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MICROPEDOLOGY OF A SEQUENCE OF SOILS IN THE TURTLE MOUNTAIN AREA

by

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ABSTRACT

Micropedological and some mineralogical studies were conducted on Orthic Dark Gray, Dark Gray Luvisol and Gleyed Gray Luvisol profiles. Descriptions and interpretations are given for the micromorphological features of the various horizons. The rearrangement of plasma constituents has been carried out by pedologic processes (eluviation and illuviation). The rearrangement has resulted in eluviated horizons which are plasma deficient and illuvial horizons which are plasma rich. The degree to which similar horizons in different profiles have developed is believed due to differences in drainage, topography and microclimate.

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INTRODUCTION

As a part of general pedology, microscopic investigation of the soil (micropedology), encompasses the study of shape and form (micromorphology), genesis, mineral identification, and general soil dynamics. Every soil feature in its microscopic realm has been a result of the life and environmental conditions of its habitat. It has been observed that soil micromorphology can be extremely varied but it is always typical of a habitat. This means that every soil type has a micromorphology associated with its genesis and that other soil types that happen to be off springs have microscopic fabrics that can be recognized as transformations of the main type (Kubiena, 1970, Chapter II). Thus, micromorphological studies have led to a much better understanding of the soil forming processes.

In the present investigation, micropedological studies were carried out on the various horizons of three soil profiles: Orthic Dark Gray, Dark Gray Luvisol and Gleyed Gray Luvisol. The main objectives of the investigation were:

1. to describe the micromorphological features,

2. to interpret these features with respect to the genesis of the soils, and

3. to give an indication of the weathering of the soil minerals in the various horizons.

LITERATURE REVIEW

The Significance of Micropedological Studies in Soil Science

As soil science has developed, the systematic description of soil profiles in the field and in the laboratory has become progressively more detailed. In the early days, the prime objective was to distinguish different kinds of profiles on the number and arrangement of recognizable horizons, which were described broadly in terms of color and texture. These descriptions were made more complete in later years by including structure, consistence and occurrence of detectable amounts of relatively soluble materials such as carbonates. As descriptions of soils were made more detailed, advancing technology allowed greater detailed descriptions by adapting petrographic geological techniques and methods.

According to Brewer (1960 a), there are four broad phases of pedological studies:

a) Characterization of the soils

Soils are essentially characterized by description and measurement of properties. Deficiencies in accuracy and completeness in descriptions have been shown up by the use of the petrographic approach. This is so because the scale of observation makes it possible to focus attention on the nature and distribution of pedological features, such as cutans, glaebules and pedotubules (defined in Appendix II), which comprise an important record of the genesis and history of soil materials and profiles. For example, clay skins (argillans) have long been observed in hand specimens, and are being used as criterion for classification; however, their internal structure and their relationships with voids and other constituents of the soil material could only be studied microscopically. Other pedological features can also be classified and interpreted on their relationship with voids and other constituents of the soil material. The highly organized, extremely heterogenous nature of the pedological features found in many soils has lead to false measurements. Such is the case where a soil chemist uses the usual methods of grinding and sieving before analysis, which reduces the soil material to a homogenous mass. The analysis on the ground sample averages the data for the whole soil, and provides inadequate information of the internal chemistry of the undisturbed ped interior. Clay mineralogists use the petrographic approach to get away from homogenizing the soil sample. Using this technique an accurate separation of the argillan can be obtained, and the x-ray analysis data can be made more meaningful. This enables the clay mineralogist to determine whether these accumulations are a new clay formation or clay normally found in the s-matrix but translocated in colloidal suspension and deposited elsewhere in the soil.

b) Study of soil genesis

Quantitative evaluations of soil formation can be carried out, providing uniformity of parent material has been established by conducting mineral analysis on the various horizons in a soil profile. The ratio of the percentage of some stable constituent in each horizon to that of the parent material is a measure of the volume change that has occurred in each horizon. Also, qualitative study of weathering can be carried out, but knowledge of properties and conditions of the minerals in the parent material must be known.

This is to be sure the features of weathering observed are due to soil formation. Observed differences in structure and fabric analyses of a horizon and that of its parent material is also a reflection of the effects of soil forming processes.

c) Classification

Structure and fabric descriptions are an integral part of the description and classification of soils. Each horizon within a soil profile has its own characteristic fabric. These fabric arrangements are important characteristics for soil classification, whether it is based on description or genesis.

d) Soil-plant relationships

Structure (size, shape, and arrangement of the constituents and voids) is very important in soil-plant relationships. Since plant roots tend to follow voids, the void pattern and the properties of their surfaces are most important. Clay mineral films may control the environment of plant roots by forming a membrane, coating a porous soil material and thus locking the bulk of the soil material from the activity of plant roots. This type of observations would be of interest to a fertility specialist, in that these coatings control the chemical environment of the roots. Soil physicists have found that these clay films influence such soil characteristics as porosity and water holding capacity.

Terminology

Up to a few years ago, there were only a few terms specific to the science of micropedology. Many observers recorded only those features which they had been trained to recognize and for which adequate terms existed. It was most inconvenient and inefficient to repeat long descriptions for specific features or arrangements.

Kubiena (1938, p. 125-128) made the first attempt to assign names to specific features and arrangements. With the publication of "Fabric and Mineral Analysis of Soils" (Brewer, 1964), additional new terms specific to features were described. This has made the interchange of morphological data among workers more efficient. Both Kubiena and Brewer, in describing and applying specific terms to distinguish micropedological features, drew quite heavily from geological petrographic studies.

Kubiena (1938, p. 129) pointed out that soil constituents can be divided into two broad groups on the basis of their physical and physiochemical properties: "fabric skeleton, of a soil consists mainly of residues of rock minerals and organisms not decomposable or which are only slowly decomposable; and fabric plasma, of a soil is the other group which is more easily moved, changed in composition and shape, and redeposited". The term fabric, which is a result of the dynamics of a soil system, was used to describe the arrangement of the constituents of a soil in relation to each other. Kubiena (1938, p. 129 and 154) also introduced the terms elementary fabric which described arrangement within individual aggregates, while fabric of higher order referred to the arrangement of aggregates. Some of the factors Kubiena (1938, p. 130) attributed to influencing fabric were degree of flocculation of the plasma, work of alkalis and acids, action of eluvial and illuvial processes, and wetting and drying.

Brewer and Sleeman (1960), using essentially the same micromorphological concepts, expanded on Kubiena's work. One of the major additions was the introduction of structure, which they defined as "the physical constitution of a soil material as expressed by the size, shape and arrangement of the solid particles and associated voids, including both the primary particles to form compound particles themselves". Thus, fabric is the element of structure which deals with arrangement.

According to Brewer (1960 a), the skeleton and plasma constituents become organized in various ways during soil formation. This organization can be expressed by the development of (1) peds, (2) pedological features, and (3) matrices, with their associated voids. These terms are defined as follows:

(1) Peds: Within the soil there are units which are referred to as peds. Such units have been described "as an individual natural soil aggregate consisting of a cluster of primary particles, and separated from adjoining peds by surfaces of weakness which are recognizable as natural voids or by the occurrence of cutans" (Sleeman, J.R., 1963). While there are many soils which exhibit peds, there are just as many that do not. Such soils are referred to as being apedal. These soils tend to be very friable and have a strongly interconnected arrangement of vughs.

(2) Pedological features: Within and on peds one finds pedological features which are a result of fractionation and reorganization of the mobile active plasma by soil forming processes. A pedological feature is defined as follows: "recognizable units within a soil material which are distinguishable from the enclosing material for any reason such as origin (deposition as an entity), differences in concentration of some fraction of the plasma (i.e. plasma concentration), or differences in arrangement of the constituents (fabric)",

(Brewer, 1964, p. 142). Pedological features are divided into two groups, orthic and inherited pedological features, the latter being features which are relicts of the parent rock or parent material. Examples of orthic pedological features are cutans, glaebules, and pedotubules which have been defined in Appendix II. The majority of these features are then described according to size, degree of separation and orientation.

(3) S-matrix: "of a soil material is the material within the simplest peds, or composing apedal soil materials, in which the pedological features occur; it consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations" (Brewer and Sleeman, 1960). This term is also used in sedimentary petrology in the same sense. These features are also described in terms of size and shape in Appendix III.

The majority of the terms used in this study were those proposed by Brewer (1964). A glossary of the terms is found in Appendix II.

Interpretation of Soil Micromorphological Data

The kinds of soil forming processes that have been operative can be inferred directly from structure and fabric analysis, providing one has sufficient background data, and experience in interpreting thin sections. The differences between the structure of the soil material of a particular soil horizon and that of the parent material has been recognized as a reflection of the effect of soil forming processes, and it is a matter of interpreting these observed changes in terms of the processes which caused them. With the aid of micromorphological data, a number of hypotheses have been put forward in recent years concerning the processes involved in formation of various kinds of plasmic fabrics and pedological features. According to Brewer (1960 a), these hypotheses, concerning genesis of profiles and processes of formation of particular fabric features, provide a basis for research projects needed to reproduce the observed phenomena.

A number of papers have been published on interpretations of prepared thin sections, and the following is a summary of the papers reviewed.

Fabrics of humified surface mineral horizons

Kubiena (1953) was one of the first to describe the humified microfabrics of the surface horizons. His descriptions have been widely used and quoted by other investigators. He described a number of different humus forms which occur in mineral surface horizons, three of which are defined as follows:

(1) Mull: "typical spongy fabric, characterized by complete decomposition and humification of the organic substance, lack of recognizable plant remains, good clay formation, and binding of finely dispersed humic substance by the clay substance".

(2) Moder: "loose mixture of broken through plant remains, mineral fragments and arthropod dropping".

(3) Mull-like moder: "loose mixture of mineral rich aggregates. In the aggregates little chemical decomposition of the mineral substance, relatively good humification (the humic substance acts mainly as binding substance), but also existence of slightly decomposed plant fragments with well preserved plant structure".

According to Kubiena the mull humus and mull-like moder humus form were found in the Chernozemic and Chernozemic-like soils. The mull-like moder humus form occurs where there is more pronounced eluviation taking place. The type of fabrics which contained the mull or mull-like moder humus form were referred to as a intertextic fabric and degraded intertextic, respectively; but they were referred to as a chernozemic type when found in a Chernozemic soil. Fabric containing similar humus forms were described by Pettapiece and Zwarich (1970), and St. Arnaud and Whiteside (1964). Dumanski and St. Arnaud (1966) described a fabric containing the mull-like moder humus form which they called a modified intertextic fabric. Barratt (1964, 1969) also devised a classification for humus forms found in organic-rich horizons. The classification was based entirely on micromorphological observations patterned after Kubiena's work.

Fabrics of eluviated mineral surface horizons

Eluviated horizons are found in certain Chernozemic, Solonetzic, Luvisolic, and Gleysolic soils. These horizons, found in the upper portion of a soil profile are characterized by a bleached appearance, low organic matter content, and a platy appearance in thin section. McMillan and Mitchell (1953) studied thin sections from the eluvial horizons, of a degraded Chernozem, a Solonetz, and a Gray Podzol (Gray Luvisol in present classification). Their study revealed a banded fabric in the eluvial horizons, with the presence of invasion amygdali (referred to as nodules in this study). Dumanski and St. Arnaud (1966) in their study of eluvial horizons noted an increasing occurrence of banded fabric, a decreasing occurrence of isoband, and a more pronounced and finer platy structure in soils grading from Chernozemic to Podzolic (Luvisolic in present classification). Banded fabric has been attributed to the physical action of ice lenses

(Pettapiece and Zwarich, 1970, and St. Arnaud and Whiteside, 1964), and to drying of soil from top down (Acton and St. Arnaud, 1963, and Kubiena, 1938, p. 193). Kubiena (1938, p. 192) was the first to describe the banded fabric.

Fabrics of illuvial mineral horizons

Illuvial B horizons are characterized by an accumulation of colloidal plasma which makes for a denser and a more compact fabric. This accumulation modifies the texture and fabric of the natural soil surfaces and gives rise to plasma concentrations (cutans). The degree of anisotropy, and the arrangement of the plasma domains, has been used by Brewer (1964) and others to classify these plasmic fabrics. Early researchers (Buol and Hole, 1959; Nettleton, *et al.*, 1969) referred to these accumulations as being clay skins, while other authors referred to them as encrusted clay (Frei and Cline, 1949) or optically oriented clay (Brewer, 1956; Minashina, 1958). From analysis carried out on these coatings by Buol and Hole (1959) and Beke (1964), it was observed that they contained considerable amounts of iron and organic matter in addition to the clay. With this information, plus the realization that these clay coatings could have different genesis and were associated with different soil entities (mineral grains and voids), led Brewer (1960 b) to introduce the term cutan.

In most instances, clay accumulations occur as thin coatings on the surface of mineral grains, around voids, and along conducting channels. These accumulations have been reported in many soils including Chernozemic (Acton and St. Arnaud, 1964; Pettapiece, 1964; Redmond and Omodt, 1964; St. Arnaud and Whiteside, 1964), Solonetzic

(Pawluk, 1969; Yarilova, 1964), Luvisolic (Cline, 1949; Frei and Cline, 1949; McCaleb, 1954; McKeague and Cann, 1969; Pettapiece, 1964; St. Arnaud and Whiteside, 1964; Thorp, et al., 1959), and Gleysolic (Acton and St. Arnaud, 1963; McKeague and Cann, 1969).

Several workers (Brewer, 1956; Frei and Cline, 1949; McCaleb, 1954; Minashina, 1958) have regarded these optically oriented clays as being indicative of the presence of illuvial clay. According to Frei and Cline (1949), the increase in clay content of B horizons could be accounted for in three ways:

(1) Clays may migrate in suspension in percolating water and become oriented by settling out under influence of surface tension.

(2) Synthesis of weathering products from A and B horizons into clay minerals.

(3) Removal of other constituents such as calcium carbonates from a B horizon may concentrate residual clay.

While agreeing with Frei and Cline, Buol and Hole (1959), Brewer (1956), and Minashina (1958) postulated that oriented clay could also be formed by mechanical pressure.

Optically oriented clays have been produced by several workers (Bartelli and Odell, 1960; Brewer and Haldane, 1956; Polyakov and Florinsky, 1968; Thorp, et al., 1957) by passing clay suspensions through columns of sand. The laboratory studies of Brewer and Haldane (1956) showed that the type of cation saturation of clay material did not affect the degree of orientation of the clay particles, but that silt size particles tend to disrupt clay orientation. Thorp, et al. (1957) demonstrated movement of fine clay from leaching columns to effluent water and the deposition of clay in lower layers of the column.

