MORPHOLOGICAL, CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF ORTHIC GREY WOODED AND DEGRADED BROWN WOODED SOIL PROFILES DEVELOPED ON COARSE TEXTURED PARENT MATERIALS

A Thesis
Submitted to
The Faculty of Graduate Studies and Research
University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
MASTER OF SCIENCE

by
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May, 1965

ACKNOWLEDGEMENTS

The author wishes to extend his sincere appreciation and gratitude to Dr. M.A. Zwarich, Assistant Professor, Department of Soil Science, University of Manitoba, under whose direction this work was carried out.

Acknowledgements are also made to various members of the Manitoba Soil Survey staff for their helpful suggestions, and to R.H. Sitko and R. DePape for their help in the drafting of maps and graphs.

Gratitude is expressed to my wife for her patience and encouragement throughout this study, and for her assistance in preparing and typing the manuscript.

ABSTRACT

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Gordon F. Mills

In Eastern Manitoba, Orthic Grey Wooded and Degraded Brown Wooded soils are found on sandy textured outwash and aeolian materials. These two soil types occur under similar drainage, climatic and biotic conditions. The main difference in morphology between the two soil profile types is associated with the presence of limestone cobbles in the B horizon of the Orthic Grey Wooded soil and the degree of development of the B horizons. The Orthic Grey Wooded soils are characterized by a fairly large clay accumulation in the B horizon whereas the Degraded Brown Wooded soils have very little accumulation of clay in the B horizon.

The sola of all profiles are medium acid to neutral in reaction. The high degree of unsaturation that is typical of podzolic soils is not evident in the two profile types investigated. The B horizons of all soils have been enriched in free iron, organic matter and clay with the latter component being dominant. Free iron in the B horizon can be attributed to in situ release of iron from iron bearing minerals and to translocation of iron from the A horizon. Organic matter appears to have been translocated from the A to the B horizon. The clay in the B horizons can be attributed to in situ release from the limestone cobbles as well as translocation of clay from the A horizons. The most strongly pronounced Bt horizons occur in soils that have a fairly continuous layer of flat lying limestone cobbles in the B horizon.

In the fine sand fraction, quartz, potash feldspars and soda-calcic feldspars occur in the light mineral fraction, (sp.gr. <2.85), and

hornblende, garnet and opaque minerals are dominant in the heavy mineral fraction (sp.gr. >2.85). In the coarse clay fraction, quartz, vermiculite, chlorite, illite, montmorillonite and random mixed-layer minerals were identified. Alteration of illite and vermiculite appears to have occurred in the coarse clay fraction of the A horizon. In the fine clay fraction of the A horizon, mixed-layer minerals and montmorillonite have been formed from the alteration of illite and from the breakdown of coarse clay mixed-layer minerals. Some of the vermiculite in the coarse clay fraction may have been altered to montmorillonite of fine clay size. Analysis of the limestone cobbles showed quartz, illite and random mixed-layer minerals to be present. Illite and mixed-layer minerals released from the limestone cobbles probably also have been altered as outlined above.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

I INTRODUCTION

Eastern Manitoba is divided into two main Physiographic Divisions known as the Manitoba Lowlands and the Precambrian Drift Plain. The Manitoba Lowlands is that portion of Manitoba forming the Lake Agassiz Basin and as such the surface deposits are mainly glacio-lacustrine and glacio-fluvial in nature along with some reworked glacial till. The Precambrian Drift Plain is characterized by acid igneous rock outcrop and associated organic and mineral deposits.

The soils included in this study occur within the Winnipeg Lake Terrace and in the South-Eastern Lake Terrace sections of the Manitoba Lowlands. These two sections of the Manitoba Lowlands have a sub-humid climate with an excess of precipitation over evaporation. This is reflected in the vegetation, which is classed as a Mixed Boreal Forest. The soils were classified on the basis of profile type into the Orthic Grey Wooded subgroup of the Podzolic Order and into the Degraded Brown Wooded subgroup of the Brunisolic Order. A total of six profiles were sampled. The profiles selected were of similar texture and drainage and developed under similar climatic and biotic conditions. The objectives of the present study were to:

1. characterize the two main profile types found under the aforementioned conditions in Eastern Manitoba;
2. study the formation of a B horizon in these soils; and in particular to determine the relationship between the clay accumulation and the limestone cobbles in some of the B horizons.

II LITERATURE REVIEW

SOIL CLASSIFICATION

The Canadian taxonomic classification of soils has six categories; type, series, family, subgroup, great group and order (45). The grouping of soils at the higher levels of abstraction, i.e. subgroup, great group and order, is based on selected features of the soil profile. Thus the differentiating criteria for these higher levels are largely the morphological features which reflect the effects of climate, vegetation, local moisture relations and age on the parent material. In other words, although soil classification in Canada is based on morphological features, concepts of soil genesis affect the selection of criteria used for the higher groupings.

Soils at the order level are recognized on the major morphological features of the entire profile but not necessarily on the absence or presence of any one horizon. Each soil in an order is recognized by several distinctive features common to all soils in the class.

Each order is subdivided into two or more great groups. The differentiae used in this category vary from one class to another. In the case of Podzolic and Brunisolic soils the criteria used are based on composition and morphology.

Soils at the subgroup level represent the orthic and intergrade members of the great groups. In the subgroup the soils are classified on more specific characteristics and consequently are defined more exactly. Separations in this category are made on the presence or absence and kind (i.e. calcium carbonate, clay, free iron, gleying, etc.) of horizons.

THE PODZOLIC ORDER OF SOILS

According to the National Soil Survey Committee Classification for Canadian Soils (N.S.S.C.) (45), soils in the Podzolic Order are, "well and imperfectly drained soils developed under forest or heath having light coloured eluviated horizons (Ae) and illuvial B horizons with accumulation of sesquioxides, organic matter or clay or any combination of these. They may have organic (L-H) and mineral-organic (Ah) surface horizons." The Podzolic Order is divided into the following Great Groups: Grey Brown Podzolic; Grey Wooded; Grey Forested; Humic Podzol; and Podzol. The Grey Wooded Great Group is discussed here as it pertains to some of the soils in this study.

Grey Wooded Great Group

Grey Wooded soils, according to the N.S.S.C. (45) are soils "with organic surface horizons (L-H) with light coloured eluvial horizons (Ae) and with illuvial horizons (Bt) in which clay is the main accumulation product. An increase of free sesquioxides is usually associated with the accumulation of clay. The solum generally has a medium to high degree of base saturation."

The best developed Grey Wooded soils are found under cool climatic conditions with mean annual temperature of 40°F or less, although they also occur under warmer conditions. The majority of Grey Wooded soils occur under boreal forest. Some Grey Wooded profiles also develop under forest conditions in the grassland-forest transition zone. They generally have developed on basic parent materials.

Orthic Grey Wooded Subgroup.

Orthic Grey Wooded soils are the well drained members of the Grey Wooded Great Group. They exhibit the modal concept in that they have well developed Ae and Bt horizons.

THE BRUNISOLIC ORDER OF SOILS

The N.S.S.C. report (45) defined the Brunisolic Order of soils as "well to imperfectly drained soils developed under forest, mixed forest and grass, or heath vegetation with brownish coloured sola without marked eluvial or illuvial horizons. They may or may not have a distinct Ah horizon." The Brunisolic Order is divided into the following Great Groups: Brown Forest; Brown Wooded; Acid Brown Wooded; Acid Brown Forest; Concretionary Brown; and Subalpine Brown. Only the Brown Wooded Great Group is discussed here as it applies to some of the soils in this study.

Brown Wooded Great Group.

Brown Wooded soils, according to the N.S.S.C. (45), are soils with "weakly acidic to mildly alkaline sola and without a distinct Ah horizon. An L-H horizon is usually present. The parent material is usually calcareous. The thickness of the solum is usually less than two feet."

Brown Wooded soils have a wide range of occurrence from dry valleys in the Cordillera to upper river terraces in the forested region of the Great Plains. In the Cordillera they appear to be developing as zonal soils of the dry forest areas and also under similar climatic and biotic conditions as the Grey Wooded soils. "The Brown Wooded soils appear to represent a stage of soil development between a Regosol and a Grey Wooded soil. Their lack of distinct eluvial or illuvial horizons appears to be due to dry climate, youthfulness, high lime parent material or a combination of all these factors" (45).

