p. 11); 2) Thermal efficiency may influence the degree of mineral alteration; 3) Seasonal water deficiency may affect the degree of gleyzation in soil material on sites within the same drainage class; 4) Summer concentration of potential evapotranspiration is relatively uniform throughout the province and would aid rapid organic matter decomposition in all soils.

3. 3. Vegetation of the sites.

The original distribution of natural vegetation in Southern Ontario has been studied by Chapman and Putnam (1966) who distinguished two regions : a) the Niagara hard-wood region, largely on Alfisols. This region was covered by maple, beech, oak and hickory trees; b) the eastern hard-wood region, on soils of Spodosol order. This region was covered with mixed evergreen and deciduous forest. The northern part possessed sugar maple tree growth and white and yellow birch trees, while the southern was covered with various pines, oak and bass trees.

The modern vegetation of the twelve sample locations is largely affected by the geographical position. Mixed forest, fruit trees, crops and meadow occur in the Alfisol areas. Natural forest, second class forest (reforested) and meadow vegetation characterize the Spodosol areas. In the Alfisol region the Haldimand and Ancaster sites are covered with mixed forest trees (shrubs and trees). The Vineland and Winona sites are covered with apples, pears and vine trees. Such vegetation may contribute large amounts of fibric organic matter which leads to a lower degree of humification. The Huron site is in meadow and the Guelph site is cultivated (wheat 1969). Such vegetation has recently contributed large amounts of humified organic matter to the soil.

In the Spodosol region, natural forest or first class forest cover the Port-Cockburn, Hendrie and Alliston sites. Sugar maple trees dominate the Port-Cockburn and Hendrie sites while conifers dominate the Alliston site. Second class forest or planted conifers occur at the Wyevale and Tioga sites. Deforestation, followed by ploughing and grazing alter the soil physically and chemically and have changed the ecological relationships at the last two sites and at the Monteagle site which is presently covered with meadow vegetation and gains large amounts of humified organic matter in the upper horizon of the profile.

3. 4. Geological history.

Precambrian rocks with an age in excess of one billion years, form the foundations of Southern Ontario. These outcrop to the north of an unconformity which trends from Georgian Bay to the Thousand Islands. These rocks belong to the easternmost division of the Canadian Shield.

The Paleozoic rocks comprise alternations of soft layers (shales) and more resistant layers (carbonate and sandstone). This geology is the foundation for the more recent glacial deposits.

Within the last one million years, radical and comparatively rapid changes have remoulded the geomorphological patterns of Southern Ontario. The agents of these changes were ice sheets of continental proportions. The ice sheets formed lobes emanating from the major depressions now occupied by Lakes Ontario, Erie, Huron and Georgian Bay. Since the last ice sheet retreated, surface weathering, stream and wave erosion and deposition have slightly altered the distribution of glacial and lacustrine deposits (Martini, 1970). Figures 4 and 5 show the bedrock geology and the twelve soil sites in Southern Ontario are shown in figure 4.

3. 5. The physiography of the studied sites.

Chapman and Putnam (1966) have divided Ontario into four major physiographic regions according to gross structure, mainly related to bedrock :

a) the broad half-dome that slopes from the Niagara escarpment to Lakes Huron and Erie (Huron, Haldimand and Vineland series);

b) the Niagara escarpment itself, (Guelph,and Ancaster series);

c) South-Central Ontario between the edges of the Canadian Shield and Lake Ontario (Wyevale, Alliston, Hendrie, Tioga and Winona series);

d) the lowlands between the Saint-Lawrence and Ottawa rivers (Monteagle).

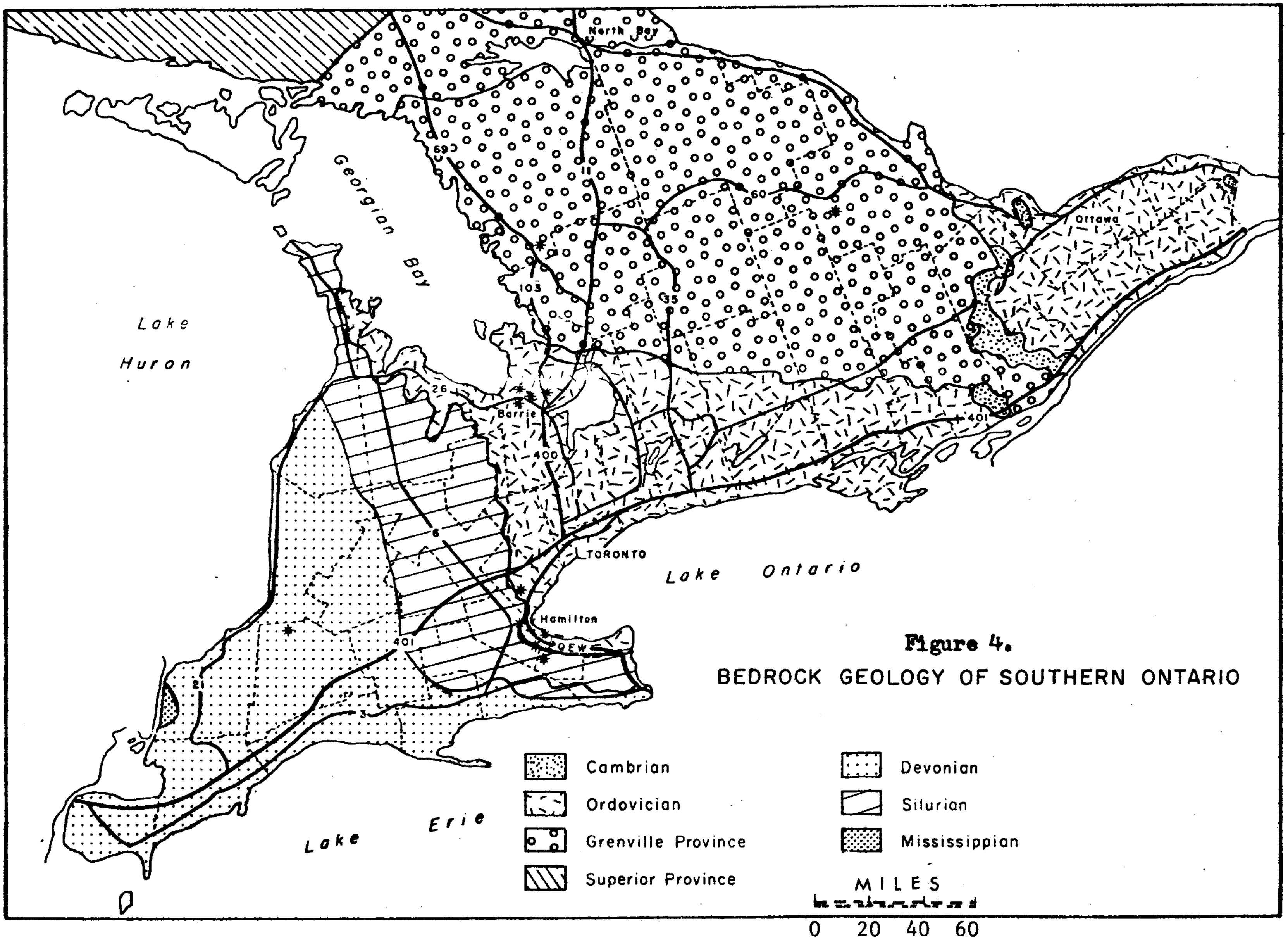
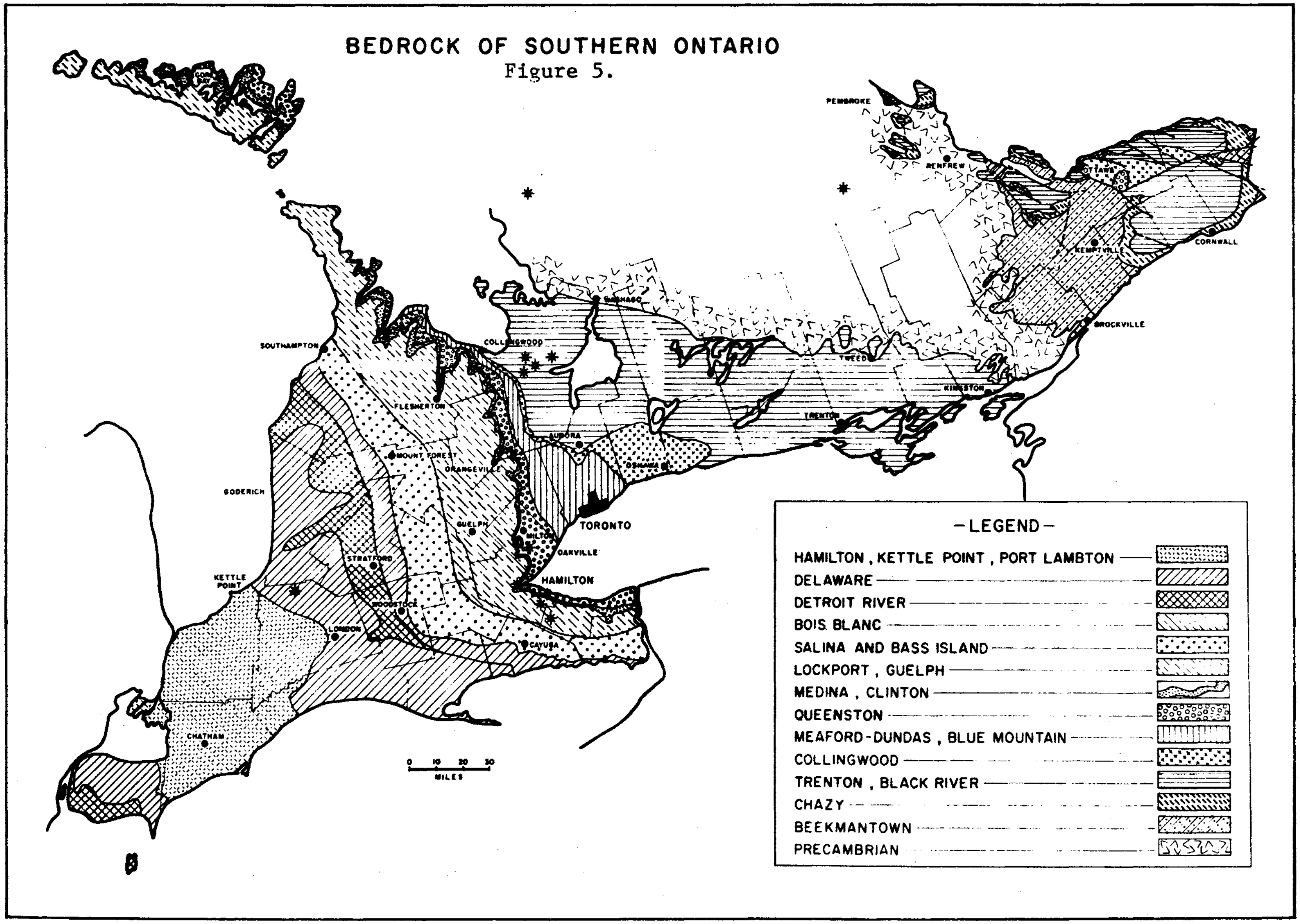


Figure 4.

BEDROCK GEOLOGY OF SOUTHERN ONTARIO



BEDROCK OF SOUTHERN ONTARIO

Figure 5.

Local landforms, usually of glacial drift occur within the major divisions. Their distribution pattern is variable. Chapman and Putman recognize fifty two minor physiographic regions (fig. 6). At the studied sites the following geomorphological information is relevant :

i) The minor physiographical region associated with the Guelph series is the Flamborough Plain, which forms an isolated tract (150 sq. miles) of shallow drift on the Niagara Cuesta north of Hamilton. It is bounded by the Galt moraine on the north-west and by the silts and sands of glacial lake Warren to the south. A few drumlins are found scattered over this limestome plain, and inter-drumlin swamps are numerous. The plain slopes to the south from 1,200 to about 900 feet a.s.l. It is drained by Spencer Creek to the Dundas valley. Productive soils are scarce in this area, being either wet or stony shallow and most of the area is in woods or pasture. Cultivated soil is found mainly on the drumlins and deeper gravel terraces.

ii) The Winona series occurs on the Iroquois plain, which is located between Lake Ontario and the Niagara escarpment extending eastwards from Hamilton to the Niagara river, including terraces adjacent to the escarpment. West of Grimsby the Winona series occurs on red clay derived from Queenston shale. This soil series is heavy in texture and of low permeability. Approximately 70% of the land is in crops chiefly grapes and peaches but other tree fruits and small fruits are grown extensively. The advantages of the area for this production are primarily climatic, due to the proximity of the area to lake water.

iii) The Vineland, Haldimand and Ancaster soil series occur on the Haldimand clay plain (1,350 sq. miles) which lies between the Niagara escarpment and Lake Erie. The northern part has more relief than the southern where a level lake plain occurs. The underlying rocks are a series of parallel belts of limestones, the drainage of which is controlled by modest ridges which direct streams eastward in several parallel valleys. Heavy texture and poor drainage characterize the soil, and where better drained, the most important crops are hay, oats, wheat and corn. The Vinemount moraine with silt-loam soils is planted with grapes, pears and apples. Poorly-drained land is still tree covered.

iv) The Huron series is associated with the Huron slope, which occupies an area of about 1,000 sq. miles along the eastern side of Lake Huron. The land between the Algonquin shorecliff and Wyoming moraine slopes gently upward from 600 to 900 feet a.s.l. It is essentially a clay plain modified by a narrow strip of sand. The shallow till is formed of a brown calcareous clay, containing a minimum of pebbles and boulders, which rests on stratified brown clays. Farmers on these slopes generally emphasize the raising of livestock though oats and hay are the usual crops.

v) The Wyevale, Hendrie and Alliston series are associated with the Simcoe Lowlands, (1,100 sq. miles), located between Georgian Bay and Lake Simcoe. Both the lowlands and the transverse valleys were flooded by Lake Algonquin and are bordered by shorecliffs, beaches and bouldery terraces, and floored by sand, silt and clay. The boundary of this lowland is generally the upper Algonquin beach which lies between 725 and 850 feet a.s.l. The Simcoe lowlands are divided in the Nottawasaga basin which includes the studied soil sites, and the Lake Simcoe basin. The Nottawasaga basin has large areas of imperfectly-drained bogs and valleys which, properly drained, are useful for special crops. The Alliston sandy-loam soil areas are the most important for potato production in the Province, the Wyevale series have better drainage as the Wye River has cut deeply into the adjacent clay beds. Hay, pasture potatoes, tobacco and corn are the most important argiculture products grown.

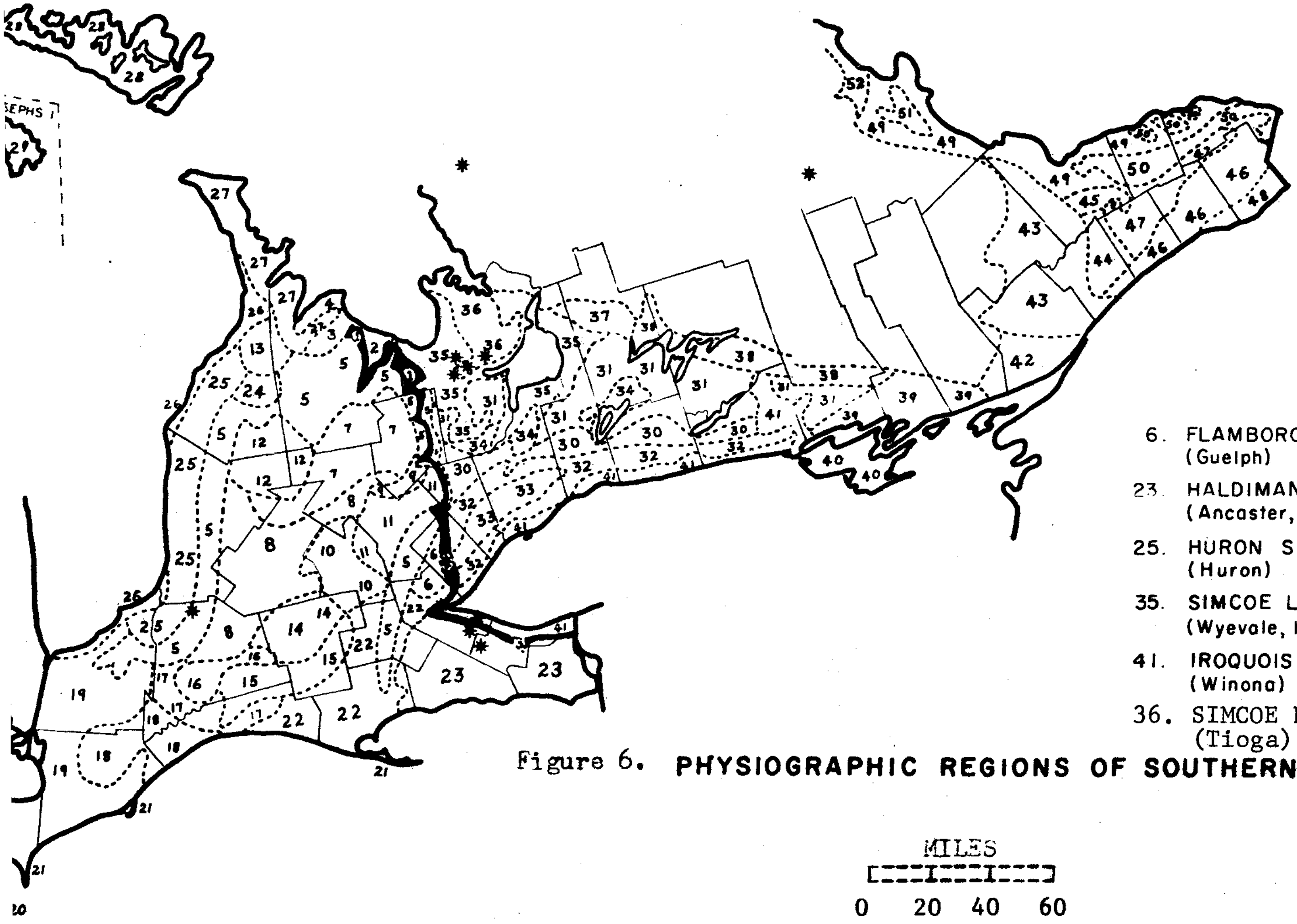
vi) The Tioga soil series occurs in the Simcoe Upland (400 sq. miles), which is composed of a series of broad, curved till ridges standing about 200 feet above the adjoining lake plains at an average of about 1,000 feet a.s.l. The upland tills differ from the till found east of Lake Simcoe, being derived mainly from Precambrian rocks rather than limestones, hence the texture is a gritty loam, becoming more sandy and bouldery towards the north. Well-drained soils dominate these uplands. The agriculture of the Simcoe Upland is classified as mixed farming with a variety of products. It is cultivated more intensively towards the south, possibly as a result of the better soil conditions and a more favourable climate.

vii) The Monteagle soil series is widely developed in Renfrew County where the physiography is controlled to a major extent by the bedrock though some variability of local relief is caused by glacial deposits. Two major physiographic divisions are designated, the Precambrian Upland and the Ottawa Lowland, the elevation of the Upland ranges between 500 and 700 feet in the south and 1,000 and 1,500 feet in the north and west. The surface drainage is provided by a number of rivers, which rise in the Precambrian Upland and flow in a south-easterly direction. The land area is covered with second-growth tree vegetation and with grass where the trees have been cut for pulp wood or destroyed by fire.

viii) The Port-Cockburn soil site occurs in the Parry Sound district which is to the north of the area classified by Chapman. This district is in greater part a hilly or rolling area, made up of Precambrian rock with a thin cover of stony or gravelly material derived from granites.

Because of the differences in the thickness of the soil mantle, there is considerable difference in the amount of moisture that is available for the forest vegetation, depending on the thickness of the soil. In general this soil is of no value for agriculture and is only referred to for its use in forestry.

The local sites of the twelve soil profiles studied are variable. Ten of the twelve studied profiles are located in Southern Ontario, while two are found north of the boundary. This variability in site related to climate, vegetation, parent material and relief has produced soil profiles which differ in their use for agricultural production.



6. FLAMBOROUGH PLAIN
(Guelph)
23. HALDIMAND CLAY PLAIN
(Ancaster, Vineland, Haldimand)
25. HURON SLOPE
(Huron)
35. SIMCOE LOWLANDS
(Wyevale, Hendrie, Allistan)
41. IROQUOIS PLAIN
(Winona)
36. SIMCOE HIGHLANDS
(Tioga)

Figure 6. **PHYSIOGRAPHIC REGIONS OF SOUTHERN ONTARIO**

CHAPTER IV

FIELD AND LABORATORY PROCEDURES

4. 1. Field procedures and sampling methods.

Twelve soil profiles have been selected in Southern Ontario and studied during the summers of 1969 and 1970. Six soil profiles of the Alfisol order were collected from Wentworth, Halton, Middlesex and Lincoln Counties. These soils are largely related to glacial tills and lacustrine clays. Six soil profiles of the Spodosol order were collected from Simcoe and Renfrew Counties and Parry Sound District. These soils are largely related to late-glacial sandy deposits. Figure 1 shows the approximate location of the sampling sites.

Soil descriptive information is given for each horizon in the following order : depth, colour, texture, structure (grade, class and type), consistency (dry, moist and wet), special features (wormcasts, cutans, voids and concretions), roots and the boundary with the next horizon (U.S.D.A, 1960).

Profiles were collected from each site by means of aluminium monolith trays with dimensions of 48" x 6" x 2". Site descriptions were made at the time of sampling. The monoliths were then taken to the pedology laboratory for analysis.

4. 1. 1. Collecting samples for soil analysis.

The samples for soil analysis were taken from fresh pits. The pits were dug at least to a depth of 5 feet and sometimes deeper. Samples were taken at the bottom of the pit and then upwards, collecting about 10 pounds of material from each horizon. The surface of the samples was about 18 inches wide and as thick as the horizon. Rock fragments of more than 3/4 inch in diameter were separated and discarded after identification. Natural horizons that were more than 18 inches thick in the lower part of the profile or 12 inches in the upper part, were divided equally and sampled separately.

The seventy soil samples from the twelve profiles were placed in separate polyethylene bags and made airtight. For the purpose of measuring field bulk density, a flat surface in the sampling pit, either horizontal or vertical, was prepared at the desired depth. The core sampler was pressed into the soil, using caution to prevent compaction. For measuring field compaction a flat surface was prepared in each horizon. The penetrometer (Pocket Penetrometer Model CL-700), was pressed into at least three random places in the soil at each horizon. The average of these three direct readings represents the degree of compaction.

4. 1. 2. Collecting samples for fabric analysis.

Thirty six undisturbed soil samples from twelve profiles were collected for the purpose of studying fabric analysis. Three samples were collected from each profile, one each in the A, B and C horizons respectively. Metal boxes of Kubiena Type were used for this purpose (80 x 65 x 40 cm). The undisturbed soil samples were carefully cut from the flat wall of the soil profiles, using a knife or trowel to make the sample cutting more easy and to cause less disturbance of the soil material. The filled boxes, wrapped in foil, were kept closed by using one or two broad rubber tapes. The orientation of soil samples was done with much care. An arrow was marked on each box to indicate the top of the profile and to show the X axis. Information regarding the depth at which the sample was taken and the name of the soil series were also indicated on the box. The aluminium box was then placed in a polyethylene bag and secured.

4. 2. Laboratory procedures.

When the soil samples arrived in the laboratory, drying was carried out at a 105°F temperature in a drying oven for the purpose of full moisture determination. High temperature was avoided to prevent any irreversible changes in the soil. Soil samples in the right dry condition were passed through a 2 mm round hole sieve, usually by rubbing with the fingers for the Spodosol soil samples, while crushing was necessary in the Alfisol soil samples. The fine soil, with particles less than 2 mm, was used for the physical, mechanical and chemical determinations. The following procedures were used as cited by the U.S.D.A. (1967).

4. 2. 1. Mechanical analysis.

The pipette method for granulometric analysis was used as follows :

a) Preparation of the samples :

- drying (air dry) of 10 gm soil.
- elimination of the fragments > 2 mm (sieving).

- elimination of the organic matter (with H_2O_2).
- elimination of the $CaCO_3$ (with HCl).

b) Procedures :

- wet sieving of 5 gm soil, to separate particles at 0.05 mm.
- the > 0.05 mm particles were separated in different size classes by dry sieving (coarse, medium and fine sand).
- the particles < 0.05 mm were measured after addition of 10 ml 10 % sodium hexametaphosphate to achieve dispersion after stirring.

The sedimentation method was based on Stoke's law, using the pipette apparatus of Köhn. The different fractions were taken at depths of 10 cm. Varying sedimentation times depended on the temperature of the water bath. Different fraction size classes were taken according to the standard classification of particle size distribution (Brewer, 1964).

4. 2. 2. Physical analysis.

4. 2. 2. 1. Field moisture determination : 2 gm samples of soil in an air dry condition were placed into a tared, shallow, weighing bottle. The uncovered bottles were heated for several hours in a drying oven at 110°C. After drying, the soil in the bottles was covered and cooled in a desiccator and weighed again. The percentage of loss in weight was reported as moisture percent for air-dried soil.

4. 2. 2. 2. Loss on ignition determination : The dried samples were transferred to a crucible and heated slowly in an electric muffle furnace to 850°C. This temperature was held for 30 minutes, then the samples were removed and cooled in a desiccator. They were then weighed. The loss of weight represents the percentage of loss on ignition.

4. 2. 2. 3. Bulk density determination : i) Field moist samples; the core method was used. A cylindrical metal sampler was pressed into the soil to the desired depth and was carefully removed to preserve a known volume of soil as it existed in situ. The sample was dried at $105^{o}C$ and weighed. The volume of the oven dried mass, divided by the field volume of the sample was reported as field bulk density. ii) Oven dry samples; the clod method was used. The bulk density of clods was calculated from their mass and volume. The volume was determined by coating the clod with paraffin wax and by weighing it first in air and a second time while immersed in a liquid of known density (water).

4. 2. 2. 4. Specific gravity determination : The particle density of a soil was calculated from two measured quantitites; mass of compacted sample and its volume. The mass of 5 gm soil was determined by weighing; the volume by calculating the amount of water displaced by the mass of the samples.

4. 2. 3. Chemical analysis.

The following procedures were used as cited in 'Methods of Chemical Analysis' by W. J. Hanna in F.E. Bear (ed.). Chemistry of the Soil, 1967, p. 474.

4. 2. 3. 1. Determination of pH value : The test was carried out with glass electrode equipment. The soil suspension was prepared by mixing 10 gm of soil and 50 ml KCl (N). The suspension was left overnight at a constant temperature (usually $20^{o}c$). The test was done after calibrating the instrument with buffer solution, the direct pH reading was reported.

4. 2. 3. 2. Salt concentration (conductivity test) : The soil suspension was prepared by mixing 50 gm of the soil sample with 100 ml of distilled water. The suspension was left for 30 minutes, then the suspension was

shaken every 30 minutes for 3 hours. It was filtered in a Buchner funnel. The filtrate was used to measure the conductivity by a YSI 31 bridge and conductivity cell.

4. 2. 3. 3. Chloride determination : The same extract was used for measuring the chloride with Orion Ionalyzer (model 401 liquid membrane electrode). The electrode potential was observed and the activity (concentration) of the soil extract determined by using the calibration curve.

4. 2. 3. 4. Determination of calcium carbonate : A simple titration method was used. 10 gm of soil in a 150 ml beaker was mixed with 50 ml HCl. The beaker was covered with a watch glass and boiled gently for 5 minutes, cooled, filtered and washed with water to discard all the acid from the soil. The amount of unused acid was determined by adding two drops of phenolphthalein and backtitration with NaOH.

$$CaCO_3 \text{ (meq/l)} : 5 \times \frac{50 \times \text{N of HCl} - \text{ml NaOH} \times \text{N of NaOH}}{\text{gm of soil sample}}$$

4. 2. 3. 5. Organic carbon determination : (Walkley and Black method) : 1 gm of fine soil sample was mixed with 10 ml of N $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4, swirled vigorously for one minute, then add 200 ml water and 10 ml concentrated H_3PO_4 and 0.5 ml of diphenylamine indicator. Titration was carried out with 0.5 N $FeSO_4$ to a light green end point. The organic carbon (pct) is calculated by the formula :

$$\frac{\text{ml } FeSO_4 \text{ blank} - \text{ml } FeSO_4 \text{ sample} \times \text{N of } FeSO_4}{\text{gm of soil sample}} \times \frac{0.30}{0.77}$$

4. 2. 3. 6. Nitrogen determination : Microkjeldahl digestion was used for this test. 5 gm of soil were digested in a 500 ml Kjeldahl flask with 25 ml of 96 % H_2SO_4 and 5 gm $NaSO_4$ for ½ hour or until clear, cooled and diluted with 200 ml distilled water, 100 ml of the NaOH solution added, and a pinch

of zinc dust. The flask was connected to the Microkjeldahl apparatus, distilled about 150 ml into a 250 ml flask containing 50 ml boric acid solution. Titration was carried out with standard acid, using 5 drops of mixed indicator.

$$\text{N (pct)} : 100 \text{ X } \frac{\text{(ml of acid used in sample - used in blank) N}}{\text{gm of soil sample}} \text{ X } 0.014.$$

4. 2. 3. 7. Cation exchange capacity determination : The method of Peech et al (1947) was used for this test : 50 gm of air dried soil (< 2 mm Ø) was placed into a 250 ml flask, 100 ml NH_4O-Ac solution added and shaken occasionally for 2 hours, filtered by suction through a Buchner funnel into a 500 ml flask, the soil washed with 50 ml portion of NH_4O-Ac, eight times, until the filtrate reached 500 ml. The filtrate was used for determining the exchangeable cations, Ca, Mg, K and Na by atomic absorption (Spectrophotometer model 303). The soil was washed with 50 ml portion of ethyl alcohol to remove excess NH_4, the suction flask rinsed and leached with 400 ml NaCl solution. The NaCl extract was transferred to a 600 ml Kjeldahl flask, 0.2 gm Zn granules and 25 ml NaOH solution added, connected with the Kjeldahl distillation aparatus and 200 ml of the solution were distilled with 0.01 N HCl, using a mixed indicator.

$$\text{C.E.C. (meq/100 gm soils)} : \frac{\text{ml HCl x N HCl}}{\text{Wt of soil used}} \text{ X } 100.$$

4. 2. 3. 8. Extractable acidity (total acidity) determination : the North-Central Regional Research Committee method (1955) was used to determine the total acidity in the soil sample. 10 gm soil were leached in 50 ml KCl-triethanolamine solution at pH 7 and followed by washing with 50 ml unbuffered N KCl. A known volume of standard acid was added to the leachate which was then washed. Back titration was carried out on an equal volume

of acid to the same end point for a blank. E. A. (meq/100 g) :

$$\frac{\text{ml NaOH blank} - \text{ml NaOH sample} \times \text{N of NaOH}}{\text{gm of soil sample}} \times 100.$$

4. 2. 3. 9. Silicon determination : Sodium carbonate fusion was used for the determination of silicon. 2 gm of finely ground soil was mixed with five times its weight of $NaCO_3$ in crucible, heated in a muffle furnace to $900^{\circ}C$ for 15 minutes and cooled. The melt was removed with a dilution of HCl. Then 100 ml of concentrated HCl and 10 ml of perchloric acid $HClO_4$ (70 %) were added. The solution was heated in a steam bath until evaporated to dryness. The beaker was washed and the suspension was filtered with a dilution of HCl to a volume of 200 ml. The filter paper, containing the dehydrated silicon residue was transferred to the crucible and dried in the oven at $120^{\circ}C$, then slowly ignited until $900^{\circ}C$ for 15 minutes, cooled in a dessicator and weighed. The percentage loss in weight was reported as silicon.

4. 2. 3.10. Determination of Fe and Al ; Atomic absorption Spectrophotometer (Perkin - Elmer, model 303) was used for this test. 1 gm of soil sample was digested in Nitric and Perchloric acid. The silica was removed with hydrofluoric acid and the solution dried by evaporation. The residue was dissolved in 5 % perchloric acid and this solution was diluted to 50 ml. Cu, Zn and Mn were determined by the same method.

4. 2. 4. Soil Micromorphology.

Preparation of thin sections (Altemüller, 1962). The technique of making thin sections was carried out in the Pedology laboratory where the undisturbed samples were air dried at room temperature (20 to $26^{\circ}C$). During drying, the boxes were uncovered on one side. Small blocks were cut from each sample and put into cartridges made of thin foil of aluminium, the oriented position of the samples being maintained. The impregnating material was then added to each cartridge under vacuum. This material was obtained by mixing the following solutions in order : 100 cc of Vestopal H, 20 cc of monostyrene, 3 drops of Cobalt-octoate (accelerator), 6 drops of Cyclohexanoperoxide (catalyzer). The impregnation should ideally accomplish a complete filling of all existing voids (pores, cracks, interpedal spaces) present in the soil material, without disturbing the soil compounds in their physical arrangements (fabric) and without causing any chemical reaction within the soil constituents. The polymerization of Vestopal H impregnation took about two months at room temperature, then the polymerised material was cut into equal parts; one half was kept in reserve, the other half was mounted on a petrographic slide with a mixture of Vestopal H(9cc), catalyzer (4 drops) and accelerator (3 drops). The thin sections were then cut with a saw (model 105 Ingram Laboratories Incorp.), this to reduce the thickness of the block sample to ± 5 mm. Further grinding with a thin section grinder (model 305) was carried out for every sample to reduce thickness to ± 2 mm. Then the manual surface grinder, using carborundum No 500 was used till the colour of the quartz grains was first order grey. A cover slip was placed on the slide using a drop of the mixture : 9 cc Vestopal H, 6 drops of catalyzer and 4 drops of accelerator to glue it. After drying for a day the thin section was ready for study.

4. 2. 5. Heavy mineral preparation and analysis.

About 5.0 gm of the soil was put in 1N citric acid and stirred with an ultrasonic shaking machine. This process dispersed the grains and also removed the coatings. The samples were dried and the heavy fractions separated with bromoform (S.G. 2.87). The heavy fractions were collected in a petridish and washed with alcohol. The grains were then embedded in Canada Balsam, on a glass slide and protected with a cover slip.

A petrographic microscope was used to identify and count the various grains. The counting procedure consists of traversing the slides in vertical strips. Each mineral that crosses the cross hair is identified and counted. At first one hundred opaque and transparent minerals were counted. This gives the proportion of opaque minerals. Next further counting of only transparent minerals was made till at least one hundred were counted. This gives an estimate of the various types of transparent minerals. Three samples of every profile were studied : the first heavy mineral sample was collected from the top of the profile (A horizon), the second from the diagnostic horizon (B horizon), the third from the bottom (C horizon).

4. 2. 6. X-ray analysis.

The following procedure was cited by Vemuri (1967) :

4. 2. 6. 1. Preparation of the sample :

a) crushing 50 gm oven dry soil by using agate mortar,

b) removing carbonates, by soaking about 20 gm of the crushed soil in 400 ml of 0.25 N CH_3COOH for one week,

c) repeated washing to free from acid,

d) dispersion by using an ultrasonic probe (Ficher Scientific B-P-10/CW-10) for 10 to 20 minutes,

e) size fractioning by transferring the suspension to one litre cylinders and diluting, stiring and allowing to settle for 3 hours and 45 minutes. The top 5 cm of the suspension was removed (around 170-200 mls). This removed part would supposedly contain < 2 u size fractions;

f) recovering the < 2 u size fractions by centrifuging (Sorvall superspeed RC_2-B automatic refrigerated centrifuge 10,000 RPM, 5 min.),

g) mixing the clay to avoid density segregation while centrifuging, a small part was used for preparation of slides for clay mineral identification.

4. 2. 6. 2. Glass slide preparation : 5 slides have been prepared for every sample and three samples were selected in every profile. A small proportion of the well stirred clay from the centrifuge tube was taken with a thin nickel spatula and applied to the frosted sides of four slides. The smear technique was adopted as it was found to be more accurate and precise (Gibbs, 1965). The first slide was left without treatment, the second slide was heated in a muffle furnace to 350°C for 12 hours, the third slide was heated in a muffle furnace to 550°C for 12 hours, the fourth slide was glycomated for 12 hours in glycol vapour, generated in dessicator at 60°C. The slides were left sitting on a large-holed porcelain plate. The clay of the fifth slide was left in the centrifuge tube for K saturation. A N KCl solution was added and centrifuged in a table model cylinder centrifuge, then the KCl solution was removed. Distilled water was added and again centrifuged to remove the excess KCl. The fifth slide was prepared with KCl saturation-clay. The glass slides were identified by marking with a glass scribe.

An x-ray generator of Phillips (East Europe), of the Department of Metallurgy and Material Science, Faculty of Engineering, McMaster University was used for testing the samples.

The scheme for identification of clay mixture by x-ray diffraction of R. Vemuri (personal communication) was used as follows :

a) Kaolinite : peaks at 7 Å, 3.5 and 2.3 Å; the peaks died by heating to 550°C.
b) Illite : 10 Å.
c) Chlorite : peaks at 14 Å, 7 Å, 4.7 Å; no change after glyconation, K saturation or heating to 350°C.
d) Montmorillonite : 14 Å expanding to 17 Å on glyconation.
e) Vermiculite : peaks at 14, 7, 4.5 Å; no change after glyconation.
f) Mixed layer clays : 10 - 14 Å.

4. 2. 7. <u>Electron microscope analysis</u>.

The parent material, the diagnostic B horizon and the upper layer of the soil profiles of the Alfisol order were sampled to study clay minerals by the electron microscope. Clay is usually examined in the form of the individual particles which may be dispersed either by wet or dry method (Kittrick, 1965). In this case the wet method was used as described below :

a) A diluted suspension of the clay sample was taken from the centrifuge during the preparation of x-ray samples.
b) A small amount of this suspension was sprayed on the film-coated grid, so that each drop covered one discrete unit square.
c) Black and white pictures were taken from the screen of the electron microscope for the purpose of identifying the clay minerals.

The test was carried out by electron microscope column (Phillips E M 300 model) at the Department of Metallurgy and Material Science, Faculty of Engineering, McMaster University.

CHAPTER V

MORPHOLOGY, MICROMORPHOLOGY AND ANALYSES OF THE SIX ALFISOL PROFILES

The six Alfisol profiles are developed upon glacial till or lacustrine deposits. The diagrammatic horizon patterns of these profiles are illustrated in Figure (7). The Canadian series and group names and the American names for the soils are appended. Soil morphological characteristics and descriptions are given for each horizon in the following order : depth, color, texture, structure, consistency, organic matter, pedological features and the boundary of the following horizon. This system of soil characteristics and description was confirmed for international usage by the West European Working Group on Soil Structure (1967).

Soil micromorphological characterization and description were made on thin sections with a Vickers polarizing microscope for each of the three main horizons of each profile. These are, the upper surface horizon, the textural ($B_{22}t$) horizon and the lower C horizon. The micromorphological descriptions are given in the following order : skeletal material, plasma, voids, nodules, cutans and elementary structure:

1) Skeletal material : The distribution pattern of the skeleton grains was classified according to Brewer (1964) into continuous, striated or flaked distribution patterns.

2) Plasmic material : Descriptions of plasmic fabric were based on interpretation of optical properties under crossed nicols, especially extinction phenomena. The degree of orientation of the clay was described according to Brewer (1964).
3) Voids : The voids were classified at a magnification of X 30 according to their morphological types as suggested by Brewer (1964).
4) Nodules and Concretions : The micromorphology of these features was generally described at X 30 according to Brewer's criteria, noting (i) internal fabric, (ii) morphological nature, (iii) distinctness.
5) Elementary structure : Descriptions were based on the arrangement of the soil constituents in relation to each other. The elementary structures were described according to the terminologies of Kubiena (1938), Brewer (1964) and Beckman and Geyger (1967).
6) Dimensions and abundance of micromorphological features (nodules, concretions, skeleton grains and voids) and the thickness of cutanic features were measured with an eye-piece graticule.
7) Photographs : Photographs of micromorphological features were taken with a 35 mm camera, mounted on the microscope with a separate field ocular for viewing the specimen and focussing the camera. Black and white pictures were taken. The photomicrographs are X 3 enlargements of the original positives.

There follows detailed descriptions of each soil series at the site chosen, which are also annotated for future reference purposes, while micromorphological descriptions of each horizon and the

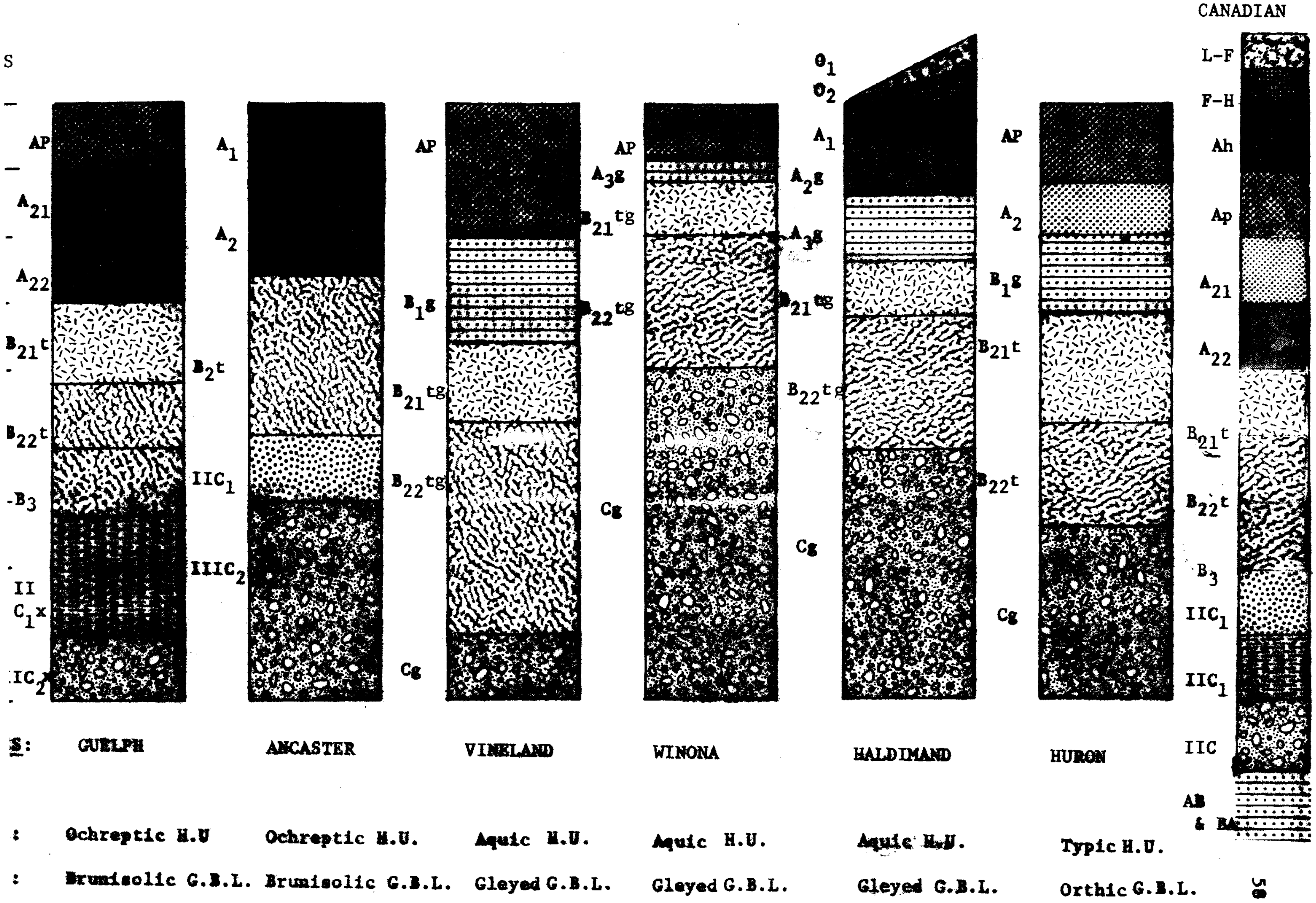


FIGURE 7 : DIAGRAMMATIC HORIZON PATTERNS OF THE SIX ALFISOL PROFILES

appropriate photographs are provided. Each sequence of independent data on each series is then compared in a review which attempts to establish relationships of macro and micromorphological features and the mineralogical and physico-chemical soil properties.

5. 1. GUELPH SERIES

5. 1. 1. Site description.

Location : a) Mount Nemo, b) Top. Map Hamilton, Ontario, 30 M/5 West half. 91.2 - 07.7, c) Reference Map, 43°45' N, 79°30' W.

Weather condition : Sunny, no rain in previous week, temp. 72°F (21/5/1969).

Soil series : Guelph Series : 12,900 acres, Halton Co. Survey Rpt. 43.

Soil type : Loam soil with textural B horizon, moderately deep phase, weathering clay and calcareous shales at a shallow depth. Good drainage (Kf-aba).

Canadian classification (1970) : Brunisolic Gray-Brown Luvisol.

American classification (1968) : Ochreptic Hapludalf.

Climatic classification : a) Guelph b) $B_1 d\ C'_2\ b'_2$ type.

Vegetation : The field was cultivated with wheat in good condition; the area is surrounded by forest on three sides and was formerly forested.

Parent material : Loam till, mainly dolomite.

Geology and bedrock : Guelph formation, cream to buff dolomite, Siluran.

Topography : a) Geomorphology - soils developed on drumlins and rolling glacial land forms; slopes ranging from 6 to 15%. b) Relief - gentle slope, 3-5%, from the north to the south. c) Elevation - 940 feet. d) Drainage; i) external - moderately, slow run off, ii) internal - moderately slow, iii) drainage class - good. e) Ground water table - temporary water table, pseudogley soils, depends on the presence of the fragipan horizon in the subsoil.

Land capability : The Guelph soils used principally for forage crops, spring grains and winter wheat; some level areas used for growing silage, grain corn and potatoes. Erosion is a problem in some areas and gullies are frequently on some steeper slopes.

Remarks : Profile is deep-phased with insequent albic horizon and a fragipan.

5. 1. 2. Horizon description.

0- 5" Ap Dark reddish-brown (2.5YR 2/4), clay loam, moderately weak aggregation with medium crumb to blocky structure, soft, friable, abundant fibrous roots and many earthworms, numerous fine pores, diffuse boundary.

5-10" A_{21} (Ae_1) Dark reddish-brown (5YR 3/4), clay loam, moderately strong aggregation, medium subangular blocky slightly hard, firm and sticky, few old roots and some earthworms, numerous fine pores on aggregate surfaces, gradually merging boundary.

10-15" A_{22} (Ae_2) Reddish-brown (5YR 4/3), silt loam, moderately strong aggregation, medium angular blocky, hard firm sticky, some old roots and occasional earthworms, some fine pores on ped surfaces, few nodules of weathering limestone, light gray (10YR 7/2); old root channels coated by decayed humus, boundary gradually merging.

15-21" $B_{21}t$ Dark reddish-brown (2.5YR 3/4), clay, strong aggregation, medium to fine angular blocky, hard firm sticky, 5% small gravel of weathering limestone and shale, some fine pores, a few fine fissures on ped surfaces, few old root channels coated with clay diffuse boundary.

21-26" $B_{22}t$ Reddish-brown (2.5YR 4/4), clay, very strong aggregation, medium sub-angular, very hard firm and sticky , 2-3% small gravel of weathe-

Fig. 8, medium crumb structure in the Ap horizon of the Guelph series.

Fig. 9, medium subangular blocky structure in the B_{22}t horizon of the Guelph series

Fig. 10, coarse angular blocky structure in the IIC_2x horizon of the Guelph series.

ring shale and limestone, abundant skins on surface of aggregates, distinct boundary.

26-31" B_3 Reddish-brown (2.5YR 5/4), silty clay loam, strongly aggregated, medium to fine angular blocky, hard firm and slightly sticky consistency, boundary distinct, wavy.

31-40" IIC_1x Yellowish brown (10YR 5/6), silt loam, very strong aggregation, thin platy, very hard firm slightly sticky, boundary distinct wavy.

40"+ $IIIC_2x$ Grayish-brown (2.5Y 5/2), loamy, very strongly aggregated fine to medium angular blocky, very hard firm and sticky consistency.

5. 1. 3. Micromorphological description.

Ap horizon (0-5").

S-MATRIX

Skeleton : 200 u angular to subangular fragmented quartz, 150 u subangular plagioclase, scattered in the s-matrix, some muscovite flakes randomly distributed.

Plasma : Light brownish-yellow in general, few reddish patches as a result of plasmification of the organic matter.

Plasma fabric : Argill-silasepic; ma- skelsepic plasmic fabric.

Voids : 900 x 300 u very fine macro-prolate irregular ortho-vughs and 60 u meso-tubular ortho-channels.

Organic matter : 200 to 600 u prolate and tubular isotropic brown reddish-brown to black, strongly decayed fragments of plant residues. The plasmified organic matter was incorporated with the s-matrix (Fig. 11).

Basic structure : Ortho-vughs with argillasepic plasmic fabric, high proportion of plasma mass as well as voids and small proportion of skeleton grains. Related distribution was porphyroskelic in most parts.

Proportion : Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Most dominant separations occur subcutanically to skeleton with low interference colour, other separations occur in various patches to give varied types of plasmic fabric.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : The plasma mass was in an ultimate stage of weathering hence no lithorelicts.

Sedimentary relict : Argill-silasepic plasmic fabric indicated evidence of well sorted material in the s-matrix. The pedoturbation process may affect the microstratification.

ELEMENTARY STRUCTURE

After Kubiena (1938): Porphyropectic fabric.

After Brewer (1964) : Ortho vughs with argillasepic plasmic fabric.

After Beckman (1967): Fragmented structure.

$B_{22}t$ horizon. (21-26").

S-MATRIX

Skeleton : 100 u subangular to subrounded quartz, some muscovite flakes scattered, 75 u angular flakes of biotite, 125 u rounded tourmaline.

Plasma : Compact brown to light-brown with very small patches of iron stain scattered in the s-matrix.

Plasma fabric : Ma-vo-skel-omnisepic plasmic fabric.

Voids : 70 u meso-tubular regular meta-channels; 125 u macro-round irregular ortho-meta-vesicles and, 65 u meso-arcuate mammilate meta-vughs.

Organic matter : 100-500 u rounded to angular fragments dispersed sparsely in the s-matrix, isotropic, brownish-black.

Basic structure : High proportion of plasma mass and relatively low proportion of skeleton grains and voids were scattered in the s-matrix. Related distribution was porphyroskelic.

Proportion : Pl > Sk > V.

ORTHO PEDOLOGICAL FEATURES

Plasma separation : The patches in the s-matrix with striated orientation have adjoined each other with well developed plasma separations. In a few patches the separations were banded and had continuous extinction colour, other types were mainly subcutanic to voids and skeleton.

Plasma concentration : i) Glaebules - strongly adhesive 150 u round regular sharp sesquioxide nodules and very strong adhesive 200 u round irregular manganiferous nodules were generally without differentiation; ii) Cutan - 50 u illuvial ortho-vugh argillan with parallel orientation; 80 u illuvial channel argillan occur as a thin layer around the inside wall of the channel and 25 u stress free-grain argillan.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large rock grains (quartz, feldspar and mica) were found floated from the parent material.

Pedo-relict : Normal nodule with plasmic fabric. Figure 12.

Sedimentary-relict : Microstratification, seen around the channel type voids.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic plasma fabric.

After Brewer (1964) : Illuvial channel argillan with regular meta vesicles and masepic fabric.

After Beckman (1967) : Irregular jointed structure.

IIC$_2$x Horizon (31-39").

S-MATRIX

Skeleton : 50 u subrounded quartz, a small number of muscovite flakes, 75 u rounded to subrounded plagioclase, scattered in the s-matrix.

Plasma : Homogeneous material of light yellow, well compacted.

Plasma fabric : Silasepic (Figure 13) some insepic plasmic fabric.

Voids : 70 u meso-round to prolate irregular ortho-compound packing; 9 u crypto-acicular irregular meta-joint planar, 25 u micro-arcuate mammilate meta-vughs.

Basic structure : High proportion of plasma mass with very few voids and skeleton grains. Skeleton grains appear embedded in the plasma mass. Related distribution was porphyroskelic.

Proportion : Pl > Sk ≃ Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Insepic plasmic fabric related to dark yellowish-brown patches, generally moderate birefringent extinction colour.

Plasma concentration : Glaebules - strong adhesive 350 u round sharp regular sesquioxidic nodules; strong adhesive 400 x 200 u prolate regular shale-nodules (rock fabric), strong adhesive 500 u round regular sharp natural nodules.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz, pyroxene and muscovite grains were floated from the parent material.

Pedo-relict : Natural argillan nodules with rock fabric.

Sedimentary-relict : Microstratification features were related to the planar voids that have horizontal direction to the surface of the profile.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric.

After Brewer (1964) : Natural nodules, compound packing with silasepic fabric.

After Beckman (1967) : Porous structure.

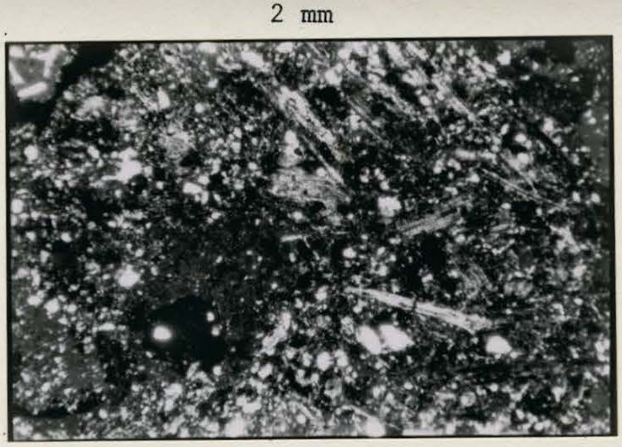


Fig. 11, plant fragments, slightly decomposed, are scattered in the s-matrix of the Ap horizon of the Guelph series at 4 inches depth, under normal light. 35X.

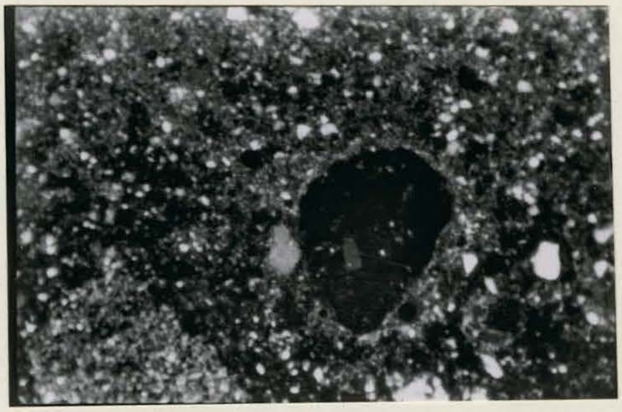


Fig. 12, normal nodule with soil fabric (pedorelict) in the B_{22}t horizon of the Guelph series at 25 inches depth, under normal light. 35X.

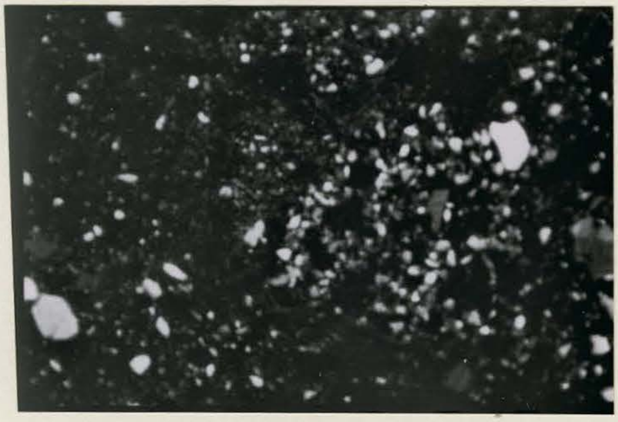


Fig. 13, silasepic plasmic fabric in the IIC_2x horizon of the Guelph series at 35 inches depth, under normal light. 35X.