According to Brewer (1960) "the occurrence of cutans will also have a considerable effect on plant growth, not only because of their effect on the course of soil formation, but more immediately because they affect the environments of the plant roots". In studying root soil relationships, one finds that plant roots are frequently confined to ped faces and channels which are coated with thick illuviation cutans composed of clay minerals. Soileau, _et al_. (1964) found that while the cutans tended to stabilize the soil aggregates, they restricted plant growth and potassium uptake.

Mineral Analysis

Minerals at the time of their formation, presumably are at equilibrium with their environment, and therefore stable. When these minerals are disturbed and thrust into a different environment, many of these minerals become unstable and undergo changes. Such changes do occur in soils and sedimentary deposits. Mineral counts have been used to determine amount of weathering that has taken place in a profile and to determine similarity of soil parent materials.

Petrographic mineral analysis of soil materials depend on separation and concentration of mineral species in the medium, fine and very fine sand. In most instances, one separation is made, resulting in two mineral fractions, "light", having a specific gravity less than 2.89, and "heavy", with specific gravity greater than 2.89. The light mineral fraction of soils consists mainly of quartz and feldspars, and accounts for about 95 per cent of the particular size separate. Although the heavy mineral fraction of a soil accounts for only 2 to 3 per cent of the size separate, it contains a wide variety of minerals such as amphiboles, garnets, pyroxenes, iron oxides, zircon epidote, olivine, tourmaline and others. Many of the heavy minerals are very resistant to chemical weathering.

Goldich (Pettijohn, 1957, p. 503), as a result of quantitative studies on several soil profiles, arranged the common rock making minerals into the following mineral stability series:

	Calcic plagioclase
Olivine	Calcic-alkalic plagioclase
Augite	Alkalic-calcic plagioclase
Biotite	Alkalic plagioclase
Potash feldspar	
Muscovite	
Quartz	

↓ increasing stability

One can infer from the mineral stability series that the more basic a mineral the more unstable it is. Quartz and potash feldspars would be the most stable, and the alkalic plagioclase such as albite would be moderately stable, whereas the calcic plagioclases, bytownite and labradorite would be relatively unstable. This inference was strengthened by Graham's (1949) study in which he found the more calcic a plagioclase feldspar, the higher its weathering rate. Cann and Whiteside (1955) found that potash feldspars showed a net gain in the profile, while plagioclases showed a net loss, and that plagioclase losses decreased downward in the profile. This suggested that orthoclase feldspars were as resistant to weathering as quartz grains. A study of relative proportions of light or heavy mineral species of different stability could give a qualitative estimation of weathering of surface horizons were compared to the parent material.

The origin of any sedimentary deposit is reflected in the mineral suite present, particularly the heavy mineral suite. The heavy minerals include some species of highly resistant character (Carver, 1971, p. 459; Pettijohn, 1957, p. 504) such as rutile, zircon, tourmaline garnet and others which are capable of surviving more than one cycle of weathering, and therefore, remain in constant proportions in a profile for long periods of time. Since heavy minerals are found in relatively small quantities, variations in species within a certain size separate throughout a profile can be readily ascertained. These variations are used in determining similarity of parent material within a profile and between profiles. Sawhney, et al. (1962), Seale (1956), and Yassoglou and Whiteside (1960) used heavy mineral studies to determine similarity of parent materials. A study carried out by Marshall and Haseman (1942) on the total heavy minerals in a Grundy silt loam revealed that mineral breakdown was most severe in upper 20 inches of the profile and fell off with increasing depth.

Technology

Thin section preparation

According to Kubiena (1938, p. 70), as early as 1904 Delage and Lagatu attempted to prepare thin sections of crushed soil by adding hardening substances to the soil. Day (1948) quoted Pigulevsky's study of 1914, in which soil clods were impregnated with paraffin wax and napthalene so that photo-micrographs of soil structures could be made from the thin sections. Kubiena (1938, p. 72), in 1923, developed a method for impregnating friable materials without destroying the natural fabric. He carried out experiments using bakelite, Canada balsam and kollolith, and found kollolith to be the most suitable impregnating material. The main problem encountered using bakelite, Canada balsam, and kollolith was that the procedures required prolonged heating with the danger of boiling the resin and disrupting the specimen. Volk and Harper (1939) found bakelite varnish number 1305 to be the best impregnating agent.

Bourbeau and Berger (1947) introduced the first use of synthetic resin, Castolite, which has since been used by many investigators. Bartelli and Odell (1960), Buol and Fadness (1961), McMillan and Mitchell (1953), and Pettapiece and Zwarich (1970), used Castolite as an impregnating agent quite successfully, but all used differing proportions of Castolite to styrene in their procedures. In all cases where Castolite was used, a hardener, cumene peroxide, was added to aid in polymerization of the Castolite. Curing time for Castolite varies from 12 hours at 100°C (Buol and Fadness, 1961), to five to seven days at room temperature followed by 30 minutes at 82°C (McMillan and Mitchell, 1953).

Yarilova (1963) stated in his paper that Atemueller in Germany had good success using Vestopol H as an impregnating agent. Gile (1967) used Laminac Resin and Lupersol DDM as a hardening agent when impregnating sandy to clayey soils. He concluded that the procedure was successful on calcareous and noncalcareous soils. Innes and Pluth (1969), in their study used Scotchcast No. 3 to get complete impregnation of dense blocks. The advantages in using this resin was its simple preparation, low viscosity, short polymerization period, and high thermal stability. Some studies (Mackenzie and Dawson, 1961) have been carried out using Carbowax to impregnate moist or wet soils. These studies have been successful as far as the impregnation is concerned, because Carbowax melts at 55°C and is readily soluble in water in all proportions. Cutting and grinding of samples impregnated with Carbowax present some problems because of the material's softness.

Many investigators (Buol and Fadness, 1961; Guertin and Bourbeau, 1971; Innes and Pluth, 1970; Pettapiece, 1964) using different resins and procedures, found that impregnation was more complete if the samples were evacuated prior to and during the impregnation procedure.

Mounting and grinding techniques have not changed much over the years and have remained the same essentially. Kerosene has been found to be the best cooling, and lubricating material during the grinding procedure. Water or any other polar liquids tend to disperse and swell clay mineral grains. Some investigators (Brewer, 1962; Guertin and Bourbeau, 1971) have used dry grinding with varying degrees of success.

Sections of appropriate thickness are cut from the impregnated sample and trimmed to fit on a glass slide. In recent years, it has been found that grinding the side of the section to be afixed to the slide resulted in a better bond between the section and the slide. Lakeside 70 and Canada balsam have been used in the past to glue the soil section to the glass slide. More recently, epoxy has been used because of its better bonding properties. Soil sections, once glued to the slide, are then ground using Alundum or Silicon Carbide grinding compounds, to a thickness of 30 to 50 microns as judged by the interference colors of certain minerals. The final grinding using diamond pastes or an oxide is usually done on glass, wood or on a lapidary wheel using different types of cloth or paper. Once the desired soil thickness on the slide is obtained, the complete slide is thoroughly cleaned, and a cover slip is affixed using Canada balsam or Caedax. More recently, Caedax has been used mainly for the reason that it can be redissolved using xylene and also because it does not darken with age as does Canada balsam. Cover slips attached with Caedax may also be removed, and a polished surface can be imparted to the section if microprobe work is required.

Mineral mounts

Petrographic mineral analyses are preceded by specific gravity separations. Specific gravity separations are carried out using either bromoform (specific gravity 2.89), tetrabromethane (specific gravity 2.90), or other heavy liquids, or a mixture of the heavy liquids to arrive at a desired specific gravity. The most common procedures used are those of Jackson (1956, Chapter 10), or Milner (1962, Chapter 3).

A variety of resins are available for permanent light mineral grain mounts. Canada balsam (n 1.54) and Caedax (n 1.55) seem to be the most widely used. Other low index resins are kollolith (n 1.54), lakeside 70 (n 1.54), and permount (n 1.53). For heavy minerals it is generally preferable to use a resin of high refractive index to help facilitate heavy mineral identification. Resins such as piperine (n 1.68), hyrax (1.71), and Aroclor 4456 (n 1.66) have been used for heavy mineral mounts. For temporary mounts of heavy or light minerals, different immersion oils can be used.

Light mineral identification can be carried out by determining refractive indices or by chemical staining. The advantage of chemical staining over the determination by refractive indices is the rapidity of identification and counting. A number of methods (Gross and Moran, 1970; Jackson, 1956, p. 504; Reeder and McAllister, 1957) for chemical staining have been used. Before staining the grains are etched in hydrofluoric acid (Reeder and McAllister, 1957) for two minutes or in its fumes (Gross and Moran, 1970; Jackson, 1956) for ten minutes. After the treatment with hydrofluoric acid, all the investigators immersed the mineral grains in a concentrated sodium cobaltinitrite solution to stain the potash feldspars yellow. Each investigator used a different solution to stain the plagioclase feldspars. Reeder and McAllister (1957) immersed the grains in a buffered hematein solution to stain the plagioclase feldspars purple, while Jackson (1956) immersed the grains in a one percent malachite green dye solution staining the plagioclase feldspars green to greenish-blue, and Gross and Moran (1970) immersed the grains in a one percent solution of amaranth red staining all plagioclase feldspars a bright red. The depth of color of the plagioclase feldspars in all the staining methods became successively lighter with the less calcic feldspars. Quartz remains unchanged.

METHODS AND MATERIALS

Sampling

Soil pits, 1 meter wide, 1.2 meters long, and 1.5 meters deep were dug at selected sample sites. A number of soil peds from each horizon were taken and wrapped in Saran wrap, with the orientation being marked on the Saran wrap. The wrapped peds were placed in cartons and packed in plastic bags to prevent drying, and disturbing the samples. Two monoliths from each site were also taken, one for obtaining soil macromorphological descriptions and the bulk samples for chemical and physical analysis, and the other for mounting as a permanent record of the profiles.

Soil Macromorphological Descriptions

The soils used in this study are well drained and imperfectly drained members, developed on strongly calcareous glacial till of mixed limestone, shale and granitic rock. The texture is dominantly a loam and the topography is undulating. The elevation of the area is between 2025 and 2050 feet above sea level. The three profiles were sampled from a single west facing slope, with the Orthic Dark Gray profile being approximately ten feet higher than the Gleyed Gray Luvisol. The Dark Gray Luvisol was slightly lower down the slope, than the Orthic Dark Gray. The Dark Gray and Dark Gray Luvisol profile on the gentle slope were under aspen and hazelnut cover predominantly, while the Gleyed Gray Luvisol in the depression had fewer aspen present and the presence of willows and grasses were noted.

The field descriptions were based on "The System of Soil Classification for Canada" (Canada Department of Agriculture, 1970). Photographs of representative profiles are shown in Plate 7 in Appendix I.

1. Orthic Dark Gray

Location:	Southeast 1/4 of section 9, township 2, range 21 west
Vegetation:	Aspen and balsam poplar, hazelnut, odd grasses
Drainage:	Well drained to rapidly well drained
Parent Material:	Strongly calcareous regional till
Topography:	Undulating to gently undulating

Horizon	Depth-inches	Description
L-F-H	1 - 0	Leaf litter
Ah	0 - 2	Black (10YR 2/1, moist), dark grayish brown (10YR 4/2, dry), loam; moderate, medium to fine subangular blocky; very friable; moist; clear, wavy boundary; pH 6.3.
Ahe	2 - 6	Very dark grayish brown (10YR 3/2, moist), grayish brown (10YR 5/2, dry), clay loam; moderate, medium granular; friable; moist; clear, wavy boundary; pH 6.5.
Bt_1	6 - 11	Dark brown (10YR 3/3, moist), brown (10YR 5/3, dry), clay loam; moderate, fine subangular blocky; friable; moist; clear, wavy boundary; pH 6.7.
Bt_2	11 - 14	Dark brown (10YR 3/3, moist), brown (10YR 4.5/3, dry), clay loam; moderate, coarse blocky to moderate medium blocky; firm; moist; clear, wavy boundary; pH 6.9.
BCk	14 - 20	Dark brown (10YR 3/3, moist), brown to pale brown (10YR 5.5/3, dry), clay loam; moderate coarse blocky to moderate medium to fine blocky; firm; moist; gradual, irregular boundary; moderately calcareous; pH 7.6.
Ck	20 - 29	Brown (10YR 4.5/3, moist), brown to pale brown (10YR 5.5/3, dry), clay loam; strong medium subangular blocky; friable; moist; gradual, irregular boundary; moderately calcareous; pH 7.7.

Horizon	Depth-inches	Description
Cca_1	29 - 34	Dark yellowish brown to yellowish brown (10YR 4.5/4, moist), pale brown (10YR 6/3, dry), silt loam; moderate coarse subangular blocky to moderate medium subangular blocky; friable; moist; strongly calcareous; pH 7.7.
Cca_2	34 - 38	Dark yellowish brown to yellowish brown (10YR 4.5/4, moist), very pale brown (10YR 7/3, dry), carbonates (10YR 8/1, dry), clay loam; moderately coarse subangular blocky to moderate medium subangular blocky; friable; moist; gradual, irregular boundary; strongly calcareous; pH 7.9.
Ck_2	38 - 50	Brown (10YR 4.5/3, moist), pale brown (10YR 6/3, dry), loam; strong coarse subangular blocky to strong medium subangular blocky; friable; moist; moderately calcareous; pH 7.9.

2. Dark Gray Luvisol

Location:	Southeast 1/4 of section 9, township 2, range 21 west
Vegetation:	Aspen and balsam poplar, willow, wild rose, and hazelnuts
Drainage:	Well drained to moderately well drained
Parent Material:	Strongly calcareous regional till
Topography:	Undulating

Horizon	Depth-inches	Description
L-F-H	2 - 0	
Ahe	0 - 2 1/2	Black to dark grayish brown (10YR 2/1 - 4/2, moist), dark grayish brown to grayish brown (10YR 4.5/2, dry), loam; weak, medium subangular blocky to weak fine platy; very friable; moist; clear, wavy boundary; pH 6.1.