Degraded Brown Wooded Subgroup.

Degraded Brown Wooded soils are the well drained degraded members of the Brown Wooded Great Group. The slight degree of degradation is expressed in weakly developed illuvial horizons as shown by some clay accumulation.

THE RELATIONSHIP BETWEEN PODZOLIC AND BRUNISOLIC SOILS

The National Soil Survey Committee (45) has suggested a sequence of development for Brown Wooded soils: Regosol→Orthic Brown Wooded → Degraded Brown Wooded→Grey Wooded. As the Brown Wooded soils can be found with varying degrees of development under similar conditions as well developed Grey Wooded profiles, the above sequence of development seems quite logical.

Pawluk and Lindsay (40) in a study of Brunisolic soils of Northern Alberta found that with further development of Orthic Brown Wooded soils, the degraded solum meets the morphological criteria suggested for the Degraded Acid Brown Wooded Subgroup. In some cases a Minimal Podzol profile had developed. They consider this soil to be an intergrade toward the Degraded Brown Wooded, representing an intermediary stage in the development of Podzols from Orthic Brown Wooded soils.

Wright *et al.*(65) describe three distinct profile types on alluvial deposits in northern Canada which appeared to represent a chronosequence in soil formation. The sequence of soils studied was an Alluvial soil on the lowest terrace of the river, a Brown Wooded soil on the middle terrace, and a Grey Wooded soil on the highest terraces above the river. It appeared that the degree of soil development was related to their height above the river and so was a function of the time which the various soil forming factors had acted on the parent material.

Kelley and Holland (28) state that Brown Wooded soils are the first in the development sequence of a Grey Wooded soil. Such profiles show some weathering but leaching and accumulation are not pronounced.

As precipitation and eluviation increase Grey Wooded soils develop.

A review of the literature on "The Concept of Braunerde (Brown Forest Soil) in Europe and the United States" by Tavernier and Smith (59) indicates that some of these soils are intrazonal in nature whereas others are classified with Podzolic soils. However, it appears that the name Brown Forest has been used in the United States to describe soils that are comparable to the Brown Forest soils as defined by the N.S.S.C. In their review they do not appear to describe a soil that is comparable to the Brown Wooded soils as described in the Canadian Classification scheme.

THEORIES ON THE PODZOLIZATION PROCESS

Podzolic soils develop under climatic and biologic conditions that result in the accumulation of an organic surface layer and the formation of acid decomposition products of organic matter. This occurs most readily in moist cool climates under forest or heath vegetation.

Robinson (49) states that the dominant factor in the development of a Podzol soil is the prevalence of intense leaching owing to the continual excess of rainfall over evaporation.

Lutz and Chandler (29) apply the term podzolization to "the process or processes which lead to depletion of bases, development of acidity and formation of eluvial A horizons and illuvial B horizons. Colloids and iron and aluminum compounds are removed from the A horizons and accumulated in the B horizons."

According to Stobbe, (55) before an appreciable translocation of organic compounds and sesquioxides can take place (podzolization), a considerable fraction of the exchangeable cations of the upper part of the

replaced by H^+ ions. The rapidity of this unsaturation process will vary with the type of parent material. In calcareous materials, the carbonates must first be removed and some unsaturation must occur. This is followed by the dispersion and translocation of clay before any appreciable translocation of organic matter and sesquioxides takes place.

Stobbe suggests that the term "decalcification" be used to describe the genetic processes of "podzol-like" soils in their primary phase of weathering. The process of decalcification is essentially a depletion of bases in the solum, development of acidity and the formation of an eluvial "A" horizon and an illuvial "B" horizon.

Ehrlich (11) concurs with Stobbe's ideas and adds that calcium either directly or indirectly plays a dominant role in the profile formed. He states that the "podzol-like" profile will remain until most of the calcium is replaced by hydrogen. True podzolization then occurs only in that part of the solum low in bases i.e. the Ae horizon. Where decalcification has been in effect long enough to produce a fairly deep Ae horizon, podzolization will take place in the Ae horizon to produce a Podzol profile. Ehrlich concludes that because each profile is a separate entity each must have been influenced by a different process.

Swindale and Jackson (58) use podzolization as a collective term for the large number of chemical, physical and biological processes contributing to the formation of podzols. They propose two individual processes to account for podzolization: (1) <u>soluviation</u>, defined as the decomposition by solution combined with eluviation to remove the dissolved ions from their original environment and (2) <u>cheluviation</u> which is defined as the dissolution of a silicate mineral in contact with a liquid containing chelating agents.

Wright and Levick (66) developed a podzolic profile by leaching a column of calcareous sand with a chelating agent, EDTA (ethylene-diamine tetraacetic acid). A check was set up using water. The columns were leached for approximately seventeen months. The results showed that in the EDTA column the carbonates were removed to a greater depth, a larger portion of the profile was made acid and iron and aluminum were transferred further down than in the column leached with water. The authors suggest the following mechanism for the removal of iron and aluminum:

"As leaching progresses, carbonates are destroyed and calcium and magnesium transported downward in both chelate and ionic forms. As the pH and concentration of alkaline earth metals in solution at the top decrease, increased amounts of iron and aluminum are sesquestered and transported downward."

Schnitzer and Delong (51) in a review of the podzolization process state that Bloomfield found that aqueous extracts prepared from the leaves and bark of the New Zealand Kauri tree and also from pine needles, dissolved hydrous oxides of iron and aluminum, reduced ferric iron and formed complexes with ferrous ions. Bloomfield concluded that natural leachates from undecomposed coniferous litter provided all the conditions essential for podzolic translocation of sesquioxides.

A Russian worker, Karpachevsky (26) states that in the podzolization process intensive decomposition of primary minerals (feldspars and accessory minerals) occurs in the upper horizons. The decomposition products thus formed, in particular the iron and silica colloidal material is moved down by water into the lower horizons. These colloids move as hydrosols.

Duchaufour (10) suggests that there are two different podzolization processes. He applied the word "lessivage" to the processes of the movement of the clay size material from the upper into the illuvial horizons without change in its composition (along with hydrated ferric oxides). He contrasts this process with podzolization proper during which he thinks the clay in the upper horizons is decomposed and only its decomposition products move downward. Duchaufour concludes that lessivage conditions the solum for the development of podzolization.

Parfenova and Yarilova (37) after reviewing Duchaufour's work concluded that clay movement was evident in the micro-morphology of all soils in which the eluviation process is dominant, including podzolic soils and podzols.

Fridland (14) proposes the term "illimerization" to take care of the movement of undifferentiated clay (clay migration) without destruction of the clay minerals. The related process involving the destruction of the clay with differential removal of the products of this destruction is podzolization.

The Movement of Clay Minerals.

Robinson (49) classifies the eluvial process into two main types; namely, (1) mechanical eluviation in which the finer fractions of the mineral portion of the soil are washed down by the action of percolating water to lower levels and (2) chemical eluviation in which decomposition occurs and certain products thus liberated are translocated in true or colloidal solution to be deposited in other horizons. Eluviation as Robinson describes can thus result in the development of a textural profile with a light textured Ae horizon and an underlying heavy textured Bt horizon.

Brown *et al.*(6) and Jenny and Smith (20) suggest that the process of eluviation and subsequent formation of a textural B horizon involves firstly the dispersion of colloidal material in the Ae and then its deposition in the B horizon. They suggest two types of deposition. One method is a sieve action in which coagulation by electrolytes plays a part and a second method involved attraction based on the adherance of positive sols to quartz grains.

It is quite possible for clay particles to move mechanically in soils as the mineral size as shown in Grim's data is under one micron. This is considerably less than the soil pores and cavities which are in the order of several hundred microns in size (18).

Gorbunov in 1961 (15), in his summary on the movement of colloidal and clay particles in soils, states that the colloids in order to move in the soil must be in the form of a sol or a highly swollen gel. Highly dispersed hydrophylic minerals such as montmorillonite, allophane, hydromicas and organic matter move more rapidly than hydrophobic minerals under the same conditions. The latter types of minerals usually move under the protection of hydrophylic minerals. Gorbunov concludes that colloids and clay move in the soil in the form of minerals, organo-mineral and organic compounds.

The Movement of Sesquioxides.