TABLE 1. CLIMATIC DATA (GUELPH)

Soil Series : GUELPH

Climatic type = $B_1 C_2 d b_2$

Months Data	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN.
Mean temperature (F°)	20	18	29	42	54	63	68	66	59	48	36	24	44
Mean precipitation (Inches)	2.4	1.7	1.8	2.4	2.7	2.8	3.1	2.9	2.5	2.4	2.4	2.1	29.3
Potential evapotranspiration (P.E.) mm.	0	0	0	28	75	110	133	109	79	49	7	0	581
Precipitation (P) mm.	61	44	45	60	69	72	78	73	64	61	62	54	743
Storage (St) mm.	372	416	462	300	294	259	215	191	181	202	257	311	---
Actual evapotranspiration (A.E.) mm.	0	0	0	28	75	107	122	97	74	40	7	0	550
Water deficiency (D) mm.	0	0	0	0	0	3	11	12	5	0	0	0	31
Water surplus (S) mm.	0	0	0	161/32		0	0	0	0	0	0	0	193

Aridity index = 5.64 per cent (d)

P-E = 55.0 mm. (C_2)

Summer concentration = 59.27 per cent (b_2)

Moisture index = 31.71 per cent (B_1)

TABLE 2. PARTICLE SIZE ANALYSIS (u%)

Soil Series : GUELPH

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
Ap	0-5	2.6	3.8	34.0	11.0	4.0	5.8	13.6	11.9	13.3	46.2	40.4
A_{21}	5-10	2.5	4.0	26.3	15.7	0.0	7.1	10.2	14.8	19.5	47.8	32.7
A_{22}	10-15	1.8	2.9	20.7	8.3	12.4	8.7	17.0	13.9	14.3	60.3	25.4
$B_{21}t$	15-21	2.3	3.5	11.7	8.3	0.7	14.6	9.9	7.5	41.7	41.0	17.3
$B_{22}t$	21-26	2.6	1.0	19.1	8.7	9.6	8.4	8.9	2.0	42.0	37.6	20.4
B_3	26-31	0.8	2.4	16.4	24.6	1.2	14.8	11.0	3.6	27.3	55.2	17.5
IIC_1	31-40	2.7	2.9	11.9	5.0	10.8	13.2	17.6	19.9	16.1	66.5	17.4
$IIIC_2$	+40	1.1	2.9	33.6	18.9	2.6	12.4	12.2	1.5	17.4	47.6	35.0

TABLE 3. PHYSICAL ANALYSIS

Soil Series : GUELPH

Horizon	Depth Inches	Compaction Kg/cm^3	Horizon Domin. %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
Ap	0- 5	1.7	13	2.5YR	2	4	-	1.56	2.49	37	24.5	5.18	8.66
A$_{21}$	5-10	2.0	13	5 YR	3	4	-	1.66	2.67	39	19.5	0.94	4.75
A$_{22}$	10-15	2.3	13	5 YR	4	3	-	1.55	2.72	44	21.3	0.46	4.71
B$_{21}$t	15-21	2.9	15	2.5YR	3	4	-	1.31	2.51	48	21.3	1.44	5.10
B$_{22}$t	21-26	3.2	13	2.5YR	4	4	-	1.40	2.50	45	25.4	0.24	3.60
B$_3$	26-31	3.8	13	2.5YR	5	4	-	1.33	2.47	48	27.9	0.10	3.38
IIC$_1$x	31-40	4.5	25	10YR	5	6	-	1.50	2.50	41	22.8	0.14	3.92
IIC$_2$x	+40	4.3	-	2.5Y	5	2	-	1.58	2.42	36	30.0	0.16	3.07

TABLE 4. CHEMICAL ANALYSIS

Soil Series : GUELPH

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil					C.E.C meq./100 g	$CaCO_3$ equiv. %	Cl (ppm)	E.C mm./cm. 20° (10^{-3})	C %	N %	C/N
		H_2O	KCl	Ca	Mg	Na	K	H							
Ap	0- 5	5.0	4.9	1.82	2.18	2.67	1.21	8.10	15.99	3.74	139	6	2.59	0.136	19
A_{21}	5-10	5.1	4.7	2.38	1.44	1.42	0.52	5.80	11.57	0.51	69	71	0.47	0.034	16
A_{22}	10-15	5.2	4.8	2.89	1.72	0.83	0.34	4.20	9.99	0.99	80	11	0.23	0.020	12
$B_{21}t$	15-21	5.9	5.4	3.15	2.22	0.99	0.34	6.30	13.01	2.14	84	13	0.72	0.056	12
$B_{22}t$	21-26	6.1	5.7	3.22	2.16	1.23	0.42	2.40	9.43	0.48	110	80	0.12	0.021	6
B_3t	26-31	5.8	5.3	3.14	1.78	1.27	0.45	5.20	11.83	1.32	115	14	0.05	0.005	5
IIC_{1x}	31-40	6.8	6.0	4.07	2.15	1.66	0.48	1.00	9.36	11.68	105	10	0.07	0.020	3
IIC_{2x}	+40	8.2	7.5	7.00	1.29	1.20	0.33	0.20	10.01	10.72	115	13	0.08	0.028	4

TABLE 5. ELEMENT ANALYSIS

Soil Series : GUELPH

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
Ap	0- 5	6.3	231	251	4.46	15.26	53.4	3.48	6.34	5.25
A_{21}	5-10	13.8	273	248	5.60	17.25	65.1	3.81	6.89	5.58
A_{22}	10-15	17.6	313	262	6.01	17.82	51.1	4.25	6.04	4.78
$B_{21}t$	15-21	14.9	217	244	5.56	15.32	69.5	4.66	7.67	6.28
$B_{22}t$	21-26	15.4	215	245	5.52	16.22	64.9	3.36	8.17	6.57
B_3	26-31	14.8	200	236	5.22	14.36	59.3	3.28	7.43	5.96
IIC_1x	31-40	15.3	233	248	5.58	13.96	67.4	3.78	8.66	6.47
$IIIC_2x$	+40	12.6	163	236	4.62	13.14	64.3	2.91	8.89	7.17

TABLE 6. CLAY MINERAL ANALYSIS

Soil Series : GUELPH

Horizon	Depth Inches	Montmorillonite	Illite	Kaolinite	Chlorite	Vermiculite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
Ap	0- 5		+	++++	+	+	++	+			
$B_{22}t$	21-26		+	+++	+	+	++++	+++			+
IIC_1x	31-40		+	++++	+	+++	++++	+++	+		

5.1.4. Discussion and First Interpretation

The Guelph profile has developed on a loam till derived mainly from dolomite. This profile (Fig.'s 8 to 13) conforms to the Brunisolic Gray-Brown Luvisol sub-group, according to the Canadian soil classification (1970). Guelph soils are associated with loam surfaces, good drainage and thick textural B horizon. A small amount of weathering shale and calcareous fragments was found at a shallow depth in the $B_{22}t$ horizon. The Guelph profile studied is a deep phase with an intensely eluviated A_2 horizon and bisequal development in the C horizon. Kaolinite was found to be dominant clay mineral throughout the Guelph profile, derived from the parent material.

The relationship between the soil morphology, micromorphology and soil analysis will now be discussed in detail in the Ap, $B_{22}t$ and IIC_2x horizons of the Guelph profile. The Ap horizon with 5.25 silica - sesquioxide ratio and clay loam texture exhibits an argillsilasepic plasmic fabric. The $B_{22}t$ horizon with silica-sesquioxide ratio of 6.57 ratio and clayey texture exhibits masepic plasmic fabric while the II C_2x horizon with 7.17 ratio and silt loamy texture exhibits silasepic plasmic fabric. It is clear that a relatively light texture is largely associated with plasma fabric without separation while the heavy texture is related to plasma fabric with a separation pattern.

The relationship of soil porosity and penetrability to soil microvoids pattern in the three horizons of Guelph profile show that the Ap horizon with penetrability of 1.7 kg/cm^3 and 37% porosity exhibits numerous fine pores on the surface of the weakly-aggregated peds and some infrequent 900 U very fine macro ortho-vughs. The B$_{22}$t horizon with 45% porosity and strong degree of aggregation and a penetrability of 3.2 kg/cm^3 exhibits 125 u macro meta-vesicle voids while the II C$_2$ x horizon with 48% porosity, very strong aggregation and 4.5 kg/cm^3 penetrability exhibits 70 U meso ortho-compound packing voids in thin sections. It may be explained that the size and form of the voids tends to decrease with depth in the profile while the total porosity and penetrability increases simultaneously.

Textural discontinuity was established in the II C$_2$x horizon because of significant changes in texture, structure and consistency in this horizon. There is an increase of 28.9% in silt material below this discontinuity. Such an increase is reflected in the high proportion of plasma as a soil constituent.

The Ap horizon with medium crumb structure and fragmented micro-structure can possibly be related to the high organic matter content of 5.18%. The B$_{22}$t horizon with medium subangular blocky structure and irregular jointed microstructure is affected by accumulation of clay, of which 28.7% is accumulated. The II C$_2$x horizon with platy structure and porous microstructure may be influenced by the presence of almost 12 percent carbonate.

5. 2. ANCASTER SERIES

5. 2. 1. Site description.

Location : a) Ancaster Town - between Highways No 99 and 2. b) Soil Map - Wentworth County, Ontario, Soil Survey Report No 32, c) Reference Map, Lat. 43° 14' N., Long. 80° 00' W.

Weather condition : Sunny, no rain, no clouds, temp . 75°F (26/6/1969).

Soil series : Ancaster series, 5,850 acres.

Soil type : Clay soil with texture B horizon and good drainage (Eba).

Canadian classification (1970) : Brunisolic Gray-brown Luvisol.

American classification (1968) : Ochreptic Hapludalf.

Climatic classification : a) Hamilton Station. b) $B_1d\ C'_2\ b'_2$ type.

Vegetation:: First class forest, pine trees.

Parent material : Deep silt loam and fine sand.

Geology and bedrock : Lockport Amabel formation (buff), and Silurian gray dolomite.

Topography : a) Geomorphology - the Ancaster soils consist predominantly of brown-silty clay loam soils which are found on the ridges and moraines surrounding and separating the ravines of the Dundas Valley. The slopes range between 10 and 15%. b) Relief - moderately gentle slope, 5-7%, from N to S. c) Elevation - 550 feet. d) Drainage - i) external - moderately rapid run off, ii) internal - moderately slow permeability, iii) drainage class - good. e) Ground water table - pseudogley with sloping ground water table.

Land capability : Crop production on the Ancaster soils is mainly limited to forage and winter-wheat. Growing of tree-fruits is popular on these soils. The agricultural production is limited in general because of the many steep slopes and their accompanying problems of erosion and management.

Remarks : The topography has much influence on the development of this soil type.

5. 2. 2. Horizon description

0-6" A1 (Ah) Very dark, grayish-brown (10YR 3/2), silty loam, weak aggregation, fine crumby blocky, soft, friable and slightly sticky consistency, abundant fibrous roots, and a few long woody roots, numerous fine pores on the surface of the aggregation, boundary gradually merging.

7-13" A_2 (Ae) Very dark grayish-brown (10YR 3/2) upper layer and brown (7.5YR 5/4) lower layer, silty loam, moderately strong aggregation with medium crumb and subangular blocky structure, moderately hard, friable, slightly sticky, few fibrous roots, few small woody roots, few earthworms, abundant fine pores on ped surfaces, irregular diffuse boundary.

13-25" B_2t Brown (7.5YR 5/4), clay loam, strong aggregation with medium subangular blocky structure, hard, firm and sticky consistency, 5% weathering shale fragments, few small roots and plenty of earthworms, abundant fine pores on ped surfaces, few root channels, coated by reddish brown (5YR 4/3) humus, diffuse irregular boundary.

25-30" II C_1 Grayish-brown (10YR 5/2), sandy loam, weakly aggregated fine granular to blocky, soft consistency, friable, no biological activity, distinct wavy boundary.

Fig. 14, fine crumb structure in the A_1 horizon of the Ancaster series.

Fig. 15, coarse angular blocky structure in the B_2t horizon of the Ancaster series.

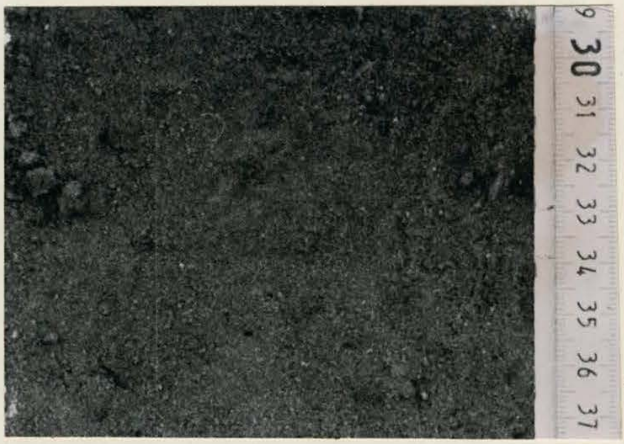


Fig. 16, fine granular structure in the IIC_1 horizon of the Ancaster series.

30" + III C2 Reddish-brown (2.5YR 5/4), silty clay, very strong aggregation with medium angular blocky structure, very hard consistancy, very fine and very sticky, 5% weathering shale fragments, some fine pores and numerous fine fissures on ped surfaces.

5. 2. 3. Micromorphological description.

Ah (Al) horizon (0-6").

S-MATRIX

Skeleton : 50 - 200 u angular to subangular quartz, some muscovite flakes, scattered, 90 u rounded tourmaline and 80 u rounded augite were scattered in a small amount.

Plasma : Yellowish-brown in general with small patches of reddish brown colour.

Plasma fabric : In-vosepic plasmic fabric. (Fig. 17).

Voids : 450 u very fine macro-round mammilate ortho-vughs, 550 x 250 u macro-prolate regular ortho-vughs, the origin of these types of voids was suggested as a result of the pedoturbation process. 700 u meso ortho-channel voids. (Fig. 17)

Organic matter : Fragments of organic matter were scattered in the s-matrix and were strongly humified, few undecomposed plant remains with cellular structure intact; an isotropic reddish to brownish black. Plasmification of organic matter gives the yellowish-brown colour of the s-matrix.

Basic structure : Ortho vughs with insepic plasmic fabric, the plasma mass was very compact in general, with embedded skeleton grains. Related distribution was porphyroskelic.

Proportion : Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURE

Plasma separation : The in-vosepic plasmic fabric was generally related to the lighter yellow patches in the s-matrix and highly birefringent.

Plasma concentration : Glaebules - Very strong adhesive 200 u equant regular very sharp sesquioxidic nodules (without differentiation).

Cutans - 10 u stress free-grain organo-argillan without orientation.

Bioformation : Pedotubules - 1500 u tubular sharp paragranotubules (without differentiation).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Intergraded large grains of mica and feldspar were floated from the parent material.

Sedimentary-relict : There was no evidence of stratification as a result of the activity of fauna in this horizon.

ELEMENTARY STRUCTURE

After Kubiena (1938): Porphyropectic plasma fabric.

After Brewer (1964): Meta sesquioxidic nodules with ortho vughs and insepic plasmic fabric.

After Beckman (1967): Spongy structure.

B_2t horizon (13-25")

S-MATRIX

Skeleton : 150 u angular to subangular fragmented quartz, small number of flakes of muscovite, 150 u subrounded plagioclase and microcline were scattered in the s-matrix. 100 u rounded tourmaline and 75 u flakes of biotite, were in small number and randomly distributed.

Plasma : Yellowish-brown, in general with small patches of reddish-brown.

Plasma fabric : Vo-mo-skelsepic plasmic fabric. (Fig. 18)

Voids : 155 u very fine macro-round regular meta-vughs; 30 u micro-acicular regular meta-joint planar; 55u meso-round irregular ortho-compound packing and 200 u macro-tubular regular meta-channels were vertical on the surface of the horizon.

Basic structure : Relatively dense plasma fabric, compact with randomly distributed skeleton grains, a few large voids. Related distribution was porphyroskelic.

Proportion : Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The dominant type of separation was mosepic plasmic fabric, most of the mosepic types were confined to the few microstratifications with lighter coloured material; only a few separations occuring subcutanically to voids and skeleton grains.

Plasma concentration : Glaebules - Strongly adhesive 500 x 350 u prolate sharp regular meta-sesquioxidic nodules, Fig. 18, very strongly adhesive. 400 u equant sharp meta-manganiferous nodules, were without differentiation, 850 x 390 u prolate sharp regular shale nodules and 600 u round regular quartz nodules have rock fabric. Cutans - 40 u illuviation vughs argillan with strong orientation; 13 u stress free-grain argillan without orientation; 85 u diffuse vugh sesquans with weak orientation and 23 u illuvial embedded grain-sesquan with weak orientation. Subcutans - Argillan neo-cutans associated with channels and sesquans; neo-cutans associated with channels.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large shale and quartz grains were floated from the parent material. (Fig. 18)

Pedo-relict : Natural shale nodules with parallel orientation.

Sedimentary-relict: Microstratification was found related to the joint-planes, well sorted material was scattered in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938): Porphyropeptic plasmic fabric.

After Brewer (1964): Illuvial vugh argillan with meta vughs and vosepic plasmic fabric.

After Beckman (1967): Fragmented structure.

IIC_1 horizon (25-30")

S-MATRIX

Skeleton : 425 u subangular to subrounded quartz, 550 u subangular freshly weathered plagioclase, 350 u edge corroded muscovite flakes were scattered in the s-matrix, small number of 250 u rounded hornblende were randomly distributed.

Plasma : Reddish-brown in colour, homogeneous.

Plasma fabric : Coated organo-ferric ortstein intergrading to moder like humus ortstein (after Kubiena, 1938); skelsepic plasmic fabric (after Brewer, 1964).

Voids : 70 u meso-angular regular meta-simple packing voids (Fig. 19) as a result of compaction process, 125 u macro-round regular meta-compound packing and 350 x 150 u macro-prolate irregular meta-vughs.

Basic structure : High proportion of skeleton grain, moderate proportion of voids and small proportion of plasma mass, were scattered in the s-matrix. Related distribution was porphyroskelic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Moderately high birefringent extinction colour related to the lighter reddish-brown colour in the s-matrix.

Plasma concentration : Glaebules - Strong adhesive 500 u round sharp meta-organo-ferran nodules; strong adhesive 700 u round sharp meta-sesquioxidic nodules were scattered in the s-matrix, without plasma differentiation. Cutans - 40 u illuvial free-grain organo-argillan with weak continuous orientation and 25 u illuvial free-grain sesquan with weak continuous orientation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large feldspar and quartz grains were floated from the parent material.

Sedimentary-relict : The deposition process was related to the dense material on the upper part of the skeleton grains and the sedimentation process was related to the well sorted material in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena, (1938): Chlamedomorphic fabric.

After Brewer, (1964): Illuvial free-grain organo-argillan with simple packing voids and skelsepic plasmic fabric.

After Beckman, (1967): Porous structure.

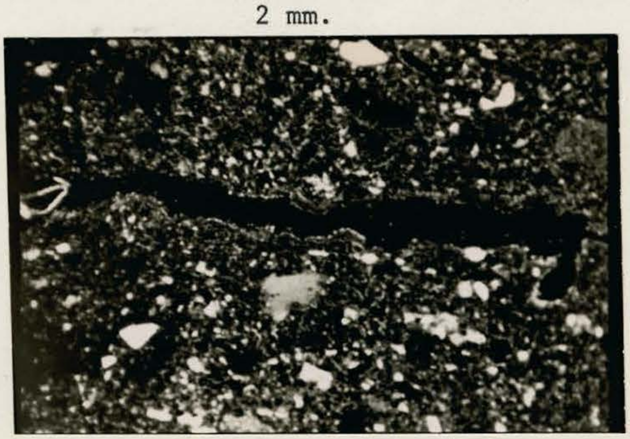


Fig. 17, ortho channel voids and insepic plasmic fabric in the A_1 horizon of the Ancaster series at 5 inches depth under normal light. 35X.

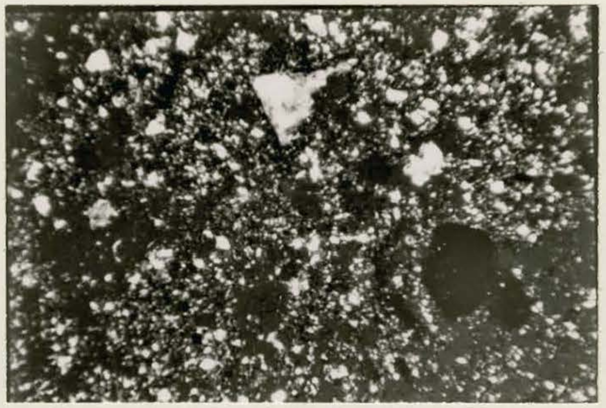


Fig. 18, vosepic plasmic fabric, large shale grain and sesquioxide nodule in the B_2t horizon of the Ancaster series at 20 inches depth, under normal light. 35X.

Fig. 19, simple packing voids in the IIC_1 horizon of the Ancaster series at 25 inches depth, under normal light. 35X.

TABLE 7. CLIMATIC DATA (HAMILTON)

Soil Series : ANCASTER

B_1 C_2 d b_2

Months	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
(F^o)	23	23	31	43	55	65	71	68	61	50	38	27	46
ion (Inches)	2.7	2.4	2.7	2.2	2.3	2.6	3.1	2.3	2.9	2.6	2.6	2.5	30.9
ranspiration	0	0	0	30	74	114	139	120	82	43	11	0	613
) mm.	68	61	70	56	59	67	78	59	73	66	65	63	185
	365	426	300	300	285	244	198	162	157	180	234	297	—
spiration	0	0	0	30	74	108	124	95	78	43	11	0	563
(D) mm.	0	0	0	0	0	6	15	25	4	0	0	0	50
) mm.	0	0	126/70	26	0	0	0	0	0	0	0	0	222

8.88 per cent (d)

Summer concentration = 58.07 per cent (b_2)

C_2)

Moisture index = 34.10 per cent (B_1)

TABLE 8. PARTICLE SIZE ANALYSIS (u%)

Soil Series : ANCASTER

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A_1	0-7	2.9	1.8	28.7	33.7	14.4	3.4	7.4	4.3	3.4	33.4	63.2
A_2	7-12	3.5	0.5	19.1	34.2	32.7	4.2	6.7	7.7	11.5	23.1	65.4
B_2t	12-26	2.6	0.7	34.6	12.2	12.2	4.9	2.5	5.2	24.7	37.9	36.9
IIC_1	26-31	1.7	0.6	50.0	11.1	10.0	11.7	5.8	3.5	16.8	51.3	22.0
IIC_2	+31	3.9	0.4	3.4	27.9	2.7	10.6	3.2	2.2	45.8	7.6	46.6

TABLE 9. PHYSICAL ANALYSIS

Soil Series : ANCASTER

Horizon	Depth inches	Compaction Kg/cm^3	Horizon Domin.	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
A_1	0- 7	1.4	23	10 YR	3	2	-	1.65	2.69	40	21.1	2.52	6.09
A_2	7-12	2.7	16	10 YR	3	2	-	1.71	2.70	38	16.7	1.34	4.82
B_2t	12-26	3.4	45	7.5YR	5	4	-	1.59	2.93	45	17.2	1.23	5.90
IIC_1	26-31	2.1	16	10 YR	5	2	-	1.84	2,87	36	19.4	0.97	3.89
$IIIC_2$	+ 31	4.5	-	2.5 YR	5	4	-	1.59	2.54	39	22.7	0.39	5.31

TABLE 10. CHEMICAL ANALYSIS

Soil Series : ANCASTER

pH 1:5		Extractable cations meq./100 gm. soil					C.E.C meq./100 g	$CaCO_3$ equiv. %	Cl (ppm)	E.C mm./cm. 20° (10^{-3})	C %	N %	C/N
H_2O	KCl	Ca	Mg	Na	K	H							
5.8	4.3	1.72	1.49	0.81	0.17	9.2	13.39	2.72	110	10	1.26	0.084	15
6.5	5.4	2.06	1.97	0.92	0.21	8.4	13.56	1.90	110	11	0.67	0.056	12
6.7	5.3	2.24	1.81	0.77	0.21	7.9	12.93	2.80	100	20	0.62	0.056	11
6.5	5.8	3.79	2.89	2.83	0.14	5.7	15.35	11.83	100	16	0.49	0.054	9
7.6	6.5	4.65	2.89	1.14	0.24	3.6	12.32	11.42	140	16	0.20	0.028	7

TABLE 11. ELEMENT ANALYSIS

Soil Series : ANCASTER

Horizon	Depth Inches	Trace Elements (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A_1	0- 7	5.2	254	228	2.90	14.14	60.6	3.57	7.79	6.88
A_2	7-12	8.9	188	195	4.23	13.09	54.0	3.48	7.45	6.04
B_2t	12-26	12.1	194	208	4.99	14.46	51.2	4.67	6.35	5.22
IIC_1	26-31	11.3	214	196	4.56	13.19	50.2	2.92	6.80	5.51
$IIIC_2$	+31	15.6	301	226	5.72	11.85	56.0	4.92	8.47	6.36

TABLE 12. CLAY MINERAL ANALYSIS

Soil Series : ANCASTER

Horizon	Depth Inches	Mont-moril-lonite	Illite	Kaolinite	Chlorite	Vermi-culite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
A_1	0- 7			+		+	+	+		++++	+
B_2t	12-26		+	+++	+		++++	+	+++	+++	+++
IIC_2	+31			++++	+			+	+	++++	+++

5.2.4. Discussion and First Interpretation

The Ancaster profile has developed upon a deep silt loam to fine sandy till. This profile (Figures 14 to 19) conforms to the Brunisolic Gray-Brown Luvisol subgroup according to the Canadian soil classification (1970). Ancaster soils are associated with clay surface soil, good drainage and thin textural B horizons. The Ancaster profile studied is a shallow phase with bisequal development in the C horizon.

Kaolinite was found to be the dominant clay mineral in the Ancaster profile, derived from the parent material.

The relationship between the soil morphology, micromorphology and soil analysis will now be discussed in detail in the Ah, $B_{22}t$ and IIC_1 horizon of the Ancaster profile. The Ah horizon with 6.88 silica-sesquioxide ratio and silt loam texture exhibits an insepic plasmic fabric. The B_2t horizon with silica-sesquioxide of 5.22 ratio and clay loam texture exhibits vosepic fabric while IIC_1 horizon with 5.51 ratio and sandy loam texture exhibits skelsepic plasmic fabric. This result may indicate that a relatively high silica-sesquioxide ratio is largely related to undeveloped plasma fabric while the relatively low ratio is associated with plasma development. The Ah horizon with penetrability of 1.4 Kg/cm^3 and 40% porosity exhibits numerous fine pores on the surface of the weakly aggregated peds and some infrequent 450 U very fine macro ortho-vughs. The $B_{22}t$ horizon with 45% porosity, strong degree of aggregation and a penetrability of 3.4 Kg/cm^3 exhibits 155 U very fine macro meta-vughs voids while, the IIC_1 horizon with 36% porosity, weak aggregation and 2.1 Kg/cm^3 penetrability exhibit a 70 u meso meta-simple packing voids. This result may prove that a higher porosity is largely associated with small size voids. In contrast, the lower porosity possessed few large voids.

Textural discontinuity was established in the IIC_1 horizon as a result of significant change in the texture, structure and consistency proportions in this horizon. This is an increase of 13.4% in sand material below this discontinuity. Such an increase is reflected in the high proportion of skeletal material as a soil constituent.

The Ah horizon with fine crumb structure and spongy microstructure can possibly be related to the high organic matter content of 4.04% and the high sand content. The B_2t horizon with medium subangular blocky structure and fragmented microstructure is marked by accumulation of 21.3% clay. The IIC_1 horizon with fine granular structure and porous microstructure is also influenced by the presence of 51.3% sand material and 11.83% carbonates.

5. 3. VINELAND SERIES

5. 3. 1. Site description

Location : a) Vine Mount - one mile north of Highway No. 8, b) Soil map - Wentworth County, Ontario, Soil Survey report No. 32, Scale 1:63360, c) Reference Map Lat. 43°11'N. Long. 79°39'W., d) Top. Map, Grimsby Ont., 30 M/4 E, Scale 1:50000, 08.5 - 84.7.

Weather condition : Cloudy with sunny periods, temp. 74°F, recent rainfall 1.5" (3/6/1969).

Soil series : Vineland series, 7,900 acres.

Soil type : Clay soil, imperfect poor drainage, texture B horizon, less than 5% shales and weathering limestone in subsoil horizon, (fK-uda).

Canadian classification (1970) : Gleyed (Brunisolic) Gray-brown Luvisol.

American classification (1968) : Aquic Hapludalf.

Climatic classification : a) Welland Station b) B_2d B, b_2 type.

Vegetation : The area is cultivated with apple trees in good condition, some grass surrounded the trees, mainly clover.

Geology and bedrock : Lockport, Anabel formation, buff and gray dolomite, Silurian.

Parent material : Outwash sand; shale and limestone.

Topography : a) Geomorphology - clay till sediments, high compactness and impermeability of these clays acts as a barrier to water movement in the soil, b) Relief - gentle slope 3-5% from the S to the N, c) Elevation - 650 feet above sea level, d) Drainage - i) external -

moderately slow run off. ii) internal - very slow to slow permeability. iii) drainage class - imperfect poor. e) Ground water table: temporary; secondary pseudogley soil.

Land capability : The agricultural use of these soils has been adjusted to a large extent to conform to the variable depth of the sand that overlies clay. In general, in areas with thinner sandy surfaces, fruit crops, other than peaches, predominate.

Remarks : Very deep phase profile; C horizon at depth of 40 inches.

5. 3. 2. Horizon description

0-10" Ap Very dark gray (10YR 3/1), clay loam, moderate to weak aggregared, fine medium crumb to blocky structure, moderate soft consistency, friable, slightly sticky, numerous fine pores,abundant fibrous roots of grass and few large tree roots, many earthworms, diffuse regular boundary.

10-18" B$_1$g Dusky-red (2.5YR 3/2), silty clay loam, moderately strong aggregation with medium subangular blocky structure, moderately hard consistency, moderately firm and moderately sticky. Some fine pores on the surface of the ped, few old root channels coated with very dark grayish-brown (2.5YR 3/2) humus, 10% reddish brown (2.5YR 5/4) faint mottles, few fibrous roots and some earthworms, boundary gradually merging.

18-24" B$_{21}$tg Pinkish grey (5YR 6/2), silty clay, moderately strong aggregation, with medium subangular blocky structure, hard consistency firm and sticky, numerous fine pores and few fine fissures on ped surfaces, few recent and old tree roots, few earthworms, old root channels coated with dark-brown (5YR 2/2) humus, 15% yellowish-red (5YR 5/6) diffuse mottles, boundary gradually merging.

24-40" $B_{22}tg$ Grayish brown (10YR 5/2), silt clay loam, strongly aggregated with fine angular blocky structure, very hard, very sticky consistency, abundant fine pores on ped surfaces, very few fibrous roots, 20% frequency of clay skins on ped surfaces, yellowish-brown (10YR 5/4) distinct mottles, 3% light gray (10YR 7/1) calcareous nodules and 2% weak red (10 R 4/3) weathered Queenston shale nodules, boundary indistinct regular.

40" + C_g Grayish-brown (10YR 5/2), silt loam with 10% small and medium gravel (shales, silt-stone and limestone), moderately weak aggregation, fine to medium granular structure, consistency moderately hard, fine and sticky, 15% yellowish-brown (10YR 5/6) distinct mottles. No biological activity.

5. 3. 3. Micromorphological description

Ap horizon (0-10")

S-MATRIX

Skeleton : 300 u subangular to subrounded quartz, 300 u subangular fresh plagioclase, 250 u muscovite flakes, scattered in s-matrix; 85 u few subrounded augite, randomly distributed.

Plasma : Yellowish brown with few patches of dark reddish-brown from organic matter plasmification.

Plasmic fabric : Silasepic; some In-vo-skelsepic fabric (Fig. 22).

Fig. 20, fine crumb structure in the Ap horizon of the Vineland series.

Fig. 21, medium subangular blocky structure in the B_{22}tg horizon of the Vineland series.

Fig. 22, coarse angular blocky structure in the Cg horizon of the Vineland series.

Voids : 1000 to 300 u very fine macro-prolate mammilate ortho-meta-vughs; 250 u macro-prolate regular ortho-meta vesicles (Fig. 22) and 21 u micro-acicular irregular meta-craze planar.

Organic matter : 400 x 100 and 1600 x 400 u prolate, dark brown fragments of undecomposed plant remains scattered in s-matrix, very dark brown roots (wood and grass) recognized. In general organic matter incorporated in the s-matrix.

Basic structure : A relatively large proportion of skeleton grains compared to plasma mass, relatively few large voids, and organic matter proportion was almost equal. Related distribution was agglomeroplasmic to porphyroskelic.

Proportion : Pl ≃ Sk> Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Some separations lying cutanically to voids and skeleton grains, birefringence masked by organic matter.

Plasma concentration : Glaebules - strong adhesive 150 u round diffuse sesquioxidic nodules; strong adhesive 800 x 400 u prolate diffuse regular ortho-sesquioxidic concretion; strong adhesive 1200 x 700 u prolate sharp meta-ferri-organo nodules; strong adhesive 200 u round diffuse ortho-meta organo-ferro nodules and moderately strong adhesive 300 u round sharp meta-ferri-argillan nodules were without differentiation.

Bioformation : Pedotubules - moderately strong adhesive 600 u round sharp meta para-granotubules (without plasma).

Fecal pellet - 300 u round sharp opaque, homogeneous, single.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large mica and quartz grains floated from parent material.

Pedo-relict : Ortho -sesquioxidic concretion nodules.

Sedimentary-relict : Parapedotubule gave evidence of new sediment material; pedoturbation process has disrupted microstratification of the original s-matrix.

ELEMENTARY STRUCTURE

After Kubienca, (1938): Porphyropectic fabric.

After Brewer, (1964): Para-granotubules with ortho vughs and silasepic plasmic fabric.

After Beckman, (1967): Crumby structure.

B_{22}tg horizon (24-40")

S-MATRIX

Skeleton : 80 u subrounded to subangular quartz, a few grains of randomly-distributed fragmented quartz, 500 u edge-corroded muscovite flakes, 550 u angular to subangular plagioclase was dull and edge-corroded, some biotite flakes and a few 350 u rounded tourmaline present.

Plasma : Yellowish-brown, generally homogeneous.

Plasma fabric : Ma-skelsepic plasmic fabric (Fig. 23).

Voids : 120 u macro-tubular regular, nearly horizontal, ortho-branching channels; 60 u meso-acicualr irregular ortho-joint planar; 500 x 100 u macro-prolate regular meta-chambers and 600 u macro-round mammilate ortho-vughs. (Fig. 23)

Basic structure : Plasmic material and voids are nearly equal in the s-matrix, a few large skeleton grains scattered randomly in the s-matrix, related distribution was agglomeroplasmic.

Proportion : Pl ≃ Vd >Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : High birefringent domains through the s-matrix, plasma separation refers to voids and skeleton grains with moderately birefringent extinction colour.

Plasma concentration: Glaebules - strong adhesive 250 x 150 u prolate sharp meta-sesquioxidic nodules; moderately strong adhesive 400 u round diffuse irregular ortho-sesquioxidic nodules and 300 x 150 u prolate diffuse regular meta-sesquioxidic concretion; 250 u round sharp regular meta-argill-ferran concretion were undifferentiated; 450 u round sharp meta-natural shale nodules and 900 u round sharp regular meta-natural-rock nodules showed rock fabric. Cutans- 35 u illuvial channel argillan with moderately strong continuous orientation; 6 u stress free-grain argillan, 75 u illuvial vugh argillan, 13µ stress embedded free-grain argillan all with strong continuous orientation and 4 u stress joint-planar argillan with moderately continuous orientation. Neo-cutans - a neo-argillan was found at 300 u on the ortho vugh surface, 200 u from the surface of skeleton grain and 200 u from channel wall.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large intergraded mica grains were floated out from the parent material.

Pedo-relict : Natural sesquioxidic concretion, natural shale nodules and natural quartz nodules were floated during soil formation.

Sedimentary relict : Microstratification was related to horizontal channel voids as well as to well-sorted material.

ELEMENTARY STRUCTURE

After Kubiena, 1938 : Porphyropeptic fabric.

After Brewer, 1964 : Illuvial channel argillan with ortho-meta sesquioxidic nodules and ortho channels with masepic plasmic fabric .

After Beckman, 1967 : Regular joint structure.

Cg horizon (+ 40")

S-MATRIX

Skeleton : 120 u angular to subangular quartz, a small number of muscovite flakes were scattered in the s-matrix, a small number of 250 u rounded tourmaline.

Plasma : In general the plasma was reddish-brown and homogeneous.

Plasmic fabric : Argillasepic: few vosepic plasmic fabric.

Voids : 14 u crypto-acicular regular parallel meta-joint planar; 400 u macro-round irregular meta-ortho-chambers and 250 x 100 u macro-prolate irregular ortho-vughs. (Fig. 24)

Basic structure : A mass of small sized skeleton grains dispersed through a rather homogeneous plasmic mass, the s-matrix was interspersed by numerous crypto parallel planar voids, related distribution was porphyroskelic.

Proportion: Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : There were some separations lying cutanically to a planar void, birefringence was generally very high.

Plasma concentration : Glaebules - strong adhesive 500 u round irregular diffuse ortho-sesquioxide nodules; moderately strongly adhesive 250 u round sharp meta-ferri-argillan nodules were without differentiation; 250 u round normal shale nodules and 800 x 400 u prolate, sharp natural quartz nodules were with rock fabric. Cutans - 10 u stress planar argillan; 9 u stress planar mangans have strong orientation, 21 u stress veinplanar argillan with moderate orientation and 10 u illuvial vughs argillan with strong continuous orientation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz and shale grains were floated from the parent material. (Fig. 23).

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : The microstratification was related to parallel meta-ortho joint planar with homogeneous plasma mass.

ELEMENTARY STRUCTURE

After Kubienca,(1938): Porphyropectic fabric intergrading to porphyropeptic fabric.

After Brewer,(1964): Stress vein planar argillan with meta ortho-joint planar and argillasepic plasmic fabric.

After Beckman,(1967): Irregular jointed structure.

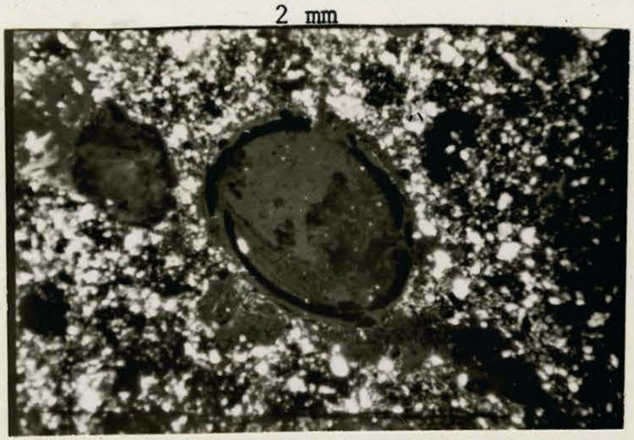


Fig. 23, meta vesicle voids, remnant old roots and an insepic plasmic fabric in the Ap horizon of the Vineland series at 5 inches depth, under normal light. 35X.

Fig. 24, masepic plasmic fabric and an ortho vugh in the $B_{22}tg$ horizon of the Vineland series at 30 inches depth, under normal light. 35X.

Fig. 25, regular nodule with rock fabric (lithorelict) and an ortho vugh in the Cg horizon of the Vineland series at 40 inches depth, under normal light. 35X.

TABLE 13. CLIMATIC DATA (WELLAND)

Soil Series : VINELAND, HALDIMAND

type = B_2 B_1 d b_2

Months	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
perature (F^o)	30	22	32	45	49	70	69	67	60	51	37	33	47.0
cipitation (Inches)	3.1	2.9	2.7	2.8	2.8	2.7	3.2	2.4	2.8	2.9	2.6	2.9	33.9
l evapotranspiration n.	0	0	0	33	77	114	139	121	84	47	12	0	627
ation (P) mm.	78	74	68	72	70	69	82	60	72	74	67	73	859
(St) mm.	396	470	300	300	293	252	208	170	163	190	245	318	—
vapotranspiration m.	0	0	0	33	77	110	126	98	79	47	12	0	582
ficiency (D) mm.	0	0	0	0	0	4	13	23	5	0	0	0	45
rplus (S) mm.	0	0	170/68	39	0	0	0	0	0	0	0	0	277

ndex = 7.73 per cent (d)

Summer concentration = 57.39 per cent (b_2)

2 mm. (B_1)

Moisture index = 42.96 per cent (B_2)

TABLE 14.PARTICLE SIZE ANALYSIS (u%)

Soil Series : VINELAND

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
Ap	0-10	4.0	3.0	21.4	10.4	12.8	5.2	10.8	11.2	21.1	28.5	50.4
$B_{1}g$	10-18	2.9	3.6	12.6	2.1	19.4	10.4	0.6	20.8	28.6	18.1	53.3
$B_{21}tg$	18-24	0.3	0.7	2.1	3.0	0.8	0.4	29.6	7.1	46.0	3.1	40.9
$B_{22}tg$	24-40	0.5	0.3	1.4	17.0	1.6	8.7	16.1	14.9	39.5	2.2	58.3
C_g	+40	6.2	6.4	13.5	13.3	1.7	4.5	13.7	25.4	15.3	26.1	58.6

TABLE 15. PHYSICAL ANALYSIS

Soil Series : VINELAND

Horizon	Depth inches	Compaction $Kg./cm^3$	Horizon Domin. %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
Ap	0-10	1.8	24	10 YR	3	1	1.45	1.36	2.44	44	25.1	2.11	8.81
B_1g	10-18	1.6	20	2.5YR	3	2	1.60	1.46	2.44	40	21.7	0.38	6.19
$B_{21}tg$	18-24	2.0	15	5 YR	6	2	1.53	1.47	2.52	41	24.8	0.83	8.33
$B_{22}tg$	24-40	5.0	40	10 YR	5	2	1.81	1.33	2.56	48	20.2	0.20	9.10
Cg	+40	3.6	-	10 YR	5	3	1.81	1.35	2.56	47	14.4	0.12	6.91

TABLE 16. CHEMICAL ANALYSIS

Sóil Series : VINELAND

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil					C.E.C meq./ 100 g.	$CaCO_3$ equiv. %	Cl (ppm)	E.C mm./cm. 20° (10^{-3})	C %	N %	C/N
		H_2O	KCl	Ca	Mg	Na	K	H							
Ap	0–10	5.7	5.6	4.32	9.29	1.13	0.35	6.1	21.20	4.05	35	250	1.06	0.102	10
B_{1g}	10–18	5.5	5.2	2.05	5.32	1.86	0.48	5.4	15.10	0.33	30	200	0.19	0.019	9
$B_{21}tg$	18–24	7.7	7.2	11.79	7.18	0.74	0.51	1.6	21.82	2.21	44	250	0.42	0.086	5
$B_{22}tg$	24–40	8.2	7.8	4.90	6.38	1.04	0.49	0.7	13.52	8.13	90	250	0.10	0.028	3
Cg	+40	8.2	7.8	3.04	5.02	1.20	0.33	0.3	9.89	10.29	120	250	0.06	0.019	3

TABLE 17. ELEMENT ANALYSIS

Soil Series : VINELAND

Horizon	Depth Inch.	Trace Elements (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
Ap	0-10	11.0	272	253	5.11	15.68	81.1	6.70	9.17	7.57
B_1g	10-18	9.2	253	203	5.70	16.15	71.5	5.81	8.37	6.68
$B_{21}tg$	18-24	14.1	266	231	6.74	18.30	76.8	7.50	7.58	6.08
$B_{22}tg$	24-40	12.3	232	200	6.13	27.17	75.4	8.90	7.96	6.39
Cg	+40	14.0	233	187	5.10	14.46	80.4	6.79	10.08	8.17

TABLE 18. CLAY MINERAL ANALYSIS

Soil Series : VINELAND

Horizon	Depth Inches	Mont-moril-lonite	Illite	Kaolinite	Chlorite	Vermi-culite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
Ap	0-10		+	+++	++	+	++	+		++	++
B_{21}t g	18-24		++++	++++	++	+++	++++	++++	+	+	++++
Cg	+40		+	++++	+++	++	++++	++++	+		

5.3.4. Discussion and First Interpretation

The Vineland profile has developed upon a mixed outwash sand from shale and limestone deposits - coarse relative to the silt loam and fine sandy deposits of the Ancaster profile. The Vineland profile (Figures 20 to 25), conforms to the Gleyed subgroup in comparison to Brunisolic Grey Brown Luvisol subgroup of Guelph and Ancaster profiles. Vineland soils are associated with clay surfaces, imperfect to poor drainage and normal textural B horizon. The Vineland profile studied is relatively deep phase. Illite and Kaolinite minerals were found to be the dominant single clay minerals in the Vineland profile - derived from the parent material.

A lower degree of chemical weathering, in terms of high silica/sesquioxide ratio, was found in the Vineland profile - relative to higher degree of weathering in the Guelph and Ancaster profiles. In Vineland profile, the Ap horizon with silica/sesquioxide ratio of 7.57 and clay loam texture exhibits silasepic plasmic fabric while the $B_{22}tg$ horizon with 6.38 ratio and silt clay loam texture exhibits masepic plasmic fabric. However the high ratio of silica-sesquioxide (8.17) and silt loam texture in the Cg horizon shows argillasepic plasmic fabric. In conclusion, for the Alfisol profiles studied, masepic plasmic fabric is largely related to the same degree of chemical weathering in both the Guelph and Vineland profiles, although they have different types of texture, clayey and silt clay loam.

Soil porosity in the Vineland profile is relatively higher than in both Guelph and Ancaster profiles, affected by the dominant void size. Visual and microscopic examination of soil porosity in Vineland indicated that numerous fine pores on the surface of moderately weak aggregated peds in the Ap horizon exhibit 1,000 u, very fine macro ortho-meta vughs associated with 44% porosity and low penetrability of 1.8 Kg/cm^3. Although a strong aggregation with high penetrability of 5 Kg/cm^3 and 1,200 u very fine macro ortho channel voids in the $B_{22}tg$ horizon of Vineland profiles are associated with 48% porosity and moderate weak aggregation with 3.6 Kg/cm^3 penetrability and 14 u crypto meta-joint planar voids are associated with 47% porosity. It is clear that about the same total porosity in the $B_{22}t$ and Cg horizons is largely related to different types of dominant voids.

The Ap horizon with fine to medium crumb structure and crumb microstructure can possibly be related to the low organic matter content of 2.11%, relative to Guelph and Ancaster profiles. The $B_{22}tg$ horizon with fine, angular, blocky structure and irregular jointed microstructure is affected by relatively low accumulation of 18.4% clay and 10.29% carbonate. The Cg horizon with fine to medium granular structure and irregular jointed microstructure may be influenced by the presence of shale and limestone gravel. Such structures may also be influenced by the presence of iron and carbonate.

5. 4. WINONA SERIES

5. 4. 1. Site description

Location : a) Winona, one mile from the Southern shore of Lake Ontario, b) Soil Map, Wentworth County, Ontario, Soil Survey Rep. 32, Scale 1:63360, c) Reference Map, Lat. 43° 13' N, Long. 79° 395'W., d) Top. Map, Grimsby, Ontario. 30M/4 E half, 1:50.000, 08.9 - 86.1.

Weather condition : Sunny, no wind, rain or clouds, Temp. 72°F (11/6/69)

Soil series : Winona series, 2,950 acres.

Soil type : Clay soil with weathering shale and limestones, less than 5%; texture B horizon, imperfect poor drainage (fK-uda).

Canadian classification (1970) : Gleyed (Brunisolic) Gray-brown Luvisol.

American classification (1968) : Aquic Hapludalf.

Climatic classification : a) St. Catherines. b) C_2 w C_2' b_2' type.

Vegetation : Vine farms neglected for two to three years, much grass - *Trifolium* spp (clover) and *Triticum* spp (wheat), *Vigna sinensis*.

Parent material : Outwash sand, moderately brown clay till.

Geology and bedrock : Queenston formation, red shale; Ordovician.

Topography : a) Geomorphology - The Winona soils are imperfectly drained sandy loams up to 24 inches deep over clay deposits. The Winona soils in Wentworth County are located along the southern shore of Lake Ontario on the Lake Iroquois plain.

b) Relief - Flat area, or very gentle slope toward the south. c) Elevation - 250 feet above sea level. d) Drainage - i) external-very slow run off, ii) internal - very slow permeability, iii) drainage - imperfect to poor. e) Ground water table - temporary water table, primary pseudogley due to the geological influence - heavy clay with very compact glacial till.

Land capability : The rapidly dwindling areas of Winona soils that are still available for agricultural use, are used for the growing of tree fruits and grapes. The sandy overburden seems to allow sufficient drainage and aeration for the healthy growth of all tree fruits, including 'tender' types such as peaches and sweet cherries.

Remarks : The soil is moderately deep phase; a very compact clay, with heavy texture and alteration in situ.

5. 4. 2. Horizon description.

0-4" Ap Dark brown (10YR 3/3), silty clay, moderately weak aggregation, fine to medium crumby and blocky, slightly soft, friable slightly sticky consistency, numerous fine pores on ped surfaces, abundant fibrous and small woody roots, many earthworms, boundary irregular, diffuse.

4-6" A_3g (ABg) Dark yellow-brown (10YR 4/4), clay, moderately strong aggregation, medium to coarse subangular blocky, moderately hard, moderately firm, slightly sticky, some fine pores on ped surfaces, many fibrous, small roots of grass and trees, many earthworms, 10% yellowish-brown (10YR 5/6) distinct mottles, boundary gradually merging.

6-10" $B_{21}tg$ Gray (7YR 5/0) silt clay loam, strongly aggregated medium sub-angular blocky, hard, firm, sticky, some fine pores, a few fissures on ped surfaces, many old root channels with very dark brown (10 YR 2/2) humus coatings, 20% strong brown (7.5YR 5/8) prominent mottles, few old fibrous roots, occasional earthworms, boundary gradually merging.

10-20" $B_{22}tg$ Dark gray (2.5YR 4/0), clay, strong aggregation, with medium angular blocky structure, very hard, very firm, and very sticky consistency, very fine pores and numerous fine fissures on the surface of the ped, some old roots channels coated with very dark brown (10YR 2/2) humus, occasionally fibrous and small roots, 15% frequency of clay skin on the surface of peds brownish-yellow (10YR 6/8) distinct mottles, boundary gradually merging.

20" + Cg Gray (10YR 5/1), silt loam, very strongly aggregated fine angular blocky, 5% small to medium weathering shale nodules, 15% prominent brownish-yellow (10YR 6/8) mottles.

5. 4. 3. Micromorphological description

Ap horizon (0-4")

S-MATRIX

Skeleton : 50 u subangular to subrounded quartz, small muscovite flakes, 200 u subangular plagioclase, scattered in the s-matrix, a small number of 75 u rounded augite and 100 u rounded tourmaline were randomly distributed.

Plasma : Light olive brown to yellowish-brown, has a rather compact appearance, few patches of dark brown colour as a result of plasmification of the organic matter.

Fig. 26, fine crumb structure in the Ap horizon of the Winona series.

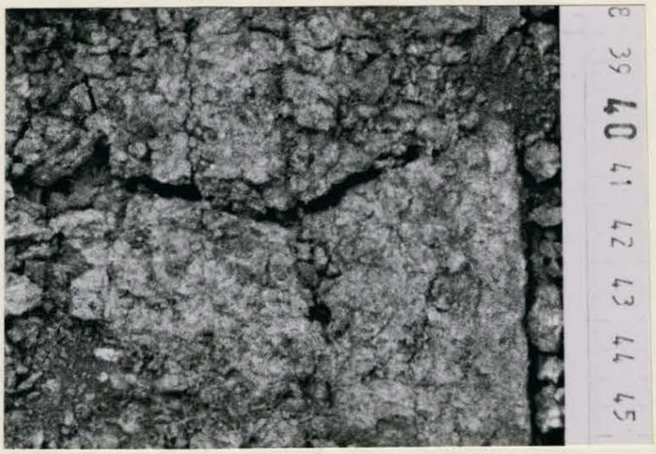


Fig. 27, medium angular blocky structure in the B_{22}tg horizon of the Winona series.

Fig. 28, fine angular blocky structure in the Cg horizon of the Winona series.

Plasma fabric : Silasepic, Fig. (27) vo-skelsipic plasmic fabric.

Voids : 150 x 70 u macro-prolate irregular ortho-vughs Fig. (27), and 25 u micro-round irregular meta-compound packing voids were scattered randomly in the s-matrix.

Organic matter : Plant remains occur as fragments of varying size of yellowish-brown colour, slightly humified, distributed randomly through the s-matrix, a few angular to subangular fragments of dusky red organic matter strongly decayed.

Basic structure : Proportion of plasma to skeleton grains was almost the same, a few large voids, related distribution was porphyroskelic in most parts.

Proportion : Pl > Sk > Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Most dominant separations occur in the lower part of skeleton grains with low interference colour, other separations occur in various patches to give the various types of plasmic fabric.

Plasma concentration : Glaebules - strong adhesive, 200 u round diffuse irregular ortho-sesquioxidic nodules, Fig. (27) strong adhesive 290 u round irregular diffuse meta-manganiferous nodules were without differentiation and 200 u round sharp meta-natural shale nodules (with rock fabric). Cutans - 10 u stress free-grain organo-argillan with weak continuous orientation and 25 u diffuse embedded grain organo-argillan with moderately continuous orientation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large feldspar and augite grains were floated from the parent material.

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : The microstratification features were disturbed by the process of pedoturbation.

ELEMENTARY STRUCTURE

After Kubiena, 1938 : Porphyropectic fabric.

After Brewer, 1964 : Sesquioxidic nodules with ortho vughs and silasepic plasmic fabric.

After Beckman, 1967 : Fragmented structure.

B_{22}tg horizon (10 20")

S-MATRIX

Skeleton : 150 u subangular to subrounded quartz, small flakes of muscovite, 300 u subangular plagioclase were well distributed, small number of 320 u subrounded to rounded augite and 100 u rounded hornblend were randomly distributed.

Plasma : Rather compact, yellowish-brown in colour, few patches of reddish-brown in colour.

Plasma fabric : In-ma-skelsepic plasmic fabric, Fig. (28).

Voids : 14 to 24 u micro-crypto regular meta-craze planar with parallel orientation, Fig. 28, 200 x 65 u macro-prolate irregular ortho-vughs and 30 u micro-round regular meta-vesicles.

Basic structure : There were two types of basic structure in the thin section, in the upper part of the thin section skeleton was the main proportion while there are only very few voids present, in the lower part the voids were the main proportion and the skeleton was very weakly present. Related distribution was porphyroskelic.

Proportion : Pl > Sk > Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Highly birefringent, first order yellow interference colour, occurring mainly in the ma-lattisepic plasmic fabric in few patches, the separation was mainly subcutanic to the voids and skeleton grains.

Plasma concentration : Glaebules - strong adhesive 550 u equant diffuse ortho-meta-sesquioxidic nodules; moderately strong adhesive 450 u round regular diffuse ortho-ferri-argillan nodules; strongly adhesive 310 u round sharp regular meta-sesquioxidic nodules, without differentiation, and 250 u round sharp argillaceous papules. Cutans - 42 u stress free-grain argillan with weak continuous orientation, 35 u illuvial craze planar argillan with strong continuous orientation and 25 u illuvial vughs argillan with strong continuous orientation.

Bioformation : Pedotubules - strong adhesive 850 x 500 u prolate sharp meta isotubules with porphyritic fabric.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz, mica and feldspar grains were floated from the parent material.

Sedimentary relict : Microstratification features were related to the parallel joint-planar and masepic planar fabric.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic fabric intergrading to porphyropectic fabric.

After Brewer (1964) : Illuvial craze-planar argillan with meta craze-plane and insepic plasmic fabric.

After Beckman (1967) : Cracked structure, intergrading to irregular jointed structure.

Cg Horizon (+ 20").

S-MATRIX

Skeleton : 80 u subrounded to rounded quartz, 150 u angular to subangular plagioclase, small number of muscovite flakes scattered in the s-matrix, 350 u subrounded tourmaline and 420 u rounded augite, randomly distributed in a small number.

Plasma : Very light brown and a few spots as a result of iron stains.

Plasma fabric : Argillasepic (Fig.29), few ma-vo-skelsepic plasmic fabric.

Voids : 13 u(W) crypto-acicular regular meta-joint planar; usually parallel to the surface of the profile; 92 u macro-round regular meta-chambers; 54 u meso-round mammilate ortho vughs (Fig. 29), and 150 u macro-tubular irregular ortho-channels.

Basic structure : Meta-joint planar with argillasepic plasmic fabric. Related distribution was porphyroskelic.

Proportion : Pl> Sk> Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : In coarser material the separations were occurring cutanically or subcutanically to the voids and to the skeleton grains, other separations in general were highly birefringent with first order interference colour.