Horizon	Depth-inches	Description
Ae	2 1/2 - 5 1/2	Brown (10YR 4.5/3, moist), light brownish gray (10YR 6/2, dry), fine sandy loam; weak, medium platy to weak fine platy; very friable; moist; clear, smooth boundary; pH 6.3.
BA	5 1/2 - 7 1/2	Brown (10YR 4.5/3, moist), brown to pale brown (10YR 5.5/3, dry), loam; weak, fine blocky to weak fine granular; very friable; moist; clear, wavy boundary; pH 6.3.
Bt_1	7 1/2 - 12	Very dark grayish brown to dark grayish brown (10YR 3.5/2, moist), brown to pale brown (10YR 5.5/3, dry), clay loam; strong fine blocky; firm; moist; clear, wavy boundary; pH 5.9.
Bt_2	12 - 15	Dark grayish brown (10YR 4/2, moist), brown to pale brown (10YR 5.5/3, dry), clay loam; moderate medium blocky to moderate fine blocky; firm; moist; clear, wavy boundary; pH 6.0.
Bt_3	15 - 19	Very dark grayish brown exped (10YR 3/2, moist), dark grayish brown inped (10YR 4/2, moist), brown to pale brown (10YR 5/3 - 5.5/3, dry), clay loam; moderate medium blocky to moderate fine blocky; firm; moist; clear, wavy boundary; pH 6.2.
BCk	19 - 23	Very dark grayish brown exped (10YR 3/2, moist), brown inped (10YR 5/3, moist), brown to pale brown (10YR 5.5/3 - 6/3, dry), clay loam; moderate medium blocky to moderate fine blocky; firm; moist; gradual, irregular boundary; weakly calcareous; pH 6.9.
Ck_1	23 - 27	Very dark grayish brown to dark brown exped (10YR 3/2 - 3/3, moist), yellowish brown inped (10YR 5/4, moist), pale brown (10YR 6/3, dry), clay loam; strong medium subangular blocky to strong fine subangular blocky; friable; moist; gradual, irregular boundary; strongly calcareous; pH 7.6.
Ck_2	27 - 31	Dark brown (10YR 3/3, moist), pale brown (10YR 6/3, dry), clay loam; strong medium subangular blocky to strong fine subangular blocky; friable; moist; strongly calcareous; pH 7.7. (odd fracture plane where some clay goes down, not as much carbonates present in streaks).

Horizon	Depth-inches	Description
Ck$_3$	31 - 58	Yellowish brown (10YR 5/4, moist), pale brown (10YR 6/3, dry), white carbonates (10YR 8/1, moist), loam; moderately coarse platy to moderately fine subangular blocky; friable; moist; strongly calcareous; pH 7.8. (Carbonates found plastered along fracture planes and also follow old root channels. At least 10 per cent old root channels contain carbonates).

3. Gleyed Gray Luvisol

Location: Southeast 1/4 of section 9, township 2, range 21 west

Vegetation: Aspen and balsam poplar, willow, grasses, odd wild rose

Drainage: Imperfect to poorly drained

Parent Material: Strongly calcareous regional till

Topography: Undulating

Horizon	Depth-inches	Description
L-H	2 - 0	
Ahe	0 - 1/2	Brown (10YR 4.5/3, moist), pale brown (10YR 6/3, dry), loam; moderate fine platy; very friable; moist; abrupt, smooth boundary.
Ae$_1$	1/2 - 2 1/2	Light brownish gray to light gray (10YR 6.5/2, moist), light gray (10YR 6.5/1, dry), silt loam; moderately fine platy; very friable; moist; pH 5.7.
Ae$_2$	2 1/2 - 4 1/2	Light brownish gray to light gray (10YR 6.5/2, moist), light gray (10YR 6.5/1, dry), loam; moderately fine platy; very friable; moist; pH 5.7.
Ae$_3$	4 1/2 - 7	Light brownish gray to light gray (10YR 6.5/2, moist), light gray (10YR 6.5/1, dry), loam; weak to moderate medium platy; very friable; moist; clear, wavy boundary; pH 5.5.

Horizon	Depth-inches	Description
AB	7 - 9	Light gray exped (10YR 6.5/1, moist), very dark grayish brown inped (10YR 3/2, moist), light gray exped (10YR 7/1, dry), dark grayish brown to grayish brown inped (10YR 4.5/2, dry), sandy clay loam; moderate medium prismatic to moderate medium subangular blocky; friable; moist; clear, wavy boundary; pH 5.8.
BA	9 - 13 1/2	Light gray exped (10YR 6.5/1, moist), dark gray brown to gray brown inped (10YR 4.5/2, moist), light gray exped (10YR 7/1, dry), grayish brown to light grayish brown inped (10YR 5.5/2, dry), sandy loam; moderate medium subangular blocky; very friable; moist; clear, wavy boundary; pH 5.8.
Bt$_1$	13 1/2 - 16	Very dark grayish brown to gray brown inped (10YR 3.5/2, moist), very dark gray brown exped (10YR 3/2, moist), dark grayish brown to gray brown inped (10YR 4.5/2, dry), gray to light gray exped (10YR 6/1, dry), sandy clay loam; moderate medium blocky; firm; moist; clear, wavy boundary; pH 5.7.
Bt$_2$	16 - 23	Very dark grayish brown inped (10YR 3/2, moist), very dark gray exped (10YR 3/1, moist), gray inped (10YR 5/1, dry), dark grayish brown exped (10YR 4/2, dry), sandy clay loam; strong medium to coarse blocky; firm to very firm; moist; clear, wavy boundary; pH 5.7.
Bt$_3$	23 - 28	Very dark grayish brown to dark grayish brown inped (10YR 3.5/2, moist), black exped (10YR 2/1, moist), brown inped (10YR 5/3, dry), very dark gray exped (10YR 3/1, dry), clay loam; strong medium blocky to strong fine blocky; very firm; moist; clear, wavy boundary; pH 6.2.
Bt$_4$	28 - 31	Dark gray inped (10YR 4/1, moist), black exped (10YR 2/1, moist), brown to pale brown inped (10YR 5.5/3, dry), very dark gray exped (10YR 3/1, dry), clay loam; strong medium blocky to strong fine blocky; very firm; moist; clear, wavy boundary; pH 6.8. (These peds are not permeated with coatings right through as in Bt$_1$, Bt$_2$, and Bt$_3$. Coatings tend to follow old root channels).

Horizon	Depth-inches	Description
BCk	31 - 36	Dark brown to brown inped (10YR 4/3, moist), black exped (10YR 2/1, moist), pale brown inped (10YR 6/3, dry), very dark gray to dark gray exped (10YR 3.5/1, dry), overall crushed brown to pale brown (10YR 5.5/3, dry), loam; moderate coarse blocky; firm to very firm; moist; clear, wavy boundary; moderately calcareous; pH 7.6.
BCkg	36 - 44	Dark brown inped (10YR 4/3, moist), black exped (10YR 2/1, moist), pale brown to very pale brown inped (10YR 6.5/3, dry), very dark gray to dark gray exped (10YR 3.5/1, dry), overall crushed pale brown (10YR 6/3, dry), loam; moderate coarse blocky; firm to very firm; moist; gradual, irregular boundary; moderately calcareous; pH 7.7.
Ckg	44 - 60	Yellowish brown (10YR 5/4, moist), pale brown (10YR 6/3, dry), white carbonated (10YR 8/1, dry), loam; moderately coarse platy to moderately fine subangular blocky; friable; moist; strongly calcareous; pH 7.9.

Thin Section Preparation

During this study, initial investigations were carried out using Castolite and Scotchcast No. 3 as the impregnating plastics. Various proportions of plastic, thinner and catalyst were used as impregnating mixtures. Several procedures were also attempted to obtain well impregnated samples of soils.

Castolite was abandoned as an impregnating medium because of its poor impregnation of the sample. Castolite impregnated samples also had a tendency to crack on curing. Good impregnation of all soil samples was obtained by using Scotchcast No. 3. The plastic Scotchcast No. 3 had additional advantages, as it was simple to prepare, had a low viscosity and a short polymerization period.

Samples the approximate size, of which were 38 x 25 x 25 mm, were cut from air dried soil clods. The samples were then placed in seven-ounce plastic lined "Dixie" hot drink cups; the horizon and orientation were marked on the cups and the sample and cup was placed in an air draft oven at 90°C, overnight. The samples and cups were then placed in a vacuum dessicator which was sitting in a water bath at a temperature of 90°C. Evacuation of the dessicator to 10-20 mm of mercury was carried out slowly. Fifty grams of epoxy resin was prepared by mixing the components of Scotchcast No. 3 in the ratio of two parts A to three parts B by weight, in a suitable container. This mixture was then heated in a water bath to a temperature of 90°C, mixing repeatedly. The mixture was then transferred immediately to the heated separatory funnel which had been adapted to the dessicator. Epoxy resin was added slowly to the samples, with care being taken to make sure resin did not strike the clod directly. Addition of resin continued until the sample was completely covered. Samples remained under vacuum until impregnation appeared complete (about one hour), as was evidenced by the absence of bubbling. The vacuum was released slowly, and the samples were removed and placed in an air draft oven at 105°C and cured for a minimum of twelve hours. After cooling, the samples were ready for cutting and grinding.

Using a diamond saw, sections of desired orientation, and about 4 mm thick were cut from the impregnated soil samples. The sections were then trimmed to a 25 x 35 mm size. The smoother side of the section was ground as smooth as possible by hand using Silicon Carbide No. 600 grit grinding compound. It was then washed ultrasonically in kerosene, dried and buffed with a cloth. Kerosene was used in conjunction with all cutting and grinding procedures for cooling and lubrication.

A 27 x 41 x 1 mm glass slide, and the soil section were placed on a hot plate and prewarmed to 70°C. Equal lengths of epoxi-patch hardner and resin were pressed out of the tubes onto a clean piece of paper, and mixed thoroughly. Using a glass slide, the epoxy glue was applied to the surface of the glass slide and to the ground surface of the soil section. Then the ground soil section was placed on the glass slide and all the air bubbles were worked out from between the ground soil section and the glass slide. Two "Bulldog" paper clamps were used to hold the soil section firmly in place on the glass slide. The epoxy was allowed to dry overnight at room temperature (21°C). After drying, each slide was labelled as to which horizon and orientation it represented. Labelling was accomplished using a diamond stylus.

With the soil section affixed to the glass slide, there still remained an excess of soil material. The soil thin section was placed in the trim saw and set so that only 1 mm of soil material would be left adhering to the glass slide.

Coarse grinding was done on a lapidary using Silicon Carbide 220 grit grinding compound until a thickness of .10 mm was attained, taking care to keep the slide level. All thicknesses were estimated by the interference color of quartz. The section was then ultrasonically washed in kerosene making sure that all coarse grinding compound was removed.

Final grinding was done by hand on a double diamond glass plate using Aluminum Oxide 600 grit grinding compound. The glass plate was placed in an illuminated table as outlined by Rudeforth (1962). This enabled easier and more frequent checks on thin section thickness which were made until the section was 0.03 to 0.04 mm thick. Upon completion of grinding, the soil thin section was ultrasonically washed, dried, and then buffed.

A small drop of Caedax was placed centrally on the cold sections. An appropriate cover slip was gently placed on top of it. The whole assembly was placed on the hot plate, prewarmed to 55°C, and allowed to sit until the Caedax had reached all corners of the cover slip. Cover slips were then pressed gently to force out the bubbles, and left on the hot plate for about one hour. The soil thin section was cooled and any excess mounting medium wiped off with a xylene dampened cloth. The thin section was now completed and ready for petrographic examination.

A minimum of two thin sections, one oriented parallel and one perpendicular to the ground surface, were made from each horizon.

Mineral Grain Preparation and Mounting

Sample preparation

The samples for heavy mineral analysis were prepared according to the methods proposed by Jackson (1956). Soil samples were ground and passed through a 2 mm sieve. Carbonates were destroyed using sodium acetate buffered at pH 5. Hydrogen peroxide was used to destroy organic matter. Iron oxides were removed using sodium dithionate and sodium citrate.

The sand fraction was collected on a 300 mesh sieve, washed with acetone, and dried. The medium, fine and very fine sands were separated using a set of screens based on U.S.D.A. size limits.

Heavy mineral separation and mounting

The entire medium, fine and very fine sand fractions obtained from the particle size separations, were separated again into light and heavy mineral fractions using bromoform as described by Milner (1962, p. 101). The separates were dried, weighed and heavy minerals calculated as a percent of the total weight of the particular particle size fraction.

The heavy minerals were mounted in Aroclor 4456. The required amount of Aroclor was placed on a microscope slide which had been placed on a hot plate set at 120°C (250°F). After the Aroclor had melted, approximately 300 mineral grains were added and stirred to give a uniform distribution. Then one edge of the cover slip was put down, and gradually lowered onto the cement. Bubbles and excess cement were forced out using gentle pressure. The slide was labelled and ready for examination.

Light mineral staining and mounting

In order to facilitate the counting of the light minerals, the mineral grains were stained according to a procedure set forth by Reeder and McAllister (1957).

The light minerals, placed in a polyethylene container, were treated by direct contact with 49 percent hydrofluoric acid. After a period of 1 1/2 minutes the acid was diluted and siphoned off. The dispersed mineral grain layer was covered with a concentrated sodium cobaltinitrite solution for a period of 1 1/2 minutes. The samples were then washed by dilution and siphoning; a 2:1 hematein buffer mixture was added, swirled for two minutes and allowed to stand for eight minutes. The grains were then washed free of the solution with 95 percent ethanol and finally washed twice with acetone and dried.

A few drops of Caedax were placed on a glass microscope slide on a hot plate set at 70°C. Approximately 300 grains were stirred into the Caedax. A cover glass was affixed as previously described in the heavy mineral mounting, and the slide was labelled. Then the slide was placed in air draft oven set at 70°C for eight hours.

Photomicrography

A Zeiss Photomicroscope equipped with polarizing attachment and a built-in 35 mm camera was used. This unit featured an automatic exposure device, in which the self setting shutter of the camera was designed for automatic exposure control from approximately one half second and upward. Kodak type B Ektachrome film was used for color slides and Panatomic X for black and white.

RESULTS AND DISCUSSION

Discussion of Mineral Grain Studies

Light minerals

The light minerals, with a specific gravity of less than 2.89, constituted from 96.0 to 98.2 percent (by weight) of the very fine, fine, and medium sand fractions in the horizons examined. Most of the soils have a lower light mineral content in surface horizons than in the parent material (Table IV, Appendix I).

Quartz, which is a very stable mineral, shows a higher percentage of grains in the surface horizons which have been most affected by weathering (Table V, Appendix I). Quartz is also more dominant in the finer sand fractions. Potassium feldspars tended to show a slight net gain in all three profiles, compared to the plagioclase which showed a net loss, and the plagioclase losses decreased with profile depth. Cann and Whiteside (1955) reported similar findings. This shows quartz to be most stable, while potassium feldspars are moderately stable. The plagioclases are the least stable of the light minerals examined. Strongest trends showing stability and instability were observed in the fine sand fraction. These results indicate that chemical weathering is taking place and is more pronounced in the strongly degraded Dark Gray Luvisol and Gleyed Gray Luvisol profiles.