A characteristic of nearly all Podzolic soils is the movement of sesquioxides out of the eluvial horizons and into the illuvial horizons. However, very little is known about the processes and mechanisms involved in the movement of sesquioxides.

According to Stobbe (55) the close connection between the movement of the decomposition products of organic matter and the sesquioxides has long been recognized. Theories on the Podzolization process also show that before an appreciable translocation of organic compounds and sesquioxides can take place, a considerable degree of unsaturation of the upper profile must take place. Early work has shown the ability of organic material and its decomposition products to mobilize iron. Organic acids, particularly hydroxy acids are effective mobilizers of iron, with the iron being associated with the electronegative part of the organic molecule.

More recent work has produced evidence to show that the translocation of organic matter and iron is brought about by the formation of mobile organo-mineral complexes. According to Bloomfield (4) leaf extracts of conifers solubilize iron by the reduction of ferric iron followed by the formation of stable organic complexes with ferrous iron. Schnitzer and DeLong (52) showed that almost all the iron brought into solution by various leaf leachates is in the ferric form. Their work indicates that extracts from various tree leaves and forest litter have the capacity to retain iron in solution and to solubilize the iron of freshly precipitated ferric hydroxide. The amount of iron brought into suspension depends on the source of the extract, the pH and the nature of the dominant cation present and on the proportion of iron to organic matter in the system. This is in opposition to Bloomfields theory that iron must be reduced before it is mobilized.

The work on leaf leachates shows that extracts of organic litter and decomposition products of plant material can solubilize iron either by peptization or by the formation of organic complexes which are soluble. Some workers now consider these complexes to be chelate complexes. Swindale and Jackson (58) suggest that the decomposing organic matter produces chelating substances that combine with the iron and aluminum in the soil. Wright and Schnitzer (67) have produced artificial Podzols in the laboratory with known chelating agents such as EDTA.

Oades (36) in his review of iron mobilization and transportation by organic matter concludes that this process is due to two main classes of compounds: (a) polyphenols and (b) low molecular weight organic acids.

The Deposition of Sesquioxides.

The mechanism of the deposition of sesquioxides in soils is also a controversial point. Some workers have suggested that precipitation is caused by an increase in pH down the profile i.e., Mattson's "isoelectric theory" (30). The isoelectric theory is based on the fact that hydro-oxides of iron or aluminum must have a hydrogen-ion concentration at which the hydroxides have a minimum solubility. The pH corresponding to this minimum solubility is called the isoelectric point. Iron, aluminum and colloidal organic matter possess different isoelectric points. Organic colloids are precipitated in the upper part of the B horizon because their isoelectric point is the lowest. Iron is precipitated lower in this horizon and below this the aluminum is found in larger quantities. The positions of these three constituents corresponds with the increasingly higher isoelectric points. The new formation originates and accumulates in the B horizon because acid hydrolysis is subdued at that point in the profile and the pH becomes basic.

Wright and Schnitzer (67) explain the precipitation of sesquioxides associated with chelating agents in the following manner: "With depth, increasing competition from hydroxyl ions with rising pH and greater concentration of the alkaline earths caused displacement of some iron and aluminum and their precipitation as hydrated oxides." They state that extremely small amounts of calcium and/or magnesium can cause displacement of the sesquioxides.

Adsorption of the iron-organic complexes by iron oxides, aluminum oxides, and soil clays may be an important factor. Two articles are cited by Oades (36) which show that a clay mineral such as kaolinite is capable of fixing 12 per cent iron oxide before the saturation point is reached. Carroll (8) suggests that clay minerals have free iron associated with them in two ways: (1) as a minor constituent where it is substituted isomorphously within the crystal lattice and (2) as iron oxide coatings on the surface of the mineral platelets. Bloomfield (5) points out that the adsorption of ferrous organic complexes by ferric oxides is carried out in lower soil horizons. Kaurichev and Nozdrunova (27) have shown aluminum oxide to be a good sorbent for iron in descending solution.

The Synthesis of Clay Minerals.

According to Grim (18) clay size particles in soil include all materials, both inorganic and organic less than two microns in diameter. The inorganic component is made up of clay minerals as well as various amorphous and poorly crystalline materials and primary minerals such as quartz, calcite, dolomite, mica, feldspars and gibbsite. These primary minerals tend to be concentrated in the coarse clay fraction. The organic component of the clay size fraction may be present as discrete organic particles or as organic molecules adsorbed on the surfaces of the clay mineral particles. As was previously noted the sesquioxides of iron and alumina are also associated with the clay mineral surfaces.

The clay mineral concept which has evolved through the works of many people is summarized by Grim (18) who states that "clays generally are essentially composed of extremely small crystalline particles of one or more members of a small group of minerals known as the clay minerals." The clay minerals are described by Grim as being hydrous aluminum silicates with magnesium or iron substituting isomorphously in whole or in part for the aluminum in some minerals. Clay minerals are classified into various groups according to their basic structure.

Mitchell (33) groups clay minerals into three categories based on their origin: (1) those inherited without change from the parent material: (2) those derived from the alteration of minerals of similar structure; (3) those synthesized from the dissolved amorphous products of weathering.

One of the major sources of material for Mitchell's first two groups is the clay minerals in sedimentary rocks. This source is very important in light of the fact that the area of exposure of sedimentary rocks is approximately three-quarters of the total land area. These sedimentary rocks contain clay minerals varying in quantity from major components (shales) to minor impurities (sandstones) (43).

Grim et al.(16) working with the fine fraction of the insoluble residues of 35 Illinois limestones and dolomites found that illite was present in all of the samples. Moorhouse (34) also found that illite is a common clay mineral found in sedimentary limestones whereas glauconite is found in some limestone and chlorite is uncommon except in argillaceous limestone.

Early workers showed that much of the clay minerals in sedimentary rocks were authigenic in origin (16,17,34). Weaver (63) has shown that in general clay minerals do not originate in total in their depositional environment, and that they are not strongly modified by this environment. Weaver states that as little as 5 per cent of the clay minerals in sedimentary rocks are authigenic in origin, the remainder being detrital. The cations may be authigenic if acquired in the depositional area or detrital if they are the original cations from the source area. Weaver states that the detrital clay minerals are relatively stable and their original structure does not materially change except under relatively intense weathering.

Partial alteration of minerals as in the case of Mitchell's second group is probably most important for those with the basic mica structure, that is illite, vermiculite, chlorite and montmorillonite, but other clay minerals also may be partially altered. The weathering of layer-type minerals may take the form of the removal of cations or chemical groups from a particular portion of the mineral but the remainder of the crystal may remain largely unaltered.

Jackson *et al.*(22) have arranged the alteration of the clay minerals into weathering sequences. They propose the following weathering sequence in which potassium is abundant in the system: mica⇌illite⇌ "intermediates"⇌vermiculite⇌montmorins. Montmorin, according to the authors, is an isomorphous series of expanding 2:1 layer silicates including saponite, beidellite, montmorillonite, nontronite, etc. On the basis of x-ray diffraction, D.T.A., glyceration and elemental analysis they concluded that the "intermediates" in the above sequence are essentially interstratified x-amorphous zones in 2:1 layer silicates. They suggest that as a true mica weathers the interlayer K is depleted along preferential weathering planes, and is replaced by other cations. The loss of some of the mica charge (because of removal of K) is compensated by hydroxylation and dealumination in the octahedral layer. With increasing numbers of weathered planes in the mica sheets various combinations of x-amorphous—x-crystalline zones are formed.

These authors go on to state that there are four chemical reactions which affect weathering of layer silicates; depotassication, hydroxylation, dealumination, and desilication. Depotassication, or the removal of interlayer K along preferential weathering planes would be the initial step. Balancing of the excess charges resulting from depotassication can be accounted for by hydroxylation and/or dealumination, the latter taking place especially under acid conditions. Desilication refers to silica removal from 2:1 layer silicates to form kaolinite and gibbsite.

Walker (61) also described a progressive weathering in soil through mixtures of mica and vermiculite to vermiculite.

> "........leaching of K from interlayer positions together with replacement of iron in the interior of the silicate layers by Mg and other ions from percolating waters, reduce the attractive interlayer forces and permit the entry of double layers of water molecules. This latter phenomenon spreads through the crystal layer by layer by giving at first a mixed-layer structure in which increasing numbers of layers become the vermiculite type."