Plasma concentration : Glaebules - strong adhesive 150 x 30 u prolate regular sharp meta-sesquioxidic nodules; moderately adhesive 250 u round irregular diffuse ortho-sesquioxidic nodules were without differentiation; strong adhesive 420 u sharp regular meta-sesquioxidic nodules (with plasma fabric); 300 x 75 u prolate, regular sharp meta-argillan nodules (rock fabric) and moderately strong adhesive 350 u round diffuse irregular ortho-ferri-argillan nodules. Cutans - 18 u diffuse joint planar argillan with strong continuous orientation; 16 u diffuse joint planar ferri-argillan with moderately continuous orientation and 12 u stress free-grain argillan with weak continuous orientation. Subcutans - 200 u from the wall of the joint planar neo-argillans were found.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz and shale grains were floated from the parent material (Fig. 29).

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : Microstratification feature was related to the parallel joint planar in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric intergrading to porphyropeptic fabric.

After Brewer (1964) : Diffuse joint planar argillan meta sesquioxidic nodules with meta-joint planar and argillasepic plasmic fabric.

After Beckman (1967) : Regular jointed structure.

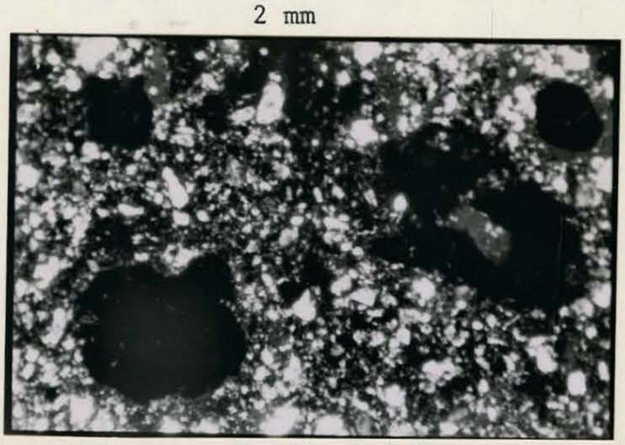


Fig. 29, irregular sesquioxide nodule, macro-ortho vughs and silasepic fabric in the Ap horizon of the Winona series at 8 inches depth, under normal light. 35X.

Fig. 30, bi-masepic plasmic fabric and craze planar voids in the B_{22}tg horizon of the Winona series at 15 inches depth, under normal light. 35X.

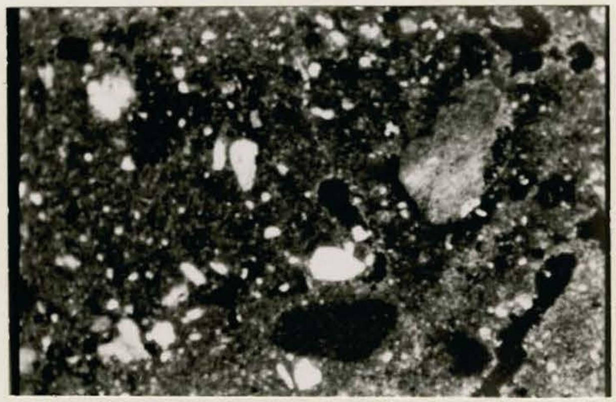


Fig. 31, argillasepic plasmic fabric, large shale and quartz grains (lithorelicts) and macro-ortho vughs in the Cg horizon of the Winona series at 20 inches depth, under normal light. 35 X.

TABLE 19. CLIMATIC DATA (ST. CATHERINES)

Soil Series : WINONA

Climatic type = C_2 C_2 w b_2

Months Data	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
Mean temperature (F°)	31	23	32	44	48	69	69	67	59	42	31	32	--
Mean precipitation (Inches)	2.3	1.8	2.1	2.4	2.1	2.5	2.4	2.5	2.6	2.2	2.1	2.0	27.0
Potential evapotranspiration (P.E.) mm.	0	0	0	28	74	116	139	124	86	47	15	0	629
Precipitation (P) mm.	58	45	53	61	54	63	61	64	66	55	55	52	687
Storage (St) mm.	296	341	300	300	280	235	181	148	138	146	186	238	--
Actual evapotranspiration (A.E.) mm.	0	0	0	28	74	108	115	97	76	47	15	0	560
Water deficiency (D) mm.	0	0	0	0	0	8	24	27	10	0	0	0	69
Water surplus (S) mm.	0	0	41/53	33	0	0	0	0	0	0	0	0	127

Aridity index = 12.32 per cent (w)

Summer concentration = 57.15 per cent (b_2)

P-E = 56.0 mm. (C_2)

Moisture index = 15.29 per cent (C_2)

TABLE 20. PARTICLE SIZE ANALYSIS (u%)

Soil Series : WINONA

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
Ap	0-4	0.2	0.8	15.1	14.7	13.1	15.1	9.4	8.0	23.7	6.0	70.3
Ag	4-6	1.0	1.1	8.6	12.7	13.3	0.0	16.1	11.4	36.0	10.7	35.3
$B_{21}tg$	6-10	0.2	0.8	6.7	17.4	2.8	3.9	26.3	1.4	40.6	7.6	51.8
$B_{22}t_g$	10-20	3.0	3.4	12.0	2.1	2.8	4.6	6.5	15.5	50.1	18.4	31.5
C_g	+20	3.2	3.8	12.6	14.9	6.5	2.6	9.0	31.0	16.4	19.6	64.0

TABLE 21 . PHYSICAL ANALYSIS

Soil Series : WINONA

n	Depth Inches	Compaction Kg./cm^3	Horizon Domin. %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
	0- 4	2.8	20	10 YR	3	3	2.33	1.45	2.45	40	12.7	2.84	8.61
	4- 6	2.7	10	10 YR	4	4	2.36	1.42	2.31	39	17.9	1.44	8.56
	6-10	4.2	20	7.5YR	5	6	2.52	1.27	2.28	44	14.7	0.78	8.13
	10-20	3.6	50	2.5YR	4	0	2.70	1.32	2.51	47	12.5	0.39	7.32
	+20	5.0	-	10 YR	5	1	2.98	1.42	2.52	43	10.5	0.34	5.73

TABLE 22. CHEMICAL ANALYSIS

Soil Series : WINONA

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil					C.E.C	$CaCO_3$	Cl	E.C. mm./cm. 20°C (10^{-3})	C	N	C/N
		H_2O	KCl	Ca	Mg	Na	K	H	meq./ 100 g	equiv. %	(ppm)		%	%	
Ap	0- 4	5.8	4.7	1.72	1.74	0.73	0.21	15.1	19.20	3.48	135	135	1.02	0.053	19
A3g	4- 6	5.5	4.2	2.88	2.62	1.00	0.37	12.0	18.88	3.16	145	142	0.72	0.056	15
B_{21}tg	6-10	5.8	4.4	3.96	3.64	0.90	0.34	14.3	23.14	0.68	185	166	0.39	0.056	8
B_{22}tg	10-20	6.0	5.4	5.54	5.03	1.02	0.28	9.0	20.86	9.24	240	200	0.30	0.084	4
Cg	+20	8.1	7.9	4.72	6.66	0.78	0.26	0.8	13.22	10.05	350	333	0.17	0.056	3

TABLE 23. ELEMENT ANALYSIS

Soil Series : WINONA

Horizon	Depth Inch.	Trace Elements (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
Ap	0- 4	8.5	239	117	3.88	20.57	66.9	5.77	5.87	5.25
A3g	4- 6	9.1	254	60	6.54	17.33	65.8	7.12	6.86	5.48
B_{21}t g	6-10	15.0	317	119	6.75	19.41	55.2	7.35	5.14	4.14
B_{22}tg	10-20	15.6	422	210	6.72	19.51	58.3	6.93	5.43	4.40
Cg	+20	13.1	246	205	6.18	17.70	59.6	5.39	6.10	4.93

TABLE 24. CLAY MINERAL ANALYSIS

Soil Series : WINONA

zon	Depth Inches	Mont-moril-lonite	Illite	Kaolinite	Chlorite	Vermi-culite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
	0- 4		+	+++	+		++	+	+	+	+
	6-10			++	+	++++	++++	+			
	+20			++	+	+	++++	++++	+	+	

5.4.4. Discussion and First Interpretation

The Winona profile has developed on an outwash sand and a brown clayey deposit. This profile (Figures 26 to 31) conforms to the Gleyed Gray-Brown Luvisol subgroup according to the Canadian soil classification (1970). Winona soils are associated with clay surfaces, imperfect to poor drainage and moderately developed textural B horizons. A small amount of weathering shale and limestone gravels were found at shallow depth in the Bt horizon. The Winona profile studied is a relatively shallow phase. Vermiculite and mixed clay layer minerals were found to be the dominant clay minerals in the Winona profile, derived by the weathering in situ.

The relationship between the soil morphology, micromorphology and soil analyses will now be discussed in detail in the Ap, $B_{22}tg$ and Cg horizons of Winona profile. The Ap horizon with 5.87 silica-sesquioxide ratio and silty clay texture exhibits silasepic plasmic fabric. The $B_{22}t_g$ horizon with silica-sesquioxide of 5.43 ratio and clayey texture exhibits insepic plasmic fabric while the Cg horizon with 6.10 ratio and silt loam texture exhibits argillasepic plasmic fabric. These results indicate that heavy texture and relatively higher degree of chemical weathering in the $B_{22}tg$ horizon are largely associated with a sepic plasmic fabric.

In contrast, relatively light texture and lower degree of chemical weathering in the Ap and Cg horizons are associated with asepic plasmic fabrics. The same result was found in the Vineland Alfisol profile.

The Ap horizon with penetrability of 2.8 Kg/cm^3 and 40% porosity exhibits numerous fine pores on the surface of the weakly-aggregated peds and some 150 U very fine macro ortho-vughs. The $B_{22}t_g$horizon with 47% porosity and strong degree of aggregation and a penetrability of 3.6 Kg/cm^3 exhibits 14 to 24 U micro crypto meta-craze planar voids while the Cg horizon with 43% porosity, very strong aggregation and 5 Kg/cm^3 penetrability exhibits 13 U crypto meta-joint planar voids. It is clear that the percent porosity, degree of aggregation and penetrability are largely associated with the size and the type of soil microvoids, with the rather compact B and C horizons having very high penetrability and very fine pores.

The Ap horizon with fine and medium weak crumb structure and fragmented microstructure can possibly be related to the relatively low organic matter content of 2.84% and high silt material of 70.3%. The B_{22}tg horizon with medium angular blocky structure and cracked microstructure is affected by the higher accumulation of 26.4% clay and 6.72% Fe_2O_3. The Cg horizon with fine angular blocky structure and regular jointed micro structure may be influenced by the presence of a very high content (64.0%) of silt material, carbonates and iron.

5. 5. HALDIMAND SERIES

5. 5. 1. Site Description.

Location : a) Haldimand area - Farm of G. Ashea, 4 miles south of Highway No 20. b) Soil Map - Lincoln County, Soil Survey Report No 34, Scale 1:63360. c) Reference Map - Lat. $43^{\circ}7'$ N., Long. $79^{\circ}43'$ W.

Weather conditions : Cloudy with a few showers, winds, southerly 15°, Temp. 54°F, 2" of rain previous week (23/4/1970).

Soil series : Haldimand series, 98,400 acres.

Soil type : Clay soil, with weathering shale and limestone less than 5%, heavy clay sub-soil horizon, imperfect drainage, textural B horizon (fk Uha).

Canadian classification (1970) : Gleyed (Orthic) Gray-brown Luvisol.

American classification (1968) : Aquic Hapludalf.

Climatic classification : a) Welland station. b) $B_2\ d\ B'_1\ b'_2$ type.

Vegetation : The area is covered with mixed shrub, peach trees and second class oak forest.

Parent material : Dark grey clay till.

Geology and bedrock : The entire area is underlain by Ordovician and Silurian sedimentary rocks. The rock strata consist for the most part of shales and limestone, the latter being dolomitic in the beds that form the capping of the Niagara escarpment.

Topography : a) Geomorphology - the soil material is of glacio-lacustrine origin and is remarkably uniform in texture and composition. It is a stone-free clay till but it does contain sufficient small pebbles to identify it as being of till origin. b) Relief - flat but there are sufficient aspect south-east. c) Elevation - 675 feet above sea level. d) Drainage class - i) external - gentle slope, slow run-off, ii) internal - slow to moderate permeability, iii) Drainage class - imperfect poor. e) Ground water table - pseudogley soil with temporary ground water table.

Land capability : Agricultural production is less satisfactory, the area produces hay and grain crops and generally supports a dairy type of farming.

Remarks : a) 0_1 and 0_2 horizons are not commonly found in the Alfisols of Southern Ontario. b) Calcareous ped coatings in the C horizon.

5. 5. 2. Horizon Description.

2- 1" 0_1 (L-F) Litter organic matter, dry leaves of peach trees, some tree capsules have been recognized.

1- 0" 0_2 (F-H) Dark gray (10YR 4/1) (dry), considerably humified organic matter, friable, small fragments.

0- 3" A_1 (Ah) Very dark brown (10YR 2/2), silt clay loam, moderate aggregation with medium and coarse crumb structure, soft, friable and slightly sticky consistency, numerous fibrous roots and some small woody roots, common earhtworms, very few fine fissures and many pores on ped surfaces, distinct irregular boundary.

3- 7" A_2g (Aegj) Dark brown (7.5YR 4/4), silty clay loam, moderately strong aggregation medium subangular blocky, slightly hard, slightly firm and sticky consistency, rare fine pores, common fibrous roots and small (1-3mm) woody roots, few fine and medium faint mottles, diffuse gradual boundary.

7-12" A_3g Dark yellowish-brown (10YR 4/3), clay strong aggregation with medium subangular and angular blocky structure, hard, firm, and sticky, very few pores <0.3mm Ø; few fissures (1mm wide), few small woody and some fibrous roots, many earthworms, 10% faint and distinct mottles, <5mm Ø, boundary gradually merging.

12-16" B_{21}tg Dark yellowish-brown (10YR 4/4), silty clay, very strong aggregation, with fine angular blocky structure, very hard, very firm and very sticky, some small roots and few large woody roots, 20% reddish-brown (7.5YR 7/6), faint mottles, frequency of clay skin, indistinct undulating boundary.

16-26" B_{22}tg Very dark greyish-brown (10YR 3/2), clay, very strong aggregation with medium angular blocky structure, very hard, very firm and very sticky, clay skins remain, fibrous roots on ped surfaces, plenty of clay skins on the ped and few clay skin on the old root channels, 20% faint yellowish-brown (10YR 5/6) of mottles, occasional earthworms, indistinct gradually merging boundary.

26"+ Cg Dark yellowish-brown (10YR 4/3) clay, strong aggregation, coarse subangular blocky structure, hard, firm, and sticky, very few pores, less than 5mm Ø and few fissures 1 mm wide on the surface of the ped, few small woody roots, 5% weathering shale and limestone, 3% nodules of limestone and shale, 15% large distinct brownish-yellow (10YR 6/6) mottles.

5. 5. 3. Micromorphological Description.

Ah (A_1) Horizon (0-3").

S-MATRIX

Skeleton : 500 u subangular to subrounded quartz, 150 u flakes of muscovite dispersed in the s-matrix, 250 u rounded tourmaline randomly distributed.

Fig. 32, the site of Haldimand profile is located on glacio-lacustrine till with very gentle slope. The land is covered with pine trees.

Fig. 33, Haldimand profile with the depth at which the soil was sampled being shown by the soil horizon code.

Plasma : Dark brown to brown rather compact appearance,

Plasma fabric : Argill-silasepic (Fig. 33), few vosepic plasmic fabric.

Voids : 75 to 150 u macro-arcuate irregular meta-craze planar; 50 to 500 u meso-macro round regular meta-vesicles, 1200 x 500 u macro-prolate irregular meta-vughs and 120 u macro-tubular irregular meta-channels.

Organic matter : Dark brown isotropic fragments of plant residues in variable size and scattered in the s-matrix, a few round strongly decayed fragments of plant remains, dark reddish-brown to opaque in colour, scattered in the s-matrix (Fig. 33).

Basic structure : Proportion of plasma mass to voids was almost the same, some patches were without skeleton grain. Related distribution was agglomeroplasmic, intergrading to porphyroskelic.

Proportion : $Pl \simeq Vd > Sk$.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Most dominant separation was related to craze planar voids, other separations occur in various patches to give various types of plasmic fabric with moderate birefringent colour.

Plasma concentration : Glaebules - moderately weak adhesive 225 u round diffuse irregular ortho-sesquioxidic nodules; moderately adhesive 200 u round regular sharp meta-ferri-argillan nodules; very strong adhesive 400 u round sharp regular meta-ferri-organo nodules and moderately strong adhesive 250 u round sharp regular meta-ferri-argillan concretion without differentiation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Very small number of free skeleton grains were floated from the parent material.

Pedo-relict : Natural ferri-argillan concretion.

Sedimentary-relict : Very small evidence of microstratification was related to the craze-planar voids and the sorting material in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric.

After Brewer (1964) : Ortho sesquioxidic nodules with meta-craze planar and argillasepic plasmic fabric.

After Beckman (1967) : Fragmented structure (Fig. 33).

B_{22}tg Horizon (16-26").

S-MATRIX

Skeleton : 50 u round to subrounded fragments of quartz, 69 u muscovite flakes, 70 u subangular plagioclase, scattered in the s-matrix.

Plasma : Rather compact yellowish-brown, few small patches of reddish dark brown as a result of iron stains.

Plasma fabric : Mo-vo-skelsepic plasmic fabric (Fig. 34).

Voids : 40 u meso-acicular irregular ortho-joint planar and 400 x 150 u macro-prolate mammilate meta-vughs and 350 u macro-round regular meta-vesicles.

Basic structure : The plasma fabric with very compact appearance voids and skeleton grains were scattered throughout the plasma mass, related distribution was porphyroskelic.

Proportion : Pl> Vd> Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Separation occurs as small patches of differing size on the craze planes, some patches were bounded with continuous extinction color, other separations were mainly subcutanic to voids and skeleton grains.

Plasma concentration : Glaebules - moderately strong adhesive of 170 u round diffuse ortho-sesquioxidic nodules (Fig. 34); strong adhesive 350 x 200 u prolate sharp meta-sesquioxidic nodules; moderately weak adhesive of 200 u round diffuse irregular ortho-ferri-argillan nodules, were without differentiation and strong adhesive 150 u round sharp ortho-argillan nodules (with rock fabric). Cutans - 19 u illuvial vughs argillan with strong continuous orientation; 25 u diffuse vughs quart zan without orientation; 15 u illuvial joint planar argillan with strong continuous orientation; 50 u diffuse joint planar sesquan with weak continuous orientation; 17 u illuvial vesicle sesquan with moderate continuous orientation and 12 u stress free-grain argillan with weak continuous orientation. Subcutans- Ortho joint planar neo-sesquans (460 u) and ortho vughs neo-quartzan (100 u).

Bioformation : 300 u Ø moderate adhesive sharp meta-isopedotubules with porphyropectic fabric.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large feldspar, mica and quartz grains were outfloated from the parent material.

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : Microstratification features were related to the planar voids as well as the mo-vo-skelsepic plasmic fabric, there was no evidence of specific orientation found.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic fabric.

After Brewer (1964) : Illuvial joint planar argillan with ortho sesquioxidic nodules and ortho joint planar mosepic plasmic fabric.

After Beckman (1967) : Cracked structure.

Cg Horizon (+ 26").

S-MATRIX

Skeleton : 50 u round to subrounded quartz, small muscovite flakes scattered in the s-matrix, a few mica fragments, 120 u round tourmaline and 100 u rounded augite.

Plasma : Very light yellow, a few reddish brown spots from iron staining.

Plasma fabric : Argillasepic (Fig. 35), some mo-vo-skelsepic plasmic fabric.

Voids : 150 u macro-tubular irregular ortho-craze planar as a result of compaction; 300 u macro-round irregular ortho-meta-vughs; 35 u micro-acicular irregular meta-joint planar and 500 x 300 u macro-prolate irregular meta-chambers.

Basic structure : Ortho-craze planar with argillasepic plasmic fabric, very compact structure with embedded skeleton grains, voids scattered throughout the plasma mass, s-matrix perforated with many micropores, some microstratifications make the basic structure very complex, related distribution was porphyroskelic.

Proportion : Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Separations occur cutanically and subcutanically to voids and skeleton grains. Some separations have striated continuous extinction referring to planar voids in the s-matrix.

Plasma concentration : Glaebules - strongly adhesive 350 u round sharp meta-sesquioxidic nodules; strongly adhesive 120 u round diffuse ortho-sesquioxidic nodules without differentiation (Fig. 35), very strong adhesive 600 u round sharp regular meta-argillan nodules; 120 u round regular sharp meta-natural rock nodules with rock fabric and strong adhesive 750 u round sharp meta-sesquioxidic nodules (with plasma fabric).

Cutans - 18 u illuvial craze planar argillan with strong continuous orientation; 18 to 45 u diffuse craze planar sesquan without orientation; 26 u illuvial chamber argillan with strong continuous orientation; 8 u stress vughs argillan with weak continuous orientation and 28 u diffuse embedded grain calcitans with moderately continuous orientation.

Subcutans - Meta-craze planar neo-argillan, 56 u from the surface, ortho-vughs neo quartzans, 110 u from the surface.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large mica, quartz and feldspar grains and calcite, shale grains were floated from the parent material.

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : Microstratification features were related to the planar voids and plasmic fabric types.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric intergrading to porphyropeptic fabric.

After Brewer (1964) : Illuvial craze planar argillan and natural rock nodules with ortho-craze planar and argillasepic plasmic fabric.

After Beckman (1967) : Fragmented structure.

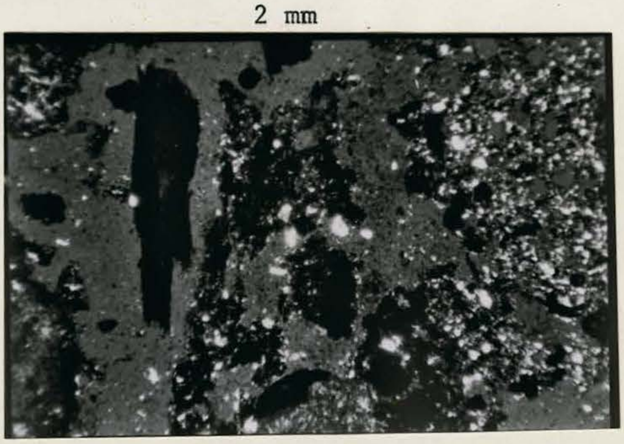


Fig. 34, fragment of old woody root, fragmented microstruture and argill-silasepic plasmic fabric in the A_1 horizon of the Haldimand series at 3 inches depth, normal light. 35X.

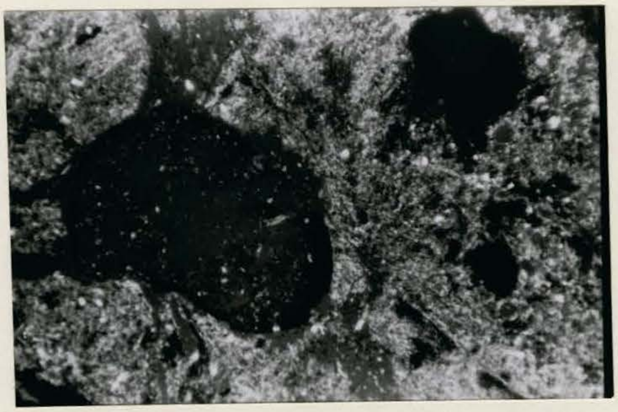


Fig. 35, meta-isopedotubule, mosepic plasmic fabric and irregular sesquioxide nodule in the $B_{22}tg$ horizon of the Haldimand series at 20 inches depth, under normal light. 35X.

Fig. 36, diffuse ortho sesquioxide nodule and an argillasepic plasmic fabric in the Cg horizon of the Haldimand series at 26 inches depth, under normal light. 35X.

TABLE 25. PARTICLE SIZE ANALYSIS (u%)

Soil Series : HALDIMAND

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A_1	0-3	4.3	0.7	0.4	22.0	0.3	19.8	3.7	19.2	29.5	5.5	65.0
A_2g	3-7	2.5	0.4	0.2	10.7	2.0	19.2	4.0	22.0	29.0	3.1	57.9
A_3g	7-12	5.8	0.3	0.4	11.1	10.0	21.4	10.3	2.9	37.7	6.6	55.7
B_{21}tg	12-16	7.5	0.6	0.5	3.8	8.9	14.0	11.8	6.8	46.2	8.5	45.3
B_{22}tg	16-26	10.4	1.8	1.4	4.1	7.8	13.2	10.4	0.3	50.5	13.7	35.8
B_3g	26-31	16.3	2.0	1.9	10.8	6.2	8.1	3.8	9.1	41.8	20.2	38.0
C_g	+31	3.3	0.9	2.2	15.8	12.7	6.2	12.0	3.9	42.9	6.5	50.6

TABLE 26. PHYSICAL ANALYSIS

Soil Series : HALDIMAND

on	Depth Inches	Compaction Kg./cm^3	Horizon domin. %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
	0- 3	0.8	12	10 YR	2	2	1.59	1.52	2.47	40	21.9	11.2	15.4
	3- 7	2.6	15	7.5YR	4	4	1.42	1.27	2.52	49	22.7	4.4	9.37
	7-12	3.1	19	10 YR	4	3	1.62	1.21	2.18	44	27.8	2.6	11.19
	12-16	3.4	15	10 YR	4	4	1.74	1.37	2.60	47	29.3	0.8	9.96
	16-26	4.0	38	10 YR	3	2	1.81	1.46	2.77	47	24.9	0.4	7.67
	+ 26	4.5	-	10 YR	5	4	1.83	1.41	2.79	49	19.5	0.0	10.46

TABLE 27. CHEMICAL ANALYSIS

Soil Series : HALDIMAND

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil					C.E.C meq./100 g	$CaCO_3$ equiv. %	Cl (ppm)	E.C mm./cm. 20°C (10^{-3})	C %	N %	C/N
		H_2O	KCl	Ca	Mg	Na	K	H							
A_1	0 - 3	5.2	4.2	6.80	0.72	1.21	0.72	7.1	16.55	0.1	135	233	5.6	0.62	9
A_2g	3- 7	5.3	4.6	9.50	6.63	1.65	0.84	5.3	23.92	0.3	165	333	2.2	0.26	8
A_3g	7-12	5.2	4.0	8.60	7.75	1.98	1.60	5.4	25.33	1.4	450	476	1.3	0.19	7
$B_{21}tg$	12-16	6.9	6.7	15.60	7.83	2.43	1.60	2.8	30.26	1.6	275	645	0.4	0.06	6
$B_{22}tg$	16-26	7.4	7.2	16.30	7.70	2.48	1.36	0.7	28.54	10.5	195	513	0.2	0.04	5
Cg	+26	7.9	7.4	15.70	7.51	2.56	1.08	0.2	27.05	12.3	145	606	0.0	0.0	0

TABLE 28. ELEMENT ANALYSIS

Soil Series : HALDIMAND

Horizon	Depth Inch.	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A_1	0- 3	16	85	119	3.89	14.39	77.9	6.52	9.68	8.24
A_2g	3- 7	25	88	143	5.13	19.15	74.9	4.97	7.05	5.97
A_3g	7-12	29	99	217	4.99	18.33	87.9	8.59	8.87	7.45
$B_{21}tg$	12-16	32	63	219	4.45	15.85	88.6	9.16	10.06	8.48
$B_{22}tg$	16-26	22	77	209	4.08	15.15	74.8	7.27	8.97	7.58
Cg	+26	35	84	206	4.58	16.11	78.8	10.46	8.77	7.38

TABLE 29. CLAY MINERAL ANALYSIS

Soil Series : HALDIMAND

th hes	Mont-moril-lonite	Illite	Kaolinite	Chlorite	Vermi-culite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
· 3		+	++++		+	+	+	+++	+	+
·16		++++	+	+	+	++	+	+	+++	++++
6		++++	+	+		++	+++	++++	+	+++

5.5.4. Discussion and First Interpretation

The Haldimand profile has developed on dark grey clay till. This profile (Figures 32 to 36) conforms to the Gleyed Gray-Brown Luvisol subgroup, according to the Canadian soil classification (1970). Haldimand soils are associated with clayey surfaces, imperfect drainage and a thick Bt horizon. A small amount of weathering shale and limestone fragments was found in the C horizon. The Haldimand profile studied is a deep phase with a surface organic horizon and intensely-eluviated A_2 horizon. The origin of the illite, kaolinite and mixed layer minerals in the Haldimand profile is unknown. They may all have been inherited remaining unchanged or they may have been formed in situ.

The relationship between soil morphology, micromorphology and analyses in the A_1, $B_{22}tg$ and Cg horizons of the Haldimand profile will now be presented. The A_1 horizon with 8.24 silica-sesquioxide ratio and silty clay loam texture exhibits an argill-silasepic plasmic fabric. The $B_{22}tg$ horizon with silica-sesquioxide of 7.58 ratio and clayey texture exhibits mosepic plasmic fabric while the Cg horizon with 7.38 ratio and clayey texture exhibits an argillasepic plasmic fabric. This result shows that the higher silica-sesquioxide ratio may indicate a relatively low degree of chemical weathering associated with less plasma development, in the Haldimand profile in contrast to the previously studied Alfisol profiles. This result shows that a clayey texture with mosepic and argillasepic plasmic fabrics is related to a relatively low degree of weathering rather than a relatively short period of pedogenesis.

Soil porosity especially microvoids will now be described in the three horizons of the Haldimand profile. The A_1 horizon with penetrability of 0.8 Kg/cm^3 and 40% porosity exhibits a few fine pores and abundant fine fissures on the surface of moderately aggregated peds and infrequent 75 to 150 u very fine macro meta-craze planar voids. The B_{22}tg horizon with 47% porosity and very strong degree of aggregation and a penetrability of 4.0 Kg/cm^3 exhibits 40 u meso ortho-joint planar voids while the Cg horizon with 47% porosity, stong aggregation and 5 Kg/cm^3 penetrability exhibits 150 u very fine macro ortho-craze planar voids. It is clear that in the B_{22}t horizon and the C g horizon planar voids are largely associated with a relatively high percent porosity, high degree of aggregation and penetrability, while, in the Ah horizon, the planar voids are associated with low percent porosity, low degree of aggregation and low penetrability which, may be influenced by the high organic matter content.

The A_1 horizon with medium and coarse crumb structure and fragmented microstructure has numerous fibrous and woody roots and plenty of earthworms. Such structure is related to the high organic matter content and faunal activity. The B_{22}tg horizon with medium angular blocky structure and cracked microstructure is affected by the accumulation of clay, carbonate and iron. The Cg horizon with coarse subangular structure and fragmented microstructure may be influenced by the marked presence of weathering shale and limestone.

5. 6. HURON SERIES

5. 6. 1. Site Description.

Location : a) Huron, Prinsley, London, Ontario. b) Soil Map, Middlesex County, Soil Survey Report No 6, Scale 1/2" to 1 mile, 6 miles north and 16 miles west from the boundary of Middlesex County. c) 200 m east of grave-yard, 250 m south of wood land, 70 m north street, west open cultivated land.

Weather conditions : Cloudy, stormy, Temp. 55°F, storm rain during last few days (5/5/1970).

Soil series : Huron clay loam, 168,000 acres.

Soil types : Clay soil with Bt horizon (Uda) moderately poorly drained.

Canadian classification (1970) : Orthic Gray-Brown Luvisol.

American classification (1968) : Typic Hapludalf.

Climatic classification : a) London. b) B_3 d B'_1 b'_2 type.

Vegetation : Mixed meadow grass (Triticum, Avena, Hordeum, Secale, Melilotus, Trifolium and Vicia spp), in good condition.

Parent material : Clay and clay-loam till, mainly limestone.

Geology and bedrock : Delaware (Devonian). The bedrock differs from dolomite, sandstone and limestone.

Topography : a) Geomorphology - glacial till plain. b) Relief - gentle undulating slope, 2° from the east to the west. c) Elevation - 800 feet above sea level. d) Drainage - i) external - slow run-off. ii) internal - very slow permeability, iii) drainage class - imperfect poor. e) Ground water table - temporary; pseudogley soil.

Land capability : General farming, dairying and beef raising, with pasture.

oats, fall wheat, corn, barley, buckwheat, beans, alfalfa, clover, timothy, roots and potatoes being the main crops grown.

Remark : Calcareous coatings on ped surfaces in the C horizon.

5. 6. 2. Horizon Description.

0- 6" Ap Dark brown (10YR 3/3), clay loam, moderately aggregated, medium crumb structure, soft friable and slightly sticky, common fine pores on ped surfaces, many fibrous grass roots, some earthworms, distinct undulating boundary.

6-10" A_2 (Ae) Dark yellowish-brown (7.5YR 4/4), clay, moderately strongly aggregated coarse subangular blocky, slightly firm and slightly sticky, common fine fibrous roots, few earthworms, indistinct irregular boundary.

10-16" Blg (BAg) Dark greyish-brown (10YR 4/2), clay, moderately aggregated medium subangular blocky, moderately hard, firm, and sticky, common fine fissures and few fine pores, on ped surfaces, 10% fine faint light yellowish-brown (10YR 6/4) mottles, few small old roots channels, gradually merging boundary.

16-24" B_{21}t Dark brown (10YR 4/3), silt clay, moderately strongly aggregated medium angular blocky, hard, firm and sticky, common fine pores and fine fibrous pores and fissures on ped surfaces, few fine fibrous roots, accosionally earthworms, dark yellowish-brown (10YR 4/4) clay skins, with old fibrous roots on ped surfaces, diffuse gradually merging boundary.

24-32" B_{22}t Brown (10YR 5/3), clay, strongly aggregated, fine angular blocky, very hard, very firm and very sticky, plenty of fine pores and a few fine fissures on ped surfaces; common very pale brown (10YR 8/4) clay skins, 5% carbonate concretions, indistinct irregular boundary.

32"+ Cg Dark yellowish-brown (10YR 4/4), silty clay texture, very strongly aggregated medium subangular blocky, very hard, very fine, very sticky, 20% yellowish-brown (10YR 4/4) faint mottles, 5% pale brown (10YR 8/4) carbonate concretions (5 mm).

5. 6. 3. Micromorphological Description.

Ap Horizon (0-6").

S-MATRIX

Skeleton : 200 u granular fragmented quartz, 300 u muscovite flakes, 175 u subangular freshly weathered plagioclase, scattered in the s-matrix.

Plasma : Yellowish-brown colour, few patches of reddish brown as a result of plasmification of the organic matter.

Plasmic fabric : Argill-silasepic; some in-vosepic plasmic fabric. Crystic plasmic fabric (Fig. 39).

Voids : 50 u meso-acicular regular meta-joint planar; 110 u macro-tubular irregular meta-craze planar and 150 u macro ortho-vughs.

Organic matter : 300 to 1000 u yellowish-brown to reddish-brown slightly decayed prolate fragments of plant residues were scattered in the s-matrix, few 100 u dark reddish-brown to opaque isotropic of decayed rounded fragments of organic matter were randomly distributed. The plasmified organic matter was incorporated with the s-matrix and occurred as reddish stains in the plasma mass. Old roots tissues were found in the s-matrix.

Basic structure : Relatively high proportion of skeleton grains in comparison

Fig. 37, the site of the Huron profile is situated on glacial till plain with gentle undulating slope. The whole landform is covered with meadow vegetation.

Fig. 38, Huron profile with the depth at which the soil was sampled being shown by the soil horizon code.

with other profiles, a few large voids were scattered in the s-matrix. Related distribution was agglomeroplasmic.

Proportion : Pl > Sk > Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : In-vosepic plasmic fabric was related to high yellowish-brown, occurs moderately birefringent in colour.

Plasma concentration : Glaebules - strong adhesive 600 u round diffuse irregular ortho-sesquioxidic nodules, moderately strong ahdesive 120 u round sharp regular meta-sesquioxidic nodules, weak adhesive 150 u round diffuse irregular ortho-ferri-organo nodules, very strong adhesive 170 u round sharp regular meta-manganiferous nodules and very strong adhesive 500 u round diffuse irregular ortho-sesquioxidic concretions, generally without differentiation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz and muscovite grains were floated from the parent material.

Pedo-relict : Natural sesquioxidic concretions.

Sedimentary-relict : Small evidence of microstratification features, related to the planar voids as a result of the pedoturbation process.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric.

After Brewer (1964) : Sesquioxidic nodules with meta-joint planar and argillasepic plasmic fabric.

After Beckman (1967) : Irregular jointed structure.

$B_{22}t$ Horizon (24-32").

S-MATRIX

Skeleton : 150 u subangular quartz, flakes of freshly weathered muscovite (200 u), 170 u angular to subangular plagioclase had corroded edges on all sides and were dull, a small number of 100 u rounded hornblende scattered in the s-matrix.

Plasma : Light brownish-yellow in colour, homogeneous.

Plasma fabric : Mo-vomasepic plasmic fabric (Fig. 40).

Voids : 9 u crypto-acicular regular meta-joint planar, 45 u meso-acicular irregular ortho-craze planar (Fig. 40), 450 x 150 u macro-prolate regular meta-chambers and 450 macro-round mammilate ortho-vughs.

Basic structure : High proportion of plasma mass and relatively high proportion of micropores, fewer skeleton grains. Related distribution was porphyroskelic intergrading to agglomeroplasmic.

Proportion : Pl > Vd > Sk.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Mo-vo-skelsepic plasmic fabric was related to the brown-yellow patches and generally high birefringence.

Plasma concentration : Glaebules - strong adhesive 300 u round regular diffuse ortho-sesquioxidic nodules; very strong adhesive 120 u round sharp irregular meta-manganiferous nodules; moderately strong adhesive 100 u round diffuse irregular ortho-ferri-organo nodules and strong adhesive 300 u round diffuse regular meta-normal sesquioxidic concretion, generally without differentiation. Cutans - 19 u illuvial ortho-vugh argillan with continuous orientation; 46 u diffuse ortho-vugh quartzan with weak orientation, 1 u stress free-grain argillan without orientation, 16 u illuvial planar argillan with strong continuous orientation (Fig. 40) and 25 u diffuse planar mangan without orientation. Subcutan - craze planar neo-cutan (Fig. 40).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large muscovite grains were outfloated from the parent material.

Pedo-relict : Regular sesquioxidic concretion.

Sedimentary-relict : Microstratification features were related to planar voids and masepic plasmic fabric.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic fabric.

After Brewer (1964) : Illuvial planar argillan with sesquioxidic nodules and meta-joint planar voids with mosepic plasmic fabric.

After Beckman (1967) : Cracked structure.

C_g Horizon (+ 32").

S-MATRIX

Skeleton : 70 u subangular to subrounded quartz, 55 u muscovite flakes, 100 u subangular plagioclase scattered in the s-matrix, a small number of 100 u rounded tourmaline and 120 u rounded hornblende were randomly distributed.

Plasma : Light brownish-yellow, homogeneous, a few dark reddish-brown stains of iron patches.

Plasma fabric : Sil-argillasepic; some ma-vo-skelsepic plasmic fabric (Fig. 41).

Voids : 900 x 150 u macro-prolate irregular ortho-vughs; 13 u crypto-acicular irregular ortho-meta joint plane and few 30 u micro tubular irregular meta-channels.

Basic structure : Relatively high proportion of skelet to the voids. Related distribution was porphyroskelic intergrading to agglomeroplasmic.

Proportion : Pl > Sk > Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Mo-vo-skelsepic plasmic fabrics were related to high brownish-yellow in colour and a moderately birefringent extinction colour.

Plasma fabric.: Glaebules - strong adhesive 400 x 150 u prolate sharp regular meta-sesquioxidic nodules; moderately adhesive 800 x 150 u prolate diffuse irregular ortho-ferri-argillan nodules; very strong adhesive 500 u round sharp regular meta-manganiferous nodules; generally without differentiation and 550 u round regular sharp meta-natural argillan nodules, with rock fabric. Cutanic - 20 to 25 u diffuse to stress joint planar argillan (Fig. 41).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz, shale and limestone grains were floated from the parent material.

Pedo-relict : Meta natural argillan nodules with parallel orientation.

Sedimentary relict : Microstratification features were related to the planar voids as well as the homogeneous plasmic fabric.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric intergrading to very little of porphyropeptic fabric.

After Brewer (1964) : Natural nodules with rock fabric with ortho vughs and silasepic plasmic fabric.

After Beckman (1967) : Fragmented structure.

2 mm

Fig. 39, crystic plasmic fabric in a carbonate glaebule and argillasepic plasmic fabric in the Ap horizon of the Huron series at 5 inches depth, under normal light. 35X.

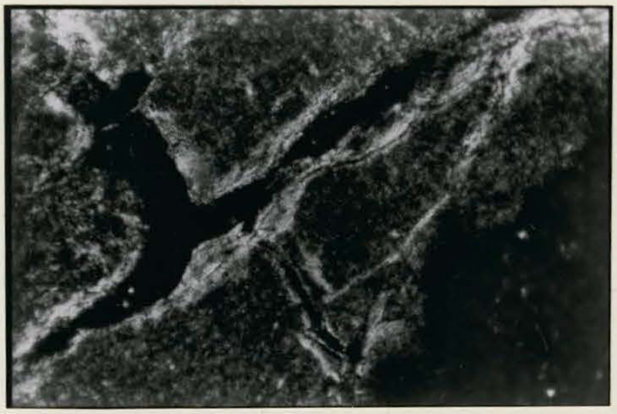


Fig. 40, craze planar neocutan, mosepic plasmic fabric and planar argillan in the $B_{22}t$ horizon of the Huron series at 30 inches depth, under normal light. 35X.

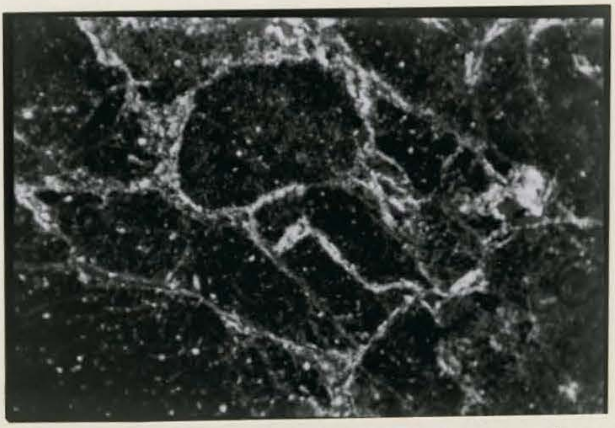


Fig. 41, planar argillan and sil-argillasepic plasmic fabric in the Cg horizon of the Huron series at 32 inches depth, under normal light. 35X.

TABLE 30. CLIMATIC DATA (LONDON)

Soil Series : HURON

Climatic type = $B_3\ B_1\ d\ b_2$

Data \ Month	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
Mean temperature (F°)													
Mean precipitation (Inches)	3.9	3.4	2.8	2.9	2.8	3.1	3.2	2.8	2.9	2.9	3.7	3.5	38.2
Potential evapotranspiration (P.E.) mm.	0	0	0	32	77	115	134	116	81	40	9	0	604
Precipitation (P) mm.	101	88	71	73	71	79	82	71	75	74	95	90	970
Storage (St) mm.	491	579	300	300	294	260	219	188	184	218	300	390	—
Actual evapotranspiration (A.E.) mm.	0	0	0	32	77	113	123	102	79	40	9	0	575
Water deficiency (D) mm.	0	0	0	0	0	2	11	14	2	0	0	0	29
Water Surplus (S) mm.	0	0	279/11	41	0	0	0	0	0	0	4	0	395

Aridity index = 5.04 per cent (d)

Summer concentration = 58.79 per cent (b_2)

P-E = 57.5 mm. (B_1)

Moisture index = 58.79 per cent (b_2)

TABLE 31. PARTICLE SIZE ANALYSIS (u%)

Soil Series : HURON

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
Ap	0-6	16.2	3.8	1.1	3.3	1.8	10.8	13.1	8.6	41.4	21.1	37.6
A_2	6-10	11.2	2.3	0.4	6.6	2.8	5.7	12.0	1.0	47.0	14.9	38.1
B1g	10-16	2.4	0.5	0.5	4.1	1.9	7.2	10.1	10.5	62.9	3.3	33.8
$B_{21}t$	16-24	1.6	0.2	0.2	2.4	5.2	13.8	11.2	10.5	56.2	2.0	43.1
$B_{22}t$	24-32	2.2	0.6	0.5	4.2	7.9	6.7	12.1	7.1	58.7	3.3	38.0
C_g	+32	5.5	3.3	0.7	15.0	2.8	10.7	2.2	3.1	47.7	9.5	42.8

TABLE 32. PHYSICAL ANALYSIS

Soil Series : HURON

Horizon	Depth inches	Compaction Kg./cm^3	Horizon domin. %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Organic matter	% Loss on ignition (850°C)
				Hue	Value	Chroma	Field	Dry					
Ap	0- 6	1.75	19	10 YR	3	3	2.14	1.51	2.56	41	25.9	8.4	12.58
A_2	6-10	2.75	13	7.5YR	4	4	2.13	1.21	2.44	50	29.2	3.6	6.98
B1g	10-16	1.75	19	10 YR	4	2	2.10	1.28	2.59	50	28.2	1.8	7.61
$B_{21}t$	16-24	3.00	25	10 YR	4	3	2.10	1.31	2.73	54	22.4	1.2	7.00
$B_{22}t$	24-32	3.25	25	10 YR	5	3	1.97	1.30	2.56	49	20.9	0.0	6.97
Cg	+ 32	4.50	-	10 YR	4	4	2.00	1.43	2.72	47	26.1	0.0	8.63

TABLE 33. CHEMICAL ANALYSIS

Soil Series : HURON

Horizon	Depth Inches	pH 1:5		Extractable cations meq. /100 gm. soil					C.E.C meq./ 100 g	$CaCO_3$ equiv. %	Cl (ppm)	E.C mm./cm. 20°C (10^{-3})	C %	N %	C/N
		H_2O	KCl	Ca	Mg	Na	K	H							
Ap	0- 6	5.9	5.4	5.90	3.71	1.94	1.60	4.5	17.65	3.02	725	500	4.2	0.35	12
A_2	6-10	6.1	5.1	9.10	5.76	1.49	1.64	2.7	20.69	0.60	350	416	1.8	0.23	8
B1g	10-16	6.8	6.5	12.80	7.71	1.03	0.48	1.6	23.63	0.40	160	344	0.9	0.12	7
$B_{21}t$	16-24	7.4	7.1	8.10	4.74	1.41	1.60	0.5	16.35	1.40	95	285	0.6	0.10	6
$B_{22}t$	24-32	7.6	7.2	8.30	7.81	1.39	1.56	0.6	19.66	1.30	120	272	0.0	0.0	0.0
Cg	+32	7.8	7.4	15.10	7.71	1.62	1.48	0.3	26.21	12.80	155	476	0.0	0.0	0.0

TABLE 34. ELEMENT ANALYSIS

Soil Series : HURON

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
Ap	0- 6	22	128	176	4.43	16.62	86.8	4.18	9.39	7.99
A_2	6-10	23	83	159	4.35	14.66	82.7	3.38	10.19	8.46
B1g	10-16	32	73	149	4.18	14.63	83.8	5.81	10.29	8.66
$B_{21}t$	16-24	16	73	144	4.26	14.06	87.8	5.80	11.29	8.35
$B_{22}t$	24-32	44	102	107	3.28	17.84	92.9	6.97	9.37	8.28
Cg	+32	19	130	177	4.65	16.07	91.8	8.63	10.39	8.68

TABLE 35. CLAY MINERAL ANALYSIS

Soil Series : HURON

Horizon	Depth Inches	Mont-moril-lonite	Illite	Kaolinite	Chlorite	Vermi-culite	Mixed layer	Kaolinite & Chlorite	Vermiculite & Chlorite	Vermiculite & Chlorite & Mixed layer	Vermiculite & Chlorite & Kaolinite
Ap	0- 6		++++	+	+	+	++++	++++	+++	++++	+++
$B_{21}t$	16-24		+++ +		+	+++	++	+	+	++++	+++
Cg	+32		++++	+	+	+++	++++	++++	+++	+++	++

5. 6. 4. Discussion and first interpretation.

The Huron profile has developed on a clay and clay loam till derived from limestone. This profile (Figures 37 to 41) conforms to the Orthic Gray-Brown Luvisol subgroup according to the Canadian soil classification (1970). Huron soils are associated with clayey surfaces, moderate drainage and thick textural B horizons. The Huron profile studied is a relatively deep phase with an Ap horizon and an intensively eluviated A_2 horizon. Illite minerals were found to be the dominant clay mineral in the Huron profile and may have developed in situ.

The relationship between the soil morphology, micromorphology and soil analysis will now be discussed in detail in the Ap, $B_{22}t$ and Cg horizons of Huron profile. The Ap horizon with 7.99 silica-sesquioxide ratio and clay loam texture exhibits an argillasepic plasmic fabric. The $B_{22}t$ horizon with silica-sesquioxide of 8.28 ratio and clayey texture exhibits mosepic plasmic fabric while the Cg horizon with 8.68 ratio and silty clay texture exhibits sil-argillasepic plasmic fabric. This result shows that the relatively high silica-sesquioxide ratio associated with a lower degree of chemical weathering may be affected by the dominant heavy texture in the Huron profile. The result also shows that a heavy texture with mosepic, argillasepic and sil-argillasepic plasmic fabrics is largely associated with a relatively low degree of chemical weathering and relative slowness of plasma development.

The $B_{22}t$ horizon of the Huron profile possessed the higher total porosity in the six Alfisol profiles studied. The Ap horizon with penetrability of 1.75 Kg/cm^3 and 41% porosity exhibits numerous fine surface of moderately aggregated peds and some infrequent 50 u meso meta-joint planar voids. The $B_{22}t$ horizon with 49% porosity and 3.25 Kg/cm^3 penetrability exhibits abundant fine pores and few fine fissures on the surface of strongly aggregated peds and some 90 u crypto meta-joint planar voids while the Cg horizon with 47% porosity and 4.5 Kg/cm^3 penetrability and strongly aggregated peds exhibits 900 u very fine macro ortho-vughs. It is clear that a moderate degree of penetrability is largely associated with the planar voids while the relatively high penetrability is associated with vughs. Such vughs may be formed by peds which do not accomodate each other.

Ap horizon with medium crumb structure and irregular jointed microstructure has many fibrous roots and few earthworms. Such structure can possibly be related to the high organic matter content rather than to activity of fauna. The $B_{22}t$ horizon with fine angular blocky structure and cracked microstructure is affected by clay accumulation. The Cg horizon with medium subangular blocky structure and fragmented microstructure may be influenced by the presence of carbonate, reflected in the faint but frequent mottle patterns.

CHAPTER VI

MORPHOLOGY, MICROMORPHOLOGY AND ANALYSES OF THE SIX SPODOSOL PROFILES

The six Spodosol profiles are developed upon outwash sands or sandy tills. The morphology and micromorphology of these profiles are illustrated in Figures 43 to 73. A similar approach to that for Alfisols was adopted for the study and analysis of soil morphology and soil micromorphology of the six Spodosol profiles.

Figure 42 shows the diagrammatic horizon patterns of the six Spodosol profiles, classified according to both American and Canadian systems of soil classification. Both systems are considered as a useful adjunct in the evaluation of the stages of pedogenetic development of the six Spodosol profiles studied.

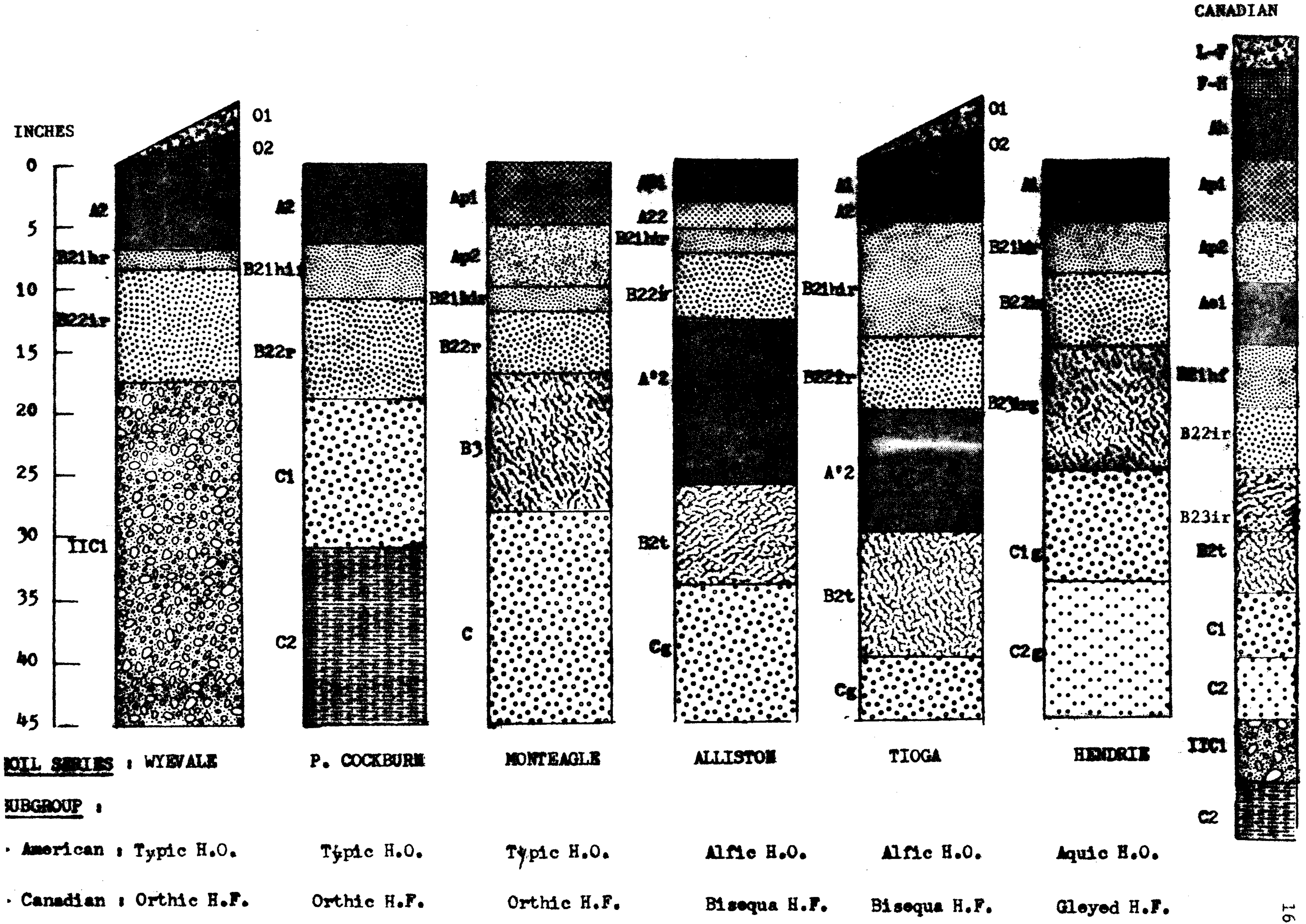


FIGURE 42 : DIAGRAMMATIC HORIZON PATTERNS OF THE SIX SPODOSOL PROFILES

6. 1. WYEVALE SERIES

6. 1. 1. Site Description

Location : a) Wyevale, one mile south of Highway 26. b) Soil Map Simco-County, Soil Survey Report No 29, Scale 1:63360. C) Top. Map, Barrie 31D/5W, 94.4 - 25.9. d) Reference Map, Lat. $44^{\circ}29'$ N., Long. $79^{\circ}48'$ W.

Weather condition : Sunny, no rain, Temp. 65°F (28/5/1969).

Soil series : Wyevale series - 10,600 acres.

Soil type : Sandy loam, good drainage with Bir horizon, 5% weathering shale in sub-soil (fLba).

Canadian classification (1970) : Orthic Humo - Ferric Podzol.

American classification (1968) : Typic Haplorthod.

Climatic classification : a) Barrie Station. b) B_2 d C'_2 b'_2 Type.

Vegetation : Reforested area of conifers, about 75 years old.

Parent material : Gray non-calcareous outwash sandy till.

Geology and bedrock : The soils of Simcoe-County are underlain by rocks of Ordovician, Silurian and Precambrian ages which latter outcrop in the north of the County. The Trenton limestone underlies most of the County, including the Wyevale series and consists almost entirely of calcite limestone with a maximum thickness of 600 feet. It is dark gray to brownish gray and silicified fossils and chert commonly occur within it.

Topography : a) Geomorphology - Wyevale soils have developed from calcareous outwash gravel, topography is gently undulating, broken in a few places by short abrupt slopes which mark the boundaries of different terrace levels. The soils are well-drained. b) Relief - flat to gentle slope 4-5% northwest for two miles. c) Elevation - 750 feet above sea level

iii) drainage class - good. e) Ground water table - temporary water table, primary pseudogley.

Land capability : The Wyevale soils are not cultivated; instead large areas are covered with trees and brush. The soil is stony, strongly acid, droughty and of low natural fertility. It would be most difficult to use these soils for cultivation.