Heavy minerals

Petrographic study of the heavy mineral suite, contained in the fine sand of the C horizons of three profiles examined, revealed a wide range of minerals. Amphiboles, garnets, iron oxides, pyroxenes, epidote, olivine, staurolite and topaz were the dominant minerals (Table VI, Appendix I). Zircon, tourmaline, rutile and others were few in number and were not present in some cases. The percentages of heavy minerals and the heavy mineral suite in the C horizons of the three profiles were very similar.

On the basis of the heavy mineral data and the particle size distributions (Table I, II, and III, Appendix I) in the C horizons, one can conclude that the parent materials of the three profiles were essentially similar.

Micromorphological Profile Descriptions

The prepared thin sections were examined using a polarizing microscope. Sections were defined by the following characteristics: plasmic fabric, structure, porosity (voidal space in peds) and type of voids found inped and exped, pedological features present in that horizon, basic fabric, and elementary fabric. The defined size and shape classes were used where applicable (Appendix III). The terminology used to describe these features follows that proposed by Brewer (1964), and are defined in the Glossary (Appendix II). Additional fabric descriptions of other authors are supplied for A horizons, and are referenced when used. Percentage figures are estimations of the area of the thin section covered by any specific feature.

1. Orthic Dark Gray

Ah:	0-2 inches (Plate I, photograph 1)	
	Plasmic Fabric:	weakly insepic porphyroskelic fabric intertextic fabric, chernozemic type (mull humus form) (Kubiena, 1938)
	Structure:	moderately expressed, coarse to very coarse granular
	Porosity:	total 25-30 per cent
	a) inped:	few, medium orthovughs, metavughs and channels
	b) exped:	medium to coarse dentritic channeling

Pedological Features:

1. Embedded grain organo - argillans: extremely fine, discontinuous, moderately separated and oriented
2. Faecal pellets: many, medium to coarse, moderately separated, exhibiting a skel-insepic fabric
3. Fungal hyphae
4. Organic fragments: unrecognizable decomposed dark brown to black

Basic Fabric:	strongly vughy, weakly insepic fabric
Elementary Fabric:	plasmic (organic) strongly vughy, weakly insepic fabric

Ahe: 2-6 inches (Plate I, photograph 2)

Plasmic Fabric: skel-insepic porphyroskelic fabric
degraded intertextic fabric (mull-like moder humus form) (Kubiena, 1938)

Structure: coarse to very coarse granular

Porosity: total 20 per cent

a) inped: medium orthovughs

b) exped: medium interconnected, irregular channels

Pedological Features:

1. Embedded grain argillans: extremely fine, moderately separated and oriented
2. Void neo-argillans: extremely fine to very fine, discontinuous, moderately separated and oriented
3. Ped neo-argillans: extremely fine, discontinuous, moderately separated, and oriented
4. Organic fragments: odd unrecognizable decomposed dark brown to black gobular masses

Basic Fabric: vughy insepic fabric

Elementary Fabric: plasmic (organic) vughy insepic fabric

Bt_1: 6-11 inches

Plasmic Fabric: weak skel-vo-lattisepic porphyroskelic fabric

Structure: moderate, very coarse, subangular blocky

Porosity: total 15 per cent

a) inped: medium to fine metavughs, mainly with odd medium channels

b) exped: medium dentritic channels with odd, medium connected metavughs

Pedological Features:

1. Embedded grain argillans: extremely fine, moderately separated and oriented
2. Void argillans: very fine, moderately separated, and oriented
3. Ped neo-argillans: very fine discontinuous, moderately separated, and oriented
4. Nodules: iron and manganese, few, fine to medium, moderately separated and unoriented

Basic Fabric: vughy weak skel-vo-lattisepic fabric

Elementary Fabric: neo-cutanic (neo-argillans) vughy weak skel-vo-lattisepic

Bt_2: 11-14 inches

Plasmic Fabric: skel-insepic porphyroskelic fabric

Structure: moderate, very coarse, subangular blocky

Porosity: as per Bt_1

Pedological Features:

1. Embedded grain argillan: extremely fine, discontinuous, moderately to strongly separated, and oriented
2. Void argillans: very fine, moderately to strongly separated, and oriented
3. Ped argillans: very fine, odd fine, moderately to strongly separated, and oriented
4. Nodules: iron and manganese, fine to medium, moderately separated, and unoriented, iron nodules were somewhat diffuse
5. Lithorelicts: shale (2 per cent)

Basic Fabric: vughy skel-insepic fabric

Elementary Fabric: cutanic (argillans) vughy skel-insepic fabric

BCk: 14-20 inches

Plasmic Fabric: Silasepic porphyroskelic fabric

Structure: massive to very weak, coarse, subangular blocky

Porosity: total 15 per cent

a) inped: medium orthovughs

b) exped: medium interconnected orthovughs and channels

Pedological Features:

1. Void neo-calcans: fine, discontinuous, weakly separated and oriented
2. Nodules: manganese, some fine, strongly separated, and unoriented; iron, odd, fine, diffuse, moderately separated, and unoriented
3. Lithorelicts: shale (5 per cent)
   limestone (8 per cent)

Basic Fabric: vughy silasepic to vughy, very weak insepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) vughy silasepic to vughy, very weak insepic fabric

Ck: 20-29 inches (Plate VI, photograph 1)

Plasmic Fabric: silasepic porphyroskelic fabric

Structure: massive to weak, pseudo platy

Porosity: total 12 per cent

a) inped: medium orthovughs and short channels

Pedological Features:

1. Void neo-calcans: very fine, weakly separated, and oriented
2. Nodules: manganese, some fine, strongly separated, and unoriented; iron, odd fine, diffuse, moderately separated, and unoriented
3. Lithorelicts: shale (5 per cent)
   limestone (8-10 per cent)

Basic Fabric vughy argillasepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) vughy argillasepic fabric

2. Dark Gray Luvisol

Ahe: 0-2 1/2 inches

Plasmic Fabric: argillasepic porphyroskelic fabric with odd, weakly insepic porphyroskelic fabric areas; degraded intertextic fabric (mull-like moder humus form) (Kubiena, 1938)

Structure: weak, coarse, granular

Porosity: total 30 per cent

a) inped: medium orthovughs, metavughs and channels

b) exped: medium to fine interconnected channels

Pedological Features:

1. Embedded grain argillan: extremely fine discontinuous, moderately separated and oriented
2. Faecal pellets: (odd one) medium to coarse, moderately separated
3. Organic fragments: mostly unrecognizable decomposed, dark brown to black, odd piece of recognizable tissue

Basic Fabric: strongly vughy argillasepic fabric

Elementary Fabric: plasmic (organic) strongly vughy argillasepic fabric

Ae: 2 1/2 - 5 1/2 inches

Plasmic Fabric: silasepic porphyroskelic with odd insepic porphyroskelic areas;
essentially a banded fabric with small areas degraded intertextic fabric (mull-like moder humus form) (Kubiena, 1938)

Structure: weak, very coarse, granular to weak, very coarse platy

Porosity: total 20 per cent

a) inped: medium orthovughs and shrinkage channels

b) exped: medium irregular interconnected channels

Pedological Features:

1. Embedded grain argillans: extremely fine, discontinuous, moderately separated, and oriented
2. Faecal pellets: odd, medium, moderately separated, with a insepic porphyroskelic fabric
3. Nodules: few iron and manganese, medium, moderately separated, and unoriented
4. Lithorelicts: shale, odd one

Basic Fabric: channeled silasepic fabric

Elementary Fabric: glaebular (nodules) channeled silasepic fabric

BA: 5 1/2 - 7 1/2 inches (Plate II, photograph 2)

Plasmic Fabric:	skel-vo-lattisepic porphyroskelic fabric
Strucutre:	very coarse, subangular blocky
Porosity:	20 per cent
a) inped:	medium to fine metavughs
b) exped:	series of interconnected, medium metavughs and channels

Pedological Features:

1. Embedded grain argillans: extremely fine to very fine, moderately separated, and oriented
2. Void neo-argillans: very fine, moderately separated, and oriented
3. Ped neo-argillans: very fine, discontinuous to none, moderately separated, and oriented
4. Ped skeletan: discontinuous
5. Nodules: iron and manganese, few, very fine, moderately separated, and unoriented
6. Lithorelicts: shale, odd one

Basic Fabric:	vughy skel-vo-lattisepic fabric
Elementary Fabric:	cutanic (argillans) vughy skel-vo-lattisepic fabric

Bt_1: 7 1/2 - 12 inches

Plasmic Fabric:	skel-vo-lattisepic porphyroskelic fabric
Structure:	very coarse, subangular blocky
Porosity:	total 16 per cent
a) inped:	medium to fine orthovughs and metavughs
b) exped:	medium to fine dentritic channels

Pedological Features:

1. Embedded grain argillans: extremely fine, moderately to strongly separated and oriented
2. Void argillans: very fine to moderately separated and oriented
3. Ped neo-argillans and some argillans: very fine and fine, moderately separated, and oriented
4. Nodules: manganese, some very fine to fine, moderately separated, and unoriented; iron, few, fine, diffuse at edges, weakly to moderately separated, and unoriented
5. Lithorelicts: shale (5 per cent)

Basic Fabric:	vughy skel-vo-lattisepic fabric
Elementary Fabric:	neo-cutanic (neo-argillans) vughy skel-vo-lattisepic fabric

Bt_2: 12 - 15 inches; as per Bt_1

Bt_3: 15 - 19 inches

Plasmic Fabric:	vo-lattisepic porphyroskelic fabric
Structure:	coarse to very coarse, subangular blocky
Porosity:	total 16 per cent
a) inped:	fine metavughs
b) exped:	interconnected medium to fine channels with odd medium metavughs

Pedological Features:

1. Embedded grain argillans: extremely fine, moderately separated and oriented
2. Void argillans: very fine, moderately to strongly separated, and oriented
3. Ped argillans and neo-argillans: very fine to fine, moderately to strongly separated, and oriented
4. Void neomangan: odd one, very fine, strongly separated, and unoriented
5. Nodules: manganese, some fine, moderately separated, and unoriented; iron, few, fine, weakly to moderately separated and unoriented

Basic Fabric:	vughy vo-lattisepic fabric
Elementary Fabric:	cutanic (argillans) vughy vo-lattisepic fabric

BCk: 19-23 inches

Plasmic Fabric: insepic porphyroskelic fabric

Structure: massive to weak, coarse to very coarse, subangular blocky

Porosity: total 12 per cent

a) inped: medium orthovughs and metavughs

b) exped: medium craze planes

Pedological Features:

1. Void argillans: very fine, strongly separated, and oriented
2. Ped argillans: very fine, strongly separated, and oriented; there are odd neo-argillans
3. Nodules: manganese, some fine, moderately separated, and unoriented; iron, few, fine, weakly to moderately separated, and unoriented
4. Lithorelicts: shale (4 per cent)
   limestone (3 per cent)

Basic Fabric: vughy insepic fabric

Elementary Fabric: cutanic (argillans) vughy insepic fabric

Ck_1: 23-27 inches

Plasmic Fabric: silasepic porphyroskelic fabric

Structure: massive to pseudo very coarse, platy

Porosity: total 10 per cent

a) inped: odd, medium metavughs

b) exped: medium horizontal craze planes

Pedological Features:

1. Void neo-calcans: odd, very fine, slightly separated, and oriented
2. Nodules: manganese, some fine clusters, moderately separated, and unoriented; iron, few, very fine, diffuse, weakly to moderately separated, and unoriented
3. Lithorelicts: shale (5 per cent)
   limestone (8 per cent)

Basic Fabric: horizontally fractured silasepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) horizontally fractured silasepic fabric

Ck$_2$: 27-31 inches

Plasmic Fabric: silasepic porphyroskelic fabric

Structure: massive to pseudo platy

Porosity: total 10 per cent

a) inped: odd, medium metavugh

b) exped: medium, horizontal craze planes

Pedological Features:

1. Void neo-calcans: with odd associated calcans, medium, weakly separated, and oriented neo-calcan and extremely fine, discontinuous, moderately separated, and weakly oriented calcan
2. Nodules: as per Ck$_1$
3. Lithorelicts: as per Ck$_1$

Basic Fabric: horizontally fractured silasepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) horizontally fractured silasepic fabric

Ck$_3$: 31-58 inches; as per Ck$_2$

3. Gleyed Gray Luvisol

Ae$_1$: 1/2 - 2 1/2 inches

Plasmic Fabric: silasepic porphyroskelic fabric; banded fabric (Kubiena, 1938)

Structure: upper part of section weak, coarse, granular; lower part moderate, coarse, platy

Porosity: total 10 per cent

a) inped: odd, fine, orthovugh

b) exped: fine to very fine horizontal curvilinear channels

Pedological Features:

1. Organic fragments: mostly decomposed dark brown to black with some recognizable plant material
2. Nodules (3 per cent): iron, few, fine, faint diffuse, weakly to moderately separated and unoriented; manganese, odd, coarse, strongly separated and unoriented with odd one having rock fragment inclusions

Basic Fabric: channeled silasepic fabric

Elementary Fabric: glaebular (nodules) channeled silasepic fabric

Ae_2: 2 1/2 - 4 1/2 inches (Plate II, photograph 1)

Plasmic Fabric:	silasepic porphyroskelic fabric; banded fabric (Kubiena, 1938)
Structure:	strong, coarse, platy
Porosity:	total 10 per cent
a) inped:	odd, fine, orthovughs
b) exped:	medium, horizontal curvilinear channels

Pedological Features:

1. Nodules (5 per cent): iron, many, coarse, strongly separated, and unoriented, with rock inclusions; manganese, odd, very fine to fine, moderately separated, and unoriented (and associated with iron nodule)

Basic Fabric:	channeled silasepic fabric
Elementary Fabric:	glaebular (nodules) channeled silasepic fabric

Ae_3: 4 1/2 - 7 inches

Plasmic Fabric: silasepic porphyroskelic fabric; banded fabric (Kubiena, 1938)

Structure: moderate, very coarse, platy

Porosity: total 10 per cent

a) inped: odd, medium, orthovughs

b) exped: medium, interconnected, horizontal, curvilinear channels

Pedological Features:

1. Nodules (5 per cent): iron, some medium, strongly separated and unoriented containing rock inclusions; manganese; odd, fine, moderately separated, and unoriented and associated with the iron nodule

Basic Fabric: channeled silasepic fabric

Elementary Fabric: glaebular (nodules) channeled silasepic fabric

AB: 7-9 inches

Plasmic Fabric: insepic porphyroskelic fabric

Structure: very coarse, subangular, blocky, breaking to weak, coarse, platy

Porosity: total 12 per cent

a) inped: medium orthovughs

b) exped: medium dentritic channeling

Pedological Features:

1. Embedded grain argillan: odd, extremely fine, discontinuous, moderately separated, and oriented
2. Nodules: iron, some fine to medium, diffuse, moderately separated, and unoriented; manganese, odd, medium, clustered, and strongly separated, and unoriented
3. Void skeletans: fine and discontinuous, moderately separated

Basic Fabric: channeled insepic fabric

Elementary Fabric: glaebular (nodules) channeled insepic fabric

BA: 9 - 13 1/2 inches

Plasmic Fabric: skel-masepic porphyroskelic fabric

Structure: very coarse, subangular blocky

Porosity: total 15 per cent

a) inped: medium orthovughs and metavughs

b) exped: medium dentritics channeling

Pedological Features:

1. Embedded grain argillans: very fine, moderately separated and oriented
2. Void neo-argillans: very fine to extremely fine, moderately separated, and oriented
3. Ped neo-argillans: extremely fine, discontinuous, moderately separated, and oriented
4. Nodules: iron, some fine to medium, diffuse, moderately separated and unoriented; manganese, odd, medium, clustered, and strongly separated, and unoriented

Basic Fabric: vughy skel-masepic fabric

Elementary Fabric: neo-cutanic (neo-argillans) vughy skel-masepic fabric

Bt_1: 13 1/2 - 16 inches (Plate III, photograph 1)

Plasmic Fabric: skel-latt-vosepic porphyroskelic fabric

Structure: strong, very coarse, blocky

Porosity: total 15 per cent

a) inped: medium metavughs

b) exped: medium dentritic channeling

Pedological Features:

1. Embedded grain argillans: extremely fine to very fine, moderately to strongly separated, and oriented
2. Void neo-argillans: and some argillans, very fine, moderately to strongly separated, and oriented
3. Ped neo-argillans: and some argillans, very fine to fine, moderately separated and oriented
4. Void ferran: odd one, very fine, strongly separated and unoriented
5. Void and embedded grain mangan: odd one, very fine, strongly separated, and unoriented
6. Nodules: iron, some fine to medium, diffuse, moderately separated, and unoriented; manganese, odd, fine, moderately to strongly separated, and unoriented
7. Lithorelict: shale, odd one

Basic Fabric: vughy skel-latt-vosepic fabric

Elementary Fabric: neo-cutanic (neo-argillans) vughy skel-latt-vosepic fabric

Bt_2: 16-23 inches; as per Bt_1

Bt_3: 23-28 inches (Plate III, photograph 2)

Plasmic Fabric: skel-vo-lattisepic porphyroskelic fabric

Structure: very coarse, blocky

Porosity: total 15 per cent

a) inped: medium and odd, fine metavughs

b) exped: medium dentritic channels

Pedological Features:

1. Embedded grain argillans: extremely fine, moderately to strongly separated, and oriented
2. Void argillans and neo-argillans: very fine, moderately to strongly separated, and oriented
3. Ped argillans and neo-argillans: very fine, odd, fine, moderately to strongly separated, and oriented
4. Void neo-ferran: odd one, very fine, strongly separated, and unoriented
5. Nodules: iron, some fine to medium, diffuse, moderately separated, and unoriented; manganese, odd, fine, moderately to strongly separated, and unoriented
6. Lithorelict: shale (1 per cent)

Basic Fabric: vughy skel-vo-lattisepic fabric

Elementary Fabric: cutanic (argillans) vughy skel-vo-lattisepic fabric

Bt_4: 28-31 inches (Plate IV, photograph 1)

Plasmic Fabric: skel-lattisepic porphyroskelic fabric

Structure: very coarse, subangular blocky

Porosity: total 15-20 per cent

a) inped: medium metavughs

b) exped: medium interconnected channels

Pedological Features:

1. Embedded grain argillans: extremely fine, discontinuous, strongly separated and oriented
2. Void argillans, odd, neo-argillan: very fine, strongly separated, and oriented
3. Ped argillans, some neo-argillans: very fine, odd, fine, strongly separated, and oriented
4. Nodules: iron, some, fine, odd, medium, moderately separated, and unoriented; manganese, few, fine to very fine, moderately to strongly separated, and unoriented
5. Lithorelicts: shale (2 per cent)

Basic Fabric: vughy skel-lattisepic fabric

Elementary Fabric: cutanic (argillans) skel-lattisepic fabric

BCk: 31-36 inches (Plate IV, photograph 2)

Plasmic Fabric: insepic porphyroskelic fabric

Structure: very coarse, pseudo platy

Porosity: total 15 per cent

a) inped: mainly medium metavughs and odd orthovughs

b) exped: fine to odd medium trellised channels

Pedological Features:

1. Void argillans: very fine, strongly separated, and oriented
2. Ped argillans: very fine, discontinuous in places, strongly separated, and oriented
3. Nodules: iron, some fine, odd, medium, moderately separated and unoriented; manganese, few, fine to very fine, moderately to strongly separated, and unoriented
4. Lithorelicts: shale (2 per cent)
   limestone (4 per cent)

Basic Fabric: horizontally fractured insepic fabric

Elementary Fabric: weakly cutanic (argillans) horizontally fractured insepic fabric

BCkg: 36-44 inches

Plasmic Fabric: silasepic porphyroskelic fabric

Structure: very coarse, pseudo platy

Porosity: total 12 per cent

a) inped: medium metavughs, odd orthovughs

b) exped: fine to odd medium trellised channels

Pedological Features:

1. Void neo-calcans: very fine to fine, weakly separated, and oriented; odd ones have associated argillans; very fine, strongly separated, and oriented
2. Void neo-calcans: very fine to fine, weakly separated, and oriented; odd ones have associated calcans, extremely fine to very fine, weakly separated, and oriented
3. Clay root: very coarse to extremely coarse, strongly separated, and oriented
4. Nodules: iron, some fine, odd medium, moderately separated, and oriented; manganese, few, fine to very fine, moderately to strongly separated and unoriented
5. Lithorelicts: shale (4 per cent)
   limestone (8 per cent)

Basic Fabric: horizontally fractured silasepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) horizontally fractured silasepic fabric

Ckg: 44-60 inches (Plate V, photographs 1 and 2)

Plasmic Fabric: silasepic porphyroskelic fabric

Structure: very coarse, pseudo platy

Porosity: total 12 per cent

a) inped: few, fine orthovughs

b) exped: interconnected fine horizontal channels

Pedological Features:

1. Void neo-calcans: medium, weakly separated, and oriented, with odd associated calcans; extremely fine, discontinuous, weakly separated, and oriented
2. Void argillans: odd, extremely fine, discontinuous, strongly separated, and oriented
3. Nodules: as per BC_2
4. Lithorelicts: shale (4 per cent)
   limestone (12 per cent)

Basic Fabric: horizontally fractured silasepic fabric

Elementary Fabric: neo-cutanic (neo-calcans) horizontally fractured silasepic fabric

Discussion of Micromorphological Results

Ah, Ahe and Ae horizons

The surface horizons of the profiles studied had a very noticeable change in fabric and humus form. The Ah horizon of the Orthic Dark Gray (photograph 1, Plate I) exhibited an intertextic fabric (with mull humus form), while the Ahe horizons of the Orthic Dark Gray (photograph 2, Plate I) and Dark Gray Luvisol exhibited a degraded intertextic fabric (with mull-like moder humus form). In contrast to the Orthic Dark Gray and Dark Gray Luvisol, the Gleyed Gray Luvisol exhibited a banded fabric, which was plasma deficient and weakly platy.

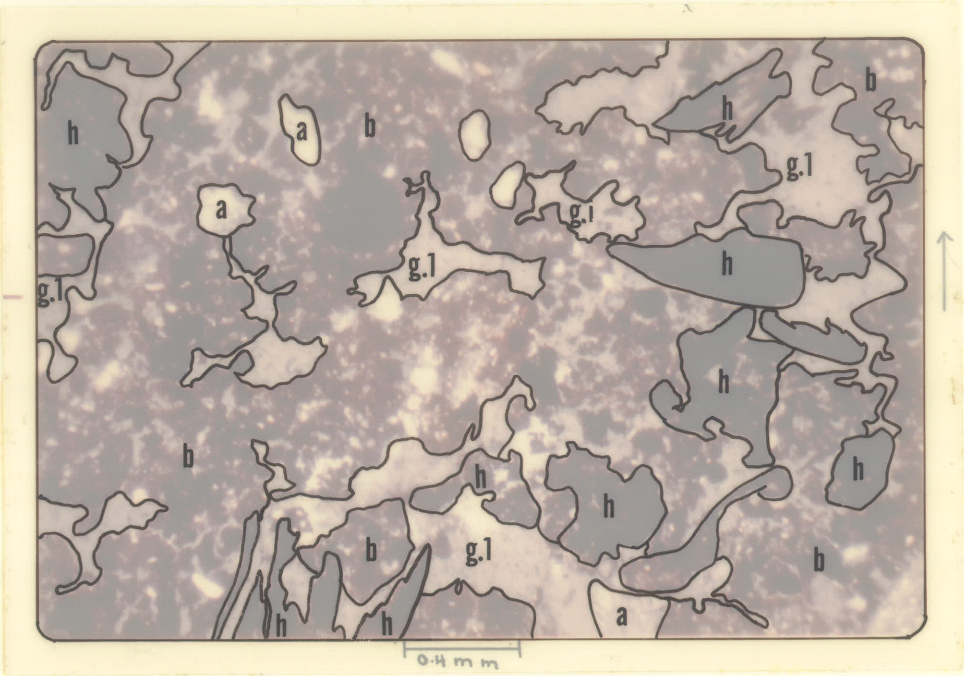
The fabric of the Ah horizon of the Orthic Dark Gray was dominated by the dark brown to black organic matter which tended to mask the clay present. This horizon also contained many irregular interconnected voids. The Ahe horizons of the Orthic Dark Gray and Dark Gray Luvisol exhibit a punctuation of finer dark organic matter particles in close association with inorganic clay and skeletal materials, and well defined peds separated by irregular interconnected channels. Similar fabrics were described by Pettapiece and Zwarich (1970) and St. Arnaud and Whiteside (1964).

The platy structure exhibited by the eluvial horizons of the Dark Gray Luvisol and Gleyed Gray Luvisol (photograph 1, Plate II) correspond to the banded fabric described by Kubiena (1939, p. 192). The strongest expressed banded fabric was observed in the Gleyed Gray Luvisol. Banded fabrics were characterized by plasma deficiencies, bleached dull grayish color, and abundant horizontally aligned

LEGEND: for schematic diagrams of photographs in the Plates

a) mineral grains
b) matrix
c) argillan .1 void
  .2 embedded grain
d) neo - argillan
e) neo - calcan
f) calcan
g) voids .1 vugh
  .2 channel
h) organic fragment
i) nodule
j) limestone

1



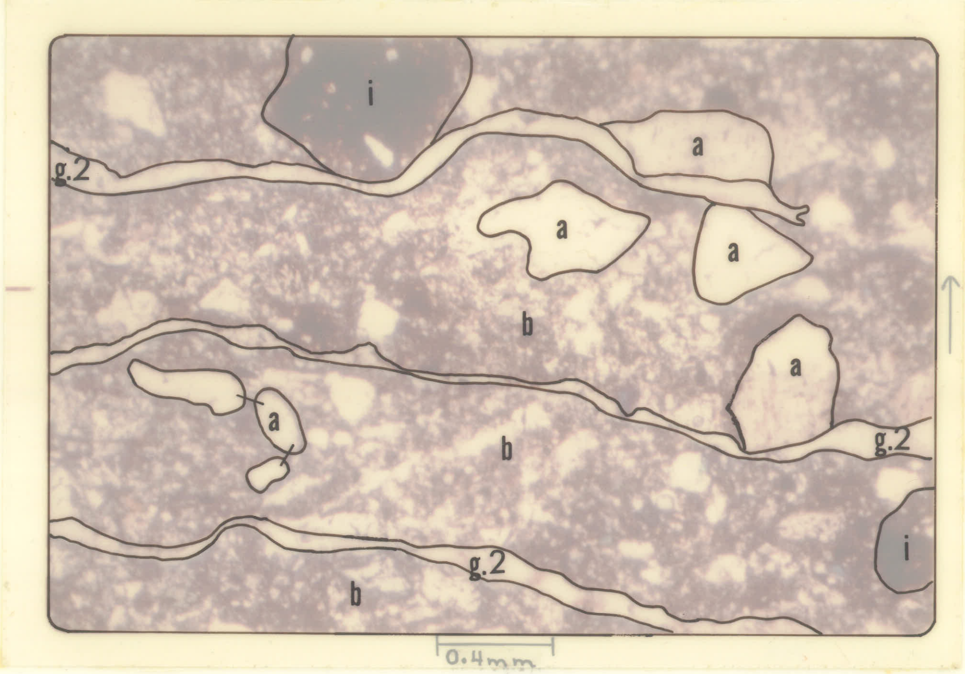
Ah - Orthic Dark Gray, x-nicols

2

Ahe - Orthic Dark Gray, x-nicols

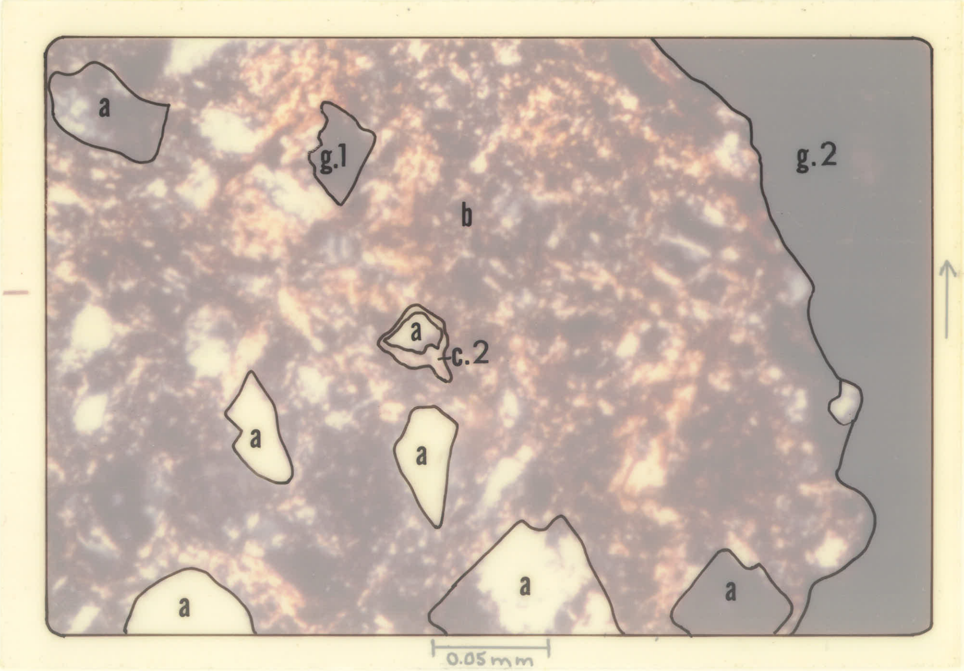
Plate I

1



Ae$_2$ - Gleyed Gray Luvisol, partially polarized light.