Rich (46) presents results which show that when muscovite-type mica weathers there is loss of potassium and the formation of vermiculite. Similarily De Mumbrum (9) in a laboratory experiment shows that mica weathers to vermiculite. A possible path of weathering of illite to vermiculite is shown in Figure 1.

Brydon (7) reports a distinct difference in the weathering of chlorite within the solum as opposed to the theoretical breakdown. Orthochlorites in acid solution should take up hydrogen and release magnesium until all the magnesium is released or until the pH rises to that which would satisfy the solubility products of magnesium hydroxide. The iron

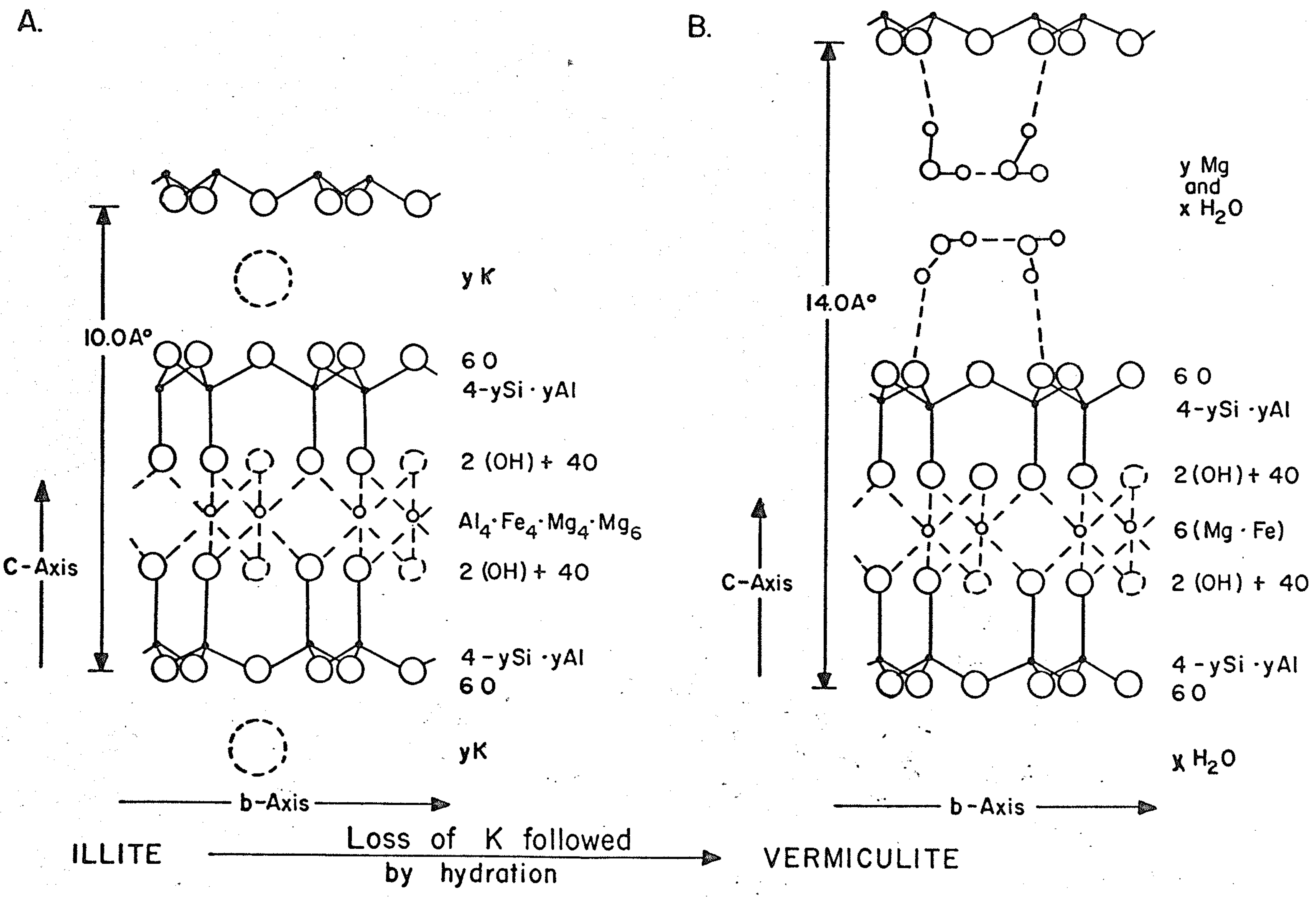

Figure 1. Schematic diagram illustrating a possible path of weathering of illite to vermiculite.

A. (After Grim, Bray, and Bradley, from Grim, 1942, J.Geol., Vol. 50, Fig. 3, p.244.)

B. (After crystal structure as outlined in Grim, R.E., 1953, Clay Mineralogy p.73-74, McGraw-Hill Book Co., Inc., New York.)

and aluminum ions of the chlorite would be exposed at the same time as the magnesium but due to the low solubility of the iron and aluminum hydro-oxides the iron and aluminum would precipitate in the pH range indicated. It is thought that the iron and aluminum hydroxides form on the chlorite surface, block the edges, impede the entry of hydrogen and the exit of magnesium thus decreasing the rate of degradation of the chlorite. Brydon then states that "this blockage could account for the persistence of chlorite in the highly acidic B or C horizons of podzols and other soils. On the other hand the leaching universally associated with the podzolization process in the Ae horizon would remove continually any protective layer of hydroxide and allow degradation to go to completion more rapidly."

Pawluk (39) notes that Podzol soils of Alberta have a 14Å spacing clay mineral in the B horizon which is not present in the parent material. The data presented indicate that the weathering of less stable feldspars to release hydrated alumina ions which are absorbed on the interlayer region of montmorillonite fine clay produce a 14Å spacing clay mineral of coarse clay size in the B horizon.

Weaver (62) states that mixed-layer clays in most cases are derived from the degradation or aggradation of pre-existing clay minerals. During weathering the removal of K from some biotite layers with subsequent deposition of Mg and H_2O could lead to the formation of a mixed-layer biotite-vermiculite. Similarily, in sea water the replacement of Ca and H_2O between some montmorillonite layers by K will form mixed-layer illite-montmorillonite. $Mg(OH)_2$ will also replace Ca and H_2O to form mixed-layer chlorite-vermiculite.

Jackson _et al._ (22) proposed that weathering of micas gave "intermediate" minerals consisting of interstratified or mixed-layer

2:1 and 2:2 (chlorite) layer silicate series. They state that interstratification is of general occurrence in clays of soils and sediments as a resultant of weathering.

Rich and Obenshain (47) presented evidence to show that the production of interlayers containing nonexchangeable Al was a pedogenic process. The process is probably controlled by the production of Al ions in acid weathering. These ions are readily sorbed as exchangeable cations or subjected to hydrolysis and the hydroxy-Al ions formed also may be sorbed by the clay minerals. In the weathering process more aluminum is released in the surface horizons as long as there is no shortage of source material. If the organic matter content is low some of the aluminum may be fixed on the clay minerals. If organic matter is abundant the aluminum is complexed and removed. In this way soils occur in which the maximum formation of interlayer minerals is found in the Ae horizon due to low organic matter content and in other soils where the maximum formation occurs in the B horizon due to high organic matter content of the A horizon.

Rich and Thomas (48) give a very good review of current work on the synthesis of the various clay minerals. They state that the origin of clay minerals in soils is usually associated with mineral weathering and weathering sequences. Kaolinite and halloysite may be inherited in soils or may form as a result of chemical weathering of feldspars, silication of gibbsite or alteration of allophane. Trioctahedral chlorites are the most abundant variety in basic igneous rocks and in sedimentary rocks. Such minerals are rare in acid soils because they weather easily. However, a group of "chlorite-like" minerals are found in acid soils and are in reality weathered and expanded micas which now contain interlayers of various completeness and composition. These interlayers contain Al as the principal cation as opposed to Mg for the trioctahedral variety. This interlayer varies from a complete gibbsite sheet to only a few islands of positively charged $Al(OH)_x$ particles. In the latter case the mineral resembles the inter-stratified clay minerals. Dioctahedral illites are much more common than trioctahedral members because of the greater weathering stability of the former. Mica-like minerals may dissolve in soils or else alter to vermiculite and/or montmorillonite. Vermiculite may weather from illite, micas or chlorite. Montmorillonite minerals are formed from soluble or amorphous material or are altered from micas, chlorites or vermiculites. This alteration will depend not only upon exchange of K or dissolution of hydroxyl groups but also on reduction of negative charge. Interstratified clay minerals in soil can be inherited from the parent material as well as derived from micas, illites, and chlorites.