Remarks : There is an insequent horizon between the B and C horizons and illuvial humus is present in streaks at shallow depth.

6. 1. 2. Horizon description.

2 - 1" 0_1 (L-F) Litter of coniferous leaves, unhumified, friable and dry,

1 - 0" 0_2 (F-H) Very dark grayish-brown (10YR 3/2) fragments of slightly humified remains of leaves (pine), boundary wavy.

0 - 7" A_2 (Ae) Dark brown (10YR 4/3), loamy sand, moderately weak aggregation with medium crumb structure, soft friable and slightly sticky, abundance of fine pores on surfaces, numerous fibrous roots and some small and large woody roots, many earthworms, distinct wavy boundary.

7 - 8" B_{21}hir (Bhf) Very dark grayish-brown (10YR 3/2), sandy loam, very weak aggregation with fine to medium granular structure, very soft very loose, abundant old roots and some earthworms, no mottles, irregular diffuse boundary.

8-17" B_{22}ir (Bf) Weak red (2.5YR 4/2),fine sand, weak aggregation with fine granular structure, soft loose and non-sticky, no mottles, few small woody roots, regular distinct boundary.

17" + IIC_1 Gray (2.5YR 5/0), loam with 6% weathered small shale fragments very strong aggregation with medium angular blocky structure, very hard, very firm and very sticky, numerous fine pores on the surface of the ped, no mottles or biological activity.

Fig. 43, very fine weak crumb structure in the A_2 horizon of the Wyevale series.

Fig. 44, fine granular structure in the B_{22}ir horizon of the Wyevale series.

Fig. 45, medium angular blocky structure in the IIC_1 horizon of the Wyevale series.

6. 1. 3. Micromorphological description.

A_2 (Ae) horizon (0-7").

S-MATRIX

Skeleton : 600 u angular to subangular quartz, 250 u muscovite flakes, 300 u subangular to subrounded microcline and plagioclase are freshly weathered, a small number of 300 u subrounded to rounded tourmaline.

Plasma : Light yellowish brown in colour with a few dark brown spots as a result of plasmification of the organic matter.

Plasmic fabric : Silicate moder humus ortstein (after Kubiena, 1938); silasepic plasmic fabric, inundulic plasmic fabric, Fig. 46 (after Brewer, 1964).

Voids : 320 u macro-round mammilate meta-vughs; 25 u micro-round irregular meta-compound packing; 9 u (W) micro-acicular regular meta-joint planar and 380 u macro-equant regular meta-chambers.

Organic matter : 250 to 3000 u dark brown isotropic strongly decayed prolate fragments of plant residues were scattered in the s-matrix, 650 u (L) light yellowish brown and slight humified acicular fragments of plant root tips, the plasmification appears as a few dark-brown spots in the s-matrix.

Basic structure : The plasma mass and the voids were in equal proportion, the skeleton grains appear in a relatively high proportion. Related distribution was porphyroskelic intergrading to agglomero-plasmic.

Proportion : $Sk > Pl \simeq Vd$.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Very weak birefringent colour in general with slight separation related to the voids and skeleton grains. The plasmification of organic matter makes a mask on the skeleton grains.

Plasma concentration : Glaebules - moderately strong adhesive 320 u round sharp regular meta-sesquioxidic nodules; moderately adhesive 300 u round diffuse irregular ortho-sesquioxidic concretions, without differentiation and 290 x300 u prolate regular meta-natural nodules with rock fabric.

Biofromation : Fecal pellet - 79 u round opaque, scattered in the s-matrix.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large pyroxene and shale grains were floated from the parent material.

Pedo-relict : Ortho sesquioxidic concretions and natural argillan nodules with parallel orientation.

Sedimentary relict : The sedimentation features were related to the presence of homogeneous plasma mass and sorted skeleton grains.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric intergrading to chlamedomorphic fabric and very little evidence of intertextic fabric.

After Brewer (1964) : Meta sesquioxide nodules with meta-vughs and silasepic plasmic fabric.

After Beckman (1967) : Spongy structure intergrading to cracked structure.

B_{22}ir (Bf) horizon (8-17").

S-MATRIX

Skeleton : 420 u angular to subangular quartz, 350 u subangular plagioclase, corroded and dull, 300 u fresh muscovite flakes, a few 250 u rounded tourmaline randomly distributed.

Plasma : Yellowish-brown, with a few dark reddish-brown spots, the result of plasmification of organic matter with iron.

Plasma fabric : Coated ferri-organo ortstein intergrading to moderate mull

Brewer, 1964).

Voids : 30 u micro-round irregular meta-compound packing voids (Fig. 47). 75 u meso-round irregular ortho-vughs and 450 u very fine round regular meta vesicles.

Organic matter : A high proportion of organic matter accumulated in this horizon, consisting of 200-2000 u dark brown, isotropic strongly decayed angular, prolate fragments of plant residues, a few intact plant remains with cellular appearance, isotropic black, randomly distributed plasmified. Organic matter was incroporated in the s-matrix and occurs as dark spots in plasma mass.

Basic structure : High proportion of skeleton grains, perforated by many micropores. Related distribution was agglomeroplasmic intergrading to porphyroskelic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The separation, with moderately birefringent colour, was related to skeleton grains, other separations with high birefringent interference colour were related to the micro-pores in the s-matrix.

ORTHIC PEDOLOGICAL FEATURES

Plasma concentration : Glaebules - very strongly adhesive 400 to 600 u round, regular sharp ortho-meta-sesquioxide nodules (Fig. 47); moderately strongly adhesive 700 x 500 u prolate, sharp regular meta ferri-organo nodules, undifferentiated and 450 x 250 u prolate sharp regular argillan nodules (rock fabric).

Cutans : 15 u illuvial free-grain organo-argillan with moderately continuous orientation and 25-45 u diffuse free-grain organo-ferri-argillan with weak orientation and strong separation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : intergraded large feldspar grains were floated from the parent material.

Pedo-relict : Natural argillan nodules with parallel orientation.

Sedimentary-relict : These were related to the well sorted material which deposits were principally associated with the dense coating of the upper surface of the skeleton grains.

Bio-relict : Seed sacs (35 u) scattered in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric with a few evidences of intertextic fabric.

After Brewer (1964) : Illuvial free-grain organo-argillan with meta compound packing voids and skelsepic plasmic fabric.

After Beckman (1967) : Porous structure with some evidence of spongy structure.

IIC_1 horizon (+ 17").

S-MATRIX

Skeleton : 290 u subangular quartz, 500 to 250 u muscovite flakes, 350 u subangular fresh weathered microcline and plagioclase were scattered in the s-matrix, a small number of 120 u rounded hornblende were randomly distributed.

Plasma : Yellowish-brown in general, homogeneous, a few reddish- and yellowish-brown spots as a result of iron mobilization.

Plasma fabric : Brownerde - brown-lehm intergrade (after Kubiena, 1938), Silasepic plasmic fabrics; some of in-skel-vosepic plasmic fabric (after Brewer 1964) (Fig. 48).

Voids : 8 u crypto-acicular irregular meta-simple packing voids result of compaction; 118 u macro-tubular irregular meta-channels, 800 x 200 u macro-prolate regular meta-vughs and 200

Organic matter : Dark brown to opaque, isotropic strong humified, angular and round fragments of plant residues were scattered in the s-matrix. The plasmified organic matter incorporated with s-matrix, occurs as small reddish-brown spots in the plasma mass.

Basic structure : A higher proportion of plasma mass occurs in this lithologically discontineous material of this horizon. Related distribution was porphyroskelic.

Proportion : Pl > Sk > Vd.

ORTHIC PEDOLOGIC FEATURES

Plasma separation : The separations were related to yellow patches in the s-matrix and generally high birefringent.

Plasma concentration : Glaebules - strong adhesive 200 x 150 u prolate sharp regular meta-sesquioxidic nodules, without differentiation, cutans - 20 u stress free-grain argillans with weak continuous orientation, 29 u diffuse free-grain ferri-argillans with moderate separation and weak orientation, 70 u illuvial free-grain ferri-organo-argillan with poor continuous orientation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large mica grains, floated from parent material (Fig. 48).

Sedimentary-relict : microstratification features were related to planar voids in the plasma mass.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic fabric intergrading to chlamedomorphic fabric.

After Brewer (1964) : Stress free-grain argillan with meta-joint planar and silasepic plasmic fabric.

After Beckman (1967) : Irregular jointed structure.

2 mm

Fig. 46, inundulic plasmic fabric in the A_2 horizon of the Wyevale series at 5 inches depth. Crossed nicol. 80X.

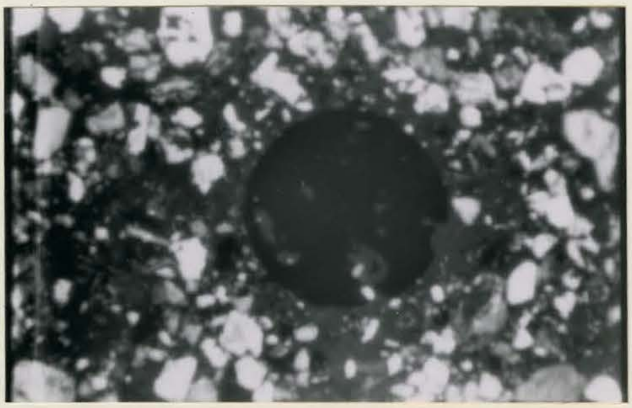


Fig. 47, meta sesquioxide nodule and compound packing voids in the B_{22}ir horizon of the Wyevale series at 15 inches depth under normal light. 35X.

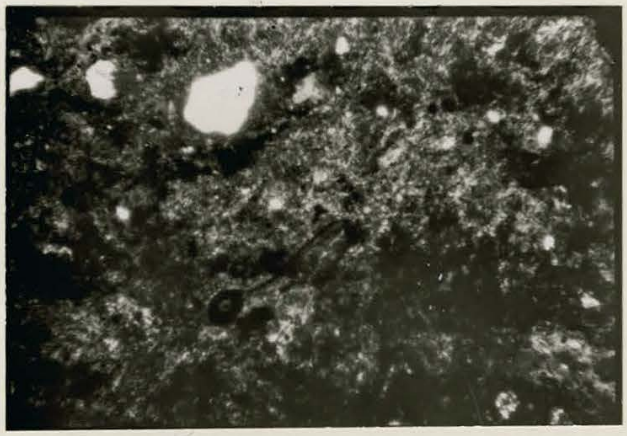


Fig. 48, insepic plasmic fabric and large mica grain (litho-relict) in the IIC_1 horizon of the Wyevale series at 17 inches depth, under normal light. 35X.

TABLE 36. CLIMATIC [redacted] (BARRIE)

Soil Series : WYEVALE, ALLISTON, HENDRIE

Climatic type = B_2 C_2 d b_2

Month / Data	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
Mean temperature (F°)	18	16	26	40	52	63	68	66	59	48	35	24	43
Mean precipitation (Inches)	3.25	2.08	2.49	2.02	2.54	2.77	2.77	2.79	2.69	2.69	3.19	2.92	32.20
Potential evapotranspiration (P.E.) mm.	0	0	0	25	71	111	135	113	78	39	6	0	578
Precipitation (P) mm.	83	53	63	51	65	70	70	71	68	68	81	74	817
Storage (St.) mm.	434	487	550	300	294	256	206	179	173	202	277	351	--
Actual evapotranspiration (A.E.) mm.	0	0	0	25	71	108	120	98	74	39	6	0	541
Water deficiency (D) mm.	0	0	0	0	0	3	15	15	4	0	0	0	37
Water surplus (S) mm.	0	0	0	250/26	0	0	0	0	0	0	0	0	276
1													

Aridity index = 6.83 per cent (d)

Summer concentration = 60.26 per cent (b_2)

P-E = 54.1 mm. (C_2)

Moisture index = 46.92 per cent (B_2)

TABLE 37. PARTICLE SIZE ANALYSIS (u%)

Soil Series : WYEVALE

Horizon	Depth ins.	Sand			Silt					Total clay < 2u	Total sand	Total silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A2	0-7	2.5	37.5	50.3	1.8	0.0	3.1	2.7	2.2	0.0	90.3	9.8
B_{21}hr	7-8	24.0	35.7	29.6	0.7	1.8	3.1	1.9	3.3	0.0	89.2	10.8
B_{22}ir	8-17	3.4	31.1	53.5	0.0	2.2	0.0	1.6	3.4	4.8	88.0	7.2
IIC_1	+17	2.9	19.7	21.9	1.0	7.4	11.0	27.7	2.5	6.7	44.4	49.6

TABLE 38. PHYSICAL ANALYSIS

Soil Series : WYEVALE

Horizon	Depth Inches	Horizon Dominant %	Color			Bulk density gm./cc		Specific Gravity gm./cc	% Pore Space	% Field Moisture Content (weight)	% Loss on Ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
A^2	0- 7	41	10YR	4	3	-	1.67	2.90	44	10.3	7.29
B_{21}hir	7- 8	6	10YR	3	2	-	2.08	2.59	21	14.3	5.81
B_{22}ir	8-17	53	10YR	4	2	-	2.03	2.72	26	13.4	7.14
IIC_1	+17	-	2.5YR	5	0	-	1.50	2.34	47	24.1	2.65

TABLE 39. CHEMICAL ANALYSIS

Soil Series : WYEVALE

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base Saturation	Chloride (ppm)	E.C mmhos. per cm at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
		H_2O	KCl	Ca	Mg	Na	K							
A_2	0- 7	5.9	5.7	1.79	1.45	1.37	0.49	5.12	149	33	4.94	2.47	0.117	24
B_{21}hir	0- 8	6.3	6.2	2.43	1.06	1.91	0.42	5.83	157	100	2.48	1.24	0.064	21
B_{22}ir	8-17	6.5	6.3	2.06	1.07	0.99	0.22	4.36	168	80	3.04	1.52	0.088	17
IIC_1	+17	7.4	7.2	10.68	1.49	1.09	0.54	13.81	176	96	0.42	0.21	0.071	3

TABLE 40. ELEMENT ANALYSIS

Soil Series : WYEVALE

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°0)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A2	0- 7	22	1060	1460	3.89	18.03	76.6	2.35	7.77	6.77
B_{21}hir	7- 8	24	1220	1830	5.21	19.29	67.9	3.31	6.57	5.48
B_{22}ir	8-17	20	1040	1500	6.46	19.58	62.8	4.10	5.75	4.68
IIC_1	+17	70	1880	1820	5.12	15.84	71.9	2.23	8.15	6.69

TABLE 41. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : WYEVALE

son	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanite	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
	0- 7	39	41	22	45	14	15	14	-	1	2	-	1	1	4	-	1
r	8-17	33	32	35	46	9	19	18	1	-	-	1	1	1	3	-	-
	+17	34	30	36	53	8	13	19	1	0	-	1	0	1	2	-	1

6. 1. 4. Discussion and first interpretation.

The Wyevale profile has developed on a gray noncalcareous outwash sand deposit. This profile (Figures 43 to 48) conforms to the Ortho Humo-Ferric Podsolic subgroup according to the Canadian soil classification (1970). Wyevale soils are associated with sandy loam surfaces, good drainage and normal Bh horizons. The Wyevale profile studied is a shallow phase with organic horizons and bisequal development in the IIC_2 horizon. Pyroxene and garnet minerals were found to be the dominant heavy minerals (after hornblend) in the Wyevale profile, derived from the parent material. The presence of pyroxene minerals shows the relatively low degree of mineral weathering in the Wyevale profile.

The relationship between soil morphology, micromorphology and soil analysis may now be discussed for the Ah, B_{22}ir and IIC_2 horizons of the Wyevale profile. The Ah horizon with 6.77 silica-sesquioxide ratio and loamy sand texture exhibits silasepic plasmic fabric. The B_{22}ir horizon with silica-sesquioxide of 4.68 ratio and fine sand texture exhibits skel-sepic plasmic fabric while the IIC_2 horizon with 6.69 ratio and loamy texture exhibits silasepic plasmic fabric. This result may indicate that the relatively high silica-sesquioxide ratio, associated with lower degree of chemical weathering and moderately light texture, are largely connected to relatively weak plasma development, while the lower ratio and the light texture of the B_{22}ir horizon are associated with developed plasmic fabrics.

Soil porosity with respect to microvoids in the Ah horizon with moderate weak aggregated peds and 44% porosity exhibits 320 u very fine macro meta vughs. The B_{22}ir horizon with low porosity and weak aggregated peds exhibits 30 u micro meta compound packing voids while the IIC_2 horizon with high porosity and very strongly aggregated peds exhibits 8 u crypto meta joint planar voids. These results may indicate that higher silt fractions are associated with higher porosities though variable void size in the s-matrix is caused by varying degrees of bridging phenomena. A significant change of soil texture, structure and consistancy between upper and lower solum of the Wyevale profile serve to indicate a textural discontinuity in the IIC_2 horizon. An increase of 42.14% silt and a decrease of 35.6% sand were noted in the IIC_2 horizon. Plasma dominance below contrasts with skeleton dominance above the discontinuity.

The Ah horizon, with medium crumb structure and spongy microstructure, has numerous fibrous and some woody roots, which exhibit considerable humification in thin section (note the C/N ratio of 24). The B_{22}ir horizon with fine granular structure and porous microstructure has very fine small dead roots and a weak red matrix colour which, in thin section, were seen to be a coated ferri-organo ortstein fabric. Such fabric, associated with the determined structure may be related to an appreciable content of clay organic matter and iron. The IIC_2 horizon with medium angular blocky structure and irregular jointed microstructure has a very sticky consistency and very strongly aggregated peds were seen in the thin section, having very compact plasma fabric of a homogeneous appearance. Such fabric may be associated with the increased silt content of this horizon.

6. 2. PORT-COCKBURN SERIES

6. 2. 1. Site Description.

Location : a) Port-Cockburn, past Clear Lake , one mile from the beach at Lake Joseph, 2 miles east of highway 69. b) Soil Map, Parry Sound District, Ontario, Soil Survey Report No 31, Scale 1:126720. c) Reference Map, Lat. 45°20' N., 79°45' W.

Weather conditions : Sunny, no clouds and no rain, Temp. 84°F (15/7/1969).

Soil series : Soil complexes, Rock-Monteagle, sandy loam, 2,352,300 acres.

Soil type : Sandy loam with good drainage and Bir horizon, few large stones in B horizon ($Lba(f)_3$).

Canadian classification (1970) : Orthic Humo-Ferric Podzol.

American classification (1968) : Typic Haplorthod.

Climatic classification : a) Lindsy Station. b) B_2 d C_2 b_2 type.

Vegetation : First class forest, the area covered with the most commonly occurring trees; sugar maple, red maple, elm, basswood, yellow birch, red and white oak, ironwood, beech, white and black oak, aspen, white birch.

Parent material : Non-calcareous sandy loam till, mainly granitic.

Geology and bedrock : The area lies near the boundary of Precambrian and Paleozoic rocks. Precambrian rocks occur in such locations as Eganville and Lake Clear; the Paleozoic formation consists of limestone beds of considerable thickness, these have been quarried for many years as stone for construction purposes and for making lime.

Topography : a) Geomorphology - the soil materials are composed of sands and silts which have been deposited either as glacial outwash or as beach deposits from early glacial lakes. b) Relief - gentle slope 5% from the north to the south with some interruption by (granite) rock and outcrops in the microrelief. c) Elevation - 750 feet above sea level. d) Drainage - i) external - moderately rapid run-off, ii) internal - moderately rapid permeability, iii) drainage class - good. e) Ground water table - slope ground water table, pseudogley soil.

Land capability : More than eighty percent of this area is unsuitable for agricultural use, the majority of these soils serve a more useful purpose in forestry. Soil which may be cultivated and used for the growing of agricultural crops are those occurring on the sand plains.

Remarks : There is platy structure in the C_2 horizons.

6. 2. 2. Horizon Description.

0 - 6" A_2 (Ae) Gray (10YR 5/1) sandy loam, very weak aggregation, very fine granular structure, friable, very soft, not sticky, plenty of fibrous and wood roots, no earthworms, indistinct irregular boundary.

6 -11" B_{21}hir (Bhf) Dark reddish-brown (2.5YR 3/4), loamy sand with 10% small gravel and 20% medium gravel (granite), moderately weak aggregation, medium granular structure, moderately friable, not sticky, plenty of fibrous and large roots, boundary gradually merging.

11-19" B_{22}ir (Bf) Dark reddish-brown (5YR 3/4), loamy sand with 30% medium gravel of granite, moderately weak aggregation, with medium granular structure, slightly firm consistency, not sticky, plenty of fibrous

Fig. 49, very fine granular structure in the A_2 horizon of the Port-Cockburn series.

Fig. 50, medium granular structure in the B_{22}ir horizon of the Port-Cockburn series.

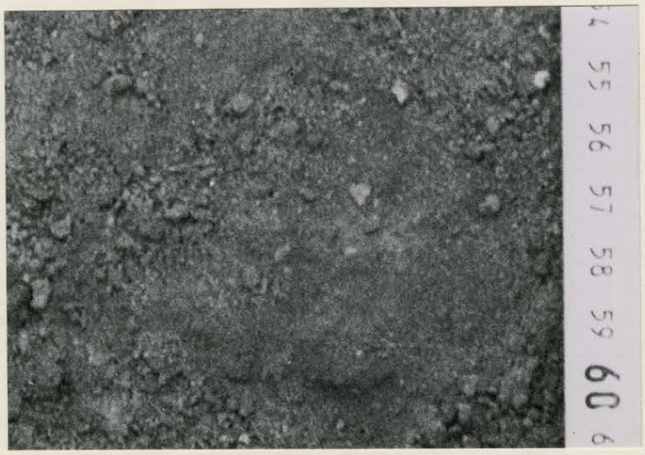


Fig. 51, fine granular structure mixed with small and medium gravels (25 %) in the C_1 horizon of the Port-Cockburn series.

31" + C_2 Olive gray (5Y 4-5/2), loam texture, moderately weak aggregation with medium platy structure, moderately firm, slightly sticky, no mottles, no biological activity.

6. 2. 3. Micromorphological Description.

A_2 (Ae) Horizon (0-6").

S-MATRIX

Skeleton : 250 u subrounded to subangular, well scattered quartz, 400 u subangular plagioclase, corroded on all sides and dull, small flakes of muscovite with corroded adges, 100 u subrounded augite and a small number of 100 u rounded hornblende.

Plasma : Dark brown homogeneous with some reddish-brown spots as a result of the plasmification of the organic matter.

Plasma fabric : Coated mull humus ortstein (after Kubiena); silasepic plasmic fabric; some skel-vosepic plasmic fabric are found (after Brewer, 1964).

Voids : 700 x 350 u macro-prolate irregular meta-orthovughs, (Fig. 52), 13 u crypto-round irregular meta-compound packing.

Organic matter : 900 u angular to round dark brown to reddish-dark brown fragments of plant residues were slightly humified, 400 u round fragments of remnant roots were scattered in the s-matrix.

Basic structure : Orthovughs with silasepic plasmic fabric, high proportion of skeleton grains are scattered in the s-matrix, related distribution porphyroskelic.

Proportion : Sk > Vd > OM > Pl.

with edge corroded, 200 u subangular to subrounded

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Skelsepic and vosepic plasmic fabric were generally related to the lighter brown patches in the s-matrix, were generally weak birefringent, the plasmification of the organic matter has produces masks on some of the skeleton grains in the s-matrix.

Plasma concentration : Glaebules - moderately strong adhesive, 500 u round sharp meta-organo-ferric nodules; strong adhesive, 700 x 300 u prolate regular meta-sesquioxidic-nodules and 650 u round regular sharp meta-natural nodules (with rock fabric).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large quartz and mica grains were outfloated from the parent material.

Sedimentary-relict : There was no evidence of microstratification as a result of pedoturbation influences.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Agglomeratic fabric with slight evidence of chlamedomorphic fabric.

After Brewer (1964) : Organo-ferric nodules with ortho-vughs and silasepic plasmic fabric.

After Beckman (1967) : Spongy structure.

B_{22}ir (Bf) horizon (11-19")

S-MATRIX

Skeleton : 300 u subangular to subrounded quartz, 400 u subangular microcline with edge corroded, 200 u subangular to subrounded plagioclase were corroded on all sides and dull, muscovite as small flakes were freshly weathered, a small number of 250 u subrounded to rounded augite.

Plasma : Reddish-brown in colour, homogeneous, filled the angular spaces of the s-matrix.

Plasma fabric : Moderately mull humus, coated organo-ferric ortstein fabric (after Kubiena, 1938); skel-vosepic plasmic fabric (after Brewer, 1964) (Fig. 53).

Voids : 25 u micro-round regular meta-simple packing voids were well scattered in the s-matix.

Organic matter : 500 u fragments of plant residues were scattered in the s-matrix, few isotropic reddish to brownish black undecomposed plant remains (primary and secondary roots) with cellular structure intact.

Basic structure : Meta-simple packing with skelsepic plasmic fabric, related distribution was porphyroskelic intergrading to agglomeroplasmic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The separation was related to the skeleton grain that has a weak birefringent colour.

Plasma concentration : Glaebules - very strongly adhesive 200 u round regular sharp meta-sesquioxidic nodules; moderately strong adhesive, 400 to 200 u prolate regular sharp meta sesquioxidic concretions and strongly adhesive 200 u round sharp regular argilliceous papules. Cutans - 20 u diffuse free-grain ferri-argillans of strong continuous coating; 40 u illuvial free-grain sesquans of discontinuous coating.

INHERITED PEDOLOGICAL FEATUES

Litho-relict : Well sorted grain with intergraded mica and feldspar were scattered in the s-matrix.

Sedimentary-relict : Well sorted grain with variable thickness of coating material were found in the upper part and were explained as a result of deposition processes.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric.

After Brewer (1964) : Sesquioxidic concretion with simple packing voids and skelsepic plasmic fabric.

After Beckman (1967) : Porous structure.

C_1 Horizon (19-31")

S-MATRIX

Skeleton : 120 u subangular to subrounded quartz, 200 u muscovite flakes with edge corroded, 200 u subangular fresh weathered plagioclase are randomly distributed, a small number of 120 u rounded to subangular augite and 100 u rounded hornblende.

Plasma : Reddish-brown except for a few dark brown spots as a result of iron mobilization.

Plasma fabric : Bleached fine sand fabric (after Kubiena, 1938); vo-skelsepic plasmic fabric (after Brewer, 1964).

Voids : 15 to 25 u crypto-micro angular irregular meta-simple packing and 250 u macro-round irregular ortho-compound packing voids. (Fig. 54).

Basic structure : High proportion of skeleton grains, many micropores with relatively low proportion of plasma mass, related distribution was porphyroskelic in most parts.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The separation was related to the lighter reddish-brown patches and generally weak birefringent extinction colour.

Plasma concentration : Glaebules - strongly adhesive 250 u round sharp regular meta-sesquioxidic nodules and strongly adhesive 250 u round sharp regular meta-manganiferous nodules; generally without differentiation. Cutans - 32 u diffuse free-grain sesquans without orientation.

INHERITED PEDOLOGICAL FEATURES

Sedimentary-relict : The sedimentary features were related to the well sorted material in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Agglomeratic fabric with slight evidence of intertextic fabric.

After Brewer. (1964) : Meta-sesquioxidic nodules with meta-simple packing and vosepic plasmic fabric.

After Beckman (1967) : Porous structure (Fig. 54).

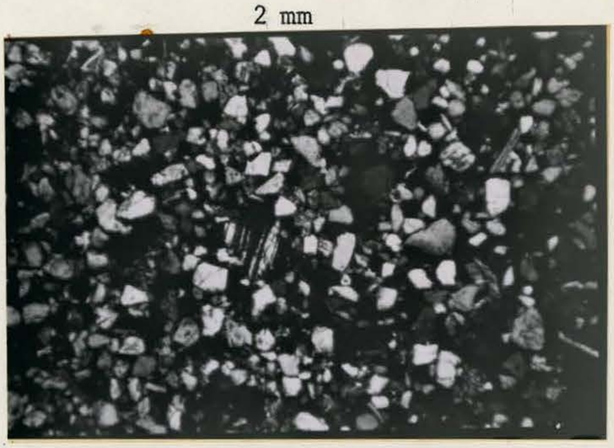


Fig. 52, meta simple packing voids and meta ortho vughs in the A_2 horizon of the Port-Cockburn series at 5 inches depth, under normal light. 35X.

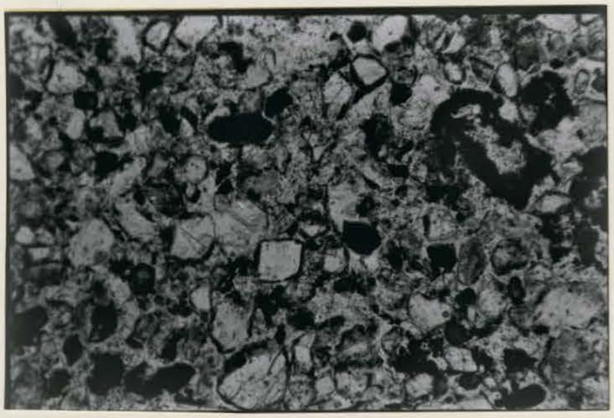


Fig. 53, skelsepic plasmic fabric in the B_{22} ir horizon of the Port-Cockburn series at 15 inches depth, under normal light. 35X.

Fig. 54, porous microstructure and compound packing voids in the C_1 horizon of the Port-Cockburn series at 25 inches depth, under normal light. 35X.

TABLE 42. CLIMATIC DATA (LINDSY)

Soil Series : PORT COCKBURN

Climatic type = $B_2\ C_2\ d\ b_2$

Month Data	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
Mean temperature (F°)	16	16	26	41	54	64	68	66	59	46	34	21	42
Mean precipitation (inches)	2.94	2.39	2.42	2.24	2.85	2.91	3.07	2.81	3.06	2.68	2.86	2.60	32.83
Potential evapotranspiration (P.E.) mm.	0	0	0	28	76	113	131	113	77	35	0	0	573
Precipitation (P) mm.	75	61	61	57	72	74	78	71	78	68	73	66	834
Storage (St) mm.	437	498	559	300	296	260	218	189	190	223	296	362	--
Actual evapotranspiration (A.E.) mm.	0	0	0	28	76	110	120	100	77	35	0	0	546
Water deficiency (D) mm.	0	0	0	0	0	3	11	13	0	0	0	0	27
Water Surplus (S) mm.	0	0	0	259/29	0	0	0	0	0	0	0	0	288

Aridity index = 4.94 per cent (d)

P-E = 54.6 mm. (C_2)

Summer concentration = 60.44 per cent (b_2)

Moisture index = 49.79 per cent (B_2)

TABLE 43. PARTICLE SIZE ANALYSIS (u%)

Soil Series : PORT COCKBURN

Horizon	Depth ins.	Sand			Silt					Total clay < 2u	Total sand	Total silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A2	0-6	42.7	20.3	13.5	5.0	3.7	5.8	7.4	1.9	0.0	76.4	23.8
B_{21}hr	6-11	45.8	21.8	14.6	2.6	2.7	4.4	2.4	5.6	0.0	82.3	17.7
B_{22}ir	11-19	54.6	17.1	9.0	1.9	4.1	4.0	2.1	7.5	0.0	80.4	19.6
C_1	19-31	50.7	18.7	11.9	2.3	2.2	5.5	3.0	6.4	0.0	80.5	19.5
C_2	+31	24.7	3.7	2.6	16.9	1.9	13.4	7.1	8.4	21.3	30.9	47.8

TABLE 44. PHYSICAL ANALYSIS

Soil Series : PORT COCKBURN

Horizon	Depth Inches	Horizon Dominant %	Color			Bulk Density gm./cc		Specific gravity gm./cc	% Pore Space	% Field moisture content (weight	% Loss on ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
A2	0- 6	19	10YR	5	1	-	1.60	2.55	39	17.6	14.10
B_{21}hir	6-11	16	2.5YR	3	4	-	1.71	2.46	30	16.5	13.23
B_{22}ir	11-19	26	5YR	3	4	-	1.63	2.62	39	8.7	10.81
C_1	19-31	39	2.5Y	7-6	2	-	1.82	2.74	34	14.5	9.82
C_2	+31	-	5 Y	4-5	2	-	1.66	2.65	39	15.6	4.47

TABLE 45. CHEMICAL ANALYSIS

Soil Series : PORT COCKBURN

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base Saturation	Chloride (ppm)	E.C mmhos. per cm. at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
		H_2O	KCl	Ca	Mg	Na	K							
A^2	0- 6	6.25	5.15	6.30	3.13	3.09	1.36	13.88	105	145	8.42	4.21	0.200	21
B_{21}hir	6-11	5.85	5.00	5.10	2.00	2.02	0.52	9.64	125	188	6.02	3.01	0.150	19
B_{22}ir	11-19	6.35	5.20	3.60	1.53	1.93	0.40	7.46	145	87	4.42	2.21	0.130	16
C_1	19-31	6.80	5.45	2.10	1.82	1.73	0.20	5.85	140	51	1.94	0.97	0.097	10
C_2	+31	6.85	5.40	2.90	1.35	1.81	0.16	6.22	180	53	0.10	0.05	0.012	4

TABLE 46. ELEMENT ANALYSIS

Soil Series : PORT COCKBURN

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A2	0- 6	9	450	1100	2.15	14.71	72.9	5.68	9.03	8.28
B_{21}hir	6-11	68	530	1360	5.52	18.02	76.8	7.21	7.77	6.37
B_{22}ir	11-19	27	690	1630	6.22	19.46	75.2	6.39	6.97	5.71
C_1	19-31	9	350	1480	4.57	14.56	76.7	7.88	9.46	7.79
C_2	+31	10	580	1810	2.88	15.88	70.8	4.37	8.35	7.37

TABLE 47. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : PORT COCKBURN

Horizon	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanite	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
A2	0- 6	37	35	28	40	18	21	8	3	2	2	-	-	-	2	1	2
$B_{22}ir$	11-19	34	30	36	42	14	21	14	4	1	-	-	1	-	-	1	2
C_2	+31	32	33	35	51	15	18	14	1	0	3	1	-	-	-	1	1

6. 2. 4. Discussion and first interpretation

The Port-Cockburn profile has developed on non-calcareous sandy loam till. This profile (Figures 49 to 54) conforms to the Orthic Humo-Ferric Podzolic subgroup, according to the Canadian soil classification (1970). Port-Cockburn soils are associated with sandy loam surfaces, good drainage and normal textural B horizons. A small amount of weathering granite was found at a shallow depth in the B_{22}ir horizon. The Port-Cockburn profile studied is a relatively shallow phase without an organic horizon on the surface of the mineral soil. Garnet minerals were found to be the dominant heavy mineral (after hornblende) in the Port-Cockburn profile, derived from the parent material.

The relationship between soil morphology, micromorphology and soil analysis will now be discussed for the A_1, B_{22}ir and C_1 horizons of the Port-Cockburn profile. The A_1 horizon with 8.28 silica-sesquioxide ratio and sandy loam texture exhibits silasepic plasmic fabric. The B_{22}ir horizon with 5.71 ratio and loamy sand texture exhibits skelsepic plasmic fabric while the C_1 horizon with 7.79 ratio and loamy sand texture exhibits vosepic plasmic fabric. This result may indicate that loamy sand texture and both higher and lower degree of chemical weathering are largely related to sepic plasmic fabrics. In contrast, sandy loam texture with lower chemical weathering possessed asepic plasmic fabric in the A_1 horizon.

The A_1 horizon with very weakly aggregated peds and 39% porosity exhibits 700 u very fine macro meta-ortho vughs, the B_{22}ir horizon with 39% porosity and moderately weak aggregated ped exhibits 25 u micro meta-simple packing voids while the C_1 horizon with 34% porosity and very weak aggregated ped exhibits 15 to 25 u crypto-micro meta-simple packing voids. This result shows that the same percent porosity can be related to different types of voids while the same type of voids was related to different percent porosity. Such porosity may be affected by the size and numbers of voids as well as by the type of the voids.

The A_1 horizon with very fine granular structure and crumby microstructure has many fibrous roots and few small woody roots, exhibits considerable humification in thin section which relates to the C/N ratio of 21 in the analysis. The B_{22}ir horizon with medium granular structure and porous microstructure has many fibrous roots. Dark reddish-brown matrix colour was interpreted as coated organo-ferro ortstein fabric, related to a high silt content (19.5%), 4.42% organic matter and 6.22% Fe_2O_3. The C_1 horizon with fine granular structure and porous microstructure has non sticky consistency and was seen in thin section as bleached sand fabric. Such fabric, associated with the previous structure may be reflected in the increase of 50.7% coarse sand material in this horizon and relatively unaltered parent material.

6. 3. MONTEAGLE SERIES

6. 3. 1. Site Description.

Location : a) Monteagle, 2 miles east of Highway 62, 5 miles north of Highway 60. b) Soil Map, Renfrew County, Ontario, Soil Survey Report No 37, Scale 1:63360. c) Reference Map, Lat. 45°28' N., Long. 77°26' W.

Weather conditions : Sunny, no rain, clouds or wind, Temp. 65°F, 3/9/1970.

Soil series : Monteagle series, 26,200 acres.

Soil type : Sandy loam soil with good drainage and Bir horizon (Lba).

Canadian classification (1970) : Orthic Humo-Ferric Podzol.

American classification (1968) : Typic Haplorthod.

Climatic classification : a) Killaloe Station, b) B_1 d C'_2 b'_2 type.

Vegetation : Neglected meadow farm for about 5 years. The area is covered with second growth trees and grass where the trees have been cut out for pulpwood or destroyed by fire.

Parent material : Non-calcareous sandy loam till, mainly granitic.

Geology and bedrock : Areas mapped as Monteagle sandy loams are widely distributed over the extensive Precambrian plateau

Topography : a) Geomorphology - rolling and quite frequently dissected by steep sided ravines, outcrops of solid rocks are frequent within the series. b) Relief - gentle slopes, 1-2% from north to south. c) Elevation - 850 feet above sea level. d) Drainage - i) external - moderately slow, ii) internal - very rapid, iii) drainage class - good. e) Ground water table - pseudogley soil with temporary ground water table.

Land capability : Parts of the largest areas of Monteagle soil have been cleared and cultivation has been attempted. In general these soils are too stony for cultivation but can be used for pasture and hay crops as adjuncts to lowland farms.

Remarks : This soil is mapped as Monteagle complex but the profile examined has the same characteristics as Monteagle series.

6. 3. 2. Horizon Description.

0 - 5" Ap_1 Dark brown (10YR 3/3), loamy sand, weak aggregation with fine crumb structure, soft, friable and nonsticky, many fibrous roots, humified pieces of organic matter, gradually merging boundary.

5-10" Ap_2 Dark yellowish-brown (10YR 4/4), loamy sand, very weakly aggregated, fine granular structure, very soft, loose and nonsticky, some fibrous roots, distinct wavy boundary.

10-12" B_{21}hir(Bhf) Dark brown (10YR 5/4), loamy sand, moderately weak aggregation medium granular structure, slightly hard, slightly firm and slightly sticky, humus deposits, discontinuous indistinct undulating lower boundary.

12-17" B_{22}ir (Bf) Dark brown (10YR 4/4), fine sand, moderate aggregation with medium granular structure, soft, slightly firm and nonsticky consistency, boundary gradually merging.

17-28" B_3 Light yellowish-brown (10YR 6/4), sandy loam, weak aggregation with fine granular structure, very soft friable and nonsticky, 5% small and medium granitic gravel, indistinct regular boundary.

28" + C Light olive-brown (2.5YR 5/4), sandy loam, very weak aggregation with very fine granular structure, very soft, very loose and nonsticky, 10% large granite stones.

Fig. 55, the site of Monteagle profile is situated on a gentle slope. The landform is covered with meadow vegetation and surrounded by natural mixed forest.

Fig. 56, Monteagle profile with the depth at which the soil was sampled being shown by the soil horizon code.

6. 3. 3. Micromorphological Description.

Ap Horizon (0-5").

S-MATRIX

<u>Skeleton</u> : 120 u round to subrounded fragmented quartz, small flakes of edge corroded muscovite were scattered, 120 - 200 u subangular to subrounded freshly weathered plagioclase and orthoclase were randomly distributed, a small number of 120 u subrounded augite and 200 u prolate and rounded hornblende.

<u>Plasma</u> : Yellowish-dark-brown in colour except for some dark brown spots as a result of a mixed humus and iron mobile.

<u>Plasma fabric</u> : Coated humus ortstein with patches of humus ortstein (after Kubiena, 1938). In-vosepic plasmic fabric with few silasepic plasmic fabric (after Brewer, 1964). (Fig. 57).

<u>Voids</u> : 15 - 20 u micro-angular to subangular meta-simple packing; 400 u very fine macro-round regular ortho-vughs.

<u>Organic matter</u> : 100 - 500 u, angular to rounded fragments of dark brown plant residues were scattered in the s-matrix; large number of undecomposed plant remains with cellular structure, intact and isotropic reddish to brownish-black were randomly distributed in a small number (Fig. 57).

<u>Basic structure</u> : High proportion of skeleton grain and voids, related distribution was porphyroskelic.

<u>Proportion</u> : Sk $\simeq$ Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

<u>Plasma separation</u> : The separation was related to the skeleton grain as well as the voids. Very weak birefringent colour of the separation material was found

Plasma concentration : Glaebules - Strong adhesive of 400 to 150 u prolate sharp regular meta-sesquioxidic nodules (without differentiation) and very strong adhesive of 250 u round regular sharp meta-manganiferous nodules (without differentiation).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Fragments of feldspar and mica together, and large fragments of quartz were found scattered in the s-matrix as a result of outfloating material during soil formation.

Sedimentary-relict : Well sorted material was indicating the sedimentation. Microstratification was absent as a result of pedoturbation by the activity of the soil fauna.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric intergrading to agglomeratic fabric.

After Brewer (1964) : Sesquioxidic nodules with meta-simple packing and insepic plasmic fabric.

After Beckman (1967) : Porous structure.

B_{22}ir (Bf) Horizon (12-17").

S-MATRIX

Skeleton : 200 u subangular to subrounded well distributed quartz, a few flakes of edge-corroded muscovite scattered in the s-matrix, a few slightly edge-corroded biotite, 500 u subangular to subrounded plagioclase, corroded and dull.

Plasma : Reddish-brown in colour, homogeneous in general.

Plasma fabric : Coated ferri-organo ortstein intergrading to weak mull humus ortstein (after Kubiena, 1938), skel-vo-insepic plasmic fabric (after

Brewer, 1964), (Fig. 58).

Voids : 100 u very fine macro-round irregular meta-ortho-compound packing voids, 1,000 u fine macro-round regular meta-vesicles and 1,200 to 800 u very fine to fine macro-prolate irregular meta-vughs.

Organic matter : 110 to 150 u fragments of plant residues were scattered in the s-matrix. Undecomposed fragments with cellular structure intact and isotropic reddish-brown, primary and secondary roots of plasmified woody plants were found, less well-incorporated with the s-matrix than in the upper horizon.

Basic structure : Compound packing with skelsepic plasmic fabric, high proportion of skeleton grains as well as voids and a low proportion of plasma mass, related distribution was porphyroskelic.

Proportion : $Sk \simeq Vd > Pl$.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Skel-vo-insepic plasmic fabric was related to the lighter reddish-brown patches in the s-matrix and was moderately birefringent.

Plasmic concentration : Glaebules - strongly adhesive, 300-500 u round regular sharp meta-sesquioxidic nodules (without differentiation); moderately strongly adhesive 150 u round regular sharp meta-argillaceous papules; strongly adhesive 500 u round regular sharp sesquioxidic concentrations and 200 u round sharp irregular normal nodules (with plasma fabric).

Cutans - 2-5 u illuvial free-grain sesquans with strong separation, 5-8 u diffuse free-grain ferri-organo argillans with weak orientation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of mica and quartz, floated from the parent material.

Pedo-relict : Natural sesquioxidic concretions.

Sedimentary-relict : Well-sorted material with abrupt contrast of skeleton-size indicated a sedimentation process.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic intergrading to porphyropeptic fabric.

After Brewer (1964) : Diffuse free-grain sesquans with meta-ortho-compound voids and skelsepic plasmic fabric.

After Beckman (1967) : Porous structure.

C Horizon (28" +)

S-MATRIX

Skeleton : 100 u angular to subangular fragmented quartz, muscovites as small flakes were freshly weathered, scattered in the s-matrix, 200 u subangular to subrounded plagioclases were randomly distributed and freshly weathered, a few 150 u rounded hornblende.

Plasma : Yellowish-brown in colour except for a few spots of red-brown as a result of iron mobilization.

Plasma fabric : Bleached fine sand (after Kubiena, 1938); silasepic (Fig. 59), skelsepic plasmic fabric (after Brewer, 1964).

Voids : 80 - 600 u very fine macro-round irregular meta-compound packing voids, and 300 u very fine macro-tubular irregular meta-craze planar voids.

Basic structure : High proportion of skeleton grains as well as plasmic mass, and small number of packing voids, related distribution was porphyroskelic.

Proportion : Sk : Pl : Vo

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Strongly-marked as higher chroma part of the s-matrix, related to skeleton grains. High birefringent colour was noticed in a few patches, the other separations were very weakly birefringent.

Plasma concentration : Glaebules - strongly adhesive, 100 u round sharp regular meta-sesquioxidic nodules (without differentiation) (Fig. 59), and very strongly adhesive 200 to 150 u prolate sharp regular meta-manganiferous nodules (without differentiation).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Homogeneous sorted material of skeleton grains without signs of any outfloated minerals. Occasionally large grains of plagioclase feldspar (> 500 u) (Fig. 59).

Sedimentary-relict : Very little evidence of microstratification as a result of an advancing process of material sorting in the s-matrix.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric with slight evidence of intertextic fabric.

After Brewer (1964) : Sesquioxidic nodules with meta-compound packing and silasepic plasmic fabric.

After Beckman (1967) : Porous structure with slight formation of irregular-jointed structure.

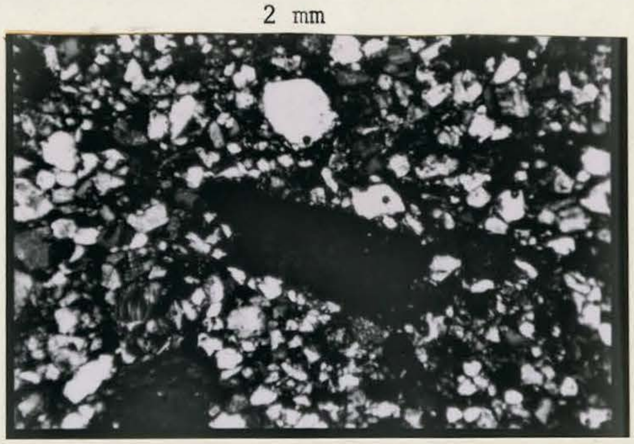


Fig. 57, plant remains, slightly decayed, and an invosepic plasmic fabric in the Ap horizon of the Monteagle series at 5 inches depth, under normal light. 35X.

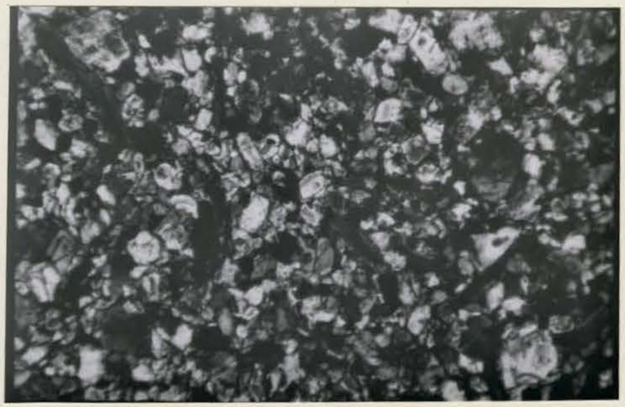


Fig. 58, skel-vosepic plasmic fabric in the B$_{22}$ir horizon of the Monteagle series at 15 inches depth, under normal light. 35X.

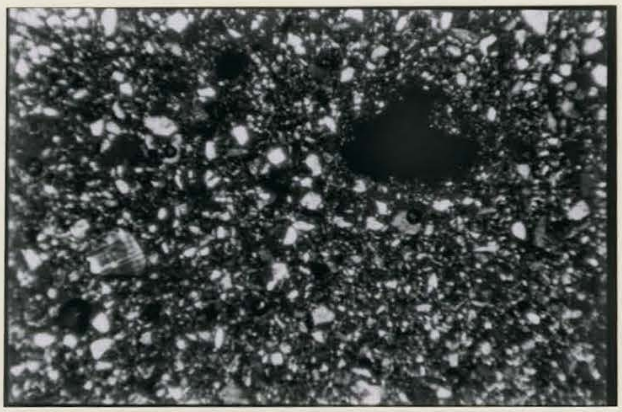


Fig. 59, silasepic plasmic fabric, meta sesquioxide nodule and feldspar grain in the C horizon of the Monteagle series at 28 inches depth, normal light. 35X.

TABLE 48. CLIMATIC DATA (KILLALOE)

Soil Series : MONTEAGLE

Climatic type = $B_1 C_2 d b_2$

Month / Data	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
Mean temperature (F°)	11	12	25	40	53	63	66	64	55	46	33	18	40
Mean precipitation (Inches)	1.8	1.6	1.8	1.9	3.1	2.3	3.1	2.6	2.9	2.1	2.2	2.1	27.3
Potential evapotranspiration (P.E.) mm.	0	0	0	25	78	115	132	111	74	33	0	0	568
Precipitation (P) mm.	53	42	48	49	63	70	66	61	65	59	53	45	674
Storage (St) mm.	338	380	428	300	285	245	196	166	161	187	240	285	--
Actual evapotranspiration (A.E.) mm.	0	0	0	25	78	110	115	91	70	33	0	0	522
Water deficiency (D) mm.	0	0	0	0	0	5	17	20	4	0	0	0	46
Water surplus (S) mm.	0	0	0	128/24	0	0	0	0	0	0	00	0	152

Aridity index = 8.81 per cent (d)

P-E = 52.2 mm. (C_2)

Summer concentration = 60.54 per cent (B_2)

Moisture index = 23.83 per cent (B_1)

TABLE 49 , PARTICLE SIZE ANALYSIS (u%)

Soil Series : MONTEAGLE

Horizon	Depth ins.	Sand			Silt					Total Clay <2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10- 5	5-2			
Ap 1	0-5	2.07	7.38	68.22	8.22	1.21	9.06	0.91	2.93	0.0	77.67	22.23
A p2	5-10	2.08	9.28	76.04	6.05	0.0	3.41	0.0	0.0	3.14	87.40	9.46
B_{21}hr	10-12	0.45	5.36	79.95	0.0	4.25	3.01	6.26	0.0	1.72	85.76	12.52
B_{22}ir	12-17	0.44	2.97	78.57	5.0	2.0	8.07	3.0	0.0	0.0	81.98	18.07
B_3	17-28	9.73	1.23	58.65	0.0	0.0	14.03	0.0	0.0	16.36	69.61	14.03
C	+28	2.62	3.13	49.15	4.69	12.85	5.13	7.72	0.0	14.71	54.90	30.39

TABLE 50. PHYSICAL ANALYSIS

Soil Series : MONTEAGLE

Horizon	Depth Inches	Horizon Dominant %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore Space	% Field moisture content (weight)	% Loss on ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
Ap 1	0- 5	18	10YR	3	3	-	1.36	2.70	41	12.7	6.20
Ap2	5-10	18	10YR	4	4	-	1.77	2.67	33	10.6	4.86
B_{21}hir	10-12	7	10YR	5	4	-	1.82	2.59	29	8.3	6.65
B_{22}ir	12-17	18	7.5YR	4	4	-	1.84	2.69	32	10.1	5.54
B_3	17-28	39	10YR	6	4	-	2.02	2.75	28	11.6	5.11
C	+28	-	2.5YR	5	4	-	2.06	2.61	23	17.7	1.75

TABLE 51. CHEMICAL ANALYSIS

Soil Series : MONTEAGLE

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base Saturation	Chloride (ppm)	E.C. mmhos. per cm, at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
		H_2O	KCl	Ca	Mg	Na	K							
Ap1	0- 5	5.4	4.9	5.27	4.41	1.58	0.14	11.42	120	156	1.84	0.92	0.031	30
Ap2	5-10	5.6	4.8	2.10	1.24	2.15	0.30	5.81	155	167	0.76	0.38	0.019	19
B_{21}hir	10-12	5.6	4.9	7.48	9.06	1.53	0.11	18.19	105	118	0.94	0.47	0.024	23
B_{22}ir	12-17	6.4	5.1	2.52	4.22	1.28	0.15	8.19	155	111	1.09	0.54	0.030	18
B_3	17-28	6.6	5.3	1.19	1.82	1.12	0.11	4.24	65	155	1.47	0.43	0.024	21
C	+28	6.3	4.9	1.54	2.49	1.13	0.20	5.38	82	106	0.32	0.16	0.019	8

TABLE 52. ELEMENT ANALYSIS

Soil Series : MONTEAGLE

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
Ap1	0- 5	37	1380	960	2.49	16.81	64.8	4.36	6.97	6.36
Ap2	5-10	32	1350	1040	2.58	17.05	67.4	4.10	7.10	6.48
B_{21}hir	10-12	32	1180	850	5.55	16.12	58.7	5.11	6.52	5.32
B_{22}ir	12-17	43	860	600	6.48	18.94	68.1	4.45	6.49	5.26
B_3	17-28	46	1000	1040	5.17	16.49	63.0	3.64	6.95	5.78
C	+28	69	1190	1220	3.73	17.19	66.6	1.43	7.07	6.17

TABLE 53. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : MONTEAGLE

Horizon	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanitee	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
Ap	0- 5	35	32	33	45	10	16	12	-	2	1	-	-	1	1	-	-
$B_{22}ir$	12-17	33	35	32	48	10	14	13	1	3	2	1	2	1	2	-	2
C	+28	31	37	32	51	13	17	12	1	3	2	1	1	1	4	2	3

6. 4. 4. Discussion and first interpretation.

The Monteagle profile has developed on a non-calcareous sandy loam till, derived mainly from granite rocks. This profile (Fig. 55 to 59), conforms to the orthic humo-ferric podzol subgroup according to the Canadian soil classification (1970). Monteagle soils are associated with sandy loam surfaces, good drainage and relatively thick textural B horizon. The Monteagle profile studied is moderately deep phase with an Ap horizon. Garnet minerals (after hornblende minerals) were found to dominate the Monteagle profile, derived from the parent material.

The relationship between soil morphology, micromorphology and soil analysis will now be discussed for the Ap, B_{22}ir and C horizons of Monteagle profile. The Ap horizon with 7.36 silica-sesquioxide ratio and loamy sand texture possessed an insepic plasmic fabric. The B_{22}ir horizon with silica-sesquioxide ratio of 5.26 and fine sand texture exhibits skelsepic plasmic fabric while the C horizon with 6.17 ratio and sandy loam texture exhibits silasepic plasmic fabric. This shows that the relatively high silica-sesquioxide ratio, associated with lower degree of weathering, and moderate light-texture are largely connected to poorly developed plasmic fabric, while the relatively low ratio and light texture are associated with strongly-developed plasmic fabric, i.e. skelsepic fabric.

The Ap horizon with 41% porosity and weakly aggregated peds exhibits 20 u micro meta-simple packing voids. The B_{22}ir horizon with 32% porosity and moderate aggregation exhibits 100 u very fine macro ortho-meta compound packing voids while the C horizon with 23% porosity and very weak

This result may indicate that the relatively low percent porosity is largely associated with compound packing voids resulting from the infilling of large pores with cement materials, while the relatively high percent porosity is associated with simple packing voids and the lack of cementing materials in the s-matrix.

The Ap horizon with fine crumb structure and porous microstructure has abundant fibrous roots, exhibits slight humification in thin section and reflects C/N ratio of 30 in the analysis. The B_{22}ir horizon with medium granular structure and porous microstructure has a dark brown matrix colour that was seen in the thin section as coated ferro-organo ortstein fabric. Such fabric associated with the previous structure may be formed by a high fine sand (78.6%), relatively highr iron (6.48% Fe_2O_3) and organic matter (1.07%) content. The C horizon with very fine granular structure and porous microstructure has light olive brown matrix colour and was seen in thin section as bleached fine sand fabric. Such fabric may be related to a higher silt content (30.4%) and the presence of 14.7% clay material in this horizon.

6. 4. ALLISTON SERIES

6. 4. 1. Site Description.

Location : a) Alliston, north of Highway 26, b) Soil Map, Simcoe County, Ontario, Soil Survey Report No 29, Scale 1:63360, c) Reference Map, Lat. $44^{o}31'$ N, Long. $79^{o}47'$ W.