2



BA - Dark Gray Luvisol, x-nicols.

Plate II

curvilinear channels. The platy peds were uniformly and randomly packed with no segregation of components. The highest percentage of iron and manganese nodules (glaebules) were found in the Ae horizons of the Gleyed Gray Luvisol (photograph 1, Plate II). These glaebules correspond to McMillan and Mitchell's (1953) "invasion amygdali", which according to them were concentrated at the bottom of the bands, but in the present study there was no definite mode of occurrence. Banded fabric was also found by St. Arnaud and Whiteside (1964) in their study of Dark Gray Wooded and Gray Wooded profiles (Luvisols according to present classification). Dumanski and St. Arnaud (1966) and McMillan and Mitchell (1953) described similar fabrics to those which were found in this study but referred to them as an isoband fabric. Pettapiece and Zwarich (1970), and St. Arnaud and Whiteside (1964) suggested that the physical action of ice lenses probably gave rise to the formation of banded fabric.

AB and BA horizons

The AB horizon of the Gleyed Gray Luvisol exhibited an insepic porphyroskelic plasmic fabric with odd areas having minor amounts of oriented inped plasma (clay). No plasma accumulations were found on inped void and ped surfaces. Sand and silt size particles were observed coating odd ped surfaces (skeletan). This horizon had all exped surfaces and inped voids stripped of plasma. Certain areas of the horizon had collapsed when the majority of the plasma had been removed, and now resembles a developing Ae horizon. Thorp, et al. (1959) described a similar occurrence. The sand and silt coatings on peds are believed to have originated in the Ae horizon, and were either dislodged by stress and fell by gravity into their present position or were washed down into the AB horizon by rain water. Eluviation and leaching are responsible for the state of this horizon.

The BA horizons of the Dark Gray Luvisol (photograph 2, Plate II) and the Gleyed Gray Luvisol contained much yellow to orange oriented inped plasma (clay). Exped surfaces had very fine discontinuous neo-argillans, while inped voids had very fine neo-argillans. The BA horizons in both profiles exhibited a skel-vo-lattisepic plasmic fabric. Buol and Hole (1959 and 1961) postulated that cyclic wetting and drying, and freezing and thawing in surface and some subsurface horizons caused disruption of former surface cutans and neo-cutans with their subsequent incorporation in ped interiors, accounting for much oriented inped plasma. Illuvial processes have contributed much plasma (neo-argillans and argillans) to these horizons at an earlier date, but now eluvial processes were starting to remove some of it.

Bt horizons

All the Bt_1 horizons contained yellow to orange oriented inped plasma, and had a skel-vo-lattisepic porphyroskelic fabric. The Orthic Dark Gray contained a small amount of oriented inped plasma (clay), while the Dark Gray Luvisol and Gleyed Gray Luvisol (photograph 1, Plate III) were packed with oriented inped plasma. The neo-argillans and argillans were thinnest in the Bt_1 horizon of the Orthic Dark Gray. Neo-argillans and argillans in all the Bt_1 horizons were moderately separated and oriented.

The Bt_2 horizons of the Dark Gray Luvisol and Gleyed Gray Luvisol were quite similar to their Bt_1 horizons. The Bt_2 of the

1

Bt$_1$ - Gleyed Gray Luvisol, x-nicols.

2

Bt$_3$ - Gleyed Gray Luvisol, x-nicols

Plate III

Orthic Dark Gray, on the other hand, was not similar to its Bt_1 horizon and exhibited a skel-insepic porphyroskelic fabric. This horizon contained odd bits of oriented inped plasma, and had thinner, moderately to strongly oriented argillans on ped and void surfaces.

The Bt_3 horizons of the Dark Gray Luvisol (photograph 2, Plate III) and Gleyed Gray Luvisol were very much similar and exhibited a vo-lattisepic porphyroskelic fabric. They both contained much less oriented inped plasma and had thinner argillans (particularly in the Gleyed Gray Luvisol) on ped and inped void surfaces, which were moderately to strongly separated and oriented.

The Bt_4 horizon of the Gleyed Gray Luvisol (photograph 1, Plate IV) exhibited very little oriented inped plasma, and had thin, very fine, strongly separated, and oriented argillans on ped and odd void surfaces. The Bt_4 horizon exhibited a skel-lattisepic porphyroskelic fabric.

Several different trends in plasma accumulation (neo-argillans and argillans), separation and orientation were observed in the Bt horizons of the profiles studied. Firstly, the plasma accumulations were thicker and weakly to moderately separated and oriented in the upper Bt horizons, whereas in the lower Bt horizons the accumulations were thinner and moderately to strongly separated and oriented. Upper Bt horizons contained more neo-argillans, while lower Bt horizons contained more argillans. Secondly, upper horizons contained much more oriented inped plasma than did the lower Bt horizons.

A number of processes account for some of the variability found in Bt horizons studied. Firstly, cyclic wetting and drying, and freezing and thawing (physical stress processes) result in the large amounts of oriented inped plasma found in upper Bt horizons. These processes cause disruption of former surface cutans and neo-cutans with subsequent incorporation into ped interiors. There is less effect of these processes in lower Bt horizons resulting in much less oriented inped plasma. These processes also account for the orientation of clay particles around mineral grains (embedded grain argillans). Secondly, the process of diffusion also accounts for some of the variability. Khalifa and Buol (1958) believed that there would be more rainfalls in a year, that would move a wetting front with suspended colloids down into the upper Bt horizon than into the lower Bt horizon. The dominance of neo-argillans in the upper B horizons in the profiles studied indicates there were more suspensions in contact with these horizons and thus more chance for diffusion of suspensions into peds. The water eventually evaporates with subsequent orientation of clay in ped matrix next to void and ped surfaces. The dominance of strongly separated and oriented argillans in lower B horizons of the Dark Gray Luvisol and Gleyed Gray Luvisol indicate surface wetting by suspensions, with subsequent evaporation and orientation parallel to surfaces or direction of flow. Thirdly, in situ weathering of shale particles also contributes a small amount of oriented inped plasma. Shale particles in the Bt horizons of the Orthic Dark Gray showed little evidence of weathering, whereas the shale in the upper Bt horizons of the Dark Gray Luvisol and Gleyed Gray Luvisol profiles had disintegrated and appeared as oriented inped plasma.

The presence of moderately to strongly separated and oriented

1

Bt_4 - Gleyed Gray Luvisol, x-nicols.

2

BCk - Gleyed Gray Luvisol, x-nicols.

Plate IV

argillans in the Bt horizons is indicative of illuvial clay. This contention is also supported by the particle size distribution data (Tables I, II and III, Appendix I).

BC horizons

The matrix of the BCk horizon of the Orthic Dark Gray was densely packed with primary lime carbonate and exhibited a silasepic porphyroskelic fabric. No oriented inped plasma was observed in this horizon. The primary carbonates consisted of coarse limestone lithorelicts and the fine earth carbonate fraction. Brewer (1972) defined fine earth carbonate as "small intercalary crystals scattered through and embedded in the plasma of the s-matrix". Secondary carbonates also occurred as thin neo-calcans along some inped voids. The BCk horizons of the Dark Gray Luvisol and the Gleyed Gray Luvisol (photograph 2, Plate IV) were very similar and exhibited an insepic porphyroskelic fabric. They were similar in that they contained small areas of oriented inped plasma and that the fine earth carbonate in the s-matrix adjacent to void and ped surfaces had been removed. It is believed the fine earth fraction and the limestone pebbles from upper horizons were dissolved and translocated in solution, and recrystallized at drying surfaces of voids and peds to give rise to the neo-calcans and calcans. Fewer and a wider size range of limestone pebbles indicates that some limestone lithorelicts have been altered.

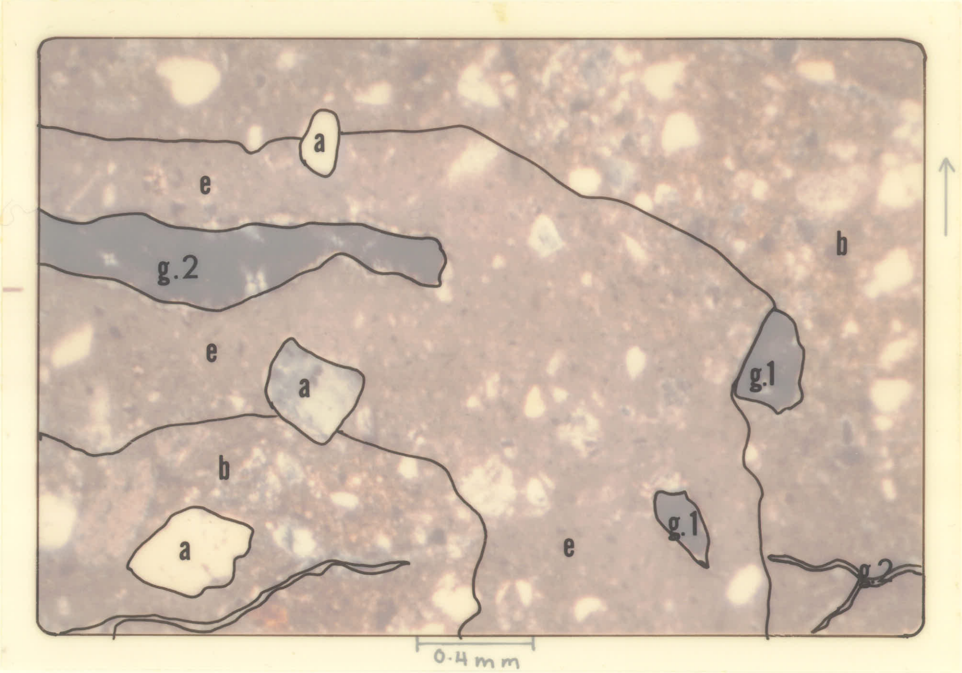
Thin, strongly separated and oriented argillans were found along some of the inped void and ped surfaces in the Dark Gray Luvisol and the Gleyed Gray Luvisol. The BCkg of the Gleyed Gray Luvisol was very similar to the BCk horizon of the Orthic Dark Gray, except that it had more neo-calcans with associated argillans and calcans (complex cutans). The processes at work are illuvial, for the carbonates were deposited first in the BCkg horizon of the Gleyed Gray Luvisol and the clay came later and formed an argillan on the neo-calcan surface.

Clay accumulations referred to as "clay roots" (photograph 2, Plate VI) were found in the BCkg and Ckg horizons of the Gleyed Gray Luvisol. These "clay roots" traversed ped interiors and in some cases followed along major fracture planes and ped surfaces. It would appear that the "clay roots" occupy former root channels. Diameters of the clay accumulations range from 3 to 13 mm. The "clay root" was strongly separated from the carbonated matrix of the two horizons and the clay in the "clay root" was strongly oriented. A similar phenomenon was described by Parefenova *et al*. (1964), and called a "clayified root". Analysis of the "clay root" (Table VII, Appendix I) showed that it contained a much higher clay content than the "clayified root" described by the Russian workers. It also contained less organic matter and extractable iron.

C horizons

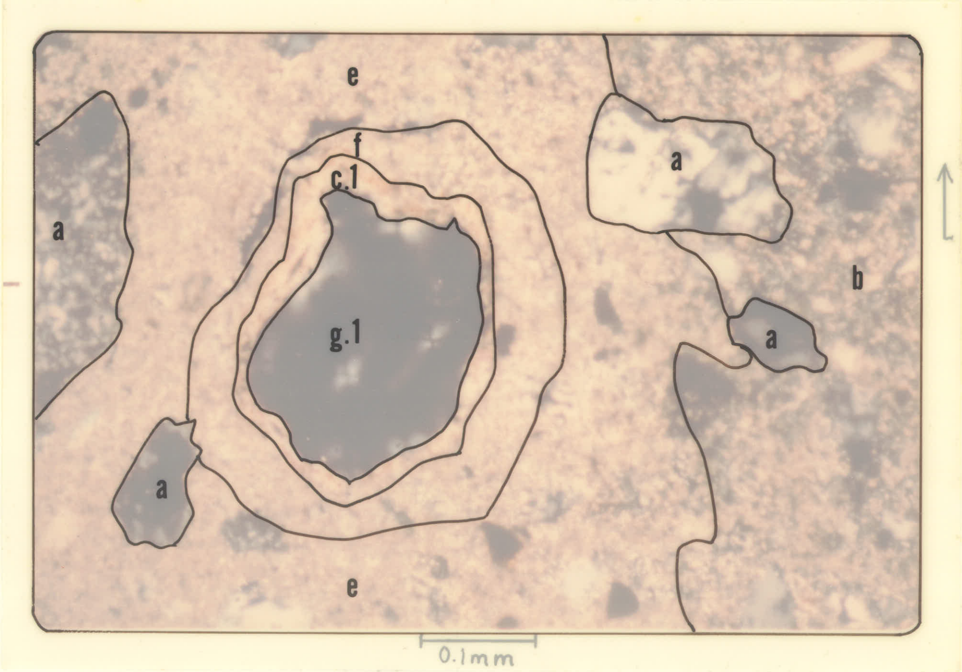
The C horizons of the three profiles studied were densely packed with primary lime carbonate similar to the BCk horizon of the Orthic Dark Gray. The Ck_1 horizon of the Orthic Dark Gray (photograph 1, Plate VI) profile exhibited a few very fine neo-calcans while the Ck_1, Ck_2 and Ck_3 horizons of the Dark Gray Luvisol exhibited more very fine neo-calcans, and the Ckg horizon of the Gleyed Gray Luvisol (photograph 1 and 2, Plate V) exhibited many medium to fine neo-calcans. Some argillans (photograph 2, Plate V) and calcans were also noted in association with neo-calcans in the Ckg horizon of the Gleyed Gray Luvisol. All C horizons exhibited fissile structure.

1



Ckg - Gleyed Gray Luvisol, x-nicols.