III MATERIALS AND METHODS

FIELD INVESTIGATIONS

General Description of Area

Glacial Geology of Eastern Manitoba A brief history of late Pleistocene Glaciation and post-glacial activity in Eastern Manitoba is presented to facilitate an understanding of the physiography of the area. Such knowledge helps in the description of the mode of deposition and the nature of the parent materials of the soils used in this study.

As the result of several glaciations during the Pleistocene Epoch the whole area known as the Manitoba Lowlands was covered by glacial drift of varying kinds (12). According to Elson (13) the oldest glacial deposit in this area is a grey till derived mainly from calcareous Palaeozoic rocks west of Lake Winnipeg. In the extreme eastern part of the area this grey till is overlain by red drift which was brought in by south and southwest flowing ice from the Canadian Shield. A second grey calcareous till overlies both the older grey drift and the red Cary till in the eastern part of the area.

Johnson (25) also cites evidence in support of the two Wisconsin Stage till sheets. Firstly, there are two sets of glacial striae trending in quite different directions. One set, from the northeast is probably the older with the younger being those trending from the north and northwest. The lower, older part of the till is mainly silicic in nature whereas the upper sheet is calcareous and contains an abundance of limestone boulders. Further support for the two till sheets is obtained from well borings which show that the lower part of the drift is quite different in character and origin from the upper part. These borings also show a substantial sheet of sand and gravel beneath the upper till sheet such as might have been deposited by outwash during a recession of the ice (25).

This ice sheet of the Mankato Substage of the Wisconsin Glaciation formed the northern and eastern boundary of Lake Agassiz I which inundated the whole of the Manitoba Lowlands (13). At this time the lake discharged southward into the Mississippi through a spillway at Lake Traverse, Minnesota. Readvancing ice of the Valderan Substage blocked the eastern outlets and Lake Agassiz II was formed. As the lake waters receded a series of more or less continuous beaches were formed due to water working of the higher sites by scouring and wave action. Later, when the ice had retreated far enough to allow normal northward drainage to continue, several lower beaches were formed due to the lowering of the waters and uplift of the land. A considerable portion of the uplift of the land due to the removal of the great weight of the ice occurred during the presence of the lake.

A series of terminal moraines rise at various places in the lake basin marking the stages of halt of the ice sheet during its retreat. The terrain formed by this oscillation of the ice sheet is a complex of superficial deposits consisting of till, sub aquatic till, resorted and water-worked till, sand with enormous boulders, and various lacustrine deposits. As the lake reached its last stages there was ponding and swamping of depressional sites along with an influx of alluvial sediments.

<u>Physiography of Landscape Areas</u> The physiographic divisions of Eastern Manitoba are shown in Figure 2 . The two main divisions are designated as the Manitoba Lowlands and the Precambrian Drift Plain. The Manitoba Lowlands is that portion of Manitoba which forms the Lake Agassiz basin, and is divided into sections on the basis of the surface deposits.

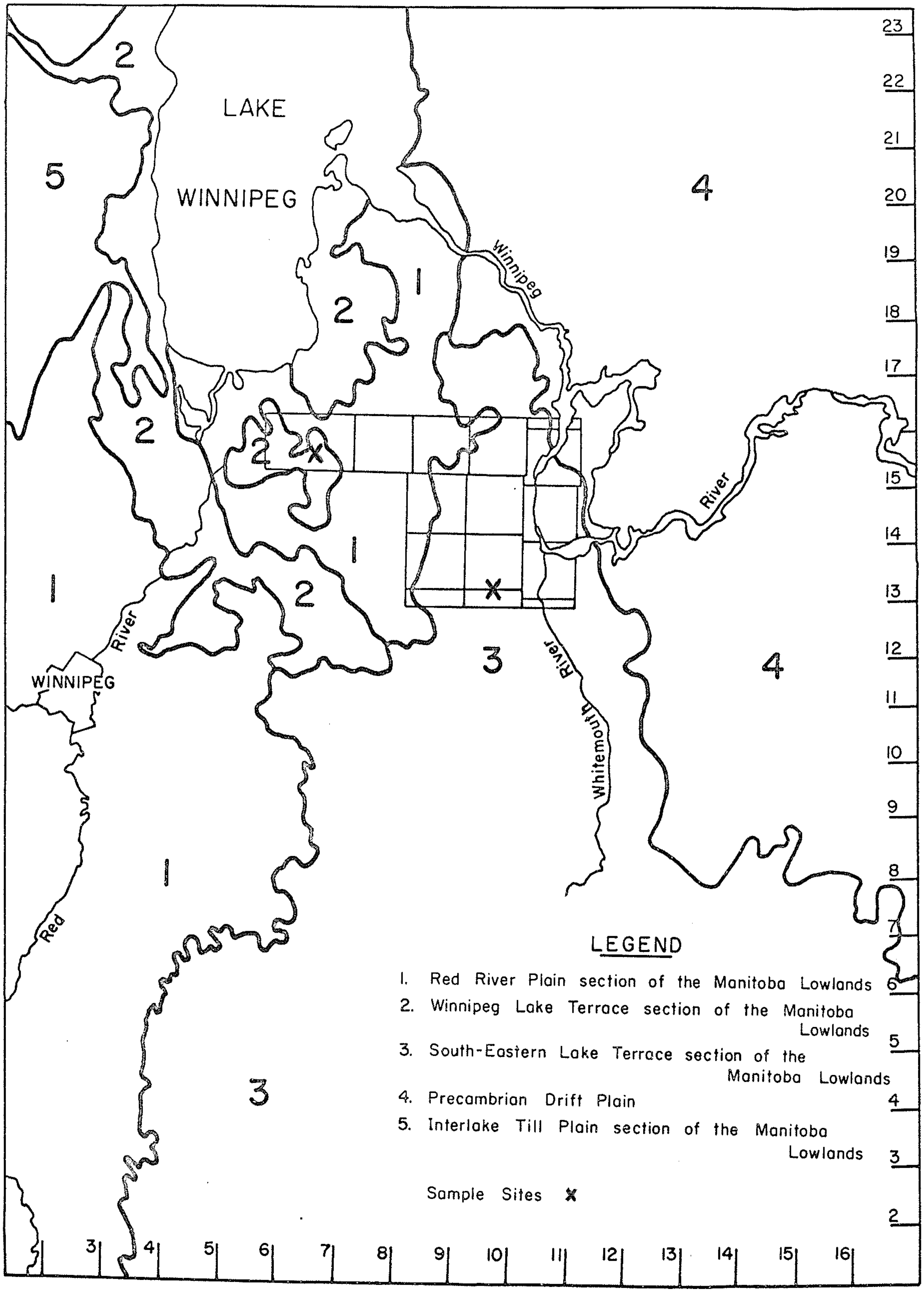

Figure 2. Map of Eastern Manitoba Showing Physiographic Areas.

According to Ehrlich et al.(12) the Red River Plain section is a flat expanse in the central and lower lying part of the Lake Agassiz basin. The major portion of this area consists of lacustrine clay and alluvial deposits. This area lies mainly below the 800 foot contour.

The Winnipeg Lake Terrace sections occur above the 800 foot contour as prominent irregular hills rising above the flat expanse of the Red River Plain. Such local hills formerly outcropped as islands in Lake Agassiz and now stand out as wooded islands in the lake plain. The surface deposits of these areas are mainly glacio-lacustrine deposits, glacio-fluvial deposits and glacial till.

The South-Eastern Lake Terrace section is described as a transitional area occurring between the Red River Plain and the Precambrian Shield, and lying above the 800 foot contour.* According to Ehrlich et al.(12) the terrain in this area is a complex of land forms that resulted from the deposition of till and sub-aquatic till by the oscillating ice sheet of the Mankato substage of the Wisconsin Glaciation. Following the laying down of this till there was modification by other geological agencies. This involved the sorting and sizing of glacio-fluvial deposits as they were carried and deposited by the melt waters of the ice. This was in turn followed by inundation of the deposits under the lake waters as the ice retreated. Further retreat of the ice sheet led to the lowering of the lake waters accompanied by scouring and wave action on the higher sites as they emerged.