Weather conditions : Temp. 64^{o}F, warm, winds light, no rain during previous week (30/5/1970).

Soil series : Alliston series, 65,900 acres.

Soil type : Sandy loam soils with imperfect drainage and Bt horizon (Lca).

Canadian classification (1970) : Bisequa (gleyed) Humo-Ferric Podzol.

American classification (1968) : Alfic Haplorthod.

Climatic classification : a) Barrie Station, b) B_2 d C'_2 b'_2 type.

Vegetation : Conifers are scattered but not in great quantity. Beech, sugar maple and wild cherry are the dominant species.

Parent material : Pale brown to gray mottled calcareous limestone, outwash sand.

Geology and bedrock : Trenton limestone consists almost entirely of calcite and has a maximum thickness of 600 feet, it also includes shales and sandstone.

Topography : a) Geomorphology - the soils commonly occupy the more level parts of the sandy outwash plains where water movement is not so free. b) Relief - regular and gently sloping (3%) from the south to the north c) Elevation - 775 feet above sea level. d) Drainage - i) external - slow run-off, ii) internal - moderate to rapid permeability, iii) drainage class - imperfect. e) Ground water table - pseudogley soil with temporary ground water table as a geomorphological result of impermeable parent material of calcareous sand.

Land capability : A wider range of crops can be grown in fields that have been artificially drained; market garden crops and certain fruits are being successfully grown on areas that are well-drained.

Remarks : These soils have many similarities to the Tioga soils, having some of the characteristics of the Spodosols but with evidence of Grey-Brown Podzolic development in the lower part of the profile.

6. 4. 2. Horizon Description.

0- 3" A_{21} (Ae1) Very dark gray (10YR 4-3/1), loamy sand, weak aggregation with fine crumb structure, soft, friable and slightly sticky, common fibrous roots, few large woody roots, distinct regular boundary.

3- 5½" A_{22} (Ae2) Gray (10YR 5/1), loamy sand, very weak aggregation with fine granular structure, very soft, very friable and non sticky, plenty of fibrous roots, few free dolomite stones indistinct regular boundary.

5½-7½"B_{21}hir (Ahf) Reddish-brown (5YR 4/3), sandy loam, structureless, very fine, granular, very soft, loose and nonsticky, plenty of fibrous roots, few small woody roots, diffuse gradually merging boundary.

7½-13" B_{22}ir (Bf) Very dusty red (2.5YR 2/4), medium sand, structureless very fine granular, very soft, very friable and nonsticky, some fibrous roots and occasionally small woody roots, diffuse gradually merging.

13-26" A'_2 (A'e) Dark reddish brown (5YR 3/4), medium sand, very weak aggregation with fine granular structure, soft, friable and nonsticky, moderately fibrous roots and occasionally woody roots, boundary gradually merging.

Fig. 60, the site of the Alliston profile is situated on a plateau in an area regular gently sloping from South to North. The land is covered with scattered mixed forest.

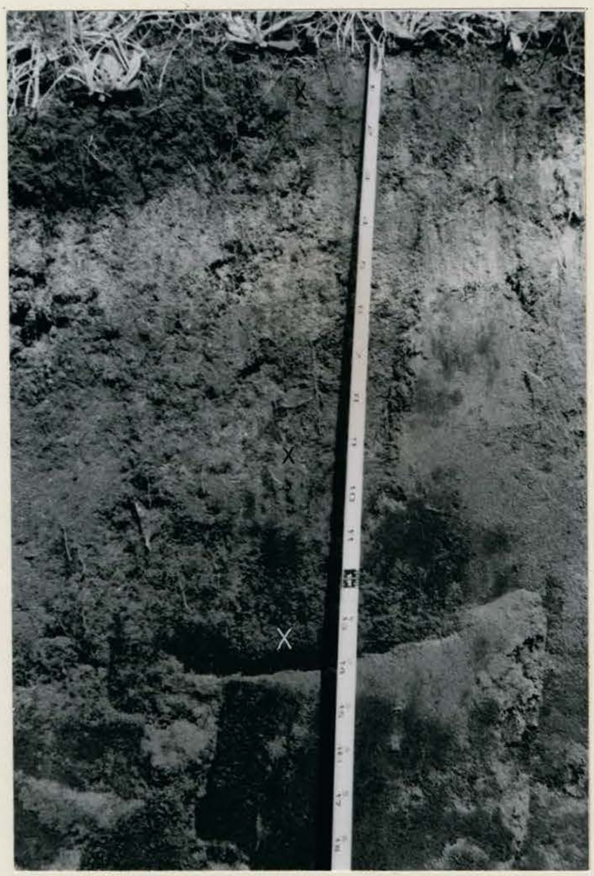


Fig. 61, Alliston profile with the depth at which the soil is sampled being shown by the soil horizon code.

26-34" B_2t Dark brown (7.5YR 4/4), loamy sand, weakly aggregated medium subangular blocky, soft, friable and slightly sticky, occasionally clay coating on the surface of the aggregates, no biological activity sharp regular boundary.

34"+Cg Grayish-brown (10YR 5/3), silty loam, moderately weak aggregation with medium angular blocky structure, moderately hard, firm and sticky, no biological activity, 10% faint mattles.

6. 4. 3. Micromorphological Description.

A_{21} (Ae) Horizon (0-3").

S-MATRIX

Skeleton : 220 u angular to subangular quartz, a few muscovite flakes, 300 u subangular to subrounded mica with corroded edges randlomly distributed, 300 u subangular plagioclase and microcline, 200 u subrounded freshly weathered intergraded feldspar, a few 200 to 150 u prolate amphibole crystals.

Plasma : Dominantly dark reddish-brown because of plasmification of organic matter, some red-brown patches as a result of iron mobilization.

Plasma fabric : Mull humus with very fine mull-like moder (after Kubiena, 1938); skelsepic plasmic fabric with some vosepic plasmic fabric (after Brewer, 1964).

Voids : 700 to 350 u very fine macro-prolate irregular meta-vughs; 30 u micro-angular irregular meta-simple packing and 70 u meso-round irregular meta-compound packing.

Organic matter : 200 to 700 u angular and rounded dark-brown to opaque fragments of slightly humified plant residues, Fig. 62. Some fragments have a cellular structure, with intact plant roots stems and leaves. The plasmification of organic matter (incorporated with s-matrix) to produce dark reddish-brown stains in the s-matrix.

Basic structure : A high proportion of skeleton grains were scattered in the s-matrix, some plasma and voids were observed, related distribution was porphyroskelic intergrading to agglomeroplasmic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasmic separation : Dense compact plasma fabric with weak birefringent colour, the plasma mass made a mask on the skeleton grain.

Plasma concentration : Glaebules - very strongly adhesive 600 to 400 u prolate sharp meta-sesquioxidic nodules undifferentiated, and strongly adhesive 300 to 500 u round sharp normal nodules (with plasma fabric).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of quartz, mica and feldspars were floated out from the parent material.

Sedimentary-relict : The upper part of the thin section has less sorted material than the lower part. The s-matrix was disturbed by fauna activity (pedoturbation).

ELEMENTARY STRUCTURE

After Kubiena (1938) : Agglomeratic fabric intergrading to chlamedomorphic fabric with some porphyropectic fabric.

After Brewer (1964) : Sesquioxidic nodules with meta-vughs and skelsepic plasmic fabric.

After Beckman (1967) : Spongy structure intergrading to fragmented structure (Fig. 62).

B_{22}ir (Bf) Horizon (7½ - 13").

S-MATRIX

<u>Skeleton</u> : 290 u subangular to subrounded quartz, 120 u subrounded plagioclase, 250 u subangular plagioclase were corroded on all sides and dull, some small muscovite flakes were scattered in the s-matrix, 320 u subrounded orthoclase, 120 u subangular to subrounded augite and a small number of 150 u rounded hornblende.

<u>Plasma</u> : Reddish-brown, homogeneous because of iron mobilization.

<u>Plasma fabric</u> : Coated ferri-organo ortstein intergraded to coated weak mull humus ortstein (after Kubiena, 1938); skelsepic plasmic fabric (after Brewer, 1964), see figures 63.

<u>Voids</u> : 250 u very fine macro-round irregular ortho-compound packing; 70 u meso-angular irregular meta-simple packing voids were well scattered in the s-matrix (Fig. 63).

<u>Organic matter</u> : 150 to 350 u prolate and tubular reddish-brown to dark brown fragments were scattered in the s-matrix; some undecomposed root remains with cellular structure intact. The plasmification of organic matter showed slight incorporation with the s-matrix to produce a dark brown staining .

<u>Basic structure</u> : A high proportion of skeleton grains and pores; a low proportion of plasma mass. Related distribution was porphyroskelic.

<u>Proportion</u> : Sk> Vd> Pl.

ORTHIC PEDOLOGICAL FEATURES

<u>Plasma separation</u> : The skelsepic fabric was related to a lighter reddish-brown s-matrix and was weakly birefringent.

<u>Plasma concentration</u> : Glaebules - strongly adhesive 200 u round regular

sharp meta-sesquioxidic nodules; moderately strongly adhesive 400 to 200 u prolate sharp meta-ferri-organo nodules and moderately adhesive 220 u round irregular ortho-ferri-argillan nodules, generally without differentiation. Cutans - 2.5 u diffuse free-grain ferrans (without orientation) with strong separation and 20 to 45 u, diffuse free-grain organo-ferrans with weak orientation and strong separation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of mica, feldspar and quartz were found outfloated from the parent material.

Sedimentary-relict : Compact well-sorted soil material and dense coatings of the upper part of the skeleton grains as a result of a sedimentation and deposition process during the soil formation.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric.

After Brewer (1964) : Diffuse free-grain ferrans and meta-sesquioxidic nodules, with simple-packing voids and skelsepic plasmic fabric.

After Beckman (1967) : Porous structure.

B_2t Horizon (26-34").

S-MATRIX

Skeleton : 750 u angular to subangular fragmented quartz, 300 u subrounded freshly weathered plagioclase, 450 u flakes of muscovite were scattered in the s-matrix. A small number of 50 u subrounded to rounded augite and a small number of 150 u rounded hornblende.

Plasma : Light yellowish-brown in colour, homogeneous, with few dark-brown spots.

Plasma fabric:: Brown lessive fabric (after Duchaufour, 1970). In-vo-skelsepic plasmic fabric (after Brewer, 1964).

Voids : 500 to 300 u very fine macro-prolate irregular ortho-vughs, (Fig. 64); 250 u very fine macro-round irregular ortho-compound packing and small number of 50 u (W) meso-angular irregular meta-simple packing.

Organic matter : 100 to 500 u fragments of organic matter were scattered in the s-matrix, undecomposed old woody roots with isotropic reddish-to brownish black in colour.

Basic structure : A high proportion of plasmic mass and relatively high proportion of voids and skeleton grains were found, related distribution was agglomeroplasmic.

Proportion : Pl > Sk ≃ Vd.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The in-vo-skelsepic plasmic fabric were generally related to the lighter yellowish-brown patches in the s-matrix and highly birefringent.

Plasmic concentration : Glaebules - strongly adhesive, 350 u round irregular meta-sesquioxidic nodules; moderately strong, 500 to 300 u prolate diffuse irregular ortho-sesquioxidic nodules; strongly adhesive 400 to 250 u prolate regular sharp meta-organo-ferri nodules and weakly adhesive 250 u round diffuse ortho-ferri-organo nodules, were without differentiation. Cutans - 10 u illuvial free-grain argillans with continuous orient ation and moderately separation; 4 - 10 u diffuse free-grain argillan with discontinuous orientation and moderately strong separation and 50 u stress vughs quartzan with weak separation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of quartz and mica were floated from the parent material.

Sedimentary-relict : Abrupt change in soil proportion gives a good evidence of new sediment material.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropectic fabric intergrading to chlamedomorphic fabric.

After Brewer (1964) : Stress vugh quartzans with sesquioxidic nodules and ortho-vughs insepic plasmic fabric.

After Beckman (1967) : Porous structure (Fig. 64).

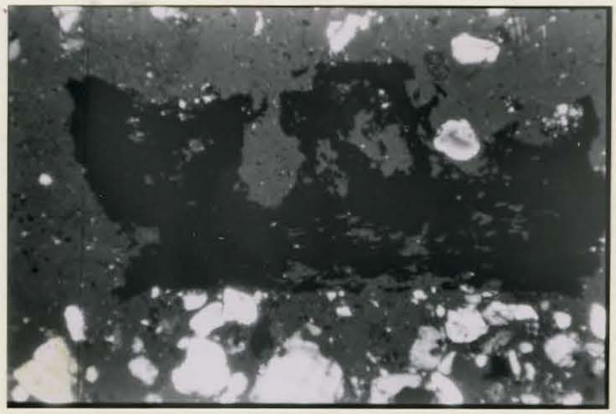


Fig. 62, plant remains slightly decayed and spongy microstructure in the A_2 horizon of the Alliston series at 3 inches depth, under normal light. 35X.

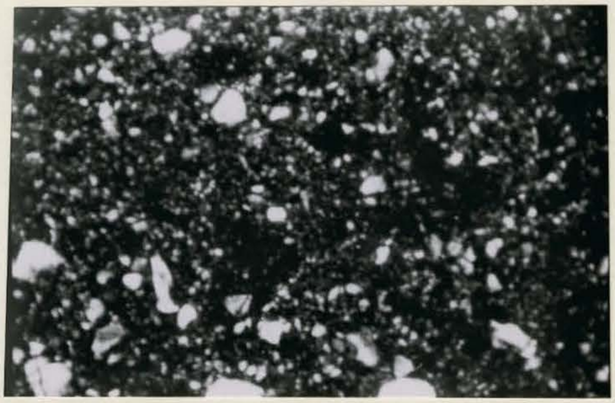


Fig. 63, simple packing voids and skelsepic plasmic fabric in the B_{22}ir horizon of the Alliston series at 10 inches depth, under normal light. 35X.

Fig. 64, ortho vughs and porous microstructure in the B_2t horizon of the Alliston series at 30 inches depth, under normal light. 35X.

TABLE 54. PARTICLE SIZE ANALYSIS (u%)

Soil Series : ALLISTON

Horizon	Depth ins.	Sand			Silt					Total Clay	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2	< 2u		
A 21	0-3	35.6	37.4	12.5	4.0	0.9	2.1	3.1	0.7	3.6	85.6	10.8
A_{22}	3-5½	36.2	40.3	11.2	3.1	0.6	1.0	0.0	5.0	2.7	87.6	9.7
B_{21}hir	5½-7½	37.8	35.0	11.2	2.8	4.2	1.9	1.1	5.9	0.0	84.1	15.9
B_{22}ir	7½-13	37.3	41.6	12.4	0.5	0.2	1.3	1.6	5.3	0.0	91.1	8.9
A'2	13-26	20.7	48.1	19.3	0.0	1.8	3.6	1.2	4.9	0.0	88.5	11.5
B_2t	26-34	14.5	41.6	27.4	1.0	1.0	4.0	4.2	3.0	4.0	82.8	13.2
C_g	+34	56.5	5.2	2.5	4.0	3.9	2.5	5.0	5.1	14.7	64.8	20.5

TABLE 55. PHYSICAL ANALYSIS

Soil Series : ALLISTON

Horizon	Depth Inches	Horizon dominant %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	& Field moisture content (weight)	% Loss on ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
A21	0- 3	10	10YR	4-3	1	1.43	1.32	2.18	39	16.5	7.86
A_{22}	3- 5½	7	10YR	5	1	1.65	1.50	2.25	34	7.0	3.75
B_{21}hir	5½- 7½	6	5YR	4	3	1.51	1.54	2.43	38	7.9	6.06
B_{22}ir	7½-13	13	2.5YR	2	4	1.53	1.79	2.64	34	12.6	4.88
A'2	13-26	38	7.5YR	4	4	1.89	1.86	2.61	30	6.7	3.83
B_2t	26-34	24	5YR	3	4	1.86	1.89	2.60	29	7.1	4.58
Cg	+34	-	10YR	5	2	2.14	2.04	2.64	24	17.5	3.16

TABLE 56. CHEMICAL ANALYSIS

Soil Series : ALLISTON

Horizon	Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base Saturation	Chloride (ppm)	E.C mmhos. per cm. at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
		H_2O	KCl	Ca	Mg	Na	K							
A21	0- 3	6.80	6.55	11.90	0.68	1.16	0.88	14.62	92	153	4.80	2.40	0.141	17
A_{22}	3- 5½	6.65	6.35	7.50	3.16	1.25	0.24	12.15	162	250	0.68	0.34	0.026	13
B_{21}hir	5½- 7½	6.25	4.85	2.60	2.86	1.22	0.40	7.08	170	137	0.90	0.45	0.028	16
B_{22}ir	7½-13	6.30	4.90	3.40	2.57	1.27	0.40	7.64	175	174	0.66	0.33	0.022	15
A'2	13-26	6.70	5.25	0.90	1.12	1.29	0.24	3.55	190	164	0.42	0.21	0.019	11
B_2t	26-34	6.95	5.40	2.90	1.08	1.19	0.24	5.41	145	154	0.00	0.00	0.00	0
Cg	+34"	6.80	5.25	3.20	2.28	1.48	0.44	7.40	160	145	0.00	0.00	0.00	0

TABLE 57. ELEMENT ANALYSIS

Soil Series : ALLISTON

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A21	0- 3	26	330	1270	2.63	14.11	68.2	3.06	8.78	7.70
A_{22}	3- 5½	49	1070	1880	3.33	13.21	63.1	3.07	8.66	7.39
$B_{21}hr$	5½- 7½	8	790	1430	3.35	12.24	63.2	5.16	9.26	7.88
$B_{22}ir$	7½-13	23	510	1570	4.27	16.01	61.3	4.22	6.89	5.88
A'2	13-26	15	510	1070	5.82	13.34	59.4	3.41	7.99	6.14
B_2t	26-34	16	390	1440	4.60	12.10	70.2	4.58	10.39	8.29
Cg	+34	13	520	1390	4.59	12.94	74.1	3.16	10.38	8.39

TABLE 58. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : ALLISTON

Horizon	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanite	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
A21	0- 3	41	44	15	45	11	13	13	4	1	1	-	2	-	1	-	2
$B_{22}ir$	13-26	39	37	23	47	12	12	12	4	1	1	2	2	-	-	-	2
Cg	+34	35	35	30	49	13	15	15	3	1	2	1	1	1	2	1	4

6. 4. 4. Discussion and first interpretation.

The Alliston profile has developed on a pale brown to gray mottled calcareous limestone and outwash deposit. This profile (Figures 60 to 64) conforms to a bisequa Humo-Ferric Podzolic subgroup according to the Canadian classification (1970). Alliston soils are associated with sandy loam surfaces, imperfect to good drainage and thick textural B horizons. The profiles studied are a relatively deep phase with an intensively eluviated A_2 horizon and bisequal development in the B_2t horizon. Tourmaline, garnet and pyroxene minerals were found to be dominant heavy minerals (after hornblende) in the Alliston profile, derived from the parent material.

The Ah horizon with 7.70 silica-sesquioxide ratio and loamy sand texture exhibits a skelsepic plasmic fabric. The B_{22}ir horizon with silica-sesquioxide of 5.88 ratio and medium sandy texture exhibits skelsepic fabric while the B_2t horizon with 8.29 ratio and loamy sand texture exhibits an insepic plasmic fabric. This result may indicate that a high silica-sesquioxide ratio in the Ah and B_2t horizons is largely associated with relatively heavy texture while a relatively low ratio in the B_{22}ir horizon is associated with a light texture. Plasma fabric reflected high degree of development in the whole profile. Such a higher silica/sesquioxide ratio may show a lower degree of chemical weathering as well as less developed plasmic fabric, in contrast, the lower ratio (higher degree of weathering) shows more developed plasma (skelsepic plasmic fabric).

The Ah horizon with weak aggregates and 39% porosity exhibits 700 u very fine macro meta-vughs. The B_{22}ir horizon with 34% porosity and very loose soil material exhibits 250 u very fine macro ortho-compound packing while the B_2t horizon with 29% porosity and weak aggregated ped exhibits 500 u very fine macro ortho-vughs. It is clear that the weakly aggregated ped is largely associated with vughs, while loose soil is linked with compound packing voids. It is also clear that the percent porosity decreases with depth of the profile, reflecting the increase of compaction with depth.

A significant change of soil structure, texture and consistency between upper and lower B horizons established a textural discontinuity in the B_2t horizon. Increases of 4% clay, 4.3% silt and 15.0% fine sand were noted in the B_2t horizon. Plasma dominance below was in contrast to skeleton dominance above the discontinuity.

Soil structure, microstructure and soil analysis may now be discussed for the Ah, $B_{22}ir$ and B_2t horizons of Alliston profile. The Ah horizon with fine crumb structure and spongy microstructure has abundant fibrous roots and a few large woody roots, exhibits slight humification in thin section and reflect the C/N ratio of 17. The $B_{22}ir$ horizon with very fine granular structure and porous microstructure has some fibrous roots and very small woody roots with very dusty red matrix colour that were seen in the thin section as a coated ferri-organo ortstein fabric. Such fabric associated with the preveous structure may be formed by 4.22% Fe_2O_3 and 0.66% organic carbon. The B_2t horizon with medium subangular blocky structure and fragmented microstructure has a slightly sticky consistency, and a dark brown matrix colour. Illuviated free-grain argillan cutans are visible. Such cutans associated with the previous structure may relate to the increase of clay and iron in this horizon.

6. 5. TIOGA SERIES

6. 5. 1. Site Description.

Location : a) Tioga, 1 mile south-east Cross Road from Highway 26. b) Simcoe County, Ontario, Soil Survey Report No 29, Scale 1:63360. c) Reference Map, Lat. 44°34' N., Long. 79°39' W.

Weather conditions : Temp. 64°F., no rain, no clouds, no rain previous week (30/5/1970).

Soil series : Tioga series, 152,700 acres.

Soil types : Sandy-loam, with good drainage and texture Bt horizon (Lba).

Canadian classification (1970) : Bisequa Humo-ferric Podzol.

American classification (1968) : Alfic Haplothord.

Climatic classification : a) Orillia station. b) B_2 d C'_2 b'_2 type.

Vegetation : Reforested areas consisting of sugar maple, red maple, white and red pines, white birch, conifers are scattered throughout. The ground is covered with mixed grasses, wheat, hay, oats and barley.

Parent material : Pale brown to gray calcareous limestone, outwash sand.

Geology and bedrock : Trenton calcitic limestone, dark gray to brownish gray silicified fossils and chert commonly occur.

Topography : a) Geomorphology - the Tioga soils have developed on calcareous outwash sands, usually stone free except in small areas where numerous stones occur on the soil surface, there are also a few areas where the surface and a large part of the subsoil have been wind-blown. b) Relief - on top of a plateau which slopes 10° to the south and 3° to the north, gently undulating east-west. c) Elevation - 1150 feet above sea level. d) Drainage - i) external - rapid run-off, ii) internal - moderately rapid permeability

iii) drainage class - well drained. e) Ground water table - pseudogley soil with temporary ground water table.

Land capability : Nearly all of the Tioga soils are cleared and used for agriculture, chiefly for mixed farming. The cash returns from general farm crops such as hay, oats, barley are low and heavy fertilization is required to obtain satisfactory crop yields.

Remarks : a) Tioga soils are very susceptible to damage by wind erosion. b) The soil has evidence of Alfisol development occurring in the lower part.

6. 5. 2. Horizon Description.

1 - ½" O_1 (L-F) Dry maple leaves.

½- 0" O_2 (F-H) Fungi are growing on the surface of slightly weathering organic matter, dark-reddish brown (5YR 2/2), friable, soft, sticky.

0-3½" A_1 (Ah) Very dark brown (10YR 2/2), coarse sand, moderate aggregated fine crumb structure, soft, friable, slightly sticky, common fibrous roots, many large woody roots, diffuse gradually merging boundary.

3½- 5" A_2 (Ae) Dark reddish-brown (5YR 3/4), loamy sand, structureless, fine granular, very soft, loose and nonsticky, many fibrous and small woody roots, gradually merging boundary.

5-14" B_{21}hir (Bhf) Dark brown (7.5YR 4/4), moderately coarse sand, structureless, fine granular, very soft, very loose and nonsticky, slightly common fibrous roots, moderately small woody roots, occasionally large woody roots, gradually merging.

14-20" B_{22}ir (Bf) Dark yellowish-brown (10YR 4/4), loamy sand, very weak aggregation, moderately fine granular structure, soft, loose and nonsticky, moderately fine fibrous roots, few woody roots, irregular undulating boundary.

20-30" A'_2 Dark brown (10YR 4/3), loamy sand, very weak aggregation, coarse and medium granular structure, soft loose, and nonsticky, 5% small shield gravel, a few fibrous roots, and very few small woody roots, occasionally old roots, gradually merging boundary.

30-40" B_2t Dark yellowish-brown (10YR 4/4), loamy sand, weak aggregation fine subangular structure, slightly hard, moderately firm and slightly sticky, 8% small shield gravels, distinct wavy boundary.

40" + Cg Pale brown (10YR 6/3), coarse sand, moderately weak aggregation with medium subangular blocky structure, slightly hard, moderately firm and slightly sticky, 5% fine faint mottles of reddish-brown colour (2.5YR 3/2).

6. 5. 3. Micromorphological Description.

Ah (A_1) Horizon (0-3½).

S-MATRIX

Skeleton : 300 u subangular to subrounded quartz, 290 u subangular fresh weathered plagioclase, a small number of intergraded plagioclase were corroded on all sides and dull, a small number of muscovite flakes were scattered in the s-matrix, 300 u edge corroded biotite, 200 to 400 u subrounded to subangular orthoclase and microcline, 300 u subangular augite and 120 u rounded hornblende, were generally in a small number.

Plasma : Very dark-brown in colour, homogeneous as a result of plasmification of the organic matter.

Plasma fabric : Mull like rendsina moder (after Kubiena, 1938), isotic

Fig. 65, the site of the Tioga profile is situated on a plateau top with gently undulating slope on three sides, flat on the other. The whole landform is covered with scrub.

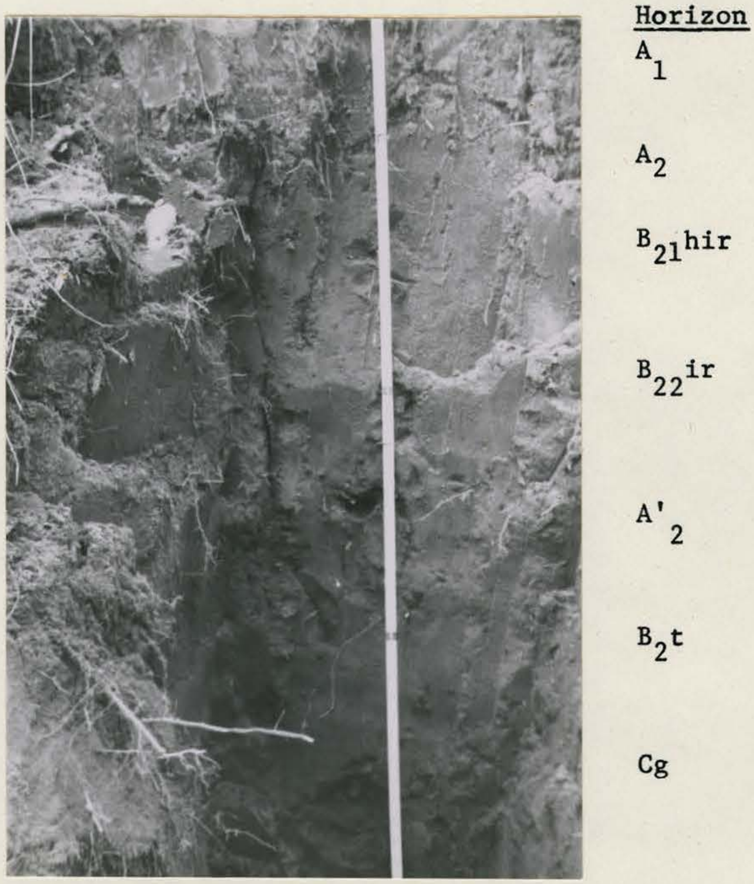


Fig. 66, Tioga profile with the depth at which the soil was sampled being shown by the soil horizon code.

plasmic fabric; vo-skel-insepic plasmic fabric (after Brewer, 1964).

Voids : 350 to 180 u very fine macro-prolate irregular ortho-meta-vughs (Fig. 67) and 40 u meso-angular irregular meta-simple packing, scattered in the s-matrix.

Organic matter : 500 to 100 u angular prolate isotropic very dark-brown to reddish-brown, occasionally opaque fragments of plant residues (Fig. 67) a few intact plant residues of primary and secondary roots were isotropic lighter dark-brown in colour.

Basic structure : High proportion of skeleton grain and small proportion of plasma mass and voids were scattered in the s-matrix, related distribution was porphyroskelic.

Proportion : Sk > Vd ≃ Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The plasmification of the organic matter was incorporated with the s-matrix that masked the skeleton grain, the vo-skel-insepic plasmic fabric were generally weak of birefringent extinction colour.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of plagioclase, mica and hornblende were floated from the parent material.

Sedimentary relict : There was no evidence of microstratification as a result of pedoturbation in the soil by the fauna activity.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Agglomeratic fabric intergrading to chlamedomorphic fabric with small evidence of porphyropectic fabric.

After Brewer (1964) : Ortho-vughs with vosepic plasmic fabric.

After Beckman (1967) : Spongy structure (Fig. 67).

B_{22}ir (Bf) Horizon (4-20").

S-MATRIX

Skeleton : 300 u subangular to subrounded quartz, a few muscovite flakes were scattered in the s-matrix, 150 u subangular freshly-weathered plagioclase, 450 u intergraded plagioclase, corroded on all sides and dull, a few biotite flakes, 250 u subangular freshly-weathered orthoclase and microcline, a few 500 u rounded hornblende and 100 u angular augite.

Plasma : Reddish-yellowish-brown homogeneous as a result of iron mobilization.

Plasma fabric : Coated organo-ferric-ortstein intergrading to moderately mull humus ortstein (after Kubiena, 1938), skel-vosepic plasmic fabric (after Brewer, 1964) (Fig. 68).

Voids : 65 u meso-angular irregular meta-simple packing voids and 350 u very fine macro-round irregular ortho-vughs.

Basic structure : High proportion of skeleton grains scattered in the s-matrix, many voids, low plasma mass, related distribution was porphyroskelic.

Proportions: Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The separation of the plasmic fabric was related to the skelsepic plasmic fabric, generally weakly birefringent.

Plasmic concentration : Glaebules - strongly adhesive 600 u round sharp meta-sesquioxidic nodules (Fig. 68); very strongly adhesive 250 to 200 u prolate sharp meta-manganiferous nodules; moderately strong adhesive, 400 u round sharp meta ferri-organo nodules and strong adhesively 300 u round sharp meta-argillan nodules without differentiation, 400 u round normal meta-nodules with plasma fabric. Cutans - 29 u diffuse free-grain ferri-argillan with strong separation and weak orientation; 34 u illuvial free-grain organo-argillans with moderate separation and orientation; 22 u diffuse embedded grain ferri-argillan with weak orientation and strong separation and 26 u diffuse free-grain sesquans with strong separation (without orientation).

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large grains of feldspar and muscovite were floated during soil formation.

Pedo-relict : Natural nodules of sesquioxide and quartz concretions

Sedimentary-relict : Dense fine material was coated on to the upper surface of the skeleton grains as a result of deposition process.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric.

After Brewer (1964) : Sesquioxidic nodules with ferri-argillan cutans and meta-simple packing with skelsepic plasmic fabric.

After Beckman (1967) : Porous structure intergrading to crumby structure.

B_2t Horizon (26-35").

S-MATRIX

Skeleton : 300 u angular to subangular quartz, 450 u subangular to subrounded plagioclase, were scattered in the s-matrix, a smaller number flakes of edge corroded muscovite, 200 u subrounded plagioclase were corroded on all sides and dull and randomly distributed, some flakes of biotite, 150 u subangular augite and 150 u rounded hornblende were in a small number present.

Plasma : Dark yellowish-brown except for a few patches of yellowish-brown.

Plasmic fabric : Brown-lehm intergraded fabric (after Kubiena, 1938);

skel-vo-insepic plasmic fabric (after Brewer, 1964), (Fig. 69).

Voids : 150 u very fine macro-angular irregular meta-simple packing; 500 u macro-round irregular ortho-vughs as a result of aggregation process by the fine material and 35 u meso-round irregular meta-compound packing was explained as an intermediate stage between the compaction and the aggregation process.

Basic structure : High proportion of skeleton grains and a relatively high proportion of plasma mass and voids were scattered in the s-matrix, related distribution was agglomeroplasmic intergrading to porphyroskelic.

Proportion : Sk > Vd ≃ Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : In the coarser material, there were separations, occurring cutanically or subcutanically to voids and skeleton grains, in the fine material there were also separations with little referred to the distribution pattern in the s-matrix. The separation in general was relatively high birefringent extinction colour.

Plasma concentration : Glaebules - moderately strongly adhesive 250 u round diffuse-sesquioxidic nodules; very strongly adhesive 130 u round sharp meta-manganiferous nodules; moderately adhesive 150 u round sharp meta-ferri-organo nodules and moderately strong adhesive 210 u round slightly diffuse ortho-sesquioxidic concretion, generally without differentiation; 400 to 250 u prolate and 900 u round of sharp natural nodules (with rock fabric). Cutan - 8 diffuse free-grain mangan with strong separation (without orientation); 20 u illuvial embedded grain ferri-argillan with weak orientation and moderately separation; 4 u illuvial free-grain argillan with strong continuous orientation and moderate separation. Subcutan - ferri-argillan neocutan, about 60 u from sesquioxidic nodules.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large rock grain of mica and quartz was floated from the parent material.

Pedo-relict : Natural sesquioxidic concretion.

Sedimentary-relict : Abrupt change in the size of the soil material from the upper horizon was an indication of a new sedimentation material deposited in this horizon.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Porphyropeptic fabric intergrading to chlamedomorphic fabric.

After Brewer (1964) : Diffuse free-grain ferri-argillan with natural nodules (with rock fabric) and meta-simple packing with skelsepic plasmic fabric.

After Beckman (1967) : Crumby structure intergrading to porous structure.

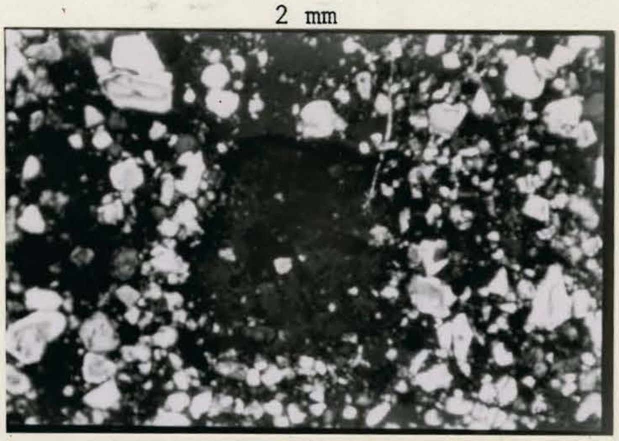


Fig. 67, ortho vughs surrounded by plant remains and spongy microstructure in the A_1 horizon of the Tioga series at 3 inches depth, under normal light. 35X.

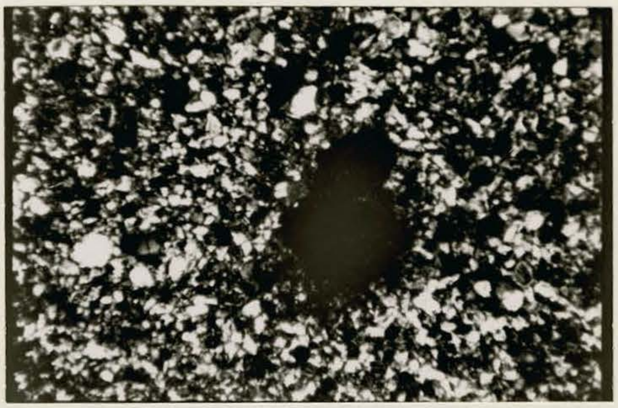


Fig. 68, meta sesquioxide and skelsepic plasmic fabric in the B_{22}ir horizon of the Tioga series at 15 inches depth, under normal light. 35X.

Fig. 69, skelsepic fabric and simple packing voids in the B_2t horizon of the Tioga series at 30 inches depth, under normal light. 35X.

TABLE 59. CLIMATIC DATA (ORILLIA)

Soil Series : TIOGA

type = B_2 C_2 d b_2

Months	J	F	M	A	My	J	Jy	Ag	S	O	N	D	ANN
erature (F^o)	17	14	26	40	53	63	68	66	59	47	34	21	42
ipitation (inches)	2.63	2.21	2.00	1.95	2.68	2.80	2.79	2.56	3.09	3.16	3.40	2.99	32.26
evapotranspiration	0	0	0	23	74	111	135	114	78	38	5	0	578
tion (P) mm.	67	56	51	50	68	71	71	65	78	80	86	76	819
St) mm.	442	498	549	300	294	257	207	176	176	218	299	375	—
apotranspiration	0	0	0	23	74	108	121	96	78	38	5	0	543
iciency (D) mm.	0	0	0	0	0	3	14	18	0	0	0	0	35
plus (S) mm.	0	0	0	249/27	0	0	0	0	0	0	0	0	276

ndex = 6.44 per cent (d)

Summer concentration = 59.86 per cent (b_2)

3 mm. (C_2)

Moisture index = 46.97 per cent (B_2)

TABLE 60 . PARTICLE SIZE ANALYSIS (u%)

Soil Series : TIOGA

Horizon	Depth ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A1	0-3½	50.9	28.6	9.2	0.2	2.8	1.9	3.1	2.3	0.9	88.7	10.4
A2	3½-5	47.6	28.2	10.3	2.3	5.6	2.5	1.4	3.1	0.0	85.1	14.9
B_{21}hr	5-14	44.5	32.6	11.5	2.6	0.2	3.4	3.7	1.9	0.0	88.2	11.8
B_{22}ir	14-26	35.8	30.9	15.6	3.9	4.4	3.9	0.3	3.4	1.5	82.6	15.9
A'2	26-33	37.5	36.7	10.1	1.5	1.3	4.0	2.3	5.6	1.7	83.6	14.7
B_2t	33-40	56.3	13.3	8.6	2.5	2.1	1.4	1.1	5.8	8.9	78.2	12.9
Cg	+40	86.8	2.8	1.1	0.7	2.9	1.9	2.6	1.1	1.2	89.6	9.2

TABLE 61. PHYSICAL ANALYSIS

Soil Series : TIOGA

Horizon	Depth Inches	Horizon ~~Dominant~~ %	Color			Bulk density gm./cc		Specific gravity ~~gm./cc~~	% Pore space	% Field moisture content (weight)	% Loss on ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
A1	0- 3½	8	10YR	2	2	1.10	1.30	2.15	41	23.2	17.86
A2	3½- 5	3	5YR	3	4	1.53	1.78	2.30	24	9.3	9.10
B_{21}hir	5-14	20	7.5YR	4	4	1.61	1.70	2.54	35	9.2	13.02
B_{22}ir	14-26	26	10YR	4	4	1.89	1.81	1.86	36	8.1	8.59
A'2	26-33	30	10YR	4	3	1.97	1.67	2.66	39	8.4	5.29
B_2t	33-40	13	10YR	4	4	1.98	1.80	2.67	34	8.9	1.30
Cg	+40	-	10YR	6	3	1.91	1.82	2.82	37	8.6	1.39

TABLE 62. CHEMICAL ANALYSIS

Soil Series : TIOGA

pth ches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base saturation	Chloride (ppm)	E.C mmhos. per cm. at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
	H_2O	KCl	Ca	Mg	Na	K							
- 3½	6.05	5.05	11.50	0.65	1.23	1.12	14.50	175	105	14.40	7.20	0.26	27
- 5	6.30	5.25	9.80	3.08	1.18	0.40	14.46	110	94	6.10	3.05	0.14	21
-14	6.55	5.15	6.20	1.61	1.30	0.28	9.39	62	227	8.44	4.22	0.24	17
-26	6.60	5.20	3.60	0.85	1.18	0.24	5.87	60	111	4.26	2.13	0.14	15
-33	6.65	5.25	4.10	1.14	1.26	0.24	6.74	65	105	1.90	0.95	0.10	9
-40	6.85	5.25	5.60	0.78	0.78	0.12	7.28	80	161	0.04	0.02	0.02	7
0	7.00	5.40	2.60	1.14	1.17	0.20	5.11	110	92	0.00	0.00	0.00	0.0

TABLE 63. ELEMENT ANALYSIS

Soil Series : TIOGA

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A1	0- 3½	13	540	1850	3.62	14.75	64.3	3.46	7.97	6.81
A2	3½- 5	18	690	1540	3.89	14.93	70.1	3.00	8.46	7.28
B_{21}hir	5-14	28	790	1240	6.92	16.02	65.2	4.58	7.36	5.69
B_{22}ir	14-26	27	610	1830	5.88	19.21	73.3	4.33	6.98	5.77
A'2	26-33	44	520	1730	4.74	19.66	73.2	3.39	6.75	5.78
B_2t	33-40	25	380	1670	3.71	14.08	62.1	1.26	7.96	6.79
Cg	+40	35	550	1810	3.34	14.26	71.3	1.39	9.00	7.87

TABLE 64. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : TIOGA

Horizon	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanite	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
A1	0- 3½	39	42	19	36	20	20	14	3	3	-	-	1	-	1	-	2
B_{22}ir	14-26	30	33	36	38	13	15	15	5	4	1	2	2	-	1	1	3
C	+40	34	31	35	49	12	15	19	1	1	1	1	-	-	-	-	1

6. 5. 4. Discussion and first interpretation.

The Tioga profile has developed on pale brown to gray calcareous limestone and outwash sand deposits. This profile (Figures 65 to 69) conforms to bisequa Humo-Ferric Podzolic subgroup, according to the Canadian soil classification (1970). Tioga soils are associated with sandy loam surfaces, good drainage and thick textural B horizons. The Tioga profile studied is very deep phase, with an organic horizon, an intensively illuviated A_2 horizon and bisequal development in the B_2t horizon. Tourmaline, garnet and pyroxene minerals (after hornblende) were found to be the dominant heavy minerals in the Tioga profile, and may be derived from either the parent material or weathering in situ.

The relationship between the soil morphology, micromorphology and soil analysis may be discusses in the Ah, B_{22}ir and B'_2t horizons of the Tioga profiles. The Ah horizon with 6.81 silica-sesquioxide ratio and coarse sand texture exhibits isotic plasmic fabric. The B_{22}ir horizon with 5.77 ratio and loamy sand texture exhibits skelsepic plasmic fabric while the B_2t horizon with 6.79 ratio and loamy sand texture exhibits skelsepic plasmic fabric. This result shows skelsepic plasmic fabric with a varying ratio and a loamy sand texture, while the isotic fabric with high ratio and lower degree of weathering is associated with coarse sand texture; maybe influenced by the high content of organic matter of 14.40%.

Soil porosity related to soil microvoids in the the three horizons of Tioga profile show that the Ah horizon with 41% porosity and a moderate degree of aggregation exhibits infrequent 350 u very fine macro ortho-meta vughs. The B_{22}ir horizon with 36% porosity and weak aggregation exhibits 65 u meso meta simple packing voids while the B_2t horizon with 34% porosity and weak aggregation exhibits 150 u very fine macro meta-simple packing voids. Hence a relatively low percent porosity is largely related to simple packing voids while the relatively high percent porosity is related to vugh voids.

A significant change of soil texture, structure and consistency between the upper and lower B horizons shows a textural discontinuity in the B'_2t horizon. Increases of 10.5% coarse sand and 7.4% clay were noted in the B'_2t horizon. Plasma dominance below was in contrast to void dominance above the discontinuity.

Soil structure, microstructure and soil analysis will now be discussed for the three horizons of Tioga profile. The Ah horizon with fine crumb structure and spongy microstructure has many fibrous roots and few large woody roots and exhibits considerable humification in thin section, reflecting the C/N ratio of 27. The $B_{22}ir$ horizon with moderately fine granular structure and porous microstructure have few fibrous roots and dark yellowish-brown matrix colour, and a coated organo-ferric ortstein fabric. Such fabric and structure relate to 17.4% fine material (clay and silt), 4.26% organic matter and 5.82% Fe_2O_3. The B'_2t horizon with fine subangular blocky structure and crumb microstructure has slight sticky consistency and dark yellowish-brown matrix colour, with a brownlehm fabric (Kubiena). Such fabric and structure may be a reflection of the increase of clay (8.9%) in a B_2t horizon.

6. 6. HENDRIE SERIES

6. 6. 1. Site Description.

Location : a) Hendrie, Cross-road on Highway 27. b) Soil Map, Simcoe County, Ontario, Soil Survey Report No 29, Scale 1:63360. c) Reference Map, Lat. $44^{o}32'$ N., Long. $79^{o}50'$ W.

Weather conditions : Temp. $64^{o}F$, no clouds, no rain previous week (30/5/1970).

Soil series : Hendrie series, 1,400 acres.

Soil type : Sandy loam, moderately poor drainage and Bir horizon (Lha).

Canadian classification - (1970) : Gleyed (Orthic) Humo-Ferric Podzol.

American classification - (1968) : Aquic Haplothord.

Climatic classification : a) Barrie station. b) B_2 d C'_2 b'_2 type.

Vegetation : The most commonly occurring trees are sugar maple, red maple, elm, basswood, yellow birch, red and white oak, beech, aspen and white birch.

Parent material : Gray non-calcareous outwash gravels (very low lime).

Geology and bedrock : Ordovician Trenton limestone underlying;the subsoil have a gentle dip to the south-west, in which direction they are overlain by Utica shale, the transition from the limestone formation to the shale formation being very gradual.

Topography : a) Geomorphology - the Hendrie soils have developed from non-calcareous outwash gravel with imperfect, poor drainage and flat to gentle undulating topography. b) Relief - low relief with very gentle slope 3^{o} from north-west to south-east. c) Elevation - 750 feet above sea level. d) Drainage - i) external - gently slope run-off, ii) internal - rapid permeability, iii) drainage class - imperfect poor. e) Ground water table - gley soil with permanent ground water table at depth of 34".

Land capability : The Hendrie soils are non-agricultural because of their low natural fertility and imperfect drainage. They should be used for forestry.

Remarks : The B horizon is yellowish-brown and contains many reddish-brown mottles.

6. 6. 2. Horizon Description.

0- 5" A_1 (Ah) Black (10YR 2/1) coarse sand, weakly aggregated fine crumb structure, soft, friable and slightly sticky, common fibrous roots and many large woody roots, indistinct wavy boundary.

5- 9" B_{21}hir (Bhf) Dark reddish-brown (2.5YR 2/4) coarse sand, structureless to weak fine granular, soft, loose, nonsticky small woody roots and many fibrous roots, diffuse gradually merging boundary.

9-15" B_{22}ir (Bf) Reddish-brown (5YR 4/4), coarse sand, weakly aggregated, moderate and fine granular, moderately hard, moderately firm and nonsticky, few old woody roots, moist, diffuse boundary, gradually merging.

15-25" B_{23}irg (Bfg) Light olive-brown (2.5Y 5/4), moderately coarse sand, moderately aggregated medium angular blocky, moderately hard, moderately firm and slightly sticky, very few old roots, 5% dark red (2.5YR 3/6) faint mottles, distinct undulating boundary.

25-34" C_1g Dark yellowish-brown (10YR 4/4), medium sand, moderate aggregation with medium angular blocky structure, moderately hard, firm and slight consistency, 5% dark grayish-brown (10YR 3/2) of 5mm Ø ortstein, 10% dark red (2.5YR 3/6) faint medium mottles, diffuse boundary gradually merging.

Fig. 70, the site of the Hendrie profile is situated on a low landform with a very gentle slope. The whole area is covered with dense mixed natural forest trees.

Horizon

A_1

B_{21}hir

B_{22}ir

B_{23}irg

Cg_1

Cg_2

Fig. 71, Hendrie profile with the depth at which the soil is sampled being shown by the soil horizon code.

34" + C_2g Yellowish-red (5YR 5/6), medium sand, moderate aggregation with coarse subangular blocky structure, hard, firm and slightly sticky consistency, 7% dark yellowish-brown (5YR 3/2) 2-3mm Ø ortstein, 20% faint 5-7mm Ø mottles, no biological activity, few small stones (sandstone gravel).

6. 6. 3. Micromorphological Description.

Ah (A_1) Horizon (0-5").

S-MATRIX

Skeleton : 300 u subangular to subrounded quartz, small muscovite flakes scattered, 300 u intergraded mica with edge corroded, 250 u intergraded feldspar were corroded on all sides and dull, a small number of 300 u subangular freshly weathered microcline and 250 u rounded hornblende.

Plasma : Dark brown with few reddish-brown spots.

Plasma fabric : Fine to coarse silica moders admixed with bleached sand soil (after Kubiena, 1938); isotic (Fig. 72) plasmic fabric; **vo-skelsepic** plasmic fabric after Brewer (1964).

Voids : 800 to 400 u very fine macro-prolate irregular meta-vughs and 70 u meso-angular irregular meta-simple packing were distributed in the s-matrix.

Organic matter : 1500 u to 200 u prolate or tubular isotropic reddish-brown, slightly decomposed fragments of plant residues were generally scattered in the s-matrix. The plasmification of the organic matter was not incorporated with the s-matrix.

Basic structure : High proportion of plant residues and skeleton grains and small proportion of voids and plasma mass, were scattered in the s-matrix. Related distribution was porphyroskelic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Vo-skelsepic plasmic fabric was related to the light reddish-brown patches, generally weak birefringent extention colour.

Plasma concentration : Glaebules - strong adhesive of 250 to 150 u prolate, very sharp regular meta-manganiferous nodules (without differentiation).

Bioformation : fecal pellet - 5 u round isotropic opaque single fecal pellets were scattered in the s-matrix.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large mica grains were floated from the parent material.

Sedimentary-relict : Well sorted material without microstratification may be as a result of pedoturbation process.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Agglomeratic fabric intergrading to chlamedomorphic fabric.

After Brewer (1964) : Manganiferous nodules with meta-vughs and isotic plasmic fabric.

After Beckman (1967) : Spongy structure.

B_{22}ir Horizon (9-15").

S-MATRIX

Skeleton : 200 u subangular to subrounded quartz, 300 u muscovite flakes were scattered in the s-matrix, 200 u subangular to subrounded plagioclase and microcline, 250 u (freshly weathering intergraded), rounded plagioclase were corroded on all sides and dull, 100 u rounded augite and 150 u rounded hornblende, were in a small number and randomly distributed.

Plasma : Reddish-dark-brown in colour, homogeneous.

Plasmic fabric : Coated ferrous ortstein intergrading to ferri-organo ortstein, in some spots few coated weak mull humus ortstein (after Kubiena, 1938); skelsepic-plasmic fabric (after Brewer, 1964), (Fig. 73).

Voids : 30 u micro-angular regular meta-simple packing (Fig. 73), as a result of compaction process; 100 u very fine macro-round regular meta-compound packing.

Organic matter : 100 to 500 u angular to round dark-brown to reddish-brown fragments of plant residues were randomly distributed.

Basic structure : High proportion of skeleton grain, relatively high in voids proportion and small quantity of plasma mass were scattered in the s-matrix. Related distribution was porphyroskelic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : The plasmic material was subcutanically associated with skeleton in the s-matrix and reflected lighter reddish-brown colour.

Plasma concentration : Glaebules - strongly adhesive 220 u round diffuse ortho-sesquioxidic nodules; strongly adhesive 250 u round sharp meta-sesquioxidic nodules; strongly adhesive 200 u round sharp meta-manganiferous nodules and moderately strong 700 to 300 u prolate sharp meta-ferri-organo nodules were generally without differentiation. Cutans - 80 u illuvial free-grain sesquans strong separate (without orientation); 250 u diffuse free-grain ferri-argillans without orientation and separation; 35 u diffuse embedded grain-ferrans weak orientation and strong separation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large intergrading feldspars and mica grains were floated from the parent material.

Sedimentary-relict : Well-sorted material with strong appearance of silt deposit on the upper surface of the skeleton grain.

ELEMENTARY STRUCTURE

After Kubiena (1938) : Chlamedomorphic fabric.

After Brewer (1964) : Illuvial free-grain sesquans with meta-sesquioxidic nodules and meta-simple packing with skelsepic plasmic fabric.

After Beckman (1967) : Porous structure.

C_1g Horizon (25-34").

S-MATRIX

Skeleton : 500 u angular to subangular quartz, 200 u subangular to subrounded plagioclase were scattered in the s-matrix, large flakes muscovite with edge corroded, 150 u subangular freshly weathered plagioclase were moderately distributed, a small number of biotite flakes, 250 u rounded to subrounded augite and 800 u subrounded hornblende were in small number present.

Plasma : Yellowish-brown in colour, homogeneous with reddish-brown spots as a result of iron mobilization

Plasmic fabric : Bleached coarse sand (after Kubiena, 1938), skel-insepic plasmic fabric (after Brewer, 1964), (Fig. 74).

Voids : 300 to 150 u very fine macro-prolate irregular meta-compound packing and 35 u micro-equant irregular meta-simple packing.

Basic structure : High proportion of skeleton grain and relatively high proportion of voids but very small proportion of plasma mass. Related distribution was porphyroskelic.

Proportion : Sk > Vd > Pl.

ORTHIC PEDOLOGICAL FEATURES

Plasma separation : Skelsepic plasmic fabric was related to the lighter reddish-brown patches of the skeleton grain, generally light birefringent extinction colour.

Plasma concentration : Glaebules - Moderately strong adhesive 600 u to 200 u prolate sharp meta-ortho-ferri-organo nodules; very strongly adhesive 600 to 400 u prolate sharp meta-manganiferous nodules and strongly adhesive 600 u round regular sharp meta-sesquioxide nodules, generally without differentiation.

INHERITED PEDOLOGICAL FEATURES

Litho-relict : Large hornblende, mica and feldspar grains were floated during soil formation.

Sedimentary-relict : Well sorted material with few fine deposit.

ELEMENTARY STRUCTURE :

After Kubiena (1938) : Chlamedomorphic fabric intergrading to bleached coarse sand fabric.

After Brewer (1964) : Meta-ortho-ferri-organo nodules with meta-compound packing voids and skelsepic plasmic fabric.

After Beckman (1967) : Porous structure.

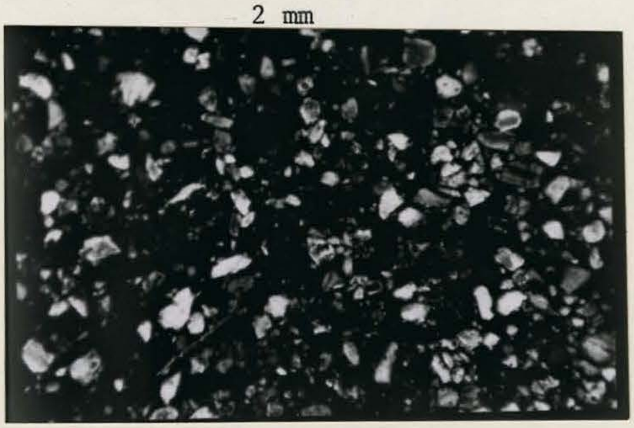


Fig. 72, isotic plasmic fabric in the A_1 horizon of the Hendrie series at 5 inches depth, under normal light. 35X.

Fig. 73, skelsepic plasmic fabric and simple packing voids in the B_{22} ir horizon of the Hendrie series at 10 inches depth under normal light. 35X.

Fig. 74, skel-insepic plasmic fabric in the C_1g horizon of the Hendrie series at 30 inches depth, under normal light. 35X.