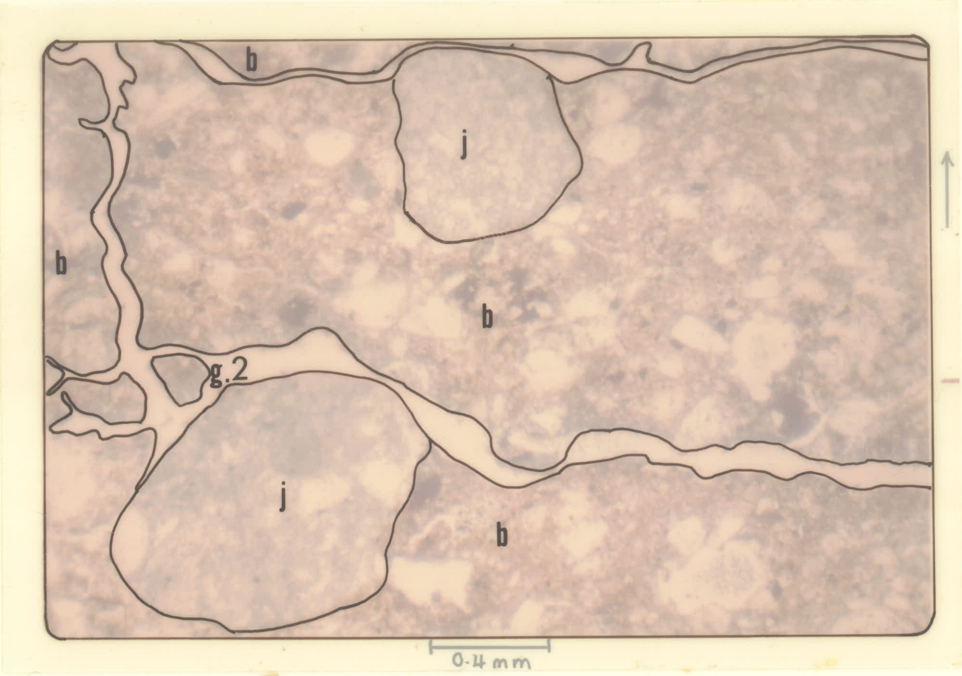
2



Ckg - Gleyed Gray Luvisol, x-nicols.

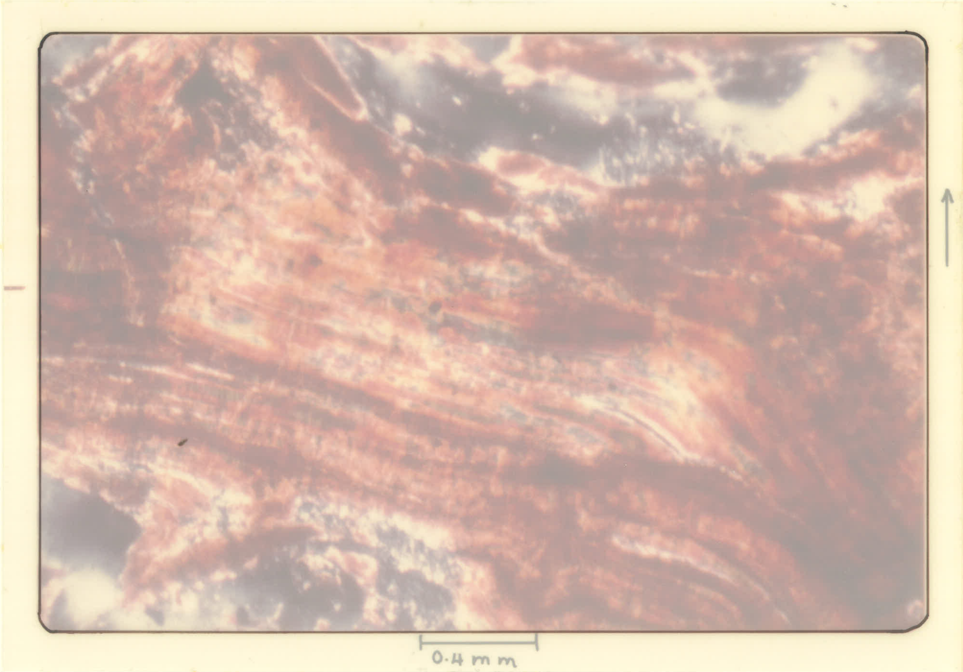
Plate V

1



Ck$_1$ - Orthic Dark Gray - plane polarized light.

2



Clay root, x-nicols.

Plate VI

SUMMARY

1. Addition of organic matter (plasma accumulation) to the surface horizon was found to be of importance in the Orthic Dark Gray and Dark Gray Luvisol.

2. The Gleyed Gray Luvisol exhibited a severely leached and eluviated (plasma deficient) Ae horizon, while the Dark Gray Luvisol had a moderately eluviated Ae horizon.

3. The transition from a B horizon to an Ae horizon was observed in the AB horizon of the Gleyed Gray Luvisol and in the BA horizons of the Dark Gray Luvisol and the Gleyed Gray Luvisol. Ped centers contained oriented inped plasma, but ped surfaces were plasma deficient (stripped).

4. Plasma accumulation (clay) was characteristic of the B horizons in all three profiles. The depth to which clay accumulated, thickness of coatings (argillans and neo-argillans), and the orientation and separation of these accumulations were found to be the main variables.

5. Upper B horizons contained much oriented inped plasma which was the result of incorporation of former ped surfaces by cyclic wetting and drying and freezing and thawing. Lower B horizons contained very little oriented inped plasma.

6. Upper B horizons contained thicker neo-argillans which were moderately separated and oriented. The neo-argillans are believed to be the result of diffusion processes. Lower B horizons had thinner but more strongly separated and oriented argillans.

7. Analysis carried out on "clay root" material, which appeared to be similar to the argillans, indicated that it had a very high clay content and was low in extractable iron and organic matter.

8. The oriented clay found in the profiles is believed to be due to a number of processes: (a) illuviation, (b) stress, and (c) in situ weathering.

9. Removal of carbonates was observed in the BC horizon of the Dark Gray Luvisol and Gleyed Gray Luvisol. Some strongly separated and oriented argillans were observed on surfaces from which carbonates had been removed.

10. Accumulation of carbonates occurred in the C horizons mainly in the form of neo-calcans and some calcans along major voids. Carbonates were present as primary carbonates (limestone) and secondary carbonates (of illuvial nature) and which had recrystallized at drying surfaces giving neo-calcans.

11. Some argillans were found in association with a neo-calcan in the Ckg horizon of the Gleyed Gray Luvisol. It would appear that the carbonates were deposited first with illuvial clay being deposited next.

CONCLUSIONS

The parent materials are similar and post glacial weathering is of minor significance. Since the age of these soils and their macroclimate are similar, the soil forming factors responsible for differences in the profiles studied are drainage, topography, and microclimate.

The rearrangement of plasma constituents has been carried out by pedologic processes (eluviation and illuviation). The rearrangement has resulted in eluviated horizons which are plasma deficient and illuvial horizons which are plasma rich.

Micromorphological studies are extremely useful in evaluating pedological features and processes as to kind and degree.

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APPENDIX I

Tables

TABLE I

Some Physical and Chemical Analyses of the Orthic Dark Gray Profile

Horizon	Depth inches	Texture	% Sand	% Silt	% Clay	pH	% Calcite	% Dolomite	% $CaCO_3$ Equiv.	% O.M.
Ah	0- 2	L	32.06	42.41	25.53	6.32				9.08
Ahe	2- 6	CL	35.23	35.36	29.41	6.45				3.39
Bt_1	6-11	CL	32.50	30.76	36.74	6.70				1.19
Bt_2	11-14	CL	32.48	32.05	35.47	6.91				0.94
BCk	14-20	CL	33.32	36.22	30.46	7.60	5.50	6.40	12.46	
Ck	20-29	CL	31.49	39.52	28.99	7.70	8.00	7.01	15.61	
Cca_1	29-34	SiL	18.10	55.31	26.59	7.75	9.63	10.35	20.87	
Cca_2	34-38	CL	20.96	50.58	28.46	7.85	9.69	9.37	25.38	
Ck_2	38-50	L	37.38	39.00	23.62	7.85	6.88	7.39	14.91	

TABLE II

Some Physical and Chemical Analyses of the Dark Gray Luvisol Profile

Horizon	Depth inches	Texture	% Sand	% Silt	% Clay	pH	% Calcite	% Dolomite	% $CaCO_3$ Equiv.	% O.M.
Ahe	0-2 1/2	L	47.38	35.61	17.01	6.10				4.59
Ae	2 1/2-5 1/2	SL	54.27	32.80	12.93	6.25				1.19
BA	5 1/2-7 1/2	L	48.40	28.22	23.38	6.25				1.02
Bt_1	7 1/2-12	CL	37.15	31.20	31.65	5.90				0.98
Bt_2	12 - 15	CL	33.36	30.67	35.97	5.95				0.88
Bt_3	15 - 19	CL	34.26	31.56	34.18	6.20				
BCk	19 - 23	CL	35.50	33.31	31.18	6.85	4.52	4.03	10.52	
Ck_1	23 - 27	CL	35.74	34.60	29.66	7.60	8.36	9.74	18.92	
Ck_2	27 - 31	CL	34.46	36.10	29.44	7.68	11.62	9.01	21.40	
Ck_3	31 - 58	L	37.35	36.08	26.57	7.75	8.67	8.16	18.14	

TABLE III

Some Physical and Chemical Analyses of the Gleyed Gray Luvisol Profile

Horizon	Depth inches	Texture	% Sand	% Silt	% Clay	pH	% Calcite	% Dolomite	% CaCO$_3$ Equiv.	% O.M.
Ae$_1$	1/2-2 1/2	SiL	36.54	53.73	9.73	5.60				1.00
Ae$_2$	2 1/2-4 1/2	L	44.42	46.77	8.81	5.70				0.64
Ae$_3$	4 1/2-7	L	51.50	39.74	8.76	5.51				0.37
AB	7 - 9	SCL	54.57	22.59	22.84	5.80				0.49
BA	9 - 13 1/2	SL	64.64	19.69	15.67	5.80				0.29
Bt$_1$	13 1/2-16	SCL	51.91	18.96	29.13	5.70				
Bt$_2$	16 - 23	SCL	46.14	20.85	33.01	5.68				
Bt$_3$	23 - 28	CL	39.05	29.15	31.79	6.21				
Bt$_4$	28 - 31	CL	33.37	31.39	35.24	6.80				
BCk	31 - 36	L	34.13	38.40	27.47	7.60	2.05	7.19	9.85	
BCkg	36 - 44	L	34.63	39.98	25.39	7.65	5.28	7.46	13.38	
Ckg	44 - 60	L	36.42	37.21	26.37	7.80	9.14	6.68	16.40	

TABLE IV

Percentage of Heavy Minerals in the Major Horizons of the Profiles Studied

Profile	Horizon	Sand Fraction	% Heavy Minerals	% Light Minerals
Orthic Dark Gray	Ah	MS	2.23	97.77
		FS	2.39	97.61
		VFS	3.66	96.34
	Bt_2	MS	2.56	97.44
		FS	1.81	98.19
		VFS	3.78	96.22
	Ck	MS	1.31	98.69
		FS	2.31	97.69
		VFS	3.30	96.70
Dark Gray Luvisol	Ae	MS	2.20	97.80
		FS	2.52	97.48
		VFS	3.98	96.02
	Bt_2	MS	2.20	97.80
		FS	2.15	97.85
		VFS	3.39	96.61
	Ck_3	MS	1.28	98.72
		FS	2.58	97.42
		VFS	3.46	96.54
Gleyed Gray Luvisol	Ae_1	MS	1.46	98.54
		FS	2.42	97.58
		VFS	3.10	96.90
	Ae_3	MS	1.53	98.47
		FS	2.58	97.42
		VFS	3.10	96.90
	Bt_3	MS	1.39	98.61
		FS	2.30	97.70
		VFS	3.28	96.72
	Ckg	MS	1.73	98.27
		FS	2.27	97.73
		VFS	2.90	96.10

TABLE V

Percentage of Quartz, K-Feldspars and Plagioclase in the Light Mineral Fractions of the Three Profiles

Profile	Horizon	MS			FS			VFS		
		Quartz	K-Feldspar	Plagioclase	Quartz	K-Feldspar	Plagioclase	Quartz	K-Feldspar	Plagioclase
Orthic Dark Gray	Ah	67	13	20	71	16	13	90	3	7
	Bt$_2$	70	12	18	70	13	17	88	3	9
	Ck	79	11	20	67	13	20	84	2	14
Dark Gray Luvisol	Ae	67	15	18	71	13	16	92	2	6
	Bt$_2$	68	14	18	73	10	17	93	2	5
	Ck$_3$	64	14	22	68	10	22	87	2	11
Gleyed Gray Luvisol	Ae$_1$	62	14	24	76	10	14	92	3	5
	Ae$_3$	57	19	24	71	15	14	92	3	5
	Bt$_3$	63	21	16	68	15	17	91	3	6
	Ckg	57	14	28	65	12	23	83	5	12