The Precambrian Drift Plain lies to the northeast of the Manitoba Lowlands. It is characterized by granitoid rock outcrop and associated organic and mineral drift deposits. The mineral deposits consist of non-calcareous sandy till derived from Precambrian rocks and local lac-

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* Smith, R.E. Unpublished information from Manitoba Soil Survey.

ustrine deposits laid down when the ice sheet was retreating for the last time.

Climate of Eastern Manitoba The two landscape areas previously described lie within the region designated by Köppen as a Dfb (humid continental) climate. This area is sub-humid with wide annual extremes in temperature, and has a definite summer maximum of precipitation. At Great Falls, the nearest climatological station, the mean annual precipitation for the thirty year period 1921 to 1950 is 18.53 inches. Approximately 70 per cent of the precipitation falls as rain during the period of April to October and about 30 per cent as snow during the five months of November to March. The mean annual temperature recorded at Great Falls for the thirty year period is 35.6°F. Winter is marked by mean monthly temperatures below 32°F during November to March, while mean monthly temperatures are above 50°F during the summer months of May to September. The average January temperature is in the vicinity of -01°F and the average July temperature is about 68°F (60).

Description of Sample Sites

The location of the sample sites is shown in Figure 3 . Both sample sites are found within the Manitoba Lowlands. Profiles 1,2,3 and 4 are sampled from Township 15, Range 7 East in the Winnipeg Lake Terrace section, arbitrarily designated as the Dencross Area. Profiles 5 and 6 are sampled from Townships 12 and 13, Range 10 East in the South-Eastern Lake Terrace section. This sample site is designated as the Milner Ridge area.

The parent material in the Dencross Area is mainly glacio-fluvial in origin with some aeolian deposits. The surface textures are dominantly fine to medium sand. Evidence for the outwash nature of the parent material is the occurrence of flat limestone cobbles and layers of stratified

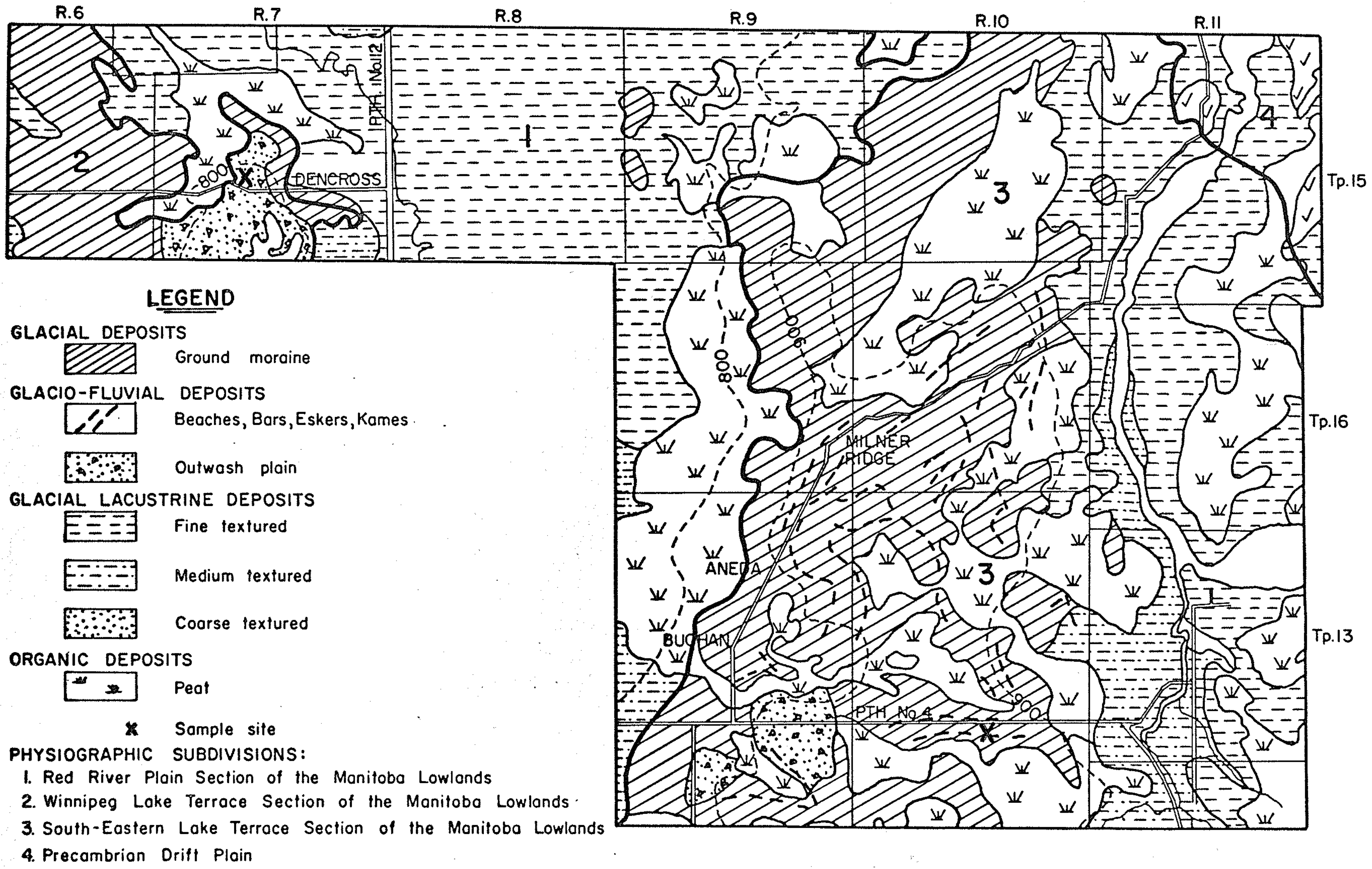

Figure 3. Map Showing Surface Deposits of Sample Sites.*

* Unpublished information from Manitoba Soil Survey.

sand and fine gravel. The duned topography and the absence of the limestone cobbles and stratified sand and gravel in portions of this area indicate that the outwash deposits have been modified by wind.

The topography is variable within the area ranging from nearly level to gently undulating. The profiles were sampled from sites with micro-relief ranging from 0 to 5 per cent slope. Stoniness ranged from stone-free duned areasto moderately stony areas occurring on the sharper slopes. The vegetation of the sample area, although falling within the Manitoba Lowlands Section of the Boreal Forest Region has been designated as having a Mixed Woods aspect because of the advent of spruce and jack-pine together with deciduous species.

The parent material in the Milner Ridge area appears to be moderately coarse-textured glacio-fluvial deposits. The surface textures are dominantly fine sand. The outwash nature of the parent material is indicated by the occurrence of limestone cobbles within the profiles.

The topography of the region varies from smooth flat areas to gently rolling undulating areas. The slope varies from about 0 to 5 per cent. The stoniness ranges from slightly stony to moderately stony. The vegetation of this area has been classed as a Mixed Boreal Forest with jack pine and birch predominating along with minor stands of aspen. Figure 4 illustrates typical vegetation on these sandy upland areas.

Profile Descriptions

Six profiles were sampled and described fully in the field. Pits were dug to facilitate the sampling and visual examination of the profile characteristics. Both dry and moist colours were derived using the Munsell color chart (35).

(1) Dencross Area

Profile No. 1 - Orthic Grey Wooded.

Location - S.E. $\frac{1}{4}$ 16-15-7 East of the Principal Meridian.

Figure 4.

Vegetation typical of sample sites.

Soil Condition - Dry to moist.

Parent Material - The parent material at this site is mainly fine sandy outwash as indicated by a discontinuous layer of limestone cobbles at about 17 inches below the surface. The deposits below the cobble layer appeared to be quite uniform to a depth of 4 feet.

Elevation - Approximately 850 feet A.S.L.

Relief - Profile was sampled in an area of complex topography, the slope varying from 0.5 to 2.0 per cent. The topography was irregular, level to undulating.

Drainage - Well to rapidly drained internally, slow runoff and rapid infiltration.

Stoniness - Varies within the area but usually a slightly stony surface.