TABLE 65 . PARTICLE SIZE ANALYSIS (u%)

Soil Series : HENDRIE

Horizon	Depth Ins.	Sand			Silt					Total Clay < 2u	Total Sand	Total Silt
		2000-500	500-250	250-50	50-30	30-20	20-10	10-5	5-2			
A1	0-5	55.8	28.7	4.4	3.8	0.6	5.1	1.8	0.9	0.0	88.8	11.2
B_{21}hir	5-9	52.7	32.8	4.9	0.1	0.1	2.0	2.0	5.0	0.0	90.3	9.7
B_{22}ir	9-15	61.8	25.1	4.0	1.7	2.9	1.3	1.4	2.7	0.0	90.9	10.0
B_{23}irg	15-25	42.0	39.3	6.8	10.9	1.3	0.1	0.1	0.1	0.0	87.5	12.5
C_1 g	25-34	37.5	40.4	18.0	2.0	0.3	1.4	1.0	0.6	0.0	94.7	5.3
C_2g	+34	40.4	44.6	9.7	1.0	0.2	1.0	3.5	0.2	0.0	94.1	5.9

TABLE 66. PHYSICAL ANALYSIS

Soil Series : HENDRIE

Horizon	Depth Inches	Horizon dominant %	Color			Bulk density gm./cc		Specific gravity gm./cc	% Pore space	% Field moisture content (weight)	% Loss on ignition (850°C)
			Hue	Value	Chroma	Field	Dry				
A1	0- 5	15	10YR	2	1	1.43	1.56	2.65	42	25.6	17.93
B_{21}hir	5- 9	12	2.5YR	2	4	1.39	1.53	2.64	44	21.2	10.00
B_{22}ir	9-15	18	5YR	4	4	1.83	1.87	2.59	29	12.7	12.99
B_{33}irg	15-25	29	2.5Y	5	4	1.97	1.81	2.64	33	18.7	7.18
C_1g	25-34	27	10YR	4	4	2.08	1.97	2.63	27	17.3	2.11
C_2g	+34	-	5YR	5	6	2.26	2.09	2.71	23	24.6	1.04

TABLE 67. CHEMICAL ANALYSIS

Soil Series : HENDRIE

Depth Inches	pH 1:5		Extractable cations meq./100 gm. soil				meq./100 gm. Base saturation	Chloride (ppm)	E.C mmhos. per cm. at 25°C 10^{-3}	Organic matter %	Carbon %	Nitrogen %	C/N
	H_2O	KCl	Ca	Mg	Na	K							
0- 5	6.15	4.65	4.60	0.74	2.35	1.16	8.86	300	56	15.00	7.50	0.220	34
5- 9	5.95	4.70	3.70	1.79	1.65	0.48	7.62	500	61	8.64	4.32	0.015	28
9-15	6.20	4.85	5.90	1.20	1.41	0.28	8.79	350	50	10.42	5.21	0.019	27
15-25	6.55	5.15	4.40	0.83	1.21	0.24	6.68	300	32	4.02	2.01	0.013	15
25-34	6.45	5.25	3.80	0.62	1.05	0.16	5.63	280	16	0.86	0.43	0.032	14
+34	6.15	5.20	1.80	0.85	1.38	0.12	4.15	290	18	0.00	0.00	0.000	0.0

TABLE 68. ELEMENT ANALYSIS

Soil Series : HENDRIE

Horizon	Depth Inches	Trace Element (ppm)			% Main Element			% Loss on Ignition (900°C)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Cu	Zn	Mn	Fe_2O_3	Al_2O_3	SiO_2			
A1	0- 5	24	980	1850	4.08	13.64	68.1	2.93	8.95	7.47
B_{21}hir	5- 9	10	430	980	5.36	14.17	69.2	1.36	8.77	6.97
B_{22}ir	5-15	17	710	1370	7.35	17.97	64.2	2.57	6.43	5.07
B_{23}irg	15-25	11	1190	1260	7.98	19.16	63.3	3.16	5.92	4.66
C_1g	25-34	11	360	970	5.98	12.79	59.1	1.25	8.28	6.32
C_2g	+34	11	340	1120	4.17	13.29	57.4	1.04	7.71	6.35

TABLE 69. HEAVY AND LIGHT MINERAL ANALYSIS (%)

Soil Series : HENDRIE

Horizon	Depth Inches	Quartz	Feldspar	Mica	Hornblende	Tourmaline	Garnet	Pyroxene	Zircon	Rutile	Kyanite	Sillimanite	Epidote	Hypersthene	Titanite	Anthophyllite	Andalusite
A 1	0- 5	43	42	15	41	15	18	10	3	4	2	1	-	-	1	2	3
$B_{23}irg$	15-25	37	38	25	45	13	17	16	2	3	1	-	1	-	-	-	2
$C_{2}g$	+34	39	41	20	52	8	16	19	1	1	1	-	1	-	-	-	1

6. 6. 4. Discussion and first interpretation.

The Hendrie profile has developed on grey non-calcareous outwash gravel deposits. This profile (Fig. 70 to 73) conforms to the Gleyed Humo Ferric Podzolic subgroup, according to the Canadian soil classification (1970). Hendrie soils are associated with sandy loam surfaces, poor drainage and moderate textural B horizon. The Hendrie profile studied is a relatively moderate phase with an organic horizon. Garnet minerals (after hornblende) were found to be the dominant heavy minerals in the Hendrie profile, derived from the parent material.

The relationship between the soil morphology, micromorphology and soil analysis in the Ah, $B_{22}t$ and C_1g horizons of Hendrie profile is as follows : The Ah horizon with 7.47 silica-sesquioxide ratio and coarse sand texture exhibits isotic plasmic fabric. The $B_{22}ir$ horizon with silica sesquioxide ratio of 5.07 and coarse sandy texture possessed skelsepic plasmic fabric, while the C_1g horizon with 6.35 ratio and medium sand texture exhibits skelsepic plasmic fabric. This result shows a lack of direct relationship between the degree of weathering and the soil texture, related to the presence of plasmic fabric, in turn influenced by the presence of high organic content, the poor drainage and the coarse texture.

The Ah horizon with 42% porosity and week aggregation exhibits 800 u very fine macro meta-vughs. The $B_{22}ir$ horizon with 29% porosity and weak aggregation exhibits 30 u micro meta-simple packing voids, while the C_1g horizon with 27% porosity and moderately aggregation exhibits 300 u very fine macro meta-compound packing voids. It is clear that the low percent porosity is largely associated with packing voids while the relatively high percent porosity is associated with vughs.

The Ah horizon with the fine crumb structure and spongy microstructure has abundant fibrous and large woody roots, exhibits slight humification in thin section and reflects the high C/N ratio of 34 in the analysis. The $B_{22}ir$ horizon with fine granular structure and porous microstructure has very few old roots and the reddish-brown matrix colour in thin section is interpreted as coated ferrous ortstein fabric. Such fabric associated with the macro structure may be induced by 5.21% organic matter and the high iron content (7.35% Fe_2O_3). The C_1g horizon with medium angular blocky structure and porous microstructure has a marked consistency. The 10% faint mottles were seen in thin section as ortho sesquioxide nodules and bleached coarse sand fabric. Such fabric associated with the previous structure may be reflection of the increase of 56.4% fine material (< 500 u) and 5.96% Fe_2O_3 in this horizon.

CHAPTER VII

EVALUATION OF SOIL PROPERTIES

7. 1. Determination of total soil porosity through physical properties.

An early focus of interest in physical characterization of soil was the specification of pore size, which pores were regarded as being filled with water and/or air, hence the measure of areal or volume porosity (Hillel 1971). Such divisions of total pore volume were more precisely defined and subscribed when Schumacher (1864) introduced the divisions of "capillary" and "non-capillary" pore space into soil moisture studies. This division remained purely hypothetical until 1935, when Schofield clarified the suction mechanism in soils, and units of suction force were introduced to distinguish between the water in capillary and non-capillary pores.

The idea of capillary porosity is largely associated with the permanent wilting point expressed as the 15 atmosphere percentage; the concept of field capacity related to $^1/_3$ atmosphere and thus with the upper limit of non-capillary potential while the moisture equivalent is associated with maximum moisture holding capacity, or total porosity (Springer and Ameryckx, 1966).

Non-capillary porosity may be defined in terms of that size of larger pore which does not hold water tightly by capillary forces. It is then clear that the tension under which a soil is drained will affect the water content in the non-capillary pores. Thus, the higher the proportion of non-capillary pores, the more such a soil body will be readily drained or leached. The determination of total porosity in this study was based on dry soil samples which still possessed hygroscopic water in voids of a probable maximum diameter of < 0.2 u. These voids are referred to as non-useful pores for plant growth and are too small to be considered as part of the capillary system. On the other hand, total porosity, as determined from a dry sample, is deemed to be most relevant to the study of relationships between total porosity and soil voids in thin section in so far as areal porosity is here studied.

The geometry of the pore system of soil is just as complex as that of the solid material. Just as soil particles vary in size, shape, regularity and swelling tendencies, so the pores differ greatly from one another in shape, lateral dimensions, length, tortuosity, continuity and other characteristics (Vomecil, 1965). Visual and microscopic methods to study pore size distribution have been developed by Kubiena (1938) and applied by Day (1948) and Altemüller (1956) (see chapter VIII). They showed that semi-quantitative analysis of soil voids in thin section can be useful in estimating the percentage porosity of most soils as well as in the description of pore-sized channels. The determination of total porosity thus yields a simple partial characterization of the soil pore system.

The calculation of porosity from measurements of soil density involves converting data from densities to volumes. Since bulk density is defined, the bulk volume can be calculated. Similarly, from the definition of the particle density, the collective volume occupied by soil particles can be calculated, and consequently the bulk volume divided by the solid volume is the fraction of the total volume occupied by solid particles. From the above definition, it follows that this fraction equals bulk density divided by the particle density. Total porosity is defined as the percentage of the bulk volume not occupied by solids, that is:

$$\text{Total porosity} : \quad 100 \; - \left[\frac{\text{bulk density}}{\text{particle density}} \times 100 \right]$$

The major difficulty in this approach is that the solid density of the soil as a whole is affected by the relative proportions of inorganic material and organic compounds in the soil which have very different densities. For this reason, the B horizons of each soil were chosen for the study of the variability of the property of porosity. They are relatively free of organic matter, except in the form of plant roots, which can be discarded.

The second difficulty in the approach to soil porosity measurement through density and void ratio measurement is that many soils experience swelling and shrinkage as the water content changes. Soil porosity in general may also vary with many of the factors which can affect the volumetric weight of soil, such as water-holding capacity, organic matter content, clay content, differential expansion of clays, particle density (especially that of heavy minerals) and other. For example De Boodt (1967) found that both the degree of soil compaction and the degree of natural aggregation affected the porosity in cultivated soils in Belgium, which may be regarded as comparable to those of Southern Ontario with respect to soil genesis. They have,however, been subjected to a longer period of cultivation. Dalrymple (1964) working in Southern England, found that the processes of clay translocation markedly influenced the pore space percentage mainly through blocking or infilling pores in the B horizon. Gillespie and Elrick (1968) found that the weathering of carbonates in the A and B horizons was accompanied by structural changes and also by increases in biological activity. Both of these served to increase the pore space percentage in the Oneida soils, studied by them in Southern Ontario.

As a conclusion to this introduction it may be asserted that direct porosity determinations on dry soil samples were considered to be important additions to micromorphological studies of soil pore pattern and distribution.

In the six Alfisol profiles the total porosity was calculated by use of the specific gravity and volumetric weight methods. This approach was used by Heinonon (1957) to determine the total porosity of clayey soils studied in Sweden. In the present study, results obtained by this method are compared with visual estimates of the size of the pores determined from the study of thin sections. The main purpose of establishing porosity both through calculation and visual estimation was to see if there exists relationship between porosity and the relative development of certain pedological features such as type and amount of argilluvial features, presence of organic and iron coatings, concretionary phenomena, and degree of horizon development in general.

The data in table 70 show that the total porosity increases with depth from the A to the B horizon in each Alfisol profile and decreases slightly to the C horizon in all except the Haldimand series. The porosity in the $B_{22}t$ horizon ranges from 45% to 49%. Lower porosities were found in the A horizon, ranging from 37% to 44% while variable porosities (36% to 49%) were found in the C horizon. Using an hydrological method to calculate the porosity, Gillespie and Elrick (1968) found the same relationship for four Alfisols in Southern Ontario. The differences between the soil porosity of the $B_{22}t$ horizons and the other horizons of the six Alfisol profiles are shown in figure 75. The Huron and Vineland profiles have the highest porosity values (48-49%), related to the high content of fines derived from the till or fine sandy outwash parent material of these soils and to the low degree of compaction in the Vineland soils. The Guelph and Ancaster profiles have lower porosity (45%) which may be affected by a higher content (5%) of unaltered shale and limestone stones and unweathered gravels in the parent materials. The Winona and Haldimand profiles have moderate porosity (47%) presumably being affected by moderate stoniness and a marked degree of compaction.

The silt + clay fraction is considered by soil physicists (Vamocil 1965, Brewer 1968 and De Boodt 1967) to be a major soil component affecting the degree of porosity, because of the direct relationship between particle size and pore spaces. Coarse materials are largely associated with larger pore spaces and lower total porosity while fine material is associated with fine pore space and higher porosity because of the greater total of pores per unit mass.

A positive linear relationship between porosity and fine content is best exhibited in the B horizons studied. Table 71 shows that the silt + clay percentage increases from A to B horizon in three of the six Alfisol profiles and decreases slightly to the C horizon in the same soils (Guelph, Vineland and Huron). These three series have developed to a deeper phase of soil horizon development, though with a slighter degree of mineral weathering in their parent materials (C horizons),when compared to the Ancaster, Haldimand and Winona soils. The Huron and Vineland profiles have high total porosities and very high silt + clay percentages (96.7 and 97.8) in the $B_{22}t$ horizons, related to the marked clay illuviation and the high clay content and compaction of the parent materials respectively. The Guelph and Ancaster profiles, with lower total porosities,have lower silt + clay percentages in the $B_{22}t$ horizons, though, as profile discontinuities occur between the $B_{22}t$ and C horizons in these two series, direct comparison is not possible. The $B_{22}t$ horizons of the Haldimand and Winona profiles have moderate porosity with silt + clay contents of 86.3% and 81.6%, which is in part the cause and in part the result of imperfect drainage and gleyzation of their parent materials. Thus there is a direct relationship between a higher percentage of silt + clay and higher total porosity. Conversely, a lower percentage of silt + clay is related to lower total porosity in most cases.

The degree of compaction, expressed by the penetrability value of soil, is considered by Vamocil (1957) and De Boodt (1967) to be among the factors affecting the degree of porosity, and also the form of channels and voids. Linear fine channels and platy structure, it is expected, would be most numerous in highly compacted materials. Continuous pore systems would be most frequently encountered in horizons of high penetrability. Richards (1941) has shown that penetrometer readings are affected by the presence of plant roots, soil moisture and compacted layers in the soils. Show, Haise and Farnsworth (1942) found a very rapid increase in the resistance of the penetrometer with decreasing moisture, and soil moisture is considered to be the dominant factor influencing penetrometer reading though there is no simple relationship between penetrometer readings and soil moisture content. However, in the present study, the moisture contents of the soil samples were used to correct the penetrometer reading in the six Alfisol profiles and to correct the penetrometer readings to those appropriate for dry conditions. These corrected figures are considered to be the most suitable for standardization in studying the relationship between total soil porosity and soil penetrability. The correction procedure used is outlined in Vamocil (1957).

The data (Table 72) show that soil penetrability values increase with depth to the C horizon in all of the six Alfisol profiles, with the exception of the B horizon in the Ancaster profile in a dry state. Higher dry soil penetrability values were found in the $B_{22}t$ and C horizons, with ranges from 12.8 to 30.0 Kg/cm^2 in the $B_{22}t$ horizons and from 14.3 to 45.4 Kg/cm^2 in the C horizons, while lower penetrability was found in the A horizons with a range from 3.6 to 12.2 Kg/cm^2. Thus in no case did the penetrability of an A horizon approach that of a B horizon with the exception of the Winona soil. The Huron and Vineland $B_{22}t$ horizons have the highest clay contents and porosities (48-49%),and their penetrability values are high, 15.7 and 25.0 Kg/cm^2 respectively; though these values are not the highest for the Alfisols studied. Such lack of direct connection between penetrability readings and porosity may be related to the textural B horizon in these two soils being expressed in greater depth and thickness rather than to a blocking of pores in a compact, shallow Bt horizon. The Guelph and Ancaster profiles show the lowest porosity with penetrability values of 12.8 and 20.0 Kg/cm^2 respectively, in thin textural B horizons which have developed over textural discontinuities. The Haldimand and Winona profiles have a moderate porosity, with penetrability values of 30.0 and 16.0 Kg/cm^2 respectively. Such variations in penetrability may result from the presence of gravels (shale and limestone) in the parent materials. In conclusion, the penetrometer readings cannot be interpreted practically in terms of specific soil properties, such as total porosity, although the penetrometer is useful as an aid in soil diagnosis.

Specific gravity and volumetric weight were also used to determine total porosity in the B_{22}ir horizons of the six Spodosol profiles studied. The data (Table 73) show that porosity decreases to the C horizon in all profiles except the Wyevale series which shows a profile discontinuity at 17 inches depth below the B_{22}ir horizon with the typical coarse C horizon absent, replaced by a IIC silt loam at the sites examined. Higher porosities were found in the A horizons of these leached sandy soils ranging from 39% to 42% - influenced by organic matter and a higher proportion of fine material than is found in many Spodosols from more northerly

TABLE 70. TOTAL POROSITY PERCENT IN THE SIX ALFISOL PROFILES.

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	37	40	44	40	40	41
$B_{22}t$	45	45	48	47	47	49
Lower C	36	39	47	43	49	47

TABLE 71. TOTAL SILT + CLAY PERCENTAGE (< 50 U) IN THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	59.5	66.6	71.5	94.0	94.5	79.0
$B_{22}t$	79.6	61.6	97.8	81.6	86.3	96.7
Lower C	65.0	92.4	73.9	80.4	93.5	90.5

TABLE 72. THE DISTRIBUTION OF FIELD (M) AND DRY (D) PENETRABILITY VALUES (Kg/cm^2) IN THE SIX ALFISOL PROFILES

Profile	Guelph		Ancaster		Vineland		Winona		Haldimand		Huron	
Horizon	M	D	M	D	M	D	M	D	M	D	M	D
Upper A	1.7	6.8	1.4	6.6	1.8	5.2	2.8	12.2	0.8	3.6	1.8	6.9
$B_{22}t$	3.2	12.8	3.4	20.0	5.0	25.0	3.6	30.0	4.0	16.0	3.3	15.7
Lower C	4.3	14.3	4.5	15.2	3.6	25.7	5.0	45.0	4.5	22.5	4.5	17.3

parts of Ontario. Lower porosities in the B horizon ranged from 26% to 39%. In the C horizon porosity varied, reflecting the presence of coarse material (coarse sand) and fine material (silt + clay) in varying deposits, some of which are discontinuous with the layers in which the A and B horizons have formed.

The porosity of the B_{22}ir horizons of the six Spodosols is shown in Figure 76. The Tioga (5) and Port-Cockburn (2) B horizons have high porosity (36 and 39%) related to high content of fines (< 50 u) derived from the parent materials. The Wyevale (1) and Hendrie (6) profiles have low porosities (26 and 29%) related to mainly coarse material. The B_{22}t of the Monteagle and Alliston soils have moderate porosity (32 and 34%) which is partly due to the homogeneous glacial or waterborne fine sandy deposits from which they originated. A low but significant silt + clay fraction sandy soils has been considered by Brewer and Haldane (1957), by Hallsworth (1963) and by Slager (1964) as a major soil component affecting the degree of porosity in sandy soils.

The data in Table 74 show that the silt + clay percentage in the six Spodosol profiles decreases with depth to the B_{22}ir horizons in Port-Cockburn, Monteagle, Alliston and Hendrie profiles, while there was a slight increase with depth to the B_{22}ir horizons of the Wyevale and Tioga profiles. Accumulation of silt + clay in such horizons may best be explained by the flotation of fine material from the C horizon through capillary forces at the ground water table in those soils which have more clayey C horizons (Brewer, 1968). Increase of silt + clay was found in the C horizons of all profiles except the Tioga and Hendrie, which have very coarse parent materials, and for which there is evidence that clay is accumulating in the upper solum through weathering and downward translocation (see page 318). As regards the relation of silt + clay percent and total soil porosity with the Spodosols; the Tioga, Monteagle and Port-Cockburn profiles have high porosities, with silt + clay contents of 17.4 to 19.6 percent, while the Wyevale, Hendrie and Alliston profiles have relatively low total porosities and low silt + clay contents of 12.0 to 8.9 percent.

Although the total sand percent (expressed as 100 - silt + clay percent) cannot be related to specific soil properties, such as total porosity, yet the degree of homogeneity within the sand fraction is a useful tool for prediction of total porosity in Spodosol profiles. The following are two examples illustrating this point: i) The B_{22}ir horizon of the Monteagle profile, with a high proportion of fine material (95% : < 250 u) and marked accumulations of amorphous iron, has a higher proportion of coarse aggregates and a high percentage of large pores, which latter account for a low total porosity (32%). ii) The B_{22}ir horizon of the Alliston profile, has a wide distribution of particle sizes and little amorphous iron, most of which has been leached through this horizon. In consequence the horizon is well aggregated with a high pore space per unit volume, which in turn causes the relatively high total porosity (34%).

In the B_{22}ir horizons of the six Spodosol profiles there was no simple relationship between total porosity and silt + clay content in most cases. It is suggested that the relative proportions of the different sand fractions, the iron content and the presence of humified organic matter all affect the concentration of cement material which promotes the formation of soil aggregates. In turn aggregation creates many coarse pores hence a relatively low porosity. For example this interpretation applies to the Monteagle soil. In contrast, the B_{22}ir horizon of the Port-Cockburn profile shows the highest total porosity (39%) and the highest amount of silt and clay in the B_{22}ir horizon. The Wyevale profile shows the lowest total porosity (26%) in the B_{22}ir horizon and a low total content of fines (12%).

In conclusion,for both Alfisols and Spodosols, there is a direct relationship between porosity and fine content, though this relationship is less clearly evident in those soils of complex origin or inhomogeneity of parent materials. Depth and intensity of argilluviation and/or compaction in Alfisols and development of concretions and sorting of parent materials in Spodosols are factors which may also disturb the simple relationship of porosity and particle size. Other influences affecting porosity and particle size distribution are drying and swell-shrink potential in Alfisols and the presence of 'floated' fine particles in ill-drained complex Spodosol profiles.

TABLE 73. TOTAL POROSITY PERCENT IN THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P. Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	44	39	41	39	41	42
$B_{22}ir$	26	39	32	34	36	29
Lower C	47	36	23	24	37	23

TABLE 74. TOTAL PERCENTAGE SILT + CLAY (< 50 U) IN SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P. Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	9.7	23.6	22.2	14.3	11.3	11.2
$B_{22}ir$	12.0	19.6	18.1	8.9	17.4	9.1
Lower C	55.6	69.1	45.1	35.2	10.4	5.9

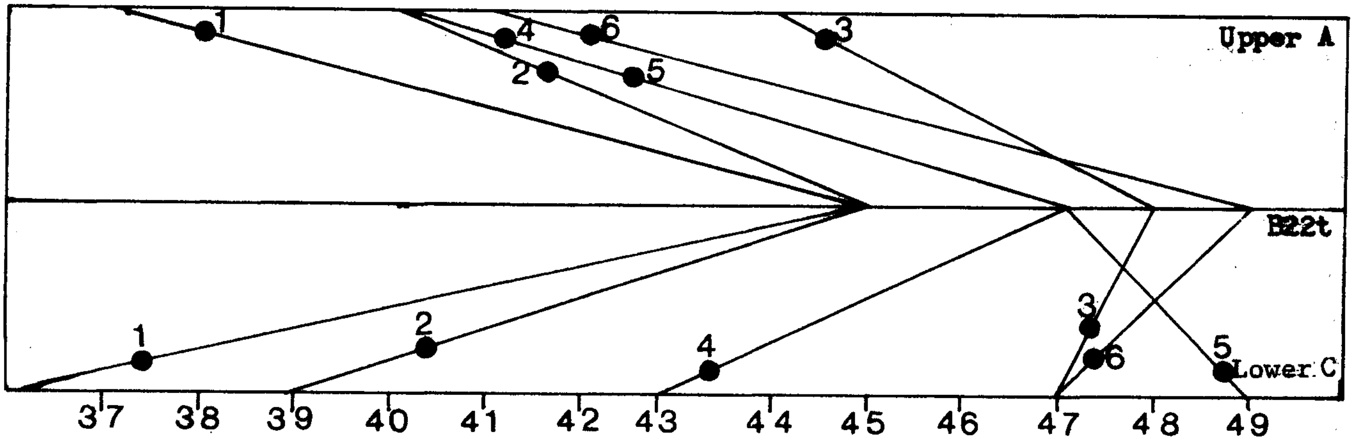
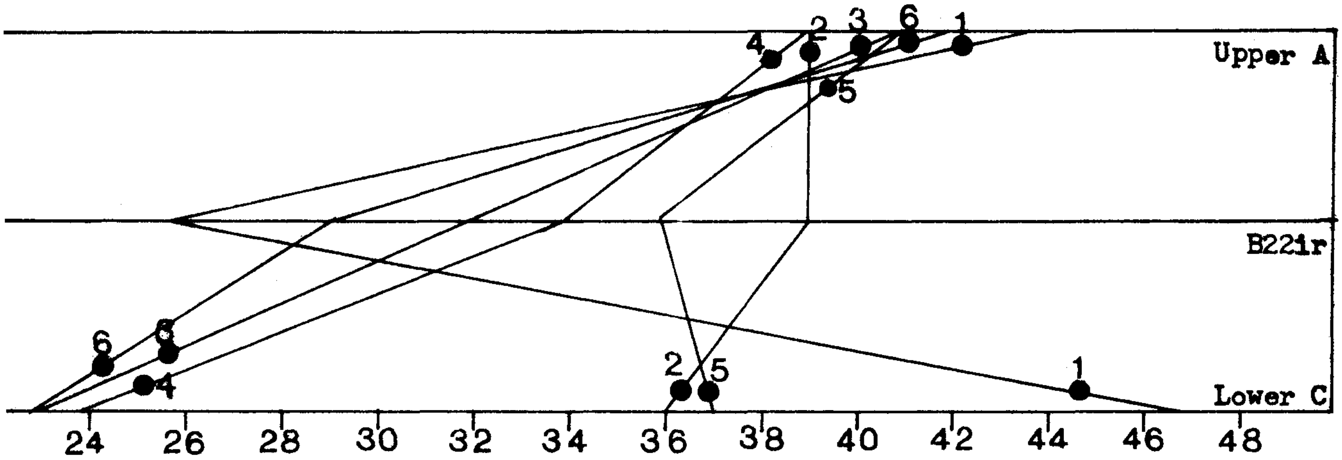


Figure 75. The distribution of soil porosity in the six Alfisol profiles (number, see page 275, table 70).

Figure 76. The distribution of soil porosity in the six Spodosol profiles (number, see page 279, table 73).



7. 2. Evaluation of soil weathering through chemical and mineralogical properties

7. 2. 1. Evaluation of soil weathering through chemical properties.

Weathering consists basically of two processes, chemical and mechanical, both often acting together. Rocks are broken down into smaller fragments and eventually individual minerals. Simultaneously the minerals may be attacked in a chemical way resulting in the formation of new minerals. So weathering is a combination of destruction and neo-formation. The most important reaction in chemical weathering is hydrolysis by which various cations are replaced by hydrogen ions. Following this, a portion of the mineral structure becomes unstable and components pass into solution as ions, molecules and small colloidal groups.

Springer and Ameryckx (1966), in climatic areas very similar to Ontario, have indicated that the potential degree of chemical weathering is associated principally with the amounts of silicon, aluminum and iron in Alfisol profiles. The behavior of these elements in such profiles will now be discussed in detail. Silicon in the soil originates from the weathering of primary silicates. Silicon oxides can be accumulated and/or evacuated from a given depth in the profile as a result of the degree of intensity of chemical weathering and leaching, activated by high temperature. Aluminum oxides can migrate in chelate form at $pH < 7$ or as colloids at $pH > 7$, while iron oxides migrate as cations in soluble phase at $pH < 3$ and precipitate at $pH > 3$. Iron can also migrate as chelate as well as a colloid.

The profile distribution of the silica-sesquioxide and silica-aluminum oxide molar ratios were first used by Robinson (1937), as indicators of desilicification of soil material. Later these ratios were used by Rode (1955) and Zonn (1950) to indicate the degree of podzolization. Lemos et al (1960) have used these ratios to order the position of soils in a weathering sequence from Sao Paulo, South America. The use of the silica-aluminum ratio implied that ferric oxide, known to be present in the clay fraction, is uncombined with silica and is present as adventitious ferric oxides. Such an assumption should not be made. Clay minerals include not only aluminosilicates but also ferrisilicates and possibly ferrasilicates. The silica-sesquioxide ratio, though of great value in distinguishing different types of clay, must not be assumed to give a complete specification of the material to which it relates (Robinson, 1937).

In the six Alfisol profiles, the molar ratios of silica-sesquioxide and silica-aluminum were used to indicate the degree of chemical weathering of the clay minerals ($< 2\mu$). The data in Table 75 show that the silica-sesquioxide ratio remains fairly constant or varies insignificantly with depth in the Alfisol profiles. Using a silica-sesquioxide molar ratio for Alfisol profiles, the U.S.D.A. Seventh Approximation (page 48) proved the same result (see Table 75). However there is a general tendency to a decrease of silica and to relative increase of iron with depth in the Alfisols. Thus iron is moved downward through the profiles while the silicon oxide, which is a less mobile element, accumulates in the upper profile.

The $B_{22}t$ horizons of the Huron and Haldimand profiles have high SiO_2/R_2O_3 ratios (> 7.5) which could indicate a low degree of chemical weathering. The $B_{22}t$ horizons of the Ancaster and Winona profiles show lower ratios (< 5.2), which indicates a higher degree of chemical weathering. Guelph and Vineland profiles show intermediate weathering in their ratios (6.57 and 6.39).

The silica-aluminum oxide molar ratio may also be used, the data (Table 76) showing that the ratio tends to increase with depth in all Alfisol series, except the Haldimand which shows a slight decrease. This may indicate that the aluminum oxide has accumulated in the upper horizon because of lower pH, which stops its migration either as chelates or colloids.

Marked increases in the silica-aluminum ratio with depth are shown in the Guelph and Huron series. The lower silica-aluminum ratio in the $B_{22}t$ of the Winona profile is related to an accumulation of aluminum and relatively high pH in the top of the profile. It is unlikely that much of this aluminum was released by the decomposition of primary minerals. Krebs and Tedrow (1957) suggested that the break-down of allogenic clay, derived from very fine sand, has possibly contributed to the accumulation of aluminum in such soils from New Jersey. The data for the distribution of the silica-aluminum oxide molar ratio confirm the relative degree of weathering already outlined for the silica-sesquioxide ratio. These results show that either the silica-sesquioxide ratio or silica-aluminum oxide ratio may be used to indicate the degree of chemical weathering in Alfisol profiles.

Base saturation or effective cation exchange capacity were suggested by McCracken et al (1964) to indicate the chemical activity of the weatherable minerals in Planosolic soils from South Caroline and Virginia. Base saturation was defined by Robinson (1937) as the content of exchangeable bases at saturation expressed in the milligram equivalent per 100 grams soils. The elements Ca, Mg, K, and Na accompany the major part of the complex and are often called exchangeable bases. Higher cation exchange capacity is largely related to 2:1 lattice clays, small particle size and poorly-defined lattice-edged clay minerals (Khalifa and Buol, 1968). The variation in cation exchanges in some Alfisol profiles from northern and southern California was thought by Harradin (1963) to be the result of progressive stages of weathering in a unique climate and characterized by the composition of their clay fraction.

In the six Alfisol profiles, base saturation was found to be consistently higher than 50% in the textural B horizons and to increase with depth to values exceeding 80 or 90% in the C horizons. The data, Table 77, show that the effective cation exchange capacity was lower in the more acid horizons and in A horizons and increased with higher pH value. The B_{22}t horizons of Huron,Winona and Haldimand profiles show a higher degree of chemical weathering with cation exchange capacity of 19.66, 20.86, and 28.54 meq./100gms soil which is probably derived from their content of very fine clay minerals with poorly defined lattice edges. The B_{22}t horizons of Guelph, Ancaster and Vineland series show a lower degree of chemical weathering with cation exchange capacity values of 9.43, 12.93 and 13.52meq./100gms soil, which is probably derived from a higher content of relatively coarse clay minerals characterized by well defined crystals.

TABLE 75 : SILICA-SESQUIOXIDE RATIO OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	5.25	6.88	7.57	5.25	8.24	7.99
$B_{22}t$	6.57	5.22	6.39	4.40	7.58	8.28
Lower C	7.17	6.36	8.17	4.93	7.38	8.68

TABLE 76 : SILICA-ALUMINUM RATIO OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	6.34	7.79	9.17	5.87	9.68	9.39
$B_{22}t$	8.17	6.35	7.96	5.43	8.97	9.37
Lower C	8.89	8.47	10.08	6.10	8.77	10.39

TABLE 77 : CATION EXCHANGE CAPACITY (meq./100 gm) OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	15.99	13.39	21.20	19.20	16.55	17.65
$B_{22}t$	9.43	12.93	13.52	20.86	28.54	19.66
Lower C	10.01	12.52	9.89	13.22	27.05	26.21

A positive linear relationship between the desilicification expressed as silica-sesquioxide and silica-aluminum ratios, relative to the cation exchange capacity, first noted by McCracken et al (1964), was found in Guelph, Vineland and Winona series. An inverse relationship between these quantities occurred in the Ancaster, Haldimand and Huron series. These may be inherited properties in the parent material of these latter soils. Further studies to establish the type of the relationship between the desilicification and the cation exchange capacity in Alfisol profiles are important.

A similar approach was adopted for the six Spodosol profiles. The silica-sesquioxide molar ratio was used by Tatarinova (1966) in Spodosol profiles from Russia to determine the degree of chemical weathering expressed in the degree of effectiveness of the podzolization process.

In the six Spodosol series, silicon remains in the A horizons, whilst aluminum and iron accumulated to some extent in the B horizons and silicon increased slightly to the C horizon. The data, Table 78, show that the silica-sesquioxide molar ratio was lower in the B_{22}ir horizons in the six Spodosol profiles than in the A or C horizons which indicates a higher degree of chemical weathering in the B horizons. Using the same ratio in Spodosol profiles, the same results (see Table 78) were found by the U.S.D.A. Seventh Approximation (page 48). A higher silica-sesquioxide ratio was found in the A and C horizons of the Spodosol profiles ranging from 6.36 to 8.28 ratios in the A horizons and from 6.17 to 8.39 ratios in the C horizons. A greater amount of silica in in both A and C horizons of the six Spodosol profiles, considered as constituting a nearly inexhaustible source of slowly available weathering products, may be derived through the weathering of pyroxene, amphibole, mica and feldspar minerals. A lower ratio was found in the B horizons with range from 4.64 to 5.88 ratios which indicates a higher degree of chemical weathering.

The differences between the silica-sesquioxide ratio in the B_{22}ir horizons of the six Spodosol profiles are shown in Fig. 78. The Alliston, Tioga and Port Cockburn have slightly lower degrees of chemical weathering with silica-sesquioxide ratios of 5.88, 5.77 and 5.71 respectively. Such figures may be associated with silicate accumulation and aluminum as well as iron evacuation in the B_{22}ir horizons. The Wyevale profile has a higher degree of chemical weathering with lower silica-sesquioxide ratio of 4.68 which results from iron and aluminum accumulation and silicate evacuation in the B_{22}ir horizon. The B_{22}ir horizons of Hendrie and Monteagle profiles have an intermediate degree of chemical weathering shown by their similar ratios, 5.07 and 5.26 respectively.

In this study, results obtained from the chemical weathering will be compared with the description of the plasmic fabric in the s-matrix of the same studied soils. The data, Table 79, show that the SiO_2/Al_2O_3 ratio decreased with depth to the B_{22}ir horizons of all the Spodosol profiles studied and increased again slightly to the C horizons. A greater decrease of silica-aluminum ratio with depth was noted in the B_{22}ir horizon of Port Cockburn profile, probably associated with the higher amount of fine material (97% of < 250 μ). The data for the silica-aluminum oxide molar ratio confirm the relative degree of weathering already outlined for the silica-sesquioxide ratio in the previous paragraphs. Though both ratios may be used to determine the degrees of chemical weathering of Spodosol profiles as the result between the two ratios do not differ significantly.

Base saturation was also suggested by Tatarinova (1966) as an indication of the activity of weatherable minerals in Spodosol from Russia. Base saturation tends to decrease with depth to the B_{22}ir horizons in all the studied Spodosol profiles and increased slightly to the C horizons in most cases. It was suggested that the influences of the exchange hydrogen increased the base saturation value in the upper A horizons while the other cations may be associated with the higher base saturation value in the lower horizons. The B_{22}ir horizons of the Alliston and Port Cockburn series show relatively higher degrees of chemical weathering expressed by lower ratios of silica-sesquioxide and base saturation of 7.64 and 7.46meq./100gms soil, respectively which may result from higher degrees of mineral alteration in these soils. In contrast the B_{22}ir horizon of the Wyevale profile shows a higher degree of chemical weathering and lower value of base saturation (4.36meq./100gms soil) which was explained as a result of a higher degree of exchangeable hydrogen and lower value of pH.

In conclusion, a direct relationship was found between the degree of desilicification expressed by the ratio of silica-sesquioxide and the value of base saturation in the B_{22}ir horizons of the Monteagle and Hendrie profiles. This probably resulted from the absence of fine

TABLE 78 : SILICA-SESQUIOXIDE RATIO OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	6.77	8.28	6.36	7.70	6.81	7.47
B_{22}ir	4.68	5.71	5.26	5.88	5.77	5.07
Lower C	6.69	7.37	6.17	8.39	7.87	6.35

TABLE 79 : SILICA-ALUMINUM RATIO OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	7.77	9.03	6.97	8.76	7.97	8.95
B_{22}ir	5.75	6.97	6.49	6.89	6.98	6.43
Lower C	8.15	8.35	7.07	10.38	9.00	7.71

TABLE 80 : BASE SATURATION (meq./100 gm) OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	5.12	13.88	11.42	14.62	14.50	8.86
B_{22}ir	4.36	7.46	8.19	7.64	5.87	8.79
Lower C	13.81	6.22	5.38	7.40	5.11	4.15

soil material (clay minerals). However, an inverse relationship was found in the other four Spodosol profiles, Wyevale, Port Cockburn, Alliston and Tioga series. This resulted from the presence of clay minerals such as chlorite, vermiculite and mixed clay minerals, characterized by a higher cation exchange capacity and a considerable degree of minerals alteration (Jackson, 1952).

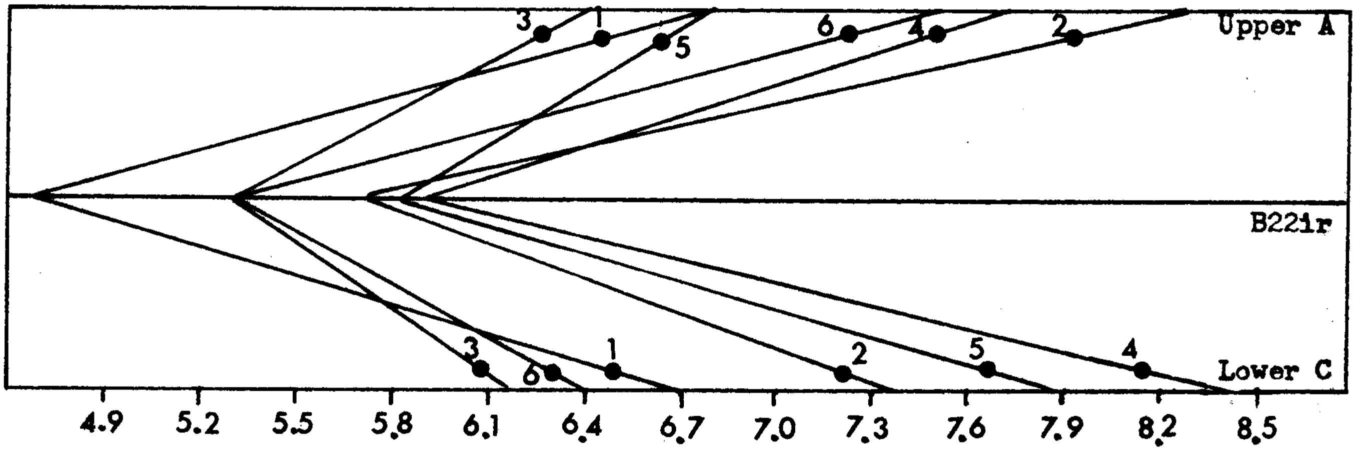
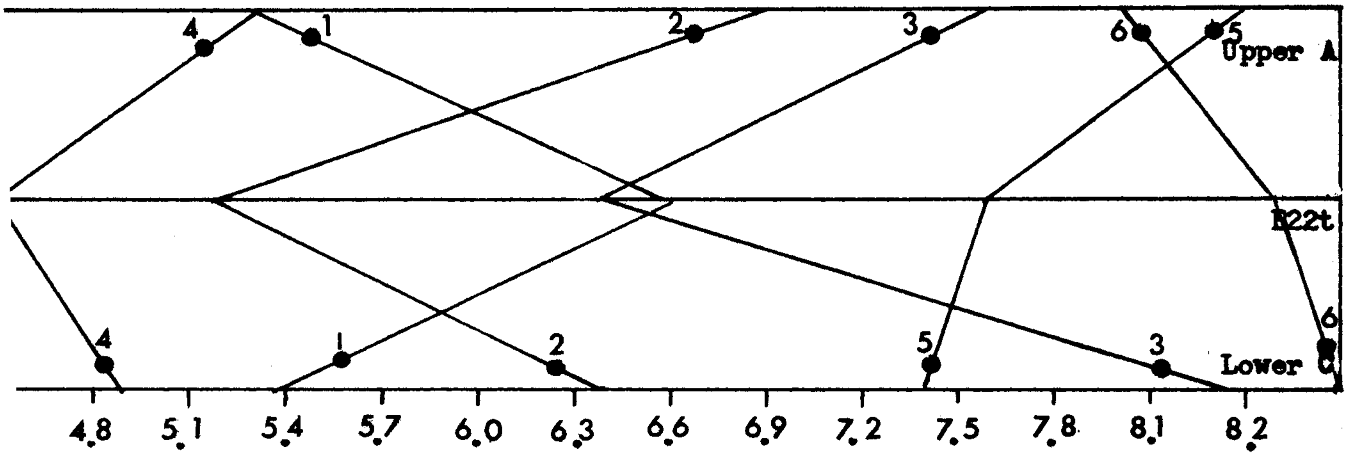


Figure 77. The distribution of Silica/sesquioxide molar ratios in the six Spodosol profiles (numbers, see page 285, table 78).

Figure 78. The distribution of Silica/sesquioxide molar ratios in the six Alfisol profiles (numbers, see page 289, table 75).



7.2.2. Evaluation of soil weathering through determination of mineral ratios.

The differences in degree of chemical weathering of separate mineral species can provide more precise indications of the degree of weathering than bulk analyses or the use of molar ratios relating to materials of differing individual provenance. As a result of these changes certain minerals have disappeared wholly or partially, and material of secondary origin which differs markedly from the parent minerals is formed. Some secondary products may originate by alterations in situ of the parent minerals, whilst others may derive from precipitation from solutions containing the soluble products of weathering. Such precipitation may occur in the zone of weathering or outside of it, having been transported by moving water. Material precipitated in the zone of weathering may be mixed with, or even enter into combination with residual products.

The chemical weathering of rocks affects principally the mineral silicates such as feldspar, micas and ferromagnesian minerals, and depends on their instability at ordinary temperature in the presence of water and carbon dioxide. For example, certain minerals are practically unaffected by chemical weathering and persist unaltered in the soil. Of these the principal is quartz. Other minerals resistant to chemical weathering are magnetite, titanite, iliumenite (Robinson, 1937 - page 41). Proportions of specific minerals in soils were suggested by Reeder et al (1961) in Canada, and Springer and Ameryckx(1966) in Belgium, as indicators, if not determinants of the degree of mineral weathering. The ratios of the resistant minerals to non-resistant minerals have often been used mainly to determine the degree of mineral weathering in different types of soils.

Clay minerals play a prominent role in determining soil physical properties such as plasticity and structure, also properties such as cation exchange. The weathering of clay minerals, especially potassium and other interlayer cations was explained as a slow diffusion out of the interlayer spaces into the soil solution, which results in enhanced cleavage at the weathering edges of the clay crystal. One example would be, according to the sequence proposed by Jackson et al, (1952) :

MICA → ILLITE → VERMICULITE → MONTMORILLONITE

which sequence is capable of being greatly extended.

The types of clay minerals from the upper A, $B_{22}t$ and lower C horizons of the six Alfisol profiles were determined by x-ray diffraction. Types of clay minerals of the $B_{22}t$ horizons were also determined and described by electron microphotograph. When using x-ray diffraction the terms chlorite, kaolinite and illite were used in their generally accepted sense (Brydon et al, 1968). The terms vermiculite, and vermiculite-chlorite, mixed-lattice clay minerals and expandable vermiculite are referred to as a transitional series of alteration products derived primarily from chlorite. This alteration sequence of clay minerals has been confirmed experimentally by Droste and Thorin (1958) who found that chlorite alters to vermiculite-chlorite, then to the partially-expandable mixed-lattice stages and finally to the expandable vermiculite stage.

The major types of x-ray diffraction for the upper A, B_{22}t and lower C horizons are shown in Figs. 79 to 84 . A higher percentage of clay minerals was found in the B horizons, while a lower percentage of clay minerals was found in the A and C horizons which may result from a higher degree of clay synthesis in the B horizons. Hydrous mica or illite (10Å) was found to be the predominant clay mineral in the six Alfisol profiles. This may be inherited from the parent materials of these soils. Chlorite (4.75Å) was found to be dominant in the A horizons whilst it was absent in the B_{22}t and lower C horizons in most cases. This may result from weathering in situ. Kaolinite (3.58Å and 2.397Å) was common in all the profiles except that of Vineland which has developed on mixed outwash sand and clay deposits. Variable amounts of mixed, loosely inter-linked vermiculite-montmorillonite-chlorite (14Å) and mixed kaolinite-chlorite-vermiculite minerals (12.3Å) were found in most cases. The origin of these mixed clay minerals is unknown. They may all have been inherited and have remained unchanged, or they may have been formed in situ by hydration forming the loose linkages (Droste and Thorin,1958).

The quartz mineral (3.3Å)in terms of non-lattice clay minerals was found to be the most resistant mineral in the Alfisol profile as shown by the strong x-ray reflection patterns. The major quartz reflection was invariably found in the lower C horizons of the six Alfisol profiles (Jackson and others, 1953). Chlorite clay minerals were found to be the less-resistant minerals in the six Alfisol profiles, shown by the weak reflection in the B_{22}t horizon in most cases. Weathering of

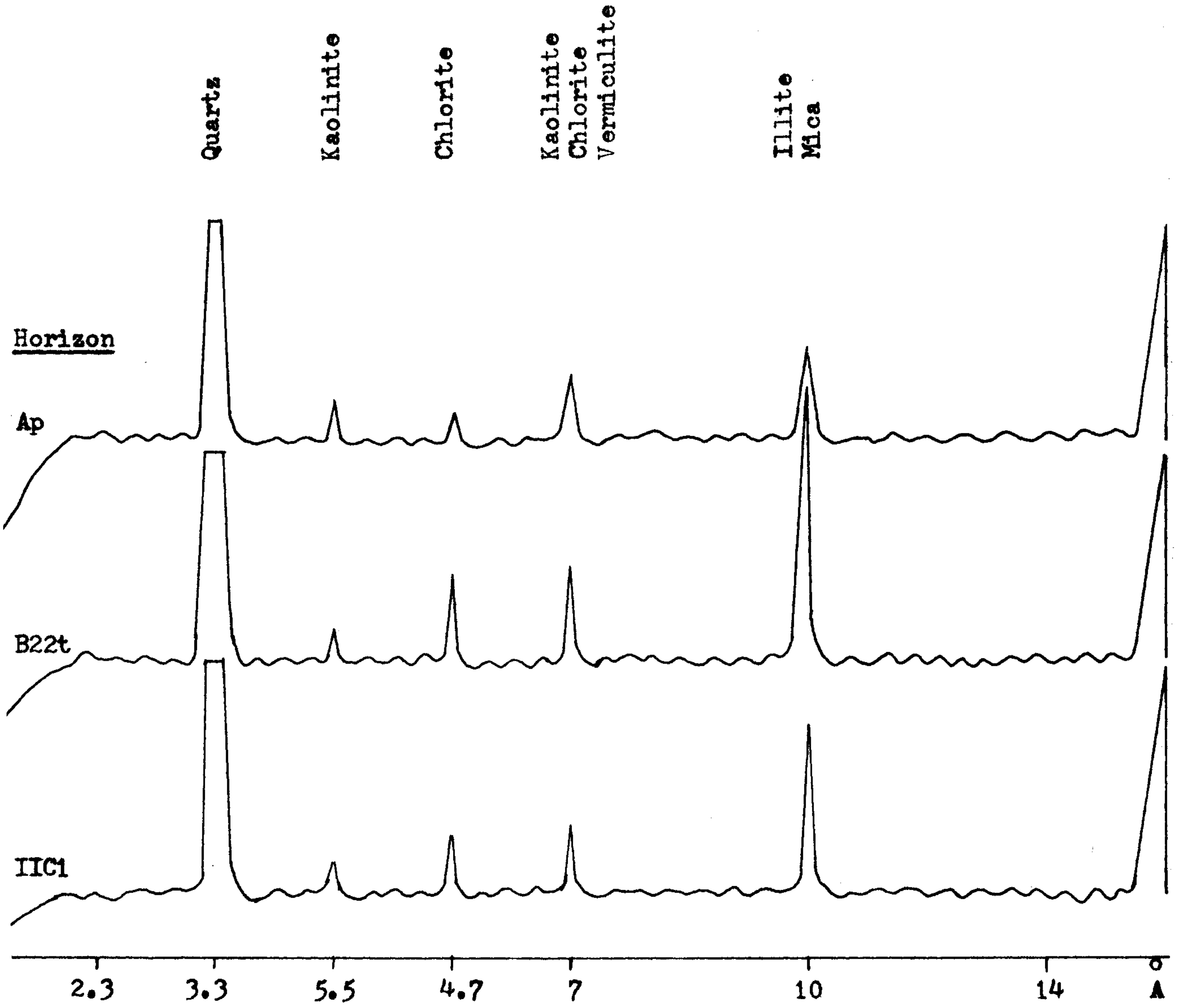


Figure 79. X-ray diffracto-gram of the Guelph series.

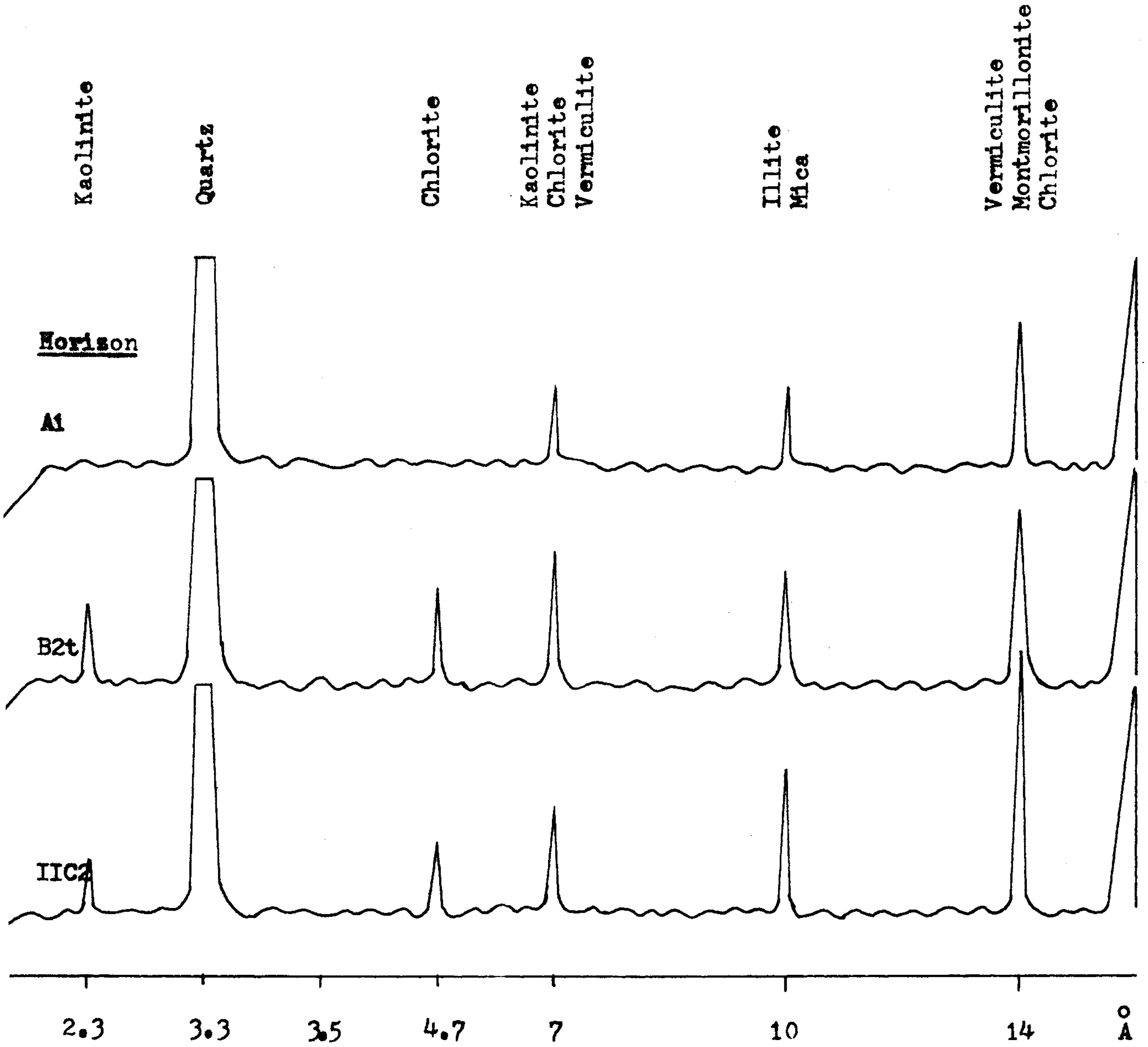


Figure 80. X-ray diffracto-gram of the Ancaster series.

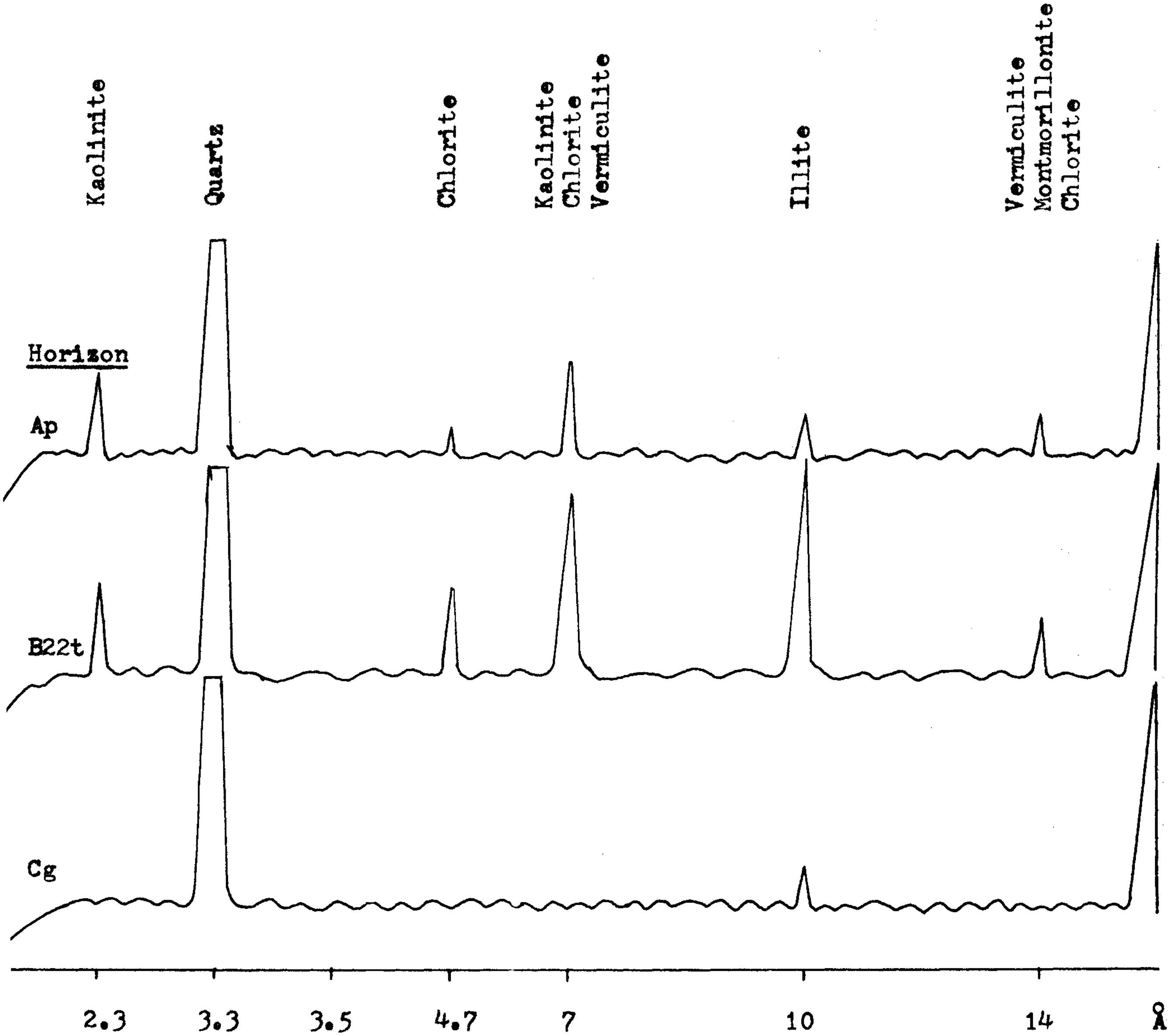


Figure 81. X-ray diffracto-gram of the Vineland series.