TABLE VI

Heavy Mineral Suite Present and Percentage of Each Heavy Mineral

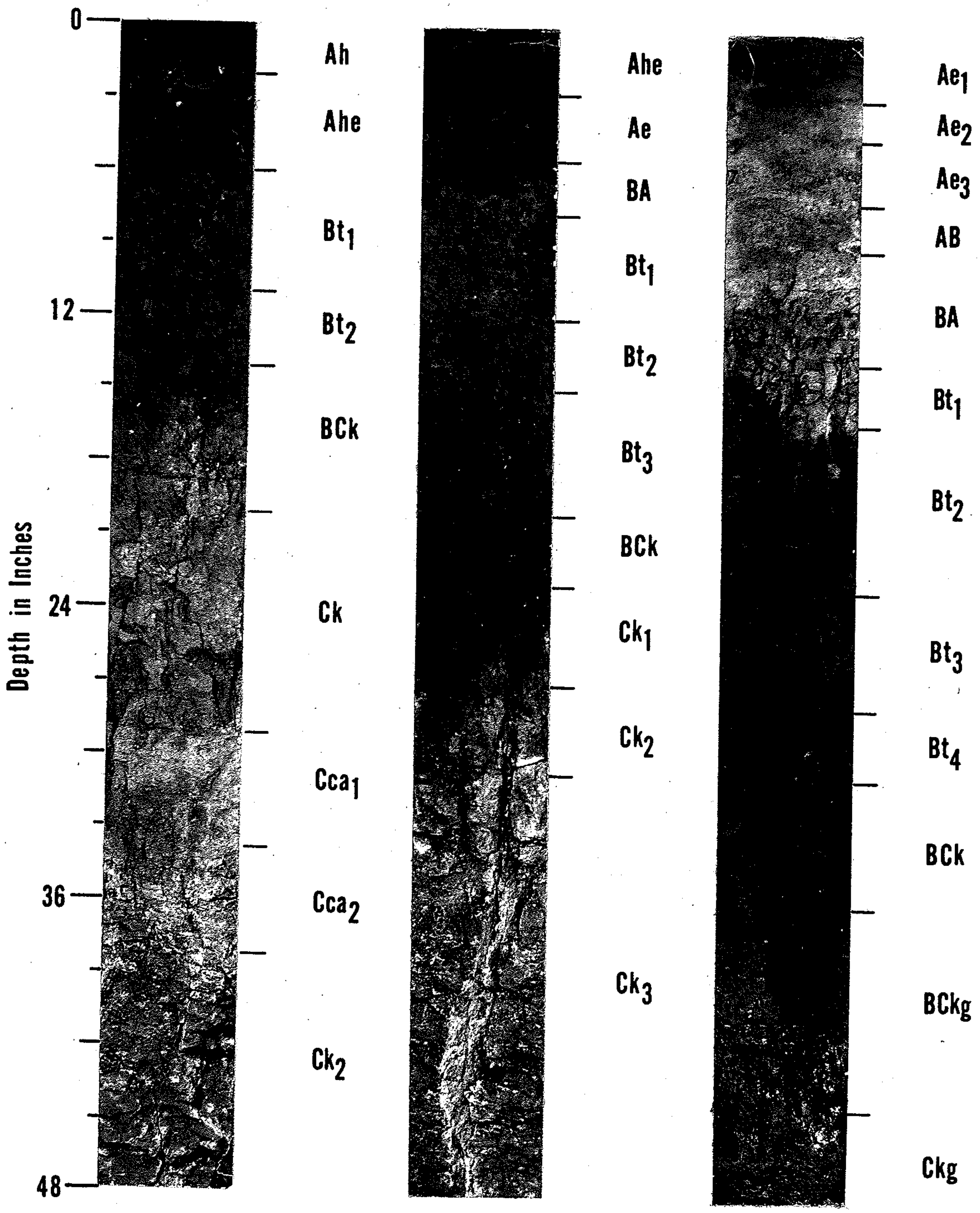
Found in the Three C Horizons

	Orthic Dark Gray Ck	Dark Gray Luvisol Ck_3	Gleyed Gray Luvisol Ckg
Amphibole (dark green hornblend with traces of colorless tremolite and pale actinolite)	46.5	46.4	45.9
Garnet (mainly colorless to pink variety grossularite)	18.3	18.9	16.6
Opaques (magnetite, haematite, limonite and illmenite)	11.9	12.6	11.9
Pyroxenes	4.9	3.9	3.9
Epidote	3.9	2.9	3.9
Olivine	1.9	3.4	3.6
Staurolite	3.0	2.4	2.0
Topaz	2.5	2.9	3.9
Zircon	0.6	0.3	0.6
Tourmaline	0.3	0.3	-
Rutile	0.3	-	0.6
Others (weathered and unidentified)	5.9	6.0	7.1

TABLE VII

Some Physical and Chemical Analyses of Clay Root and Surrounding Matrix Found in BCkg Horizon of the Gleyed Gray Luvisol

Material	Texture	% Sand	% Silt	% Clay		% $CaCO_3$	% O.M.	% Extractable Fe_2O_3
				Coarse	Medium to Fine			
Clay root	C	0.60	0.88	5.99	92.53	-	1.70	0.38
Matrix	L	38.28	32.72	14.43	14.57	16.40	1.12	0.80



Orthic Dark Gray

Dark Gray Luvisol

Gleyed Gray Luvisol

Plate VII Representative Profile Types

APPENDIX II

Glossary

GLOSSARY OF TERMS

Apedal. Applied to soil materials, without peds.

Argillan. A cutan composed dominantly of clay.

Argillasepic fabric. See asepic fabrics.

Asepic fabrics. Plasmic fabrics that consist dominantly of anisotropic clay minerals and exhibit a flecked extinction pattern under crossed polarizers. Two types are recognized: argillasepic (containing a high proportion of clay minerals) and silasepic (containing a high proportion of fine silt-size minerals that are difficult to distinguish from the areas of clay minerals present.

Banded fabric. Fabric referring to the platy nature of some eluvial horizons.

Basic fabric. The fabric of the s-matrix, that is, the arrangement and relationships of the plasma, skeleton grains, and voids.

Calcan. A cutan composed of carbonates.

Channel. A tubular shaped void.

Clay root. An accumulation of clay in old root channels.

Complex cutan. Formed by a combination of more than one process, such as stress, diffusion and illuviation.

Compound cutan. A cutan composed of two or more layers of material of different composition.

Concretion. A glaebule with a generally concentric fabric about a centre which may be a point, a line, or a plane.

Continuous orientation (fabric). Under crossed polarizers, the mass of plasma exhibits extinction lines or extinguishes as a unit.

Craze planes. Planar voids with a highly complex conformation of the walls due to the interconnection of numerous short flat and/or curved planes.

Cutan. A modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or in situ modification of the plasma.

Dendroid channels. The channels branch after the manner of a tree.

Diffuse. Applied to pedological features (especially nodules). The external boundary consists of a transition over a distance greater than one-quarter of the shortest dimension of the feature.

Diffusion cutan. Concentration at a surface due to diffusion; they are usually associated with concentration within the s-matrix of the soil material that reaches a maximum at the cutanic surface.

Elementary fabric. The fabric of the s-matrix, that is, arrangement and relationship of plasma, skeleton grains, voids and pedological features.

Embedded grain argillan. An argillan on a grain that is embedded in the plasma.

Exped. On or between ped surfaces.

Fabric. The physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids.

Faecal pellets. The excreta of fauna.

Ferran. A cutan composed of a concentration of iron oxides.

Ferri-argillan. A cutan composed of intimately mixed clay minerals and iron oxides.

Glaebule. A three dimensional pedological feature within the s-matrix of the soil material, and usually approximately prolate to equant in shape; its morphology is incompatible with its present occurrence being within a single void in the present soil material.

Illuviation cutan. Formed by movement of the cutanic material in solution or suspension and subsequent deposition.

Insepic fabric. See sepic fabrics.

Intercalary crystals. Crystallaria that consist of single large crystals or groups of a few crystals set in the soil material and apparently not associated with voids of equivalent size or shape to that of the crystallaria as a whole.

Interconnected vughs. Relatively large, highly irregular, interconnected voids that ramify the soil material.

Intertextic fabric. The skeleton grains are linked by intergranular braces or are embedded in a porous matrix of plasma and small skeleton grains.

Inped. Within ped.

Joint planes. Planar voids arranged in a fairly regular pattern such as parallel or sub-parallel sets; more than one set may occur.

Lamellar fabric. The constituents are arranged in parallel planar zones, which may be somewhat curved.

Lattisepic. See sepic fabrics.

Litho-relicts. Features derived from the parent rock and usually recognized by their rock structure and fabric.

Mangan. A cutan composed of manganese oxides.

Masepic fabric. See sepic fabrics.

Metavughs. Vughs whose walls appear to be significantly smoother than would result from the normal random packing of plasma and skeleton grains.

Micropedology. Microscopic investigation of the soil.

Micromorphology. Microscopic study of shape and form of soil.

Moder. A zoogenous forest humus form made up of plant remains partly disintegrated by the soil fauna (F layer), but not matted as in raw humus. Although incorporation of organic matter is intense, it is shallow, because none of the organisms concerned with moder formation have important burrowing activity. Mixing of organic and mineral particles is purely mechanical.

Mor. A non-zoogenous forest humus form distinguished by a matted F layer and a holorganic H layer with a sharp delineation from the A horizon. Generally matted and high organic matter content.

Mosepic fabric. See sepic fabrics.

Mull. A zoogenous forest humus form consisting of an intimate mixture of well humified organic matter and mineral soil that makes a gradual transition to the horizon below. It is distinguished by its crumb or granular structure, and because of the activity of the burrowing microfauna (mostly earthworms) partly decomposed organic debris does not accumulate as a distinct layer.

Neo-argillan. A neo-cutan composed of clay minerals.

Neo-calcan. A neo-cutan composed of a concentration of carbonates.

Neo-cutan. A pedological feature that occurs within the s-matrix but immediately adjoining and related to natural surfaces in the soil material.

Neo-ferran. A neo-cutan composed of a concentration of iron oxides.

Neo-mangan. A neo-cutan composed of a concentration of manganese oxides.

Nodules. Glaebules with an undifferentiated fabric; in this context undifferentiated fabric includes recognizable rock and soil fabrics.

Organan. A cutan composed of a concentration of organic matter.

Organic fragments. Fragments of organic plant and animal material both fresh and partially decomposed.

Oriented. Refers to degree of orientation of like individuals with regard to a specific reference feature (slightly, weakly, moderately, or strongly).

Orthovugh. Vughs whose walls appear to result from the normal random packing of plasma and skeleton grains.

Papules. Glaebules composed dominantly of clay minerals with continuous and/or lamellar fabric, and sharp external boundaries.

Ped. An individual natural soil aggregate consisting of a cluster of primary particles, and separated from adjoining peds by surfaces of weakness that are recognizable as natural voids or by the occurrence of cutans.

Pedal. Applied to soil materials; most of the soil material consists of peds.

Pedological features. Recognizable units within a soil material which are distinguishable from the enclosing material for any reason such as origin (deposition as an entity), differences in concentration of some fraction of the plasma, or differences in arrangement of the constituents (fabric).

Pedotubule. A pedological feature consisting of soil material (skeleton grains plus plasma, as distinct from concentrations of fractions of the plasma) and having a tubular external form, either single tubes or branching systems of tubes.

Phytoliths. Inorganic bodies derived from replacement of plant cells; they are usually opaline.

Plane argillan. An argillan association with the surface of a plane (planar void).

Plasma. That part of the soil material that is capable of being or has been moved, reorganized, and/or concentrated by the processes of soil formation. It includes all the material, mineral or organic, of colloidal size and relatively soluble material that is not bound up in the skeleton grains.

Plasma concentration. Concentrations of any of the fractions of the plasma in various parts of the soil material due to soil formation.

Plasma separation. Features characterized by a significant change in the arrangement of the constituents rather than a change in concentration of some fraction of the plasma.

Plasmic fabric. The fabric of the plasma of the s-matrix, that is, the arrangement of the plasma and skeleton grains.

Porphyroskelic fabric. The plasma occurs as a dense ground mass in which skeleton grains are set after the manner of phenocrysts in a porphyritic rock.

Separated. Applied to pedological features. Referred to as slightly, weakly, moderately, or strongly separated according to the degree of contrast in fabric or concentration of material between the pedological features and the s-matrix of the soil material.

Sepic fabrics. Plasmic fabrics in which patches and/or zones of plasma have striated extinction patterns under crossed polarizers. The following types are recognized: insepic (isolated patches with a striated extinction pattern), mosepic (frequent patches), vosepic (zones associated with voids), skelsepic (zones associated with grains and/or glaebules), masepic (elongated zones through the plasma), bimasepic (elongated zones in two directions through the plasma), omnisepic (all the plasma has a complex striated extinction pattern), lattisepic (type of bimasepic fabric where domains occur in lattice-like pattern). Compound fabrics can occur (e.g. Skel-ma-insepic fabric) in which several fabric elements are present; in these the weaker elements are named first (skel in the example) and the stronger elements last (insepic in the example). Sepic fabrics can also be compounded with other types.

Sesquan. A cutan composed of a concentration of sesquioxides.

Silasepic fabric. See asepic fabrics.

Simple cutan. Composed of a single mineralogical and/or chemical substance or of a uniformly intimate mixture; there is no detectable layering effect in composition of fabric.

Skeletan. A cutan composed of skeleton grains.

Skeleton grains. Individual grains that are relatively stable and not readily translocated, concentrated or reorganized by soil forming processes; they include mineral grains and resistant siliceous and organic bodies larger than colloidal size.

Skel-insepic fabric. See sepic fabrics.

Skel-lattisepic fabric. See sepic fabrics.

Skel-latt-vosepic fabric. See sepic fabrics.

Skel-masepic fabric. See sepic fabrics.

Skel-vo-lattisepic fabric. See sepic fabrics.

Skew planes. Planar voids that traverse the soil material in an irregular manner.

S-matrix (of a soil material). The material within the simplest peds, or composing apedal soil materials, in which the pedological features occur; it consists of the plasma, skeleton grains and voids that do not occur as pedological features other than those expressed by specific extinction (orientation) patterns. Pedological features also have an s-matrix.

Stress cutan. In situ modifications of the plasma due to differential forces such as shearing; they are not true coatings.

Structure. The physical constitution of a soil material as expressed by the size, shape and arrangement of the solid particles and voids, including both the primary particles to form compound particles and the compound particles themselves; fabric is the element of structure which deals with arrangement.

Trellised channels. The channels interconnected by branching and rejoining of the branches to produce an irregular network.

Void. A term used to encompass all the morphologically different types of openings in the soil (e.g. vughs, channels, planes).

Void argillans. Argillans associated with unspecified voids in the soil material (all void argillans are attributed to illuviation).

Void neo-cutans. Neo-cutans associated with unspecified voids in the soil material.

Vo-lattisepic fabric. See sepic fabrics.

Vosepic fabric. See sepic fabrics.

Vughs. Relatively large voids, usually irregular and not normally interconnected with other voids of comparable size; at the magnifications at which they are recognized they appear as discrete entities.

Vugh calcans. Calcans associated with vughs.

Unoriented. No orientation exhibited.

APPENDIX III

(Size and Shape Classes)

Size Class: (after Brewer and Sleeman, 1960)

Class name	Class limit
Extremely fine	<0.005 mm
Very fine	0.02 - 0.005 mm
Fine	0.1 - 0.02 mm
Medium	0.5 - 0.1 mm
Coarse	2.0 - 0.5 mm
Very Coarse	10.0 - 2.0 mm
Extremely coarse	>10.0 mm

Shape: (after Zingg, 1935, as quoted by Brewer, 1964)

Equant	$b/a > 2/3$	$c/b > 2/3$
Prolate	$b/a < 2/3$	$c/b > 2/3$
Tabular	$b/a > 2/3$	$c/b < 2/3$

The following terms and subdivisions were applied to shape class by Pettapiece (1964) and will be used in this study.

Equant	blocky subangular blocky granular
Prolate	prismatic
*Planar	platy
Massive	massive single grained

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* Pettapiece (1964) suggested that "Planar" would be a more appropriate term than "Tabular" in these soil studies, and it would have the mathematical limits $b/a > 1/10$; $c/b < 1/10$. Also, there would be an additional fourth shape, namely: "Massive", in which no axis is limited.