Vegetation - Jack pine are dominant; bearberry and blueberry are abundant; chokecherries, saskatoons and roses are among the taller shrubs; <u>Cladonia</u> colonies are present; various dry grasses and fescues.

Sampled by - G.F. Mills and M.A. Zwarich

Date - October 5, 1961.

<u>Horizon</u>	<u>Depth(inches)</u>	<u>Description</u>
L - H	0.5 - 0	An organic layer composed of pine needles, twigs and grasses with evidences of some humification taking place. The L-H horizon

Horizon	Depth(inches)	Description
		grades abruptly with a clear smooth boundary into .....
Ahe	0 - 2	A grey (10 YR 5/1 dry, 10 YR 4/2 moist) sand; structureless; loose when moist; medium acid in reaction; pH 6.0. Grades with a gradual smooth boundary into .....
Ae	2 - 6	A pale brown (10 YR 6/3 dry, 10 YR 5/3 moist) sand; structureless; loose when moist and dry; medium acid in reaction; pH 5.8; grading with a gradual smooth boundary into....
BA	6 - 15	A light yellowish brown (10 YR 6/4 dry, 10 YR 6/6 moist) sand; structureless; loose when moist and dry; medium acid in reaction; pH 5.9; grading with a clear irregular boundary into .....
Bt	15 - 19	A light yellowish brown (10 YR 6/4 dry, 10 YR 5/8 moist) loamy sand to sandy loam containing a discontinuous layer of limestone cobbles. This horizon appears to be an intermixture of BA and Bt associated with the broken layer of cobbles. The strongest clay accumulation occurs around the limestones. Weak fine granular structure; firm when moist; weakly cemented; medium acid to neutral in reaction; pH varies from 5.6 between the limestone cobbles to 7.2 in the sandy loam material adjacent to the cobbles; grades with a clear irregular bound-

Horizon	Depth(inches)	Description
		ary into .....
BC	19 - 23	A light yellowish brown (10 YR 6/4 dry, 10 YR 6/8 moist) sand; structureless; loose when moist and dry; slightly acid in reaction; pH 6.1; grades with a gradual smooth boundary into .....
C1	23 - 48	A very pale brown (10 YR 7/4 dry, 10 YR 6/3 moist) sand; structureless; loose when moist; medium acid in reaction; pH 6.0; grading with a gradual smooth boundary into....
C2	48 - 110	A very pale brown (10 YR 7/3 dry, 10 YR 6/3 moist) sand; structureless; loose when moist and dry; neutral in reaction; pH 6.6;

Profile No. 2 - Orthic Grey Wooded.

Location - S.E. ¼ 16-15-7 East of the Principal Meridian.

Soil Condition - Dry.

Parent Material - The parent material at this site is mainly fine sandy outwash as indicated by a continuous layer of well rounded limestones occurring at about 12 inches below the surface. The sand was calcareous immediately below the layer of limestones. The parent material seemed to be uniform to a depth of 7 feet with no further cobble layers occurring.

Elevation - Approximately 850 feet A.S.L.

Relief - Profile was sampled on a 0 - 0.5 per cent slope. Topography was level to slightly undulating.

Figure 5.

Profile 2 - Orthic Grey Wooded.

Drainage - Well to rapidly drained internally, zero runoff, and rapid infiltration.

Stoniness - Slightly stony land.

Vegetation - Jack pine are dominant; bearberry and blueberry are abundant; chokecherries and saskatoons are among the taller shrubs; Cladonia colonies are present; also various dry type grasses and fescues.

Sampled by - G.F. Mills and M.A. Zwarich.

Date - October 6, 1961.

Horizon	Depth(inches)	Description
L - H	0.5 - 0	Partially to well decomposed needles, twigs, bark and grasses. Lower boundary is clear and smooth.
Ahe	0 - 2	A dark grey (10 YR 4.5/1 dry, 10 YR 3/1 moist) sand; structureless; loose when moist; slightly acid in reaction; pH 6.1; grades with a gradual smooth boundary into .....
Ae	2 - 5	A pale brown (10 YR 6/3 dry, 10 YR 5/6 moist) sand; structureless; loose when moist; medium acid in reaction; pH 5.7; grades with a gradual smooth boundary into.....
Bt1	5 - 7	A light yellowish brown (10 YR 6/4 dry, 10 YR 5/8 moist) loamy sand; weak fine granular structure; friable when moist; medium acid in reaction; pH 5.9; an abrupt smooth lower boundary.

Horizon	Depth(inches)	Description
Bt2	7 - 11	A dark brown (10 YR 4/3 dry, 10 YR 4/4 moist) sandy loam to sandy clay loam containing a continuous layer of well rounded limestones. The strongest clay accumulation occurs around the limestones. Weak fine granular structure; friable when moist; neutral in reaction; pH 7.3; effervesces with dilute HCl; grades with an abrupt smooth boundary into .....
BC	11 - 15	A light yellowish brown (10 YR 6/4 dry, 10 YR 5/4 moist) sand; structureless; loose when moist; mildly alkaline in reaction; pH 7.7; effervesces with dilute HCl; a gradual smooth lower boundary grading into .....
C1	15 - 21	A pale brown (10 YR 6/3 dry, 10 YR 6/4 moist) sand; structureless; loose when moist; mildly alkaline in reaction; pH 7.8; effervesces with dilute HCl; grades with an abrupt smooth lower boundary into .....
C2	21 +	A very pale brown (10 YR 7/3 dry, 10 YR 7/4 moist) sand; structureless; loose when moist; moderately alkaline in reaction; pH 7.9; effervesces with dilute HCl.

Profile No. 3 - Degraded Brown Wooded.

Location - S.E. $\frac{1}{4}$ 16-15-7 East of the Principal Meridian.

Soil Condition - Dry.

Parent Material - Parent material at the site seemed to be mainly aeolian at the surface with outwash material occurring at the lower depths. There also seemed to be several old erosion surfaces at the lower depths with considerable variation in grade of the sand. The sequence of strata occurring within the parent material was a layer of sand and fine gravel; a layer of fine sand; a layer of pebbles; probably an erosion surface; a layer of sand; then a flat cobbled limestone lens just below 5 feet. This was followed by another layer of fine sand. Roots were found on the surface of the limestones.

Elevation - Approximately 850 feet A.S.L.

Relief - The profile was sampled from what appeared to be a duned area, the slopes varying from 0.5 to 5.0 per cent. Topography was undulating to gently rolling.

Drainage - Well to rapidly drained internally, zero to slow runoff and rapid infiltration.

Stoniness - Quite variable within the area, stone-free on the duned areas to moderately stony areas occurring off the slopes.

Vegetation - Jack pine are dominant; bearberry and reindeer

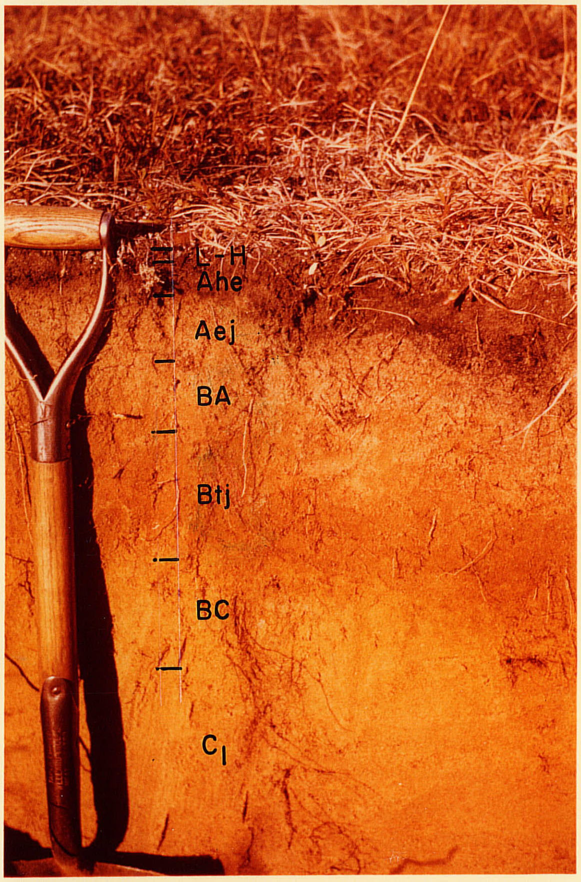

Figure 6.

Profile 3 - Degraded Brown Wooded.

moss occur.

Sampled by - G.F. Mills and M.A. Zwarich.

Date - October 5, 1961.

Horizon	Depth(inches)	Description
L - H	0.5 - 0	An organic layer comprised of undecomposed and partially to well decomposed needles, twigs, bark and grasses, grading with a clear smooth boundary into .....
Ahe	0 - 2	A greyish brown (10 YR 5/2 dry, 10 YR 4/1 moist) sand; structureless; loose when moist; Slightly acid in reaction; pH 6.3; grading with a diffuse smooth boundary into .....
Aej	2 - 5	A pale brown (10 YR 6/3 dry, 10 YR 5/3 moist) sand; structureless; loose when moist; medium acid in reaction; pH 6.0; it has a gradual smooth lower boundary grading into .....
BA	5 - 9	A light yellowish brown (10 YR 6/4 dry, 10 YR 5/6 moist) sand; structureless; loose when moist; medium acid in reaction; pH 6.0; grading with a gradual smooth boundary into .....
Btj	9 - 15	A yellowish brown (10 YR 5/4 dry, 10 YR 5/8 moist) sand; structureless; loose when moist; slightly acid in reaction; pH 6.2; grading with a gradual smooth boundary into .....
BC	15 - 19	A light yellowish brown (10 YR 6/4 dry, 10 YR 5/4 moist) sand; structureless; loose when

Horizon	Depth(inches)	Description
		moist; neutral in reaction; pH 7.0; effervesces with dilute HCl; has an abrupt wavy lower boundary.
C1	19 - 37	A white (10 YR 8/2 dry, 10 YR 7/2 moist) sand and fine gravel; structureless; loose when moist; mildly alkaline in reaction; pH 7.8; effervesces strongly with dilute HCl; has a clear smooth lower boundary.
C2	37 - 53	A white (10 YR 8/2 dry, 10 YR 7/2 moist) fine sand; structureless; loose when moist; mildly alkaline in reaction; pH 7.8; effervesces with dilute HCl; grades with a clear smooth lower boundary at the contact of a pebble layer into .....
C3	53 - 66	A very pale brown (10 YR 7/3 dry, 10 YR 6/3 moist) sand; structureless; loose when moist; mildly alkaline in reaction; pH 7.8; effervesces strongly with dilute HCl; has a clear smooth lower boundary at the contact of a flat limestone cobble layer.
C4	66 +	A very pale brown (10 YR 8/3 dry, 10 YR 7/4 moist) fine sand; structureless; loose when moist; mildly alkaline in reaction; pH 7.8; effervesces with dilute HCl.

Profile No. 4 - Degraded Brown Wooded.

Location - S.E. ¼ 16-15-7 East of the Principal Meridian.

Soil Condition - Dry.

Parent Material - The parent material at the sample site seemed to be mainly of sandy outwash. The sand becomes finer as the depth increases, being medium sand down to about 22 inches, medium to fine sand from 22 - 78 inches and fine sand below this.

Elevation - Approximately 850 feet A.S.L.

Relief - Profile obtained from a site with only a slight slope varying from 0 to 2.0 per cent. Topography is generally smooth level to slightly undulating.

Drainage - Well to rapidly drained internally; zero runoff; rapid infiltration; water table found at 7 feet.

Stoniness - Profile site was essentially stone free.

Vegetation - Jack pine are dominant; some aspen and birch are present. Bearberry is abundant; some blueberry, chokecherry, saskatoon and roses are among the taller shrubs; Cladonia colonies are present.

Sampled by - G.F. Mills.

Date - October 13, 1961.

Horizon	Depth(inches)	Description
L - H	0.5 - 0	An organic layer composed of partially to well decomposed leaf, herb and grass litter. Undecomposed needles, twigs and bark were present; grades with a gradual smooth lower boundary into .....
Ahe	0 - 2	A greyish brown (10 YR 5/2 dry, 10 YR 3/3 moist) sand; structureless; loose when moist; medium acid in reaction; pH 5.6; grades with a gradual smooth boundary into .....
Aeh	2 - 4	A pale brown (10 YR 6/3 dry, 10 YR 5/6 moist) sand; structureless; loose when moist; slightly acid in reaction; pH 6.2; grades with an abrupt smooth lower boundary into .....
Aej	4 - 7	A very pale brown (10 YR 7/4 dry, 10 YR 6/6 moist) sand; structureless; loose when moist; slightly acid in reaction; pH 6.4; it has an abrupt smooth lower boundary .....
Btj	7 - 14	A light yellowish brown 10 YR 6/4 dry, 10 YR 5/8 moist) sand; structureless; loose when moist; medium acid in reaction; pH 5.6. This horizon contains small granitic stones; no limestones however; grades with an abrupt smooth boundary into .....
BC	14 - 22	A light yellowish brown (10 YR 6/4 dry, 10 YR 6/8 moist) sand; structureless; loose when moist; medium acid in reaction; pH 6.0;

		grades with an abrupt smooth lower boundary into .....
C1	22 - 54	A very pale brown (10 YR 7/3 dry, 10 YR 6/6 moist) sand; structureless; loose when moist; neutral in reaction; pH 7.3; a gradual smooth lower boundary grading into .....
C2	54 - 78	A white (10 YR 8/2 dry, 10 YR 8/2 moist) sand; structureless; loose when moist; neutral in reaction; pH 7.3; it has an abrupt smooth lower boundary.
C3	78 - 84	A very pale brown (10 YR 8/4 dry, 10 YR 7/4 moist) fine sand; structureless; loose when moist; slightly acid in reaction; pH 6.5; grades with a gradual smooth lower boundary into .....
C4	84 +	A very pale brown (10 YR 7/4 dry, 10 YR 6/4 moist) fine sand; structureless; loose when moist; neutral in reaction; pH 7.2.

(2) Milner Ridge Area

Profile No. 5 - Orthic Grey Wooded.

Location - South ½ 4-13-10 East of the Principal Meridian.

Soil Condition - Moist to dry.

Parent Material - The parent material at this site seemed to be mainly fine sandy outwash. The outwash nature of this deposit is indicated by a layer of limestone and granitic pebbles at about 14 inches below the surface. There was no further change in the character of the parent material to a depth of 7 feet.

Elevation - Approximately 925 feet A.S.L.

Relief - This profile was sampled from a nearly level site, the slope varying from 0 to 0.5 per cent. The topography was mainly smooth and flat with a few long low slopes being present.

Drainage - Well to excessively drained internally; zero runoff and rapid infiltration.

Stoniness - Slightly to moderately stony land.

Vegetation - Jack pine and birch occur intermixed; bearberry, saskatoons and roses; horsetail; Cladonia colonies are present.

Sampled by - G.F. Mills.

Date - October 16, 1961.

Horizon	Depth(inches)	Description
L - H	0.5 - 0	An organic layer comprised of needles, twigs, bark and grasses, with evidence of some humification having taken place. It grades abruptly with a clear smooth boundary into ....
Ahe	0 - 1	A greyish brown (10 YR 5/2 dry, 10 YR 4/2 moist) fine sand; structureless; loose when moist; slightly acid in reaction; pH 6.2; grades with a gradual smooth boundary into....
Ae1	1 - 4	A pale brown (10 YR 6/3 dry, 10 YR 5/6 moist) fine sand; structureless; loose when moist; medium acid in reaction; pH 5.7; it has a diffuse smooth lower boundary.
Ae2	4 - 12	A very pale brown (10 YR 7/3 dry, 10 YR 6/3 moist) fine sand; structureless; loose when moist; medium acid in reaction; pH 5.8; grading with a diffuse smooth boundary into the horizon below.
BA	12 - 13	A light yellowish brown (10 YR 6/4 dry, 10 YR 4/3 moist) loamy fine sand; weak; medium granular; firm when moist; slightly acid in reaction; pH 6.2; grading with a diffuse smooth boundary into .....
Bt	13 - 16	A brown (7.5 YR 5/4 dry, 7.5 YR 4/4 moist) fine sandy loam to sandy clay loam containing limestone and granitic pebbles. The strongest clay accumulation occurs adjacent to the lime-

Horizon	Depth(inches)	Description
		stones. These stones are close enough together to cause formation of a continuous