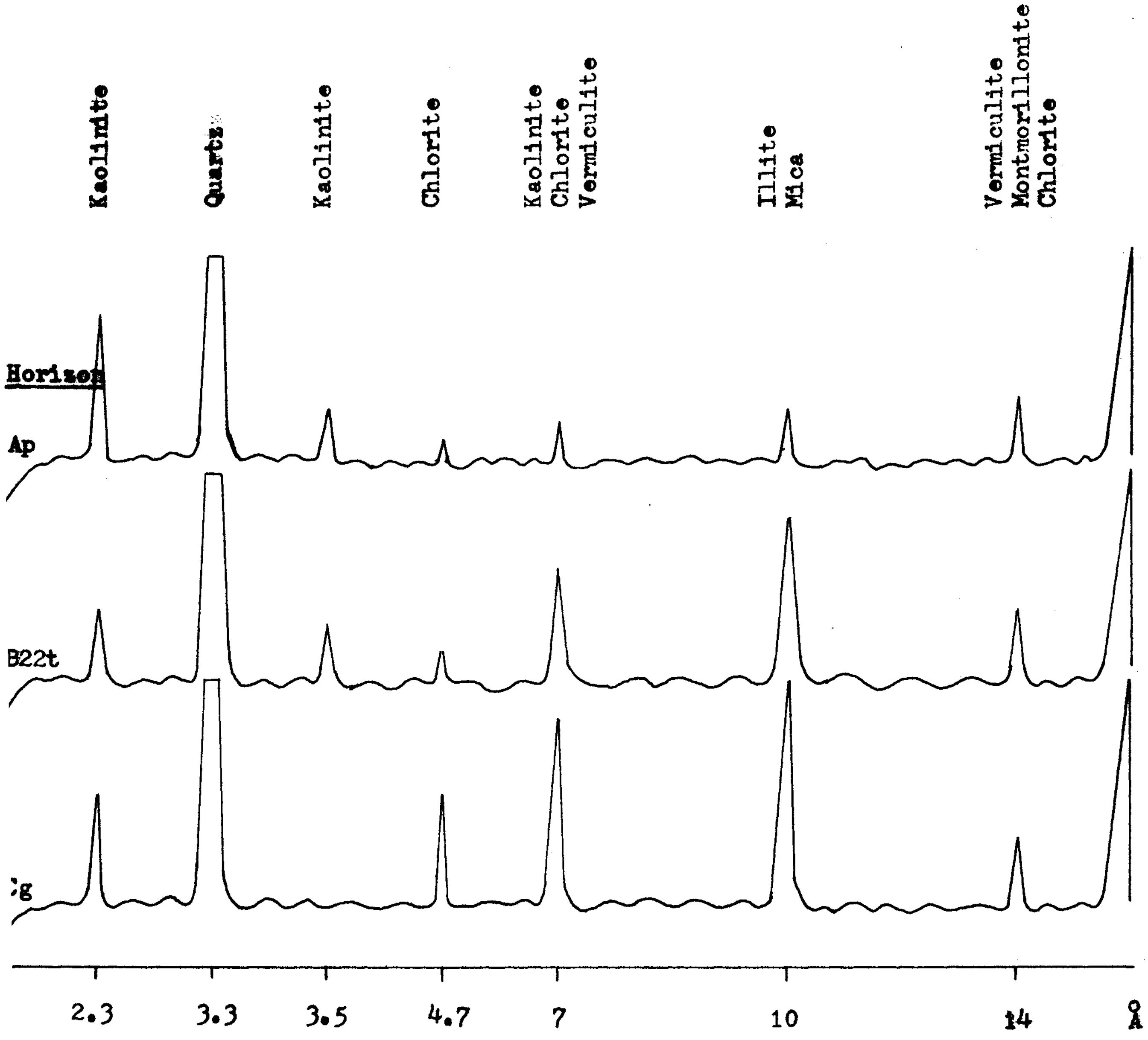


Figure 82. X-ray diffracto-gram of the Winona series.

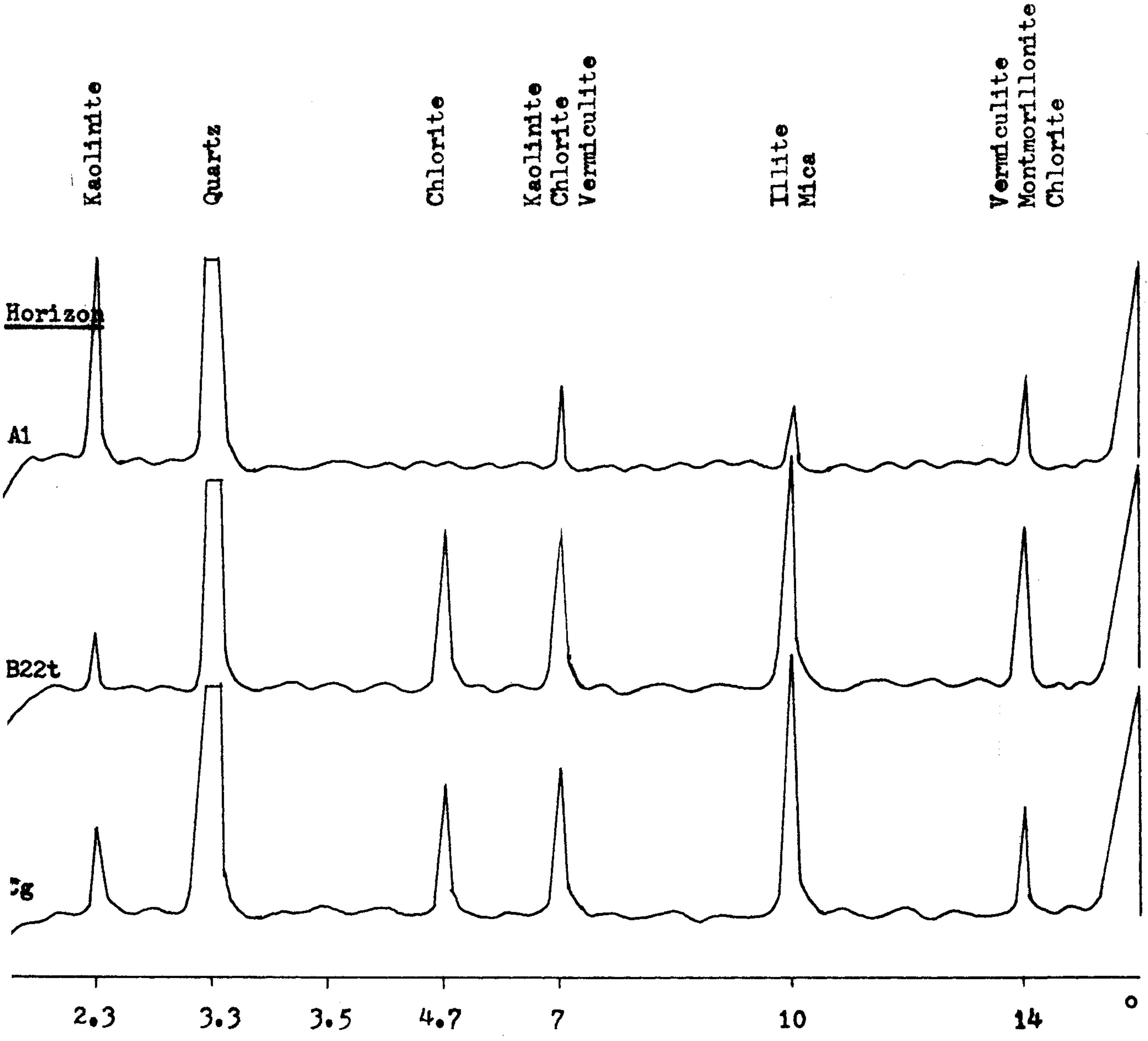


Figure 83. X-ray diffracto-gram of the Haldimand series.

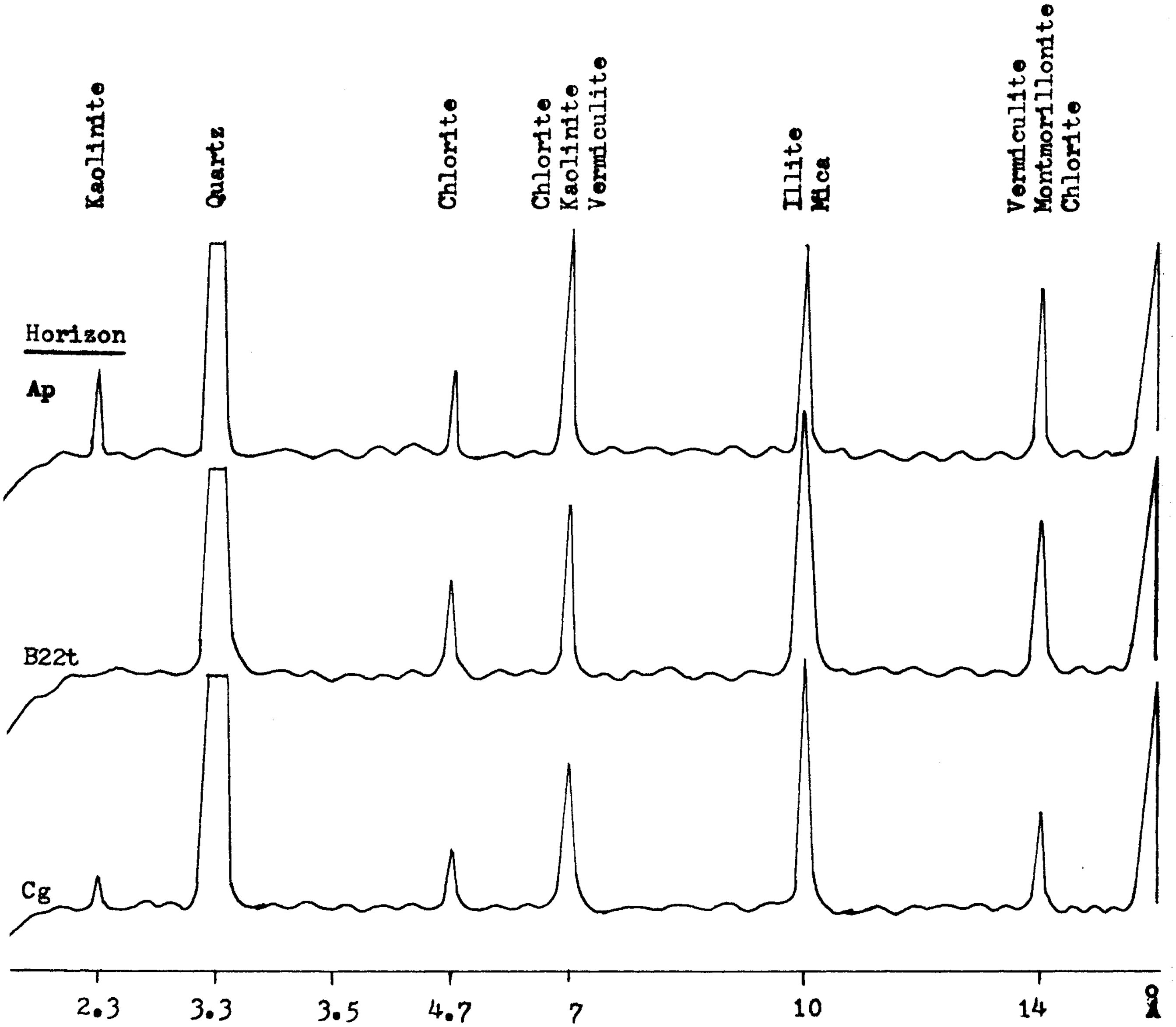


Figure 84. X-ray diffracto-gram of the Huron series.

chlorite to 2:2 and 2:1 integrades (chlorite to vermiculite) has been suggested by the acid removal of Fe from the (Fe, Al, Mg) $(OH)_{12}$ inter-layer and by replacement of OH by OH_2. The resultant structures are similar to those produced by inter-layer precipitation of sesquioxides in intergradient mixed layer clay (Jackson, 1968).

Three ratios of clay minerals were used in this study to determine the degree of mineral weathering. They were selected according to the alteration sequence of clay minerals discussed in the previous paragraphs. The quartz/chlorite ratio was used mainly to indicate the degree of weathering while the quartz/mixed-layer and quartz/vermiculite ratios were used as a transitional series of alteration products derived from the primary chlorite.

The disparities between the quartz/vermiculite, quartz/mixed-layer and quartz/chlorite ratios in the upper A, $B_{22}t$, and lower C horizons of the six Alfisol profiles are shown in Fig. 85. The data tables (81, 82 and 83) show that the chlorite in the $B_{22}t$ horizons of Guelph and Winona profiles (zero quartz/chlorite ratios) may have been altered to mixed-layer clays in the Guelph series and vermiculite-mixed-layer clay in approximately equal proportions in the Winona series. The $B_{22}t$ horizons of the Ancaster and Haldimand profiles with quartz/chlorite ratios of 7.5 have some chlorite altered to mixed-layer clays (quartz/mixed-layer ratios of 4.0 and 2.5) while chlorite has altered to vermiculite in the Huron profile shown by the quartz/vermiculite of 2.5 ratio. Such differences in ratios may indicate that the Huron profile is in a more advanced stage of clay alteration. This is expressed by the strong peak of

TABLE 81 : QUARTZ-CHLORITE RATIO OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	-	-	-	-	-	11.0
$B_{22}t$	-	7.5	11.0	-	7.5	6.0
Lower C	-	5.0	18.0	11.0	5.0	7.5

TABLE 82 : QUARTZ-MIXED CLAY RATIO OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	12.5	7.5	14.0	14.0	17.5	7.5
$B_{22}t$	5.0	4.0	4.0	5.0	2.5	5.0
Lower C	7.5	2.0	6.0	6.0	2.5	2.0

TABLE 83 : QUARTZ-VERMICULITE RATIO OF THE SIX ALFISOL PROFILES

Profile / Horizon	Guelph (1)	Ancaster (2)	Vineland (3)	Winona (4)	Haldimand (5)	Huron (6)
Upper A	-	4.0	-	21.0	17.5	5.0
$B_{22}t$	-	6.0	16.0	4.0	6.0	2.5
Lower C	-	2.0	-	-	6.0	2.5

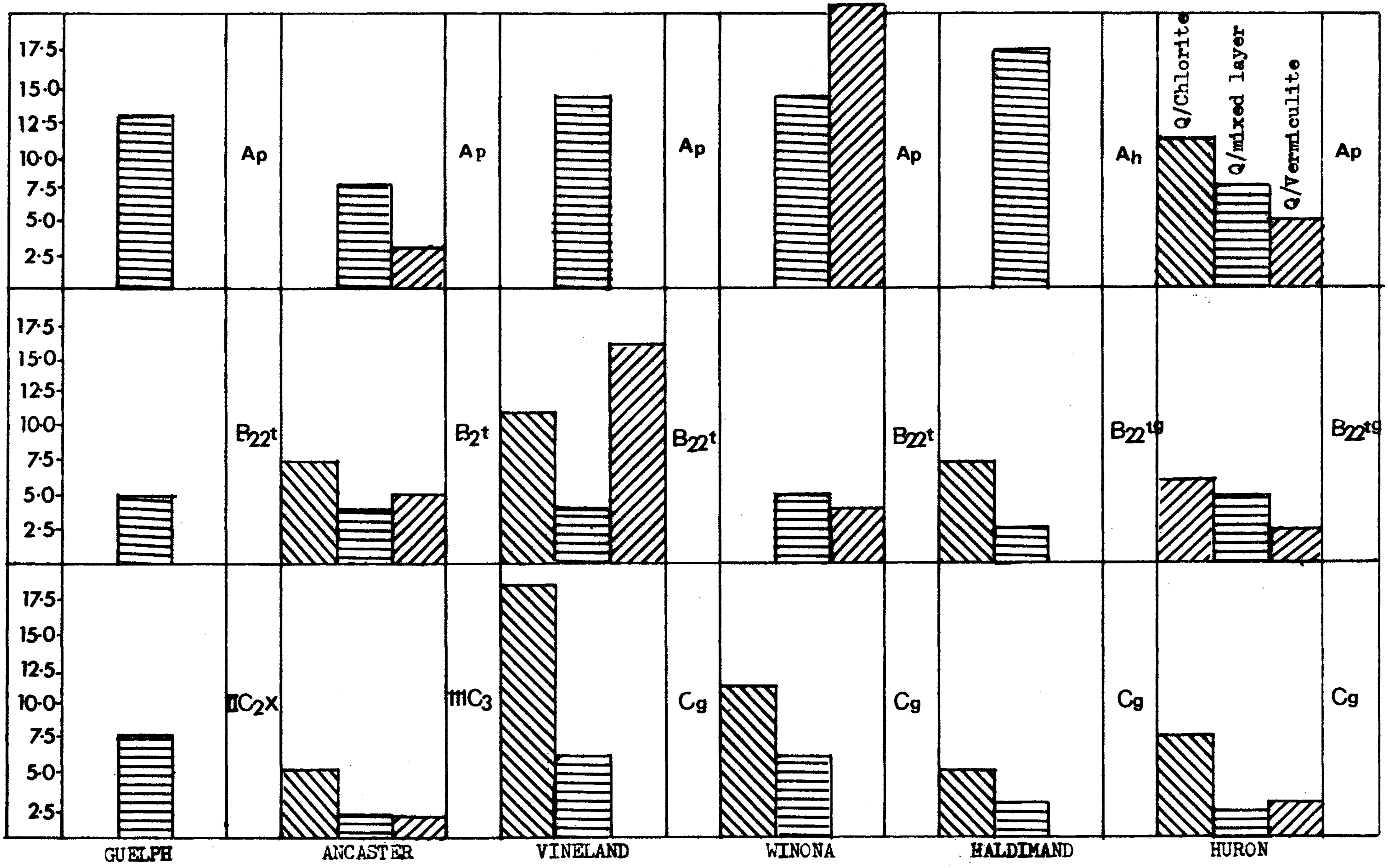


FIGURE 85. THE DISTRIBUTION OF CLAY MINERAL RATIOS IN THE UPPER A, $B_{22}t$ AND LOWER C HORIZONS OF THE SIX ALFISOL PROFILES

are in a relatively advanced stage of clay alteration characterized by the strong peak of mixed layer clays. The $B_{22}t$ horizon of Vineland profile, with a lower degree of mineral weathering, has a quartz/chlorite ratio of 11.0, quartz/vermiculite of 16.0, which may indicate that only part of the chlorite has been altered to mixed layer clays.

The electron microscope results support the X-ray diffraction data. Figs. 86 to 91 show that the transparent fragments of various shapes, representing hydromicas, are common in most cases. Kaolinite and mixed-layer clay minerals were again found to be dominant in the six Alfisol profiles, with Kaolinite better-crystallized in the top soil than in the lower horizons. Poorly-crystalline Kaolinite was found in the $B_{22}t$ horizon of the Guelph profile which indicates an intense degree of alteration while Kaolinite with sharp crystal and well-defined edges was found in the $B_{22}t$ horizons of Haldimand and Huron profiles, which indicates a lower degree of alteration.

In general, the electron micrograph observation corroborates the finding from X-ray analyses in the six Alfisol profiles, and is of especial value in that it gives more definite information on relative degrees of alteration of specific minerals, for example the well-defined mica flakes in the Vineland series (Fig. 88) and the partially-ordered clays in the more-weathered Winona series (Fig. 91).

In Spodosol profiles, the distribution and relative accumulation of light and heavy minerals with depth in the profile were used by Jackson and Sherman (1953) in Wisconsin, Brydon (1965) in Quebec and Nova-Scotia to indicate the degree of mineral weathering. They proved

Fig. 86. Kaolinite clay minerals with well crystalized structure in the $B_{22}t$ horizon of the Haldimand series. X 80.000.

Fig. 87. Kaolinite clay minerals with poor crystalized structure in the $B_{22}t$ horizon of the Guelph series. X 80.000.

Fig. 88. Mica-flakes minerals with well defined structure in the $B_{22}t$ horizon of the Vineland series. X 95.000.

Fig. 89. Kaolinite clay minerals with well crystallized structure in the $B_{22}t$ horizon of the Huron series. X 80.000.

Fig. 90. Illite minerals in the $B_{22}t$ horizon of the Ancaster series. X 75.000.

Fig. 91. Mixed layer mica-montmorillonite clay minerals partially ordered structure in the $B_{22}t$ horizon of the Winona series. X 90.000.

that the accumulation of a considerable amount of resistant minerals at a given depth of the soil profile proved a relatively greater degree of mineral weathering.

In the six Spodosol profiles, quartz, feldspar and mica (50 - 500 μ) were found to be dominant among the light minerals. The analyses show that in most cases, the quartz decreases with depth in the Spodosol profiles when derived directly from the parent material . Muscovite tends to increase with depth in the profile and shows an intense corrosion of the edges, especially in the upper soil horizons. Plagioclase feldspars remain constant with depth in the profiles. It is possibly affected by weathering in situ, as shown by the loss of crystal shape in the upper A horizons.

Analyses show that hornblende, tourmaline, garnet, pyroxene, zircon, rutile, epidote and hypersthene are found among the heavy minerals of the upper A, B_{22}ir and lower C horizons of the six Spodosol profiles. Hornblende was found to be the predominant heavy mineral, derived from igneous rocks. Tourmaline, garnet and pyroxene, derived from metamorphic rocks (schists and gneisses) are also important heavy minerals. A low amount of zircon, rutile, epidote and hypersthene, mainly derived in contact-metamorphic zones, were also found among the heavy minerals.

Garnet, tourmaline and rutile, also quartz, were described by Reeder et al (1961) as resistant minerals while horneblende, feldspars and pyroxene are non-resistant minerals. Pyroxenes tend to increase with depth, largely relatable to the degree of mineral weathering at different depths. In contrast, garnet and tourmaline tend to decrease with depth in the profile, such decreases being largely related to characteristics inherited from parent materials in the six Spodosol profiles. Ratios of resistant and non-resistant minerals were used to indicate the degree of mineral weathering in the upper A, B_{22}ir and lower C horizons of the six Spodosol profiles.

The tourmaline/pyroxene and the garnet/pyroxene ratios were established in the heavy minerals while the quartz/feldspar ratio was established in the light minerals to determine the degree of mineral weathering in the B_{22}ir horizons. These ratios were earlier used by Ruhe (1956) to determine the relative accumulation of heavy and light minerals with depth in certain Spodosol profiles while, recently they were used by Reeder et al (1961) in Quebec, by Springer and Ameryckx (1966) in Belgium and by Wall (1969) in Alberta to determine the degree of mineral weathering in Spodosols.

The data, table 84, show that the tourmaline/pyroxene ratios tend to decrease with depth in the six Spodosol profiles except in the Monteagle and Alliston profiles, where the upper organic horizons were absent and the parent material was derived from fine deposits. The same result was found by using the garnet/pyroxene ratios (table 85), while the quartz/feldspar ratios were fairly constant with depth in the six Spodosol series. Such constant relationship may be due to the relatively equal resistance of the two minerals to alteration in this environment, which is shown by their distribution with depth of the profiles.

The disparities between the tourmaline/pyroxene, garnet/pyroxene and quartz/feldspar ratios in the B_{22}ir horizon of the six Spodosol profiles are shown in figure 92. Higher ratios are largely associated with the weathering of pyroxene and feldspar and the relative accumulation of tourmaline, garnet and quartz minerals as in the Port-Cockburn and Alliston soils. The B_{22}ir horizons of Wyevale and Hendrie profiles with relatively low degree of mineral weathering show low tourmaline/pyroxene and garnet/pyroxene ratios, which low ratios may be due to a slight tendency to alteration by weathering (figure 92). The B_{22}ir horizons of Monteagle and Tioga profiles show an intermediate degree of mineral weathering.

In conclusion, a direct relationship exists between the ratios of silica/sesquioxide and silica/aluminium and the effective cation exchange capacity, to indicate the degree of chemical weathering in both Alfisol and Spodosol profiles. Such a relationship is less clearly evident between the values of desilicification and the values of base saturation in those soils of complex origin in the studied Alfisols, where bisequal development is evident, or in Spodosols where the surface organic horizon is absent or poor drainage exists. In regard to the mineral weathering, a weak relationship was found between the ratios of resistant to non-resistant minerals in the clay minerals as well as the heavy and light minerals, explained as being the result of varying degrees of mineral degradation from the original state in the parent material.

TABLE 84 : TOURMALINE-PYROXENE RATIO OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	1.02	2.11	0.83	0.83	1.42	1.52
$B_{22}ir$	0.54	1.03	0.92	1.02	0.94	0.81
Lower C	0.63	1.22	1.22	0.91	1.01	0.43

TABLE 85 : GARNET-PYROXENE RATIO OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	0.82	2.12	1.31	0.82	1.41	1.82
$B_{22}ir$	1.23	1.51	1.23	1.43	1.04	1.03
Lower C	0.74	1.34	1.41	0.92	0.73	0.84

TABLE 86 : QUARTZ-FELDSPAR RATIO OF THE SIX SPODOSOL PROFILES

Profile / Horizon	Wyevale (1)	P.Cockburn (2)	Monteagle (3)	Alliston (4)	Tioga (5)	Hendrie (6)
Upper A	0.53	1.24	1.22	0.93	0.92	1.03
$B_{22}ir$	1.02	1.22	1.01	1.22	0.94	1.01
Lower C	1.14	1.24	0.83	1.01	1.22	1.03

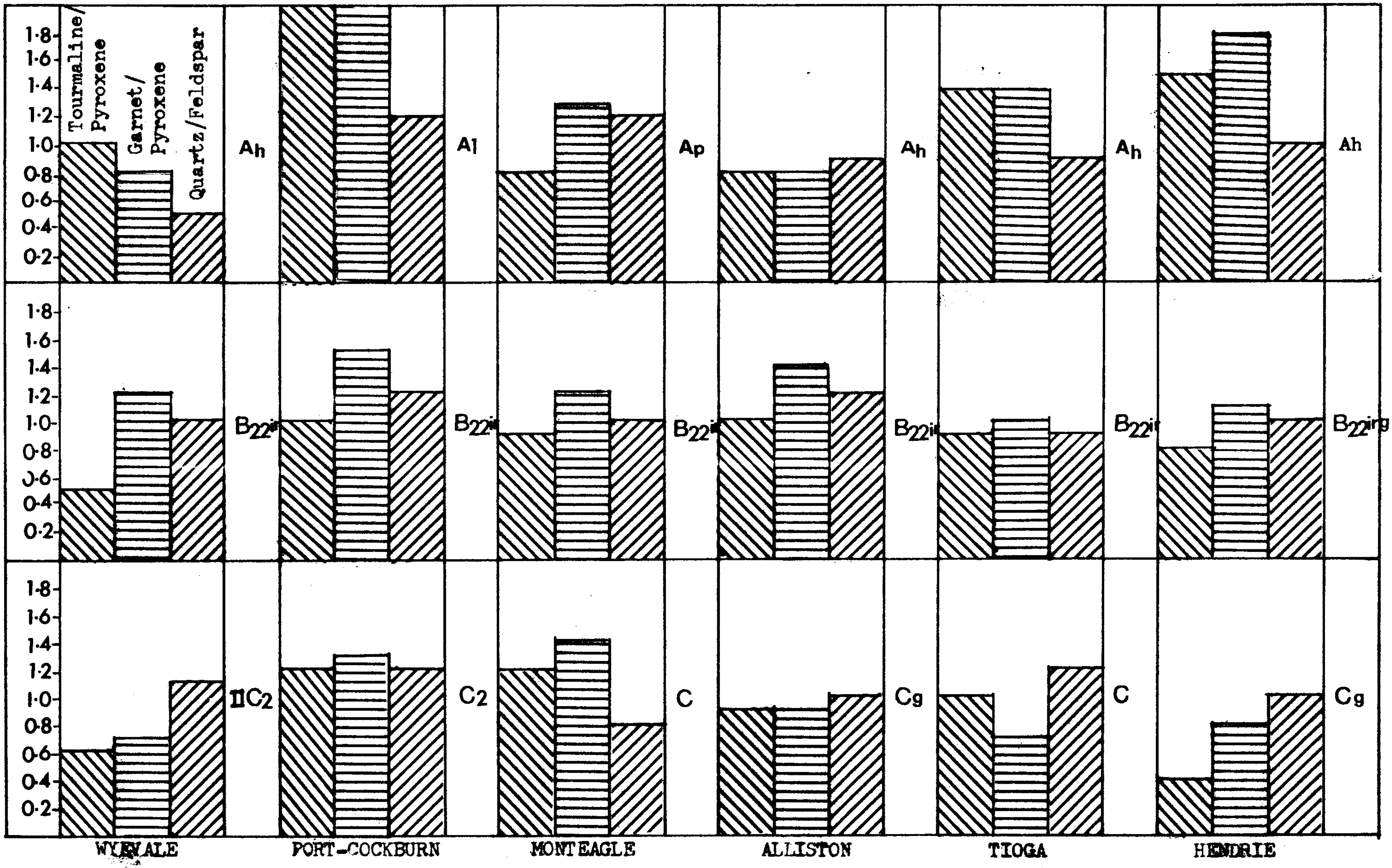


FIGURE 92. THE DISTRIBUTION OF HEAVY AND LIGHT MINERAL RATIOS IN THE UPPER A, B_{22}ir AND LOWER C HORIZON OF THE SIX SPODOSOLS

7. 3. The determination of soil profile discontinuities using analysis of mechanical properties.

A discontinuity is defined as an abrupt change in the magnitude of a soil property within a vertical soil section. Generally, the origin of discontinuities may be summarized as follows :

a) Those discontinuities related to a geologic discontinuity of material in a profile section such as sand on clay, wash on till, or other similar discontinuities related to the geomorphic history of soil parent material;

b) The discontinuities related to a pedogenic origin;

c) Discontinuities related to a combination of geologic-pedologic processes in varying relative degrees of intensity. Such would be the dissolution of calcareous materials of differing compaction for example, or the differential sequence of heavy minerals in a layer of sequence. Geologic discontinuities occur between materials of different origin of deposition and degree of weathering, while pedogenic discontinuities result from the combined processes of additions, losses, transformation and translocation of soil material, resulting in horizon differentiation. In this study both geologic and pedologic discontinuities will be described in detail.

Establishing the presence and location of discontinuities in a profile is important in the study of soil genesis. This subject has been discussed recently by Lea (1967), Arnold (1968), Asamoa (1969) and Raad (1969). They proved that an abrupt change in magnitude of several soil properties such as texture, mineralogy and chemical properties at similar depths are very useful in indicating lithological discontinuities and the causes of such discontinuities.

Textural discontinuities were observed in the field in five of the twelve profiles studied - the IICX horizon of the Guelph series, the IIC$_1$ horizon of the Ancaster and the IIC$_1$ horizon of the Wyevale series. The B'$_2$t horizons of the Tioga and Alliston profiles may also be considered as textural discontinuities resulting from the presence of more than one sequa in their profiles. Abrupt changes in percent sand, silt and clay are important indicators of discontinuities in the five profiles. Particle size analysis were first used by Acton (1970) to establish textural discontinuities in Alfisol profiles from Southern Ontario. Lea (1967) also established more than one discontinuity in four Alfisol profiles in Ontario. Regression equations of the "best-fitting" lines for the various particle-size fractions used in locating discontinuities were given by Acton (1970).

The textural discontinuities in the Alfisol profiles are established in the Guelph and Ancaster series. The IICX$_1$ horizon in the Guelph series, at a depth of 31 inches, showed that the texture changed from clayey above, to silt-loam below the discontinuity, with an increase of 29% silt material (table 87). Such an increase of silt may be associated with a geological-pedological discontinuity; geological by relation to late glacial deposits on loam till, mainly dolomitic; while the pedological discontinuity results from the compact fragipan horizon below the horizon of discontinuity with platy structure and very strong consistency. Micromorphological studies show also some evidence of the pedological discontinuity, resulting from the presence of cutan and glaebule features below the discontinuity. The textural discontinuity in the IIC$_1$ horizon of the Ancaster profile is present at 26 inches depth, texture changing from clay-loam to sandy-loam with an increase of 16 % sand below the discontinuity. Such an increase indicates a geological discontinuity related to a sequence of glacial deposits with clay till above and fine sand below the discontinuity. The micromorphological evidence indicates the existence of both geological and pedological discontinuities. Geological discontinuity was clarified by the significant change in the skeleton proportion above and below the discontinuity, while the presence of channel argillan above and illuvial grain argillan below the discontinuity was of pedological origin in the Ancaster profile.

With regard to the six Spodosol profiles studied, textural discontinuities were established in the IIC_1 horizon of the Wyevale series and the B'_2t horizons of both the Alliston and Tioga series. Geological discontinuity in the Wyevale series was exemplified by the texture change from sandy-loam to silty-loam at 17 inches depth with a 43 % increase in the silt fraction, in turn promoting a marked plasma increase. Geological discontinuities were found, in both the Alliston and Tioga profiles, related to the existence of a B_2t horizon below the spodic horizon developed above a till-like layer. In the Alliston profile texture changes at 26 inches depth from sand to loamy-sand below the discontinuity. The data table 87 shows 4 % clay below and clay absence above, in this profile. The clay presence gives rise to insepic fabric and stress vugh quartzan features beneath the discontinuity, which micromorphological evidence proves the pedological origin of such features in the bisequa profile of the Alliston series.

The textural discontinuity established in the B_2t horizon of the Tioga profile at 33 inches depth is revealed by the abrupt change of soil texture at this depth from loamy fine sand above to loamy coarse sand below the discontinuity. Median size analysis does not reveal this difference. Table 87 shows an increase of 7 % clay fractions below the discontinuity, which addition may be regarded as of pedological origin. However, the presence of fine sand above, and the pale brown calcareous limestone below the discontinuity is relatable to geological origin. Micromorphological features such as the plasma content and the void proportion in the s-matrix were also confirming this discontinuity in the Tioga profile.

In conclusion, the term 'textural discontinuity' associated with a geological origin, was revealed in the superposed materials such as clay on silty-loam in the Guelph series, clay on sandy-loam in the Ancaster series and sandy-loam on silty-loam in the Wyevale series. On the other hand, the textural discontinuity was of pedological origin in most of the profiles studied. It was based on the presence of appreciable changes in the pedogenic properties such as the presence of illuviated clay in the B_2t horizon of both Tioga and Alliston profiles.

Profile	Guelph		Ancaster		Wyevale		Alliston		Tioga	
Horizon / Soil Particles	$B_{22}t$	IIC_1	B_2t	IIC_1	$B_{22}ir$	IIC_1	$B_{23}ir$	B'_2t	$B_{23}ir$	B_2t
Depth "	26	31	12	26	8	17	13	26	26	33
Sand %	20	16	38	51	88	44	89	83	84	78
Silt %	38	67	40	22	7	50	12	13	15	13
Clay %	42	16	25	17	5	7	0	4	2	9

TABLE 87 : PARTICLE SIZE ANALYSES OF THE HORIZONS ABOVE AND BELOW THE DISCONTINUITY IN FIVE SOIL PROFILE DISCONTINUITIES

7. 4. Evaluation of soil development through soil analysis.

The most simple elegant interpretation of the development of a soil profile, mainly as the consequence of movements of water in the soil, was presented by Robinson in 1937. Under humid conditions such as exist in Southern Ontario, there is an excess of rainfall over evaporation (see chapter IV). There is thus a general tendency to downward movements of soil moisture, and the soil is subjected to a leaching process, whereby certain constituents are carried downwards and either deposited in lower horizons or completely removed in drainage water. This process may be at its height in periods of thaw or in the rewetting periods of late fall. As a result of this development, albic, spodic and argillic horizons have formed in various degrees of development. The degree of development of the argillic horizons of Alfisol series and the spodic horizons of the Spodosol series may be determined through many aspects such as the accumulation of silicate clay and the accumulation of sesquioxide and silica. There is also the relative degree of decalcification affecting the degree of argillic B_2t horizon development in Alfisols, derived from calcareous parent material. However, the accumulation of humified organic matter together with the accumulation of sesquioxide and silica can be used to determine the degree of spodic B_2ir horizon development of the Spodosols, even though these too are developed on calcareous material.

With regard to the Alfisols studied, the relative accumulation of clay minerals has been used by Frye et al (1960) and Brewer and Walker (1969) to determine the degree of argillic B_2t horizon development from Illinois and

South Australia respectively. The addition of clay minerals in the B_2t horizon was explained first by Frye et al (1960) as a result of several processes;

i) A parent material with 20 % clay minerals and 25 % carbonate may add about 5 to 7 % clay fraction from the upper horizon to replace the leaching, primarily of carbonate through decalcification;

ii) The residue from 10 % limestone and dolomite may add about 1 or 2 % to the fine earth content, the material usually being of clay size;

iii) Disaggregation of shale fragments could make an important contribution to the clay content of the Bt horizon, though generally not more than 1 or 2 %;

iv) The weathering of feldspar within the Bt horizon should not contribute more than 1 or 2 % clay content;

v) Clay from the A horizon will also be added to the Bt horizon by illuviation. This clay is derived partly from the original clay and partly from the decomposition of silicates, it is moved slowly downward by percolating water along the vertical planes or through intergranular openings. This clay is readily perceived in thin section.

In the Alfisol profiles, the percent clay gained, the clay/carbonate ratio and the clay/clay + silt ratio were used to determine the degree of B_2t horizon according to the principles outlined by Frye (1960) and by Brewer (1969). The percentage of clay gained was described by Barshad (1967) as an important criteria to indicate the degree of B_2t horizon development in Alfisols from North America. The percent clay gained was calculated by Barshad (1967) and applied in the present study as follows;

$$\%\text{ clay gained} = \%\text{ clay in the } B_2t \text{ horizon} - \frac{\text{total clay percentage in each horizon}}{\text{total number of horizons in each profile}}$$

The data, table 88, show that the $B_{22}t$ horizons of the Winona and Guelph profiles have a higher degree of $B_{22}t$ horizon development with clay gained of 16.8 and 15.7 % respectively. Such higher clay addition may be related to the higher moisture content and watertables and the presence of only a moderate degree of soil aggregation in these soils. These factors have stimulated the clay accumulation in the B_2t horizons of the Winona and Guelph series. The $B_{22}t$ horizon of the Huron series shows a relatively poor degree of argillic horizon development and a low percent of clay gained (6.4 %) that may be inherited from geological origin, associated with heavy texture (clayey) and very low percent of fine pores (micro-voids). The $B_{22}t$ horizons of the Ancaster, Haldimand and Vineland series have intermediate $B_{22}t$ horizon development shown by the clay gain of 11.5 to 10.7 and 9.4 % respectively. These Alfisol profiles studied are the most widespread soil forms in Southern Ontario, (Martini and others, 1970).

With regard to the clay/carbonate ratio, Allene and Hole (1968) described this ratio as an important indication of argillic horizon development expressed by the addition of clay in the B_2t horizon of Alfisol profiles since primary Wisconsin times. When primary carbonate is leached, transported clay minerals will replace it by illuviation, thus reducing the volume of the pores formed. Hence a higher ratio of clay/carbonate in the developed soils is related to the strongest B_2t horizon development and to addition of clay minerals. The data, table 88, show that the clay/carbonate ratio in the $B_{22}t$ horizons of the six Alfisol profiles ranged from 4.8 in the Haldimand profile which developed on calcareous clay till, to 87.8 in the Guelph profile which developed on noncalcareous loam till. It is suggested that both profiles Haldimand and Guelph series, originated from calcareous materials, but the calcareous materials dissolved earlier in the Guelph series than in the Haldimand series. The adequate drainage and aeration in the Guelph profile stimulated this decalcification. The $B_{22}t$ horizons of the Guelph and Huron profiles have a higher degree of $B_{22}t$ horizon development with clay/carbonate ratios of 87.8 and 45.2 respectively, though the disaggregation of shale fragments contributes much clay to these soils. The $B_{22}t$ horizon of the Ancaster profile is a relatively poorly developed one with a clay/carbonate ratio of 8.9, though several factors have retarded the decalcification process, such as the low moisture content, the subsoil compaction and the presence of fine pores in this soil. This is supported by the micromorphological description such as the presence of porphyropectic fabrics and micro-voids. The $B_{22}t$ horizons of the Winona, Vineland and Haldimand series are poorly developed and the clay/carbonate ratios are 5.5, 4.9 and 4.8 respectively, which low ratios are associated with marked carbonate accumulations, inherited from the parent materials of these soils.

The clay/clay + silt ratio was used by Harradine (1963) and Khalifa and Buol (1968) to determine the degree of B_2t horizon development as expressed by the degree of illuviation in Alfisol profiles from North Carolina. They proved that the higher the clay/clay + silt ratio, the higher the clay addition in the B_2t horizon derived from the intense degree of weathering of the silt material. The $B_{22}t$ horizons of Guelph and Huron profiles, with a relatively high degree of development have clay/clay + silt ratios of 0.68 and 0.61 respectively. This higher ratio, associated with low silt content may relate to weathering in situ of feldspar to more than silt-size material and partly by lack of silt-size material inherited from the parent material of these soils. These results were supported by the presence of an homogeneous plasma material and the fragmented feldspars in the s-matrix of these soils. The $B_{22}t$ horizons of the Ancaster and Vineland series with a relatively poor degree of development within the subsoil, have a clay/clay + silt ratio of 0.41, such lower ratios imply that the parent material is a source of silt as shown by the homogeneity of the s-matrix and the absence of marked plasma separation in these soils. The $B_{22}t$ horizon of the Haldimand profile has an intermediate stage of subsoil development as shown by the clay/clay + silt ratio of 0.58.

The disparities between the percent clay gained, the clay/carbonate ratio, and the clay/clay + silt ratio in the B_2t horizons of the six Alfisol profiles show that the percent clay gained method is the most simple and direct determination for most soils in Southern Ontario, while the other two methods are influenced by the sources of soil material, by the weathering of silicates clay and of silt-size materials.

In Spodosol profiles, field observation together with soil analysis have been used by soil scientists from many countries to indicate the degree of spodic B_2ir horizon development expressed, by the visible development of the spodic horizon (Dudal, 1970). Mackney (1961) in Spodosols from the West Midlands in England was able to recognize four stages of Podzol development according to morphological and chemical analysis: i) translocation of clay-poor development; ii) chemical weathering of the Ae horizon resulting in association of iron with organic matter and slight eluviation of iron - the "Podzol intergrade" stage or initial stage of development; iii) strong iron eluviation - the stage of iron Podzol or intermediate stage; iv) eluviation of organic matter, which comes to rest on, or is incorporated in the previously-developed iron B horizon - the stage of humus-iron Podzol

Profile	Total clay %	Total silt %	% Silt + clay	$CaCO_3$eq. %	Total clay of P.M. %	Clay/ $CaCO_3$	Clay/ Silt + clay	Clay gained %
Guelph	42.0	37.6	79.6	0.48	26.3	87.8	0.68	15.7
Ancaster	24.7	36.9	61.6	2.80	13.2	8.9	0.41	11.5
Vineland	39.5	58.3	97.8	8.13	30.1	4.9	0.41	9.4
Winona	50.1	31.5	81.6	9.24	33.3	5.5	0.62	16.8
Haldimand	50.5	35.8	96.3	10.50	39.8	4.8	0.58	10.7
Huron	58.7	39.0	96.7	1.30	52.3	45.2	0.61	6.4

TABLE 88 : CLAY ACCUMULATION, THE RATIOS OF CLAY/CARBONATE AND CLAY/SILT PLUS CLAY IN THE $B_{22}t$ OF THE SIX ALFISOL PROFILES

or ultimate stage of development.

In the present study, the B_{22}ir horizons will now be discussed in terms of the sequential degree of development applied by Mackney (1961) in such an environment as Southern Ontario. The initial stage of development was found in the bisequa Alliston and Tioga profiles in which translocated clay is accumulated in a B_2t horizon. However, while the Alliston series is developed on an outwash sand calcareous parent material (800 feet a.s.l.), the Tioga series is developed on an outwash sand and non-calcareous material on an higher landform at 1,000 feet a.s.l. and the clay in the Alliston B_2t horizon was translocated from the upper horizons, while the clay in the B_2t horizon of the Tioga profile was translocated by capillary forces from the ground water table, as occurs in most soils developed on elevated plateau (Springer and Ameryckx,1966).Hence, the two developments are hardly comparable. The intergrade stage is represented by the Monteagle profile in which the Ap or Ae horizon shows an association of iron with organic matter (metalo-humines or chelates). The Monteagle series has developed on well-drained outwash sand at 1,000 feet a.s.l. The intermediate degree of development (iron podzol) was found in the Hendrie and Wyevale profiles in which strong eluviation results in higher iron accumulation in the B_2ir horizons, of 14.3 and 11.6 % respectively. The ultimate stage of humus-iron Podzol development was found in the Port-Cockburn profile in which eluviated humified organic matter is incorporated in a previously developed iron B horizon as two separate compounds - fulvic acid and colloid iron.

Although the soils studied fit the above relationship between spodic horizon development and profile development, the relationship is to be considered as quasi-descriptive observation and needs more investigation and testing. Therefore, the accumulation of organic matter, the accumulation of total iron and the silt/silt + fine sand ratio in the B_2ir horizons were used to determine the relative degree of B_{22}ir horizon development in the Spodosol profiles studied. These three criteria were found to be the most relevant characteristics to clarify the stage of spodic development in Spodosols from the Atlantic provinces (McKeague, 1969) and from North America (Dudal, 1970).

The Alliston series shows low organic accumulation (0.5 %) which reflects the absence of an organic surface horizon in this profile. A marked organic accumulation is found in the B_2ir of the Hendrie profile (7.2 %), partly derived from old deep plant roots and partly from chelate material coating the skeleton grains of the s-matrix. The presence of the isotropic dark brown coating material and the existence of fragmented organic material in the s-matrix support the previous discussion. Considerable organic accumulation was found in the B_{22}ir horizons of the Tioga profiles, translocated from the organic surface horizon, as shown by the C/N ratio of 15. In contrast, most of the organic accumulation in the B_{22}ir horizon in the Hendrie profile was derived from deep plant roots and/or burried organic material with less humification and a higher C/N ratio of 27. Less accumulation of organic matter was found in the B_{22}ir horizons of the Alliston, Monteagle and Wyevale profiles which have a relatively poor degree of B_2ir development. Most of the organic matter in these B_2ir horizons was translocated from the organic surface horizons by downward movement of water and accumulated on the surface of skeleton grains in the s-matrix.

Iron oxide accumulation in the B_{22}ir horizons also indicates a degree of spodic development as was early discussed by Zonn (1950) in the USSR. Iron accumulation was further used by Mackney (1961) to indicate sequential stages of development. For the profiles studied, iron accumulation ranged from 7.6 % in the Alliston to 14.0 % in the Hendrie profiles. A low iron content was related to a higher pH value and absence of surface organic matter. A higher iron content is derived from intense iron release from the ferrosilicate minerals in the presence of highly acidic milieu (see section 7.2). This result is supported by the ferrous ortstein plasmic fabric and sesquioxide nodules, or ortstein, found in the B_2ir horizon of the Hendrie profile. The coating iron materials are formed by iron illuviation while isolated iron patches, nodules and/or sesquioxide concretions in the s-matrix are formed by in situ weathering of iron-containing minerals. Generally, iron can be eluviated or can migrate as colloids and/or chelates. It is suggested that iron accumulation, associated with chelation, may be largely responsible for the development of organo-ferric ortstein plasmic fabric in the B_{22}ir horizon of the Wyevale profile, while the iron colloids found in the B_{22}ir horizon of the Hendrie profile formed ferrous ortstein plasmic fabric. Therefore, the types and origin of iron together with the percent and form of iron accumulation in the B_2ir horizons in Spodosols are very important in the determination of degree of spodic horizon development. The gross iron accumulation in the B_2ir horizon does not show the slight degree of spodic development in most cases in the studied profiles.

The silt/silt + fine sand ratio was also used to determine the degree of B_{22}ir horizon development. This ratio was used by Wall (1969) to indicate development in Spodosols from Alberta province, proving that it expressed the degree of mechanical weathering of size fractions which in turn is related to weathering development. A high silt/silt + fine sand ratio in the B_{22}ir horizon would indicate a lower degree of spodic development resulting from the infilling of large pores by silt material by illuviation processes. In some soils few large pores may derive from the original geologic deposits, such as coarse materials, and be present in the s-matrix to be filled later by amorphous iron or humus which serve to increase microstructure formation in the s-matrix and fill the intergranular spaces or larger voids. Higher silt/silt + fine sand ratios were found in the B_{22}ir horizons of the Port-Cockburn and Tioga profiles (Fig. 89). The well-developed Port-Cockburn spodic horizon has a microgranular structure and large pores in the s-matrix, while the less well-developed Tioga horizon has a homogeneous plasmic material (silasepic fabric) without sedimented plasma - infilling of the large pores.

In conclusion, of the three soil criteria used to indicate degree of B horizon development in Alfisols -percent clay gained, clay/clay + silt ratio and clay/carbonate ratio-, the former was found most reliable because the other two could be affected by both geologic influences and pedogenic alteration in situ.

With regard to the Spodosol accumulation of organic material, accumulation of iron oxide and the silt/silt + fine sand ratio were used to evaluate the degree of spodic development. Organic materials and iron oxide exhibited promoting influences on soil development while silt exhibited retarding influences on spodic development, as in the Port-Cockburn profile. Two stages of spodic horizon development were discerned : 1) an initial stage as in the Alliston, Monteagle and Wyevale series, in which accumulation of organic matter is 2 % and of iron oxide 10 %. 2) an advanced stage as in the Hendrie, Tioga and Port-Cockburn series with 5 % organic matter and 12 % iron oxide. Regarding plasmic fabric development in the B_{22}ir horizons, three stages were found in the Spodosol profiles studied, closely linked to the presence of silt as expressed by the silt/silt + fine sand ratio : i) in the Port-Cockburn and Tioga profiles there is a poor degree of plasma development and in contrast a high silt/silt + fine sand ratio (0.69 and 0.50). ii) the Monteagle and Wyevale profiles with a lower ratio (0.19 and 0.12) show much plasma development. iii) the Alliston and Hendrie profiles show an intermediate stage with ratios of silt/silt + fine sand of 0.38 and 0.27.

Profiles	Total silt %	Fine sand %	Silt + fine sand %	Organic matter %	Fe$_2$O$_3$ %	Silt/Silt + fine sand
Wyevale	7.2	53.5	60.7	2.7	11.6	0.12
P. Cockburn	19.6	9.0	28.6	5.2	11.7	0.69
Monteagle	18.6	78.6	97.2	1.0	12.0	0.19
Alliston	8.9	12.4	21.3	0.5	7.6	0.38
Tioga	15.9	15.6	31.5	6.3	12.8	0.50
Hendrie	10.0	4.0	14.0	7.2	14.3	0.27

TABLE 89 : THE ACCUMULATION OF ORGANIC MATTER, THE ACCUMULATION OF THE IRON AND THE SILT/SILT + FINE SAND RATIO IN THE B$_2$ir HORIZONS OF THE SIX SPODOSOL PROFILES

CHAPTER VIII

SOIL MICROMORPHOLOGY AND SOIL ANALYSIS

8. 1. The study of soil microvoids as related to soil porosity.

Microvoids, in the soil material, may be individual separate units or be interconnected with each other, forming intergranular spaces. In this chapter no exact size limit is attached to the term microvoids, though Brewer (1964, p. 182) sets the limit at 5-30 u. Microvoids can be described, when viewed in thin section, with respect to the properties of size, shape, smoothness of wall, arrangement and morphology. Soil microvoids may be described using the terminologies of both Brewer (1964) and Beckman and Geyger (1967). The vugh voids described by Brewer (1964) essentially correspond to the closed and open cavities described by Beckman and Geyger (1967). Such voids are significantly larger than voids resulting from normal packing of soil particles and are usually irregular and not normally connected with other voids of comparable size. Such vughs were found in all the Alfisol profiles except the Vineland which has developed on the most sandy parent material.

Plane voids as described by Brewer (1964), essentially correspond to the fissure voids described by Beckman and Geyger (1967). Such voids result from the shrinkage of soil material on drying out, and belong to one of three subdivisions - joint, skew and craze voids - but skew plane voids were not seen in the soils studied. Joint planar voids, transversely oriented with a fairly regular distribution pattern, were observed in all Alfisols except in the Winona and Guelph profiles, while craze planar void patterns, distinguished by irregularity and intricate net-works, were only observed in the Haldimand and Winona profiles where argillic horizon had developed in compact clay materials.

The characteristic shapes of channel voids (Brewer, 1964), defined as of tubular form with regular smooth walls and branching pattern, were identified in the $B_{22}t$ horizons of the Vineland, Guelph and Ancaster profiles. As channels are related to earthworm activity and the presence of roots, this indicates that such agencies have effectively penetrated into the $B_{22}t$ horizons of these three soils.

Vesicles, as described by Brewer (1964), essentially correspond to the closed cavity voids as described by Beckman and Geyger (1967). These voids, differing from the vughs principally in their smooth simply-curved walls, were most noticeable in the Winona and Guelph textural B horizons.

Chambers, as described by Brewer (1964), are metavoids, differing from vughs and vesicles in that they are interconnected through channels. Their formation attributed to faunal activity (earthworms). They frequently exhibit characteristics of smoothness, dense-packing and dark-staining on walls, the latter due to faunal activity. Such voids were found in Huron and Vineland profiles, which voids may indicate former presence of planar voids in the s-matrix of these profiles.

Void size in the six Alfisol profiles, as observed in thin section, was determined by averaging the dimensions of 20 selected observed voids. Although this method is much less satisfactory than the measuring of cross-sectional area or actual volume, it has the advantage of relative simplicity in practice. Micro joint planar voids with width of 5 u, 9 u, 12 u and 30 u respectively, were observed in the Vineland, Huron, Haldimand and Ancaster profiles. Macro craze planar voids with greater maximum width were seen but did not exceed 400 u.

Meso- to macro channel voids, with widths from 500 u to 120 u were found in the Guelph and Vineland profiles. Very fine macro chamber voids with diameter of > 200 u were found in the Vineland, Ancaster and Huron profiles. Very fine macro vesicle voids of 300 u Ø were observed in the Winona and Guelph soil profiles. The smoothness of void walls in the Alfisol profiles was determined by averaging the smoothness of the wall of 20 selected voids. Ortho voids, described by Brewer (1964) essentially correspond to the vugh-walled voids described by Beckman and Geyger (1967). These voids were identified as voids with walls that morphologically appear to be due to unaltered, normal, random packing of skeleton grains and plasma additions. Moreover, these voids are associated with adhesive or attractive material between particles, such as humic acid, iron oxide or calcium saturated clays. Ortho voids were found dominant in the fabric of the B_2t horizon in the relatively sandy Vineland profile. Meta voids are identified by walls which seem to be significantly smoother than normal. They are termed smooth wall voids by Beckman and Geyger (1967), they may have formed through faunal activity, root pressure or through shrinking and swelling during wetting and drying. Such voids dominate the Guelph profile. Very few of these voids were found in the Vineland profile, while from 9 to 14 of the 20 counted were found in the other Alfisol profiles.

The relationship between the percentage porosity calculated by using the volumetric weight and specific gravity determinations (see section 7.1) and the type, shape and size of voids, here described, will now be discussed in detail.

The Vineland and Huron profiles have a relatively high percentage porosity of 48 to 49 % (table 1) associated with 5 u Ø micro joint planar and 9 u Ø micro ortho-meta joint planar voids. Such voids relate to a high clay content, homogeneity of material, calcium saturation and uniform regular drying in the soil materials (Sleeman, 1963). Haldimand and Winona profiles (porosity 47 %) show macro meta-craze planar voids, which form during highly irregular drying and/or in very heterogeneous materials, either highly sodium saturated and/or a high humic acid content (Brewer, 1964). Ancaster and Guelph profiles with a lower porosity of 45 % exhibit 550 u to 600 u, very fine macro meta vughs, respectively. Such voids normally originate from earthworm activity and their low porosity relates to larger regularly-shaped individual pores. Narrow ranges of porosity within both brown earths and podzols have also been cited by Hartge (1968), of 6.0 percent variation in clays and 1.6 percent in sands.

Joint planar voids tend to be related to a higher percentage porosity (table 90) in homogeneous soil materials. Vughs tend to be related to lower porosities, affected by fauna activity; the craze planar voids represent a transitional stage between joint planar voids and vughs. The study also indicates that the wide planar voids with a small number in a given unit area tend to be reflected in relatively lower percentage porosities while narrow planar voids with a larger number per unit area tend to promote higher porosities. Such observations may be related to the variable swell-shrink potential of the soil materials. The wide planar voids of the Ancaster profile,

Profile	% Pore space	Void Dominant	Average size (u) (20 counts)	Void Moderate	Average size (u) (20 counts)	Void Few	Average size (u) (20 counts)	Ortho:Meta ratio (20 counts)
Vineland	48	Joint planar	5 (W)	Channel	120 (W)	Chamber	200	16:4
Huron	49	Joint Planar	9 (W)	Chamber	450	Vughs	400	11:9
Haldimand	47	Craze planar	400 (W)	Joint planar	12 (W)	Vughs	500	8:12
Winona	47	Craze planar	250	Vughs	200	Vesicles	300	6:14
Ancaster	45	Vughs	550	Channel	200	Joint Planar	30 (W)	7:13
Guelph	45	Vesicles	125	Vughs	600	Channels	50 (W)	0:20

TABLE 90 : THE DISTRIBUTION OF VOIDS AS RELATED TO THE PERCENTAGE OF POROSITY IN THE SIX ALFISOL PROFILES

with a high swell-shrink potential, are associated with a calcium-saturated clay and increase with the progressive separation of plasma. The relatively narrow planes in the Vineland, Huron and Haldimand profiles are associated with the presence of hydrogen-and/or sodium saturated clays. The same result was cited by Czeratski and Frese (1958) working with soil from North America (see table 91). It is also possible to suggest that ortho voids are largely related to a higher percentage of porosity while meta voids are related to lower levels of porosity. The formation of ortho voids may be explained as the result of translocation of clay and clay diffusion in situ, increasing the size of voids while argilluviation processes may affect the total number of meta voids of varying sizes by diminishing the size of voids.

A similar approach to the study and analysis of types of voids, observed in thin sections of B_{22}ir horizons of the six Spodosol profiles was adopted and the voids were described using the terminologies of Brewer (1964) and Beckman and Geyger (1967). Simple packing voids, described by Brewer (1964) were not considered by Beckman and Geyger (1967) as an element for morphological characterization of structure, since their size, shape and orientation is presumed to be purely accidental. Simple packing voids were found in all the profiles except the Monteagle and Wyevale profiles. Compound packing voids described by Brewer (1964) essentially correspond to the closed cavities described by Beckman and Geyger (1967). Such voids were found in all the profiles except in the Port-Cockburn profile. It may be explained that simple packing voids are largely related to the dominant coarse material while the compound packing voids are related to mixed fine and coarse as well as fine material domains (Brewer, 1964) in thin section.

Vughs and closed and/or open cavities, were found in all the Spodosol profiles except the Hendrie and Port-Cockburn profiles which are based on finer material. Vesicles with closed cavities were found in the Monteagle and Wyevale profiles, which soils are derived from coarse sand.

Simple packing micro voids, with widths of 15 u, 25 u and 30 u were found to dominate the B_{22}ir horizons of Tioga, Port-Cockburn and Hendrie profiles respectively and, to a moderate degree, meso-voids (50 u) were found in the Alliston profile. Very fine compound packing macro voids, with widths of 100 u occurred in the Hendrie profile to a moderate degree and dominated the Monteagle soil. Larger voids, 250 u and 300 u, were noticed in the Alliston and Wyevale profiles. Meso compound packing voids (35 u) characterized the Tioga profile; very fine macro vughs (75 u Ø) were found in the Wyevale soil and larger, though still very fine, vughs (500-550 u Ø) occurred in the Tioga profile. Only a few such vughs occurred in the Alliston and Monteagle profiles. This relatively large size of vugh in the Monteagle, Wyevale and Tioga soils may relate to the lack of illuviated mobile materials and the low degree of aggregation. Macro vesicles with 450 u Ø were occasionally found in the Wyevale and to be moderately developed (1,000 u Ø) in the Monteagle profile. Such large vesicles in the latter soil were related to the presence of dead woody roots.

The relative smoothness of the voids in the Spodosol profiles was determined, and ortho voids, with rough walls, were found to dominate the Alliston profile. Such voids were absent from the Monteagle profile and very few ortho voids were found in the Port-Cockburn and Hendrie profiles. A moderate number occurred in the Tioga and Wyevale series. Meta voids with smooth walls were associated principally with the Alliston and Monteagle series.

Table 91 shows that the Port-Cockburn and Tioga soils with very high porosity for sandy soils (39% and 36% respectively) have 25 u and 15 u ortho simple packing micro-voids, resulting from the natural (random) arrangement of grain size in their subsoils. Hendrie and Alliston profiles with moderate porosities, 30 to 33%, have larger 30 u meso simple packing meta voids (Hendrie); 100 u macro meta compound packing voids (Monteagle) and 250 u macro ortho compound packing voids (Alliston). The Wyevale profile, with a very low porosity (26%) shows 300 u macro ortho compound packing voids resulting from the activity of fauna (earthworms) and shrink-swell effects.

Simple packing voids are largely related to higher porosities and to the presence of unaccommodated grains; while compound packing voids are principally associated with lower porosity and unaccommodated peds. There is also direct relationship between size of dominant voids and percentage of porosity. The smallest fine voids (meso voids 30-75 u Ø) tend to be related to higher porosity. Swanson and Peterson (1942) working with sandy soils, found the same results (see table 91). The observations also show that meta voids dominate the six Spodosol profiles, except the Alliston profile, which exception may be explained as a result of clay translocation into the lower B_2t horizon of the bisequa profile, a process not typical of podzolization.

Conclusions regarding soil porosity and soil microvoids are that there are three stages of pore development in the $B_{22}t$ horizons of Alfisols, only two in $B_{22}ir$ horizons of Spodosols: i) initial stages in which low levels of porosity relate to macro meta-vughs and vesicles in Alfisols and macro meta-compound packing voids in Spodosols; ii) intermediate stages in which ortho craze planes are formed in Alfisols; iii) ultimate stages with meso meta simple packing voids in Spodosols and micro ortho joint planes in Alfisol profiles.

Profile	% Pore space	Void Dominant	Average size (u) (20 counts)	Void Moderate	Average size (u) (20 counts)	Voids Few	Average size (u) (20 counts)	Ortho:Meta Ratio (20 counts)
Port-Cockburn	39	Simple packing	25	-	-	-	-	1:19
Tioga	36	Simple packing	15	Vugh	500	Compound packing	35	7:13
Hendrie	33	Simple packing	30	Compound packing	100	-	-	2:18
Monteagle	32	Compound packing	100	Vesicle	1000	Vugh	550	0:20
Alliston	30	Compound packing	250	Simple packing	50	Vugh	500	12:8
Wyevale	26	Compound packing	300	Vugh	75	Vesicle	450	6:14

TABLE 91 : THE DISTRIBUTION OF VOIDS AS RELATED TO THE PERCENTAGE OF POROSITY IN THE SIX SPODOSOL PROFILES

8. 2. The study of the soil fabric as related to soil weathering.

Brewer (1964) has defined a soil fabric as the physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids. Sepic plasmic fabrics exhibit domains of plasma separation which possesses some degree of striation in the extinction pattern and such sepic fabrics were found in all the $B_{22}t$ horizons of the six Alfisol profiles. It has also been suggested that sepic plasmic fabrics may have originated from the effects of pressures and tensions produced by wetting and drying (Rode et al, 1960). The other four divisions of plasma fabric discussed by Brewer (1964) -asepic, undulic, isotic and crystic fabrics- were absent in these $B_{22}t$ horizons. All of the seven subdivisions of sepic plasmic fabrics detailed by Brewer (1964, p. 308) were found in the $B_{22}t$ horizons of the six Alfisol profiles. These subdivisions are masepic, mosepic, vosepic, insepic, skelsepic, lattisepic and omnisepic plasma fabrics.

Mosepic plasma fabrics dominated the Huron and Haldimand profiles and were moderately well represented in the Ancaster profile. It is readyly acceptable that the origin of mosepic fabrics is by inheritance, since most of the sedimentary rocks have the same fabric (Brewer, 1964).

Masepic plasmic fabrics with plasma separations occurring in elongated zones unassociated with void walls or grain surfaces, were found to be dominant in the Guelph and Vineland profiles, moderately developed in the Winona profile and with a few traces in the Huron profile. Masepic fabrics are often associated with large plasmic grains, such as illite, kaolinite and chlorite, the behavior of which is affected by gravitational forces, developing parallel orientation in the s-matrix of the soils.

Vosepic plasmic fabrics, defined by Brewer as plasma separations that occur subcutanically, are associated with void walls, were found to dominate the Ancaster profile; present to a moderate extent in the Vineland, Huron and Guelph profiles; only occasionally appearing in the Haldimand profile. There is little doubt that vosepic fabrics are formed on wetting and drying, with associated planar voids which are the sites of maximum pressure due to expansion and tension due to shrinkage.

Skelsepic plasmic fabrics show plasma separations, having a striated orientation occurring subcutanically to the surface of skeletal grains. This plasmic fabric was found to be moderately developed in the Haldimand profile and occasionally present in the other profiles, though absent from the Huron profile. Skelsepic fabrics may result from differential movement of skeleton grains to produce a striated orientation pattern in the plasmic material. The same result was suggested by Lafeber (1962).

Insepic fabrics with plasma separations in isolated patches occurring in a dominantly flecked extinction pattern, were found to be dominant only in the Winona profile, presumably because of the lower clay contents and shrink-swell potential.

The relationship between degree of chemical weathering indicated by the silica/sesquioxide molar ratio and the development of plasmic fabric using Brewer's terminology for progressively-developed fabric forms, will now be discussed in detail with respect to the six Alfisol profiles. In this commentary, compound names for types of fabrics are those used by Laruelle (1965) in Belgium. Table 92 shows that Haldimand and Huron series with a relatively low degree of chemical weathering, shown by the silica/sesquioxide ratios of 7.58 and 8.28 have a mo-vo-skelsepic plasmic fabric.

Such fabrics may be inherited from the parent materials after weathering, physical softening and disintegration of mineral fragments. Guelph and Vineland profiles with moderate weathering and silica/sesquioxide ratios of 6.57 and 6.39 show ma-vo-skelsepic plasmic fabrics which generally occur in compact soils of lower moisture content subjected to pressure. Ancaster and Winona profiles, with a higher degree of chemical weathering (ratios of 5.22 and 4.40) have vo-mo-skelsepic and in-ma-lattisepic plasmic fabrics respectively. Such fabrics result from a higher moisture content and low pressure due to the shallow phasic depth of their soil profiles (Blokhuis et al, 1970). These results show that mo-vo-skelsepic plasmic fabrics are largely related to initial chemical weathering. The ma-vo-skelsepic plasmic fabrics represent an intermediate stage while insepic and vosepic fabrics occur later associated with a greater degree of chemical weathering.

A relationship of masepic plasmic fabrics to soil materials with a higher degree of swell-shrink potential has been noticed in the work of Nettleton et al (1969), Brewer (1964) and Green-Kelly (1970). This same relationship applies to the Huron and Haldimand profiles; the Guelph and Vineland profiles with a masepic (matrix-related) plasmic fabric, have a moderate swell-shrink potential and the Ancaster and Winona profiles, with vosepic, respectively insepic plasmic fabrics, have a low swell-shrink potential. Such fabrics are more open or porous and less well developed. In general, one may conclude that the planar vosepic plasmic fabric indicates the pressure which peds exert upon each other when swelling after being moistened. The masepic fabric probably results from similar stresses set up in a soil of lower pedality. Skelsepic fabric is a poor indicator of such stress processes, since the width of the skelsepic brims may depend both on stress intensity and on grain size.

Dumanski and St.Arnaud (1966) have suggested that properties of plasmic fabric types should, without doubt, reflect the overall chemical composition of the B_2t horizons. Masepic plasmic fabric was found by Bennema et al (1970) from studies in Central Africa, to be related to a moderate degree of chemical weathering. It is suggested that a relationship of development of fabric type and the degree of weathering is also possible in the much younger soils in Southern Ontario and in this regard, the relationship between the quartz/chlorite ratio, as an indicator of mineral weathering, and the plasma fabrics of the $B_{22}t$ horizons in the studied Alfisols should be examined (table 92).

The data (in table 92) show that mosepic and vosepic plasmic fabrics are largely related to a low degree of mineral weathering (a low quartz/chlorite ratio). In contrast, the insepic and masepic plasmic fabrics are related to a higher degree of mineral weathering, with a high quartz/chlorite ratio, or a zero ratio because all chlorite is removed. Such a result was accepted by Bennema et al (1970) who found that masepic fabric is related to low degree of mineral weathering in argillic horizons of moderately-developed tropical soils. The exceptionally high quartz/chlorite ratio found in the Vineland profile is probably related to sedimentation processes and weathering of clay minerals in situ in the $B_{22}t$ hroizons. The other soils have all some skelsepic fabric which is related to the continuing influence of relatively unweathered skeleton components.

Plasma fabric was studied in the $B_{22}ir$ horizons in the six Spodosol profiles and described using the terminologies of Kubiena (1938) and Brewer (1964). Three sub-classes of sepic plasmic fabrics were found by Brewer

Profile	Chemical weathering	Mineral weathering	Plasma fabric			
	SiO_2/R_2O_3	Quartz/chlorite	Dominant	Moderate	Few	Very few
Huron	8.28	6.0	Mosepic	Vosepic	Masepic	-
Haldimand	7.58	7.5	Mosepic	Skelsepic	Vosepic	Insepic
Guelph	6.57	-	Masepic	Vosepic	Skelsepic	-
Vineland	6.39	11.0	Masepic	Vosepic	Skelsepic	Insepic
Ancaster	5.22	7.5	Vosepic	Mosepic	Skelsepic	-
Winona	4.40	-	Insepic	Masepic	Skelsepic	Mosepic

TABLE 92 : THE DISTRIBUTION OF PLASMA FABRIC AS RELATED TO THE CHEMICAL AND MINERALOGICAL WEATHERING IN THE $B_{22}t$ HORIZON OF SIX ALFISOL PROFILES

(1964) in podzolic soils. These are skelsepic, vosepic and insepic plasmic fabrics. Five types of coated ortstein material were described in the six Spodosol profiles using Kubiena's (1953) classification. These are : i) ferri-organic, with coatings of sepia or dark brown humus substances with high mobile iron content; ii) organo-ferric, with coating of very dark brown humus with lower iron content, appearing as a thick layer; iii) ferrous, with visible reddish-brown coatings of mobile iron; iv) moderate mull, with coatings of sepia-brown humus substances and; v) weak mull with a coating visible only in the form of a thin dark line.

Skelsepic plasmic fabrics (Brewer) were found to be dominant in all thin sections of the spodic horizons studied. It may be suggested that differential movement of skeleton grains during the downward movement of iron hydroxide, colloids and chelates produces the striated orientation pattern in the plasma. Vosepic fabrics (Brewer) were moderately developed in the Alliston, Monteagle and Wyevale profiles and occasionally in the Tioga and Port-Cockburn profiles. Such fabrics may have originated from the unaccommodated grains and/or peds being mechanically reorientated due to pressure from an overburden. Insepic plasmic fabric (Brewer) was occasionally found in the Monteagle and Wyevale profiles resulting from weathering, physical softening and disintegration of an aggregated soil after initial alteration of the sandy parent material.

Coated ferri-organic ortstein (Kubiena) was found to be dominant in the Alliston, Tioga and Port Cockburn series. Organo-ferric ortsteins were associated principally with the Monteagle profile. Moderate mull ortsteins occurred in the Wyevale profile and occasionally in the Port-Cockburn series. Ferrous ortstein was discernible in the Hendrie profile while a weak mull ortstein was occasionally found in all the studied profiles except in the Port-Cockburn and Monteagle profiles. It may be explained that the presence of much fine sandy material and accumulation of mobile iron increased the thickness of coated ortstein in the Port-Cockburn and Monteagle series.

The relationship between degree of chemical weathering (using the silica/sesquioxide ratio) and the previous description of plasma fabrics in the B_{22}ir horizons may now be discussed. The Alliston profile (table 93) with a lower degree of chemical weathering, (silica/sesquioxide ratio of 5.88) has a skel-vosepic plasmic fabric (sensu Brewer, 1964) and a ferri-organic fabric, intergrading to weak mull ortstein (sensu Kubiena, 1938). Such fabrics may be due to abundant chelate compounds in the subsoil. Tioga and Port-Cockburn profiles, with ratios of 5.77 and 5.71, have a skel-vosepic plasmic fabric (Brewer, 1964) and a ferri-organo fabric intergrading to weak-moderate mull ortstein (Kubiena, 1938), resulting from the presence of humified organic matter. Monteagle, Wyevale and Hendrie profiles with a higher degree of chemical weathering (SiO_2/R_2O_3 ratios of 5.26, 4.68 and 4.66 respectively), have skel-vo-insepic and skelsepic plasmic fabrics (sensu Brewer) and an organo-ferric intergrading to moderate mull, moderate mull intergrading to weak mull and a ferrous intergrading to weak mull ortstein fabric (sensu Kubiena) respectively. Such fabrics may have been in connection with weak reddening processes in these soils with feeble humus participation in an ultimate stage of podzol formation.

These results show that ferri-organic ortsteins are associated principally with a lower degree of chemical weathering or podzolization. Moderate mull and ferrous ortstein occur with a slightly higher degree of chemical weathering than the organo-ferric ortsteins. The results also show that there is no relationship between the chemical weathering using the silica-sesquioxide ratio and the plasma fabrics using the terminology of Brewer (1964). Skelsepic plasmic fabric was dominant in all the studied samples resulting from the presence of amorphous iron and humified organic matter in their soils. Thus Brewer's scheme fails to characterize differing degrees of development of Spodosol profiles.

The relationship between mineral weathering, using the tourmaline/pyroxene ratio and the development fabric of a spodic horizon expressed in terms proposed by Kubiena and Brewer will now be discussed. Table 93 shows that the Alliston and Port-Cockburn profiles have higher mineral weathering, as indicated by their tourmaline/pyroxene ratio of 1.00. Tioga, Hendrie and Monteagle profiles with moderate mineral weathering show tourmaline/pyroxene ratios of 0.87, 0.82 and 0.77, respectively. The Wyevale profile has a lower degree mineral weathering, 0.50 ratio. These results show that the domination of ferri-organo ortstein fabrics is largely relatable to higher mineral weathering; moderate mull ortstein is related to lower mineral weathering. No relationship could be considered between plasma fabric and mineral weathering in the Hendrie, Tioga and Monteagle profiles. The results only show a weak relationship between the plasma fabric as described in the terminology of Brewer (1964) and the mineral weathering using the tourmaline/pyroxene ratio in the $B_{22}t$ horizons of the six Spodosol profiles. Generally, the least weathered materials show the weakest organization and development of plasma fabrics. From the study of the relationship between both chemical and mineral weathering and plasma fabric, one may conclude that there are three stages of soil weathering in connection with the plasma fabric : 1) initial stage of weathering; mosepic plasmic fabric in Alfisols and ferri-organic ortstein in Spodosols; ii) intermediate stage of weathering; masepic plasmic fabric in Alfisols and organo-ferric fabric in Spodosols; iii) ultimate stage of weathering; vosepic and/or insepic plasma fabric in Alfisol and ferrous and/or organo-ferric in Spodosols, or mull where iron is deficient.

Profile	Chemical weathering	Mineral weathering	Plasma fabric after Brewer (1964)			Plasma fabric after Kubiena (1938)		
	SiO_2/R_2O_3	Tourmaline/ Pyroxene	Dominant	Moderate	Few	Dominant	Few	Colour
Alliston	5.88	1.02	Skelsepic	Vosepic	-	Ferri-organo	Weak mull	R.B.5YR5/4
Tioga	5.77	0.94	Skelsepic	-	Vosepic	Ferri-organo	Weak mull	R.B.5YR5/4
Port-Cockburn	5.71	1.03	Skelsepic	-	Vosepic	Ferri-organo	Moderate mull	D.R.B.5YR3/4
Monteagle	5.26	0.92	Skelsepic	Vosepic	Insepic	Organo-ferric	Moderate mull	D.R.B.5YR3/4
Wyevale	4.68	0.54	Skelsepic	Vosepic	Insepic	Moderate mull	Weak mull	R.B.5YR4/4
Hendrie	4.66	0.81	Skelsepic	-	-	Ferrous	Weak mull	W.R.10 R4/4

TABLE 93 : THE DISTRIBUTION OF PLASMA FABRIC AS RELATED TO THE CHEMICAL AND MINERALOGICAL WEATHERING IN THE B_{22}ir HORIZONS OF SIX SPODOSOL PROFILES

8. 3. The relationship between textural discontinuities and the relative proportions of soil constituents.

Variations of the proportions of soil constituents - plasma, voids and skeletal material (pl, vd, sk)- and particularly the amount of plasma fabric, microvoids and orthic pedological features (glaebules and/or cutans) in the s-matrix may be used in the detection of textural discontinuities in the two Alfisol and three Spodosol profiles studied. The relative amounts of plasma, void and skeletal material, will hereafter be termed 'soil proportion properties'. Such were used mainly to indicate the probable presence of textural discontinuities. The other three particular features were used to emphasize comparative studies between profiles. Such use of the variation of relative proportions of major soil constituents as indicators of textural discontinuities has been made by Eswaran (1967).

Five examples of textural discontinuities were observed in the field - two in Alfisol profiles (Guelph and Ancaster profiles) and three in Spodosol profiles (Wyevale, Alliston and Tioga profiles). Thin sections of material from above and below these textural discontinuities show marked differences of plasma fabric type, morphology of microvoids and especially the presence of markedly contrasted types of orthic pedological features.

Table 94 shows that in the Guelph profile, the dominant orthic pedological feature present above the discontinuity, namely illuvial channel argillans, are replaced by rock nodules as dominant forms below the discontinuity. The plasma fabric is masepic above, below it is silasepic, the voids above being vughs, below compound packing voids occur. This reflects the increased gravel content in the IIC_1, material and changes in colour, consistency and structure. Soil proportions remained unchanged apart from a slight increase in the plasma proportion in the lower deposit reflected in the fine silt percentage. Change of plasma fabric may be regarded as the most important indicator of textural discontinuity in the Guelph profile.

In the Ancaster profile, orthic pedological features varied from illuvial channel argillan above to illuvial grain argillan below the discontinuity, plasma fabric from vosepic above to skelsepic below, while vughs dominated the upper layer and simple packing voids the lower layer. The proportion of skeletal material increased significantly in the lower deposit. Hence the most important indicator of a textural discontinuity in the Ancaster profile was the relative proportion of skeletal material.

With regard to the Spodosol profiles, examination of the Wyevale soil showed that the plasma fabric was skelsepic with compound packing voids above and silasepic with meta joint planar voids in the lower deposit. Plasma proportion increased whilst void proportion was decreased in the lower deposit. Orthic pedological features remained the same throughout both the upper and the lower deposit. Hence change in proportion of plasma was the most important indicator of a texture discontinuity in this Wyevale profile.

In the upper part of the B horizon of the Alliston profile, the sesquioxide nodules were the dominant orthic pedological feature whilst stress vugh quartzans were most marked below the discontinuity. Plasma fabric was skelsepic with compound packing voids above and insepic with ortho vughs below the discontinuity in the Alliston profile. In the lower part of the Alliston profile, plasma proportion increased, voids decreased significantly as well as being of different shape. Soil proportion properties were found

Alliston profile, though there were many significant changes of porosity and of plasma fabric while the skeletal proportion remained high throughout.

In the lower layers of the Tioga profile, the proportion of plasma increases and the void proportion decreases significantly. Orthic pedological features, plasma fabric and void form remain unchanged into the lower parts of this profile. The soil proportion may be considered to be the most significant indicator of the textural discontinuity in the Tioga profile and, as with all the Spodosol profiles examined, the skeletal material dominates the upper part of the profile (above the discontinuity) while below, plasmic material dominates except in this Tioga profile, though even in this profile the plasma proportion does increase slightly.

The variation in the relative proportions of plasma, voids and skeletal material was found to be the most important indicator of textural discontinuities. Change of plasmic fabric occurred above and below the textural discontinuities in all the profiles except the Tioga profile. The same result was found by McKeague et al (1967) in podzolic soils from the Atlantic provinces.

The type of voids differed above and below the textural discontinuity in all the profiles except the Tioga profile . Orthic pedological features also were different above and below the textural discontinuity in all the five profiles. The same result was found by Eswaran (1967) in Alfisol and Spodosol profiles in Belgium.

Profile	Horizon	Horizon above discontinuity				Horizon	Horizon below discontinuity			
		Orthic	Voids	Plasma	Proportion		Orthic	Voids	Plasma	Proportion
Guelph	B_3	Channel argillans	Vugh	Masepic	Pl>Sk>Vd	IIC_x	Rock nodule	Compound packing	Silasepic	Pl>Sk>Vd
Ancaster	B_2t	Channel argillans	Vugh	Masepic	Pl>Vd>Sk	IIC_1	Grain argillan	Simple packing	Skelsepic	Sk>Vd>Pl
Wyevale	$B_{22}ir$	Grain argillans	Compound packing	Skelsepic	Sk>Vd>Pl	IIC_1	Grain argillan	Joint packing	Silasepic	Pl>Sk>Vd
Alliston	A'_2	Sesquioxide nodules	Compound packing	Skelsepic	Sk>Vd>Pl	$B_2't$	Vughs quartzan	Vugh	Insepic	Pl>Sk>Vd
Tioga	B_3	Ferric nodule	Simple packing	Skelsepic	Sk>Vd>Pl	$B_2't$	Grain ferran	Simple packing	Skelsepic	Sk>Pl>Vd.

TABLE 94 ; MICROMORPHOLOGICAL PROPERTIES RELATIVE TO HORIZON ABOVE AND BELOW THE TEXTURAL DISCONTINUITIES IN THE FIVE PROFILES STUDIED

8. 4. Elementary structure as related to soil development.

Elementary fabric was described by Kubiena (1938) as the natural arrangement of the elementary particles (plasma and skeleton grains) in relation to each other. The elementary fabric in thin section of the $B_{22}t$ horizons of the six Alfisol profiles was described in detail by using the terminology of Kubiena (1938). Two types of the eight elementary fabric types described by Kubiena (1938) were found in the Alfisol profiles. These are porphyropeptic and porphyropectic fabrics. Porphyropeptic fabric is defined as mineral grains cemented within a dense ground mass in a peptized state. Such dominated all of the Alfisol profiles. Porphyropectic fabric is defined as skeleton grains, free from coatings, embedded in a ground mass which shows almost no spaces. Such fabric was found occasionally as domains in the Winona, Guelph and Ancaster profiles.

The elementary structure of Alfisol Bt horizon materials was also described according to the definition given by Brewer (1964) as 'an integration of characteristic size, shape and arrangement of specific pedological features'. This was with regard to the basic structure of the material associated with such features and to other specific reference features. Five types of elementary structure were found in the $B_{22}t$ horizons of the six Alfisol profiles studied as follows : i) meta sesquioxide nodules with ortho craze planar voids and insepic plasmic fabrics in the Winona profiles; ii) meta sesquioxide nodules with meta joint planar voids and masepic plasmic fabrics in the Vineland profile; iii) ortho vugh argillans with ortho vugh voids and masepic plasmic fabrics in the Guelph profile; iv) ortho vugh argillans with ortho vughs and vosepic plasmic fabrics in the Ancaster profile;

v) meta joint planar argillans with meta joint planar and mosepic fabrics in the Huron and Haldimand profiles.

Elementary structure was also described by Beckman and Geyger (1967) as the result of the capacity of the soil to form aggregates and/or voids. Four of the seven types of elementary structure outlined by Beckman and Geyger (1967) were found in the $B_{22}t$ horizons of the six Alfisol profiles. These are regular, irregular jointed, fragmented and cracked structures. A regular jointed structure with highly regular fissures was found to be dominant in the Guelph, and occasionally present in the Winona $B_{22}t$ horizon. Fragmented structure, with numerous fissures within the aggregates, was found to be dominant in the Ancaster profile. Cracked structures with dominant fissures that are not interconnected, were found to be dominant in the Winona, Haldimand and Huron profiles.

The relationship between the degree of the development of the $B_{22}t$ horizons using the percentage of clay gained and the elementary structures described, will now be discussed in detail. Table 95 shows that the Winona and Guelph profiles with a greater component of added clay of 16.8 and 15.7 clay respectively, and hence a relatively marked development of the argilluvic Bt horizon have porphyropeptic-pectic fabric after Kubiena (1938), sesquioxide-craze-planar insepic fabric and argillan-vugh masepic fabric, respectively (Brewer, 1964), and cracked irregular (Winona) and irregular jointed structure (Guelph) after Beckman and Geyger (1967). The Ancaster and Haldimand profiles with moderate $B_{22}t$ development with clay gains of 11.5 and 10.7% respectively, have porphyropeptic -pectic and porphyropeptic fabrics after Kubiena; argillan-vugh-vosepic and argillan-craze planar mosepic fabric after Brewer; and fragmented and cracked structure respectively, according to Beckman and Geyger's terminology. Vineland and Huron profiles, with a lower degree of $B_{22}t$ development, with only 9.4 and 6.4 % clay gained, have porphyropeptic fabric after Kubiena, sesquioxide-joint planar-masepic and argillan-joint planar-mosepic fabrics after Brewer; regular jointed and cracked structure, after Beckman and Geyger, respectively.

In the terminology outlined by Kubiena it is clear that a porphyropeptic-pectic fabric is largely related to the highest percentages of clay gained in the Bt horizons, porphyropeptic fabric occurred in lower clay gain Bt horizons of the other soils studied.

If use is made of Brewer's terminology, the results show that three types of plasma fabric (table 95) are associated with relatively large voids and, in turn, related to the highest percentages of clay gained. Two types of plasma fabric (masepic and mosepic) and relatively narrow planar voids were found to be related to lower percentages of clay gained. No relationship was found between orthic pedological features and clay gained. Sesquioxide nodules were observed only in the Winona and Vineland profiles.

By using the terminology of Beckman and Geyger (1967), the results show that cracked-irregular jointed structure was related to the higher percentages of clay gained; cracked-regular jointed structure was related to lower percentages of clay gained. It may be explained that, the greater clay gain is associated with an heterogeneous assembly of clay minerals while the Bt horizon showing lowest clay gain is influenced by a relatively homogeneous clay content.

As an explanation for the connection between soil profile development and fabric types, it is suggested that cracked structures with intergraded pedological formations and fragmented structures with clear presence of

Profile	% Clay gained	After Kubiena (1938)		After Brewer (1964)			After Beckman (1967)	
		Dominant	Few	Orthic	Void	Plasma	Dominant	Few
Winona	16.8	Porphyropeptic	Porphyropectic	Sesquioxide nodules	Craze planar	Insepic	Cracked	Irregular jointed
Guelph	15.7	Porphyropeptic	Porphyropectic	Argillan	Vughs	Masepic	Irregular jointed	-
Ancaster	11.5	Porphyropeptic	Porphyropectic	Argillan	Vughs	Vosepic	Fragmented	-
Haldimand	10.7	Porphyropeptic	-	Argillan	Craze planar	Mosepic	Cracked	-
Vineland	9.4	Porphyropeptic	-	Sesquioxide	Joint planar	Masepic	Regular jointed	-
Huron	6.4	Porphyropeptic	-	Argillan	Joint planar	Mosepic	Cracked	-

TABLE 95 : THE DISTRIBUTION OF ELEMENTARY STRUCTURES AS RELATED TO THE DEVELOPMENT OF THE $B_{22}t$ HORIZONS OF SIX ALFISOL PROFILES

little-altered geological materials may be taken as indicators of an early stage of soil fabric formation and may be termed initial stages of fabric development. Regular-jointed structures with homogeneous or simple clay mineral forms may be regarded as an intermediate stage and irregular-jointed structures with heterogeneous assemblages of clay minerals may be regardded as a later stage of fabric development in the Luvisols (Alfisols) of Southern Ontario.

Much detailed study is needed to confirm or elaborate this tentative conclusion. It is certainly clear that the greater the addition of clay through argilluviation, the greater will be the heterogeneity of the clay assemblage in the B_{22}t horizon. At any stage of fabric development, if there is intense clay formation in the B_{22}t horizon, it may be assumed that such would give a semblance of homogeneity to the clay material content.

The elementary structure of the B_{22}ir horizon of the six Spodosol profiles in thin section, was also characterized using the terminologies of Kubiena (1938), Brewer (1964) and Beckman and Geyger (1967). Using Kubiena's terminology, three elementary structures were found in the six Spodosol profiles. These are chlamedomorphic, intertextic,and porphyropectic fabrics.

Chlamedomorphic fabric is defined as mineral grains surrounded by a uniform colloidal coating, having empty intergranular spaces. This elementary fabric was found to be dominant in all six Spodosol profiles. Intertextic fabric with bare mineral grains united by intergranular braces was found occasionally only in the Wyevale profile. Porphyropectic fabric is defined as skeleton grains, free from coatings embedded in a ground mass, showing almost no spaces. Such a fabric was found occasionally in the Monteagle profile.

Four types of elementary structure may be discussed according to the system of Brewer (1964). Sesquioxide-compound packing-skelsepic fabrics were found to be dominant in the Alliston and Monteagle B_{22}ir horizons, sesquioxide-simple packing-skelsepic fabrics dominated the Tioga and Hendrie profiles and ferri-argillan-simple packing-skelsepic fabrics and ferri argillan-compound packing-skelsepic fabrics were the principle fabric types in the Port-Cockburn and Wyevale profiles, respectively (Table 96).

Three of the seven types of elementary structure were described by using the terminology of Beckman and Geyger (1967) from thin sections of the B_{22}ir horizons of the six Spodosol profiles. These are porous, spongy and crumby structures. A porous structure devoid of aggregation with isolated cavities was occasionally observed in the Tioga profile and was dominant in the other profiles. A crumby structure with numerous interconnected cavities, such that the solid material was reduced to loose aggregates (crumbs) was found to be dominant in the Tioga profile. Spongy structure, with interconnected cavities and interconnected aggregates, (no loose or separate aggregates), was occasionally found in the Wyevale profile.

The degree of development of the B_{22}ir horizon was expressed using the relationship of the silt/silt + fine sand ratio (see section 7. 4.) which may be related to the elementary structure shown in table 96. From this, the Port-Cockburn and Tioga profiles with initial stages of development have an associated fabric of chlamedomorphic type, according to Kubiena's typification; ferri-argillan and sesquioxide-simple packing-skelsepic fabric respectively after Brewer, and porous (Port-Cockburn) and crumby-porous structure (Tioga) after Beckman and Geyger.

The Alliston and Hendrie profiles with a moderate degree of development of the B_{22}ir horizon, (0.38 and 0.27 silt/silt plus fine sand ratios) have chlamedomorphic fabrics after Kubiena, sesquioxide-compound packing-skelsepic fabrics after Brewer, and porous structures after Beckman and Geyger.

Monteagle and Wyevale profiles, in ultimate stages of development in the B_{22}ir horizons show low ratios (0.19 and 0.12), chlamedomorphic-porphyropectic and chlamedomorphic-intertextic fabrics after Kubiena, sesquioxide and ferri-argillan-compound packing-skelsepic fabrics after Brewer, and porous and porous-spongy structure after Beckman and Geyger, respectively.

Using the terminology of Kubiena (1938), the data show that the simpler type of elementary structure is related to a higher silt/silt plus fine sand ratio. Three types of elementary structure are associated with lower silt/silt plus fine sand ratios. Hence it may be explained that the less developed horizon is associated with a more homogeneous soil material, while the more developed B horizon has a relatively heterogeneous soil material. This confirms the work of De Concinck et al (1964) in northern Belgium.

Using the terminology of Brewer (1964), the data show that simple packing voids were paralleled by higher silt/silt plus fine sand ratios. Compound packing voids were found to be related to horizons with lower silt/silt plus fine sand ratios. No relationship was found between the orthic pedological features and this ratio. Sesquioxide nodules were found to be dominant in all the Spodosol B_{22}ir horizons, ferri-argillan cutans were associated in horizons having widely-varied ratios and no relationship was found between occurrences of masepic and mosepic plasma fabric and the silt/silt plus fine sand ratio.

Using the terminology of Beckman and Geyger (1967), the results show that porous structure was the most dominant elementary structure in the B_{22}ir horizons of the six Spodosol profiles. The data also show that a crumby-porous structure is largely related to a higher silt/silt plus fine sand ratio. It was explained that the higher degree of loose material was probably associated with slight development of the B_{22}ir horizon. A higher degree of aggregation was probably associated with a greater degree of development of the B horizon of Spodosols.

Profile	Silt/silt plus fine sand	After Kubiena (1938)		After Brewer (1964)			After Beckman (1967)	
		Dominant	Few	Orthic	Void	Plasma	Dominant	Few
Port-Cockburn	0.69	Chlamedo-morphic	-	Ferri-argillan	Simple packing	Skelsepic	Porous	-
Tioga	0.50	Chlamedo-morphic	-	Sesqui-oxide	Simple packing	Skelsepic	Crumby	Porous
Alliston	0.38	Chlamedo-morphic	-	Sesqui-oxide	Compound packing	Skelsepic	Porous	-
Hendrie	0.27	Chlamedo-morphic	-	Sesqui-oxide	Simple packing	Skelsepic	Porous	-
Monteagle	0.19	Chlamedo-morphic	Porphyro-peptic	Sesqui-oxide	Compound packing	Skelsepic	Porous	-
Wyevale	0.12	Chlamedo-morphic	Inter-textic	Ferri-argillan	Compound packing	Skelsepic	Porous	Spongy

TABLE 96 : THE DISTRIBUTION OF ELEMENTARY STRUCTURE AS RELATED TO THE DEVELOPMENT OF THE $B_{22}ir$ HORIZON OF SIX SPODOSOL PROFILES

CONCLUSION

Six Alfisol and six Spodosol profiles representative of Southern Ontario were examined to evaluate the relationship between soil properties and micromorphological features. These twelve profiles were subjected to physical, chemical, mineralogical and micromorphological analysis. An attempt was made to establish the degree of pedological development of these soils using this information.

As is well known, Alfisols and Spodosols are the most dominant soils though there are wide differences in soil properties and morphological development within each order. Alfisol profiles have mainly developed upon clay tills or lacustrine deposits which are neutral to alkaline parent materials. Spodosols are largely related to areas of outwash sand and sandy loam till which are generally acid parent materials though initially calcic in certain areas. According to the Canadian classification (C.D.A. 1970) the six Alfisol series may be classified as follows : the Guelph and Ancaster profiles conform to the requirements of Brunisolic Gray-Brown Luvisols, the major deciding characteristic being that the difference in chroma between the upper and lower Ae horizon is greater than unity. The Huron profile is classified as Orthic Gray-Brown Luvisol, mainly because of the slight chroma differentiation in the Ae horizon. The Vineland, Winona and Haldimand profiles may be regarded as Gleyed Gray-Brown Luvisols, possessing mottling and duller colours than the associated well-drained soils, due to the periodic water-logging of the lower Ae or Bt horizons.

It is to be noted that, though general relationships between macro and micromorphology were sought, some profiles showed slightly atypical features for the series. For example the C horizon in the Guelph and Ancaster profiles demonstrated bisequal development, while the Guelph, Huron and Haldimand profiles had phasic development of deep A_2 horizons. Hence conclusions about the relationship of soil morphology ,soil development and micromorphology for these three series, apply to relatively deeply-developed phases of these three extensive Southern Ontario soils. The Haldimand soil profile studied developed under mixed forest with 0_1 and 0_2 horizons, which is uncommon for Alfisol profiles in Southern Ontario.

In the case of the Spodosols, the Wyevale, Port-Cockburn and Monteagle soil profiles are classified as Orthic Humo-Ferric Podzols. Under undisturbed conditions, the Wyevale and Port-Cockburn soils possessed distinct organic horizons (L-F-H) and light-colored mineral Ae horizons (more than one inch thick), which overlay Bfh and/or Bf horizons. Under cultivated conditions, the Monteagle profile possessed a mixed organo-mineral surface horizon, an Ae and upper B horizon; the Ae transformed to an Ap horizon underlain by remnants of underlying Ae, Bfh or of Bf horizons, depending on the depth of disturbances and/or irregularity of the deeper horizons. The Hendrie series was classified as Gleyed Humo-Ferric Podzol, because of the mottling and dull colours attributable to periodic wetness in the Ae and/or B horizons. The Alliston and Tioga profiles were classified as Bisequa Humo-Ferric Podzols with textural (Bt) horizons underlying Bf horizons at depths > 18 inches.

Conclusions concerning the relationship between soil analyses and morphology and the micromorphology of the upper A, the B_2 and the lower C horizons will now be outlined for both the Alfisols and Spodosols studied. Conclusion relating to the A horizons largely concern the varying accumulation of organic matter, the effects of losses of clay, iron and aluminum and the resulting concentration of quartz or other resistant minerals in the sand or silt ranges, also the relative dominance of the organic or mineral components in the soil fabric, which in turn indicates the relative balance of organic input and mineral loss and hence the intensity of biological activity and the weathering influence.

In the A horizons of the Haldimand and Huron profiles, high silica/sesquioxide ratios (> 7.5) are linked to dominantly argillasepic plasmic fabrics. The A horizon of Winona and Vineland profiles show strongly developed silasepic fabrics. It may be suggested that such silasepic fabrics may be, either inherited from previous sedimentation processes or the result of relatively intense weathering of such sedimentary materials in situ, with intensely jointed or cracked voids rich fabrics resulting from past clay loss and iron mobilization. In contrast, the argillasepic plasmic fabrics of the Haldimand and Huron soils show many indications of presently active weathering and translocating influences. This conclusion is supported by the fact that in the A horizons of the Spodosol profiles similar silasepic and little differnetiated isotic plasmic fabrics were present in soils which had variable but intense degrees of weathering expressed as the silica/sesquioxide ratio.

The A horizons of Guelph, Ancaster, Vineland and Winona series show a wide range of porosity, mainly attributed to vughs which are normally due to earthworm activity. In these four soils worms have been unusually active in the comminution and mixing of organic and mineral materials. The A horizons of the Haldimand and Huron profiles have higher total porosities and show planar voids related to the continuing presence of heavy-textured masses in relatively unaffected forms. This reflects the low degree of biological homogenization of these two less-altered Luvisols. Vughs also dominated the Albic horizons of the fine textured unploughed Spodosols, though the cultivated Monteagle profile has a higher porosity, (simple packing voids) presumably the result of disruption of vughs and compaction by cultivation.

Crumb macro-structures dominate all Luvisol A horizons and five Spodosols. Fragmented microstructures were also present in the A horizons of the Guelph, Winona and Haldimand profiles relatable to mixtures of humified organic matter and clayey soil materials affected by the periodic wet and dry conditions of these three soils. Crumb macro- and spongy microstructure are found where lower contents of highly-humified organic matter occur in A horizons of the Vineland and Ancaster profiles. Such microstructures also occur in Spodosols affected by their less-altered "mor" organic matter. An irregular-jointed microstructure characterizes the Huron A horizon, confirming its low degree of pedogenetic alteration. It may be suggested that highly-humified organic matter (colloidal humus) influences the rapid development of elementary mineral structures much more than less-humified organic matter.

Crumb macro- and spongy microstructures dominate all albic horizons in Spodosols except in the Port-Cockburn profile which exhibited granular structure and crumb microstructure. It may be suggested that spongy microstructures are associated with a high content of less humified organic matter with a relatively high C/N ratio, while a crumb microstructure is related to more humified organic matter, residual mobile iron and/or very fine material still existing in the A horizon. These influences may have promoted soil aggregation in the Port-Cockburn profile to a more marked degree than in the other series.

General conclusions relating to the B_2 horizons of all soils studied are that the mineral material shows one or more of the following properties : i) illuvial concentrations of silicate clay, iron, aluminium or humus, alone or in combination; ii) residual concentrations of silicate or sesquioxide clays alone or together; iii) coatings of sesquioxides sufficient to produce clearer, darker, stronger or redder colours than overlying and underlying B horizons in the same sequence; iv) various concretionary and other individual forms and structural coatings composed of various oxides liberated by weathering of primary minerals.

The mineral B_2 horizons may therefore show quite close correspondence between macro- and micromorphologic features which, in turn, may be more directly relatable to soil mineral composition. The silica/sesquioxide ratio was deemed to be the most useful indicator of the intensity of such alteration processes and directly relatable to the type of plasma fabric present as characterized by the terminologies of both Brewer (1964) and Kubiena (1938).

In the B_{22}t horizons of the Haldimand and Huron profiles, a low degree of chemical weathering (SiO_2/R_2O_3 : 8.28) was marked by a mosepic plasmic fabric. Such a fabric is largely formed and influenced by simple mechanical differential pressures through wetting and drying, which pressures did not alter the configuration of the cutanic material to any significant extent. In contrast, the B_{22}t horizons of the Winona and Ancaster profiles have experienced a higher degree of chemical weathering and posses insepic and vosepic plasmic fabrics respectively. The vosepic fabric results from accumulation of plasmic materials along voids walls; the insepic plasmic fabric of the Winona profile is related to larger mineral grains in the s-matrix exerting pressure on the plasmic material. One may conclude that stronger pressures from wetting and drying were involved in the formation of these vosepic and insepic fabrics as well as a higher degree of chemical weathering.

In the $B_{22}t$ horizons of the Guelph and Vineland soils, a masepic plasmic fabric may be related to an intermediate stage of chemical weathering and may be considered a transitional stage of plasma development. Such masepic fabric was also considered as an intermediate stage of weathering in the B_2t horizons of Alfisols from Belgium (Eswaran, 1967). Bennema et al (1970) also found that the masepic plasmic fabric was related to a moderate stage of chemical weathering in the B_2t horizons of Ultisols from Southern Brazil.

Those Spodosols with a lower degree of chemical weathering in their $B_{22}ir$ horizons (the Alliston, Tioga and Port-Cockburn profiles derived from calcic sands) exhibited ferri-organic ortstein fabrics which posses reddish-brown (5YR 5/4) coating materials in the Alliston and Tioga profiles dark reddish-brown (5YR 3/4) in the Port-Cockburn. Such colours and coatings indicate that from a relatively early stage of the formation of the spodic horizon, both the free iron and the organic matter are closely associated in the same portion of the profile and are not distinctly separated as components of the microfabric.

The $B_{22}ir$ horizons of the Wyevale and Hendrie profiles, which are more developed Spodosols, exhibit moderate mull and ferrous ortstein fabric related to a higher degree of chemical weathering than the organo-ferric ortsteins of the B_{22}ir horizon of the Monteagle profile. These mull ferrous and organo-ferric fabrics result from marked eluviation of soil material from the overlying horizons which accumulates as distinct cutanic deposits on coatings along skeleton grains in the s-matrix . It takes the form of partially-mixed humus material in Wyevale (5YR 3/4) and dominantly separated very red iron materials in the Hendrie profile (5R 4/4).

Using Brewer's terminology, skelsepic plasmic fabrics were found to dominate all the B_{22}ir horizons of the Spodosols studied. However, the terminology of Kubiena (1938) was found more useful in the differentiation of these plasma fabrics. It may be suggested that Kubiena's terms, having been evolved for the varied Spodosols of Europe, are more specific for Brewer's systems were first developed in Australia where Spodic horizons are less typical.

A further indicator of the degree of alteration of the B_{22}t horizons of the six Alfisol profiles was the ratio of quartz/chlorite. On the basis of the alteration sequences of clay minerals, Thorn and Droste (1958) found that the chlorite alters to vermiculite-chlorite, then to the partially-expandable mixed lattice mineral stage and finally to expandable vermiculite stage. Hence the ratio of quartz/chlorite may be used to express the stage that is reached in this sequence. The B_{22}t horizons of Huron, Haldimand and Ancaster profiles with mosepic and vosepic fabrics show the presence of vermiculite-chlorite with some vermiculite clay minerals resulting from the chlorite alteration. No chlorite remains in the B_{22}t horizons of the more-developed Guelph and Winona profiles which, it will be recalled exhibit masepic and insepic plasmic fabrics. However, chlorite is not present in the parent material of the Winona series, hence its insepic B horizon fabric cannot strictly be related to this criteria of weathering.

The tourmaline/pyroxene ratio has been used as an indicator of the mineral weathering stage in Spodosols (Reeder, 1961) and is herefurther related to the type of plasmic fabric of the soils studied. However, the B_{22}ir horizons of the Hendrie, Tioga and Monteagle profiles and their parent material lack pyroxene, hence the use of this ratio is very limited for Spodosols in Ontario and the narrow range of the SiO_2/R_2O_3 ratios in the spodic B horizons means that it is not a good substitute for it. Among the five spodic B horizons the least weathered materials show the weakest organization and development of plasma fabrics and relatively high tourmaline/pyroxene ratios.

On the basis of the above investigations and deductions, three stages of weathering intensity, relative to the type of plasmic fabrics, are proposed for both the B_2 horizons of Alfisols and Spodosols studied : i) initial stage - mosepic plasmic fabric in Alfisol and ferri-organic ortstein in Spodosol; ii) intermediate stage - masepic plasmic fabric in Alfisol and organo-ferric ortstein in Spodosol; iii) further stage of weathering - vosepic and/or insepic plasmic fabrics in Alfisol and moderate mull and/or ferrous ortstein fabrics in Spodosol.

Conclusions regarding soil porosity and soil microvoids in relation to developed fabric are very similar in that certain void patterns, sizes and forms characterise differing degrees of soil development. Three stages of pore development may be discerned in the B_{22}t horizons of Alfisols, while two stages may be presented for the B_{22}ir horizons of

Spodosols studied : i) initial stages show porosity with few, large (>75 u) macro meta-vughs and vesicles in Alfisols and > 75 u macro meta-compound packing voids in less-developed Spodosols; ii) intermediate stages show smaller, more frequent (> 30-75 u) ortho-meta-craze planar voids in Alfisols; iii) with progressive soil formation pore sizes are further decreased and frequence increased (< 30 u micro ortho-joint planar voids in developed Alfisols and 30-75 u meso meta-simple packing voids in developed spodic horizons). This is probably relatable to pore infilling by argilluviation (Alfisols) or pore blockage by bridging in the Spodosols.

Alfisol B_2t horizons were examined to find the relationship between their development as indicated by percentage of clay gained and their elementary structure as characterized by Kubiena (1938), Brewer (1964) and Beckman and Geyger (1967). The following conclusions may be drown : i) porphyropeptic-pectic fabrics coincided with the highest percentages of clay gained while porphyropeptic fabrics were related to lower percentages; ii) vosepic and insepic fabrics, with wide voids (> 75 u Ø), were related to high clay gains and the greatest degree of cutan development. Mosepic and masepic fabrics with narrow voids were related to lower clay increases. This narrowing of pores seems to inhibit or retard argilluviation at an early stage. However, no relationship was found between orthic pedological features and percentage of clay gained; iii) cracked-irregular jointed structures occur along with higher percentages of clay gained and heterogeneous assemblages of clay, while cracked regular jointed structure relates to a lower clay gain, possibly because such structures are derived from parent material with homogeneous clay. Therefore three stages of B_{22}t horizon development are proposed from this study :

i) an early stage with porphyropeptic-pectic fabrics (Kubiena), masepic or mosepic fabric with fine voids (Brewer), and cracked structures (Beckman) with some integrated pedological formations and fragmented structure with little-altered geological material clearly evident; ii) an intermediate stage, regular jointed structure (Beckman) with homogeneous or simple clay minerals; iii) an advanced stage with porphyropeptic fabric (Kubiena), insepic or vosepic plasmic fabric (Brewer) with large voids, and an irregular jointed structures (Beckman) with an heterogeneous clay mineral assemblage.

Conclusions concerning the relationship between the development of B_{22}ir horizons of the Spodosols using the silt/silt + fine sand ratio as an indicator, and the elementary structure using the terminologies of Kubiena (1938) and Beckman and Geyger (1967), are as follows : a) higher ratios of silt/silt + fine sand indicate a low degree of weathering, and correspond with chlamedomorphic fabrics, lower ratios are connected to mixtures of chlamedomorphic, intertextic and porphyropectic fabrics; b) higher ratio of silt/silt + fine sand were associated with simple packing voids, lower ratios link to packing voids; c) porous structures were dominant in the B_{22}ir horizons and tend to relate to higher ratios of silt/silt + fine sand.

It may be suggested that accumulation of mixed fine sand and silt, amorphous iron and humified organic matter would delay the development of the spodic B_{22}ir horizon. This confirms the proposals of Mackney (1961) and MacKeague et al (1967) in Spodosol profiles from southern England and the Atlantic provinces, respectively.

Conclusions as to the relationships between soil morphology, micromorphology and soil analysis in the C horizon of the twelve profiles in the light of the conventional view that such are only slightly affected by pedogenetic processes and lack properties diagnostic of A and B horizon though C horizons may include material modified by other processes such as gleyzation and cementation.

In the lower C horizons of the Alfisol profiles, silty loams associated with high degrees of chemical weathering exhibit silasepic fabrics, while clays and relatively little weathered silty loam parent materials possess argillasepic fabrics. The least-altered show silargillasepic fabrics. Sandy-loam materials under highly weathered sola (Ancaster series) have skelsepic plasmic fabrics. A progressive weathering sequence for the lower C horizon of the Alfisol profiles may thus be postulated : silargillasepic - silasepic - skelsepic. In the case of the Spodosol profiles, the relative uniformity of soil parent materials implies that no clear-cut variation of fabric should occur and, frequently, profile discontinuities caused albic and spodic horizons to develope in sands overlying other materials. In the Spodosols the least-altered soils are affected in matter of pore size by the nature and size of the sand in the parent material, though in the Alliston, Tioga and Hendrie profiles, subangular blocky structures and fragmented, crumb and porous microstructures respectively, were influenced by a mixture of humified organic matter, mobile iron and very fine mobile material as cementing material - the C horizon of the intensely-altered Hendrie being slightly gleyed. Such materials may stimulate aggregation in the C horizons.

In conclusion, three stages of elementary structure development, relative to soil composition may be proposed : i) an initial stage of irregular - and regular-jointed structure with an abundance of silt and/or clay material, the related compaction influence being very noticeable in smoothed macro-peds and stress cutans; ii) crumb and fragmented structures in mixed sand and silt material associated with the presence of organic matter, mobile iron and fine material - all stimulating soil aggregation; iii) final porous structure - abundance of coarse sand material and loss of finer or more easily mobilized components but with organic input reaching to a considerable depth.

Although the above relationships fit the studied soils, the relationships sequence is to be considered as tentative and needs more testing.

The last task of this thesis was to locate textural discontinuities in the profiles and examine the difficulties posed by their presence. Five of the twelve profiles studied exhibit large-magnitude changes of soil texture as well as associated micromorphological features. Changes in the relative proportion of plasma, voids and skeleton material were found to be a reliable indicator of such textural discontinuities.

Generalized conclusions for the two soil orders are : little developed Alfisols will show some or all of the following properties : dominance of mosepic fabric; joint planar voids and cracked microstructures in diagnostic B_{22}t horizons; an argillasepic fabric, planar voids and irregular jointed and/or fragmented structures in A horizons. Properties of more developed Alfisols are : dominance of insepic or vosepic, occasionally masepic fabrics; vughs or planar voids and fragmented or irregular-jointed, less frequently cracked structures in the B_{22}t horizons; an insepic, silasepic or argillasepic fabric with vughs, and crumb or spongy structures in the A horizon of such soils.

Regarding the Spodosols, little developed profiles exhibit dominance of ferric-organo fabrics (Kubiena), packing voids and porous structures in B_{22}t horizons. Silasepic, skelsepic and/or isotic fabrics with vughs and spongy or crumb structures dominate the A horizons of these soils. More developed Spodosols B_{22}ir horizons, exhibit organo-ferric or mull, or ferrous fabrics (Kubiena) with compound packing voids and porous structures, as in the Wyevale, Monteagle and Hendrie series. The A horizons of these soils show silasepic, insepic or isotic fabrics (Brewer) with vughs or simple packing voids and spongy and/or porous structures in thin sections.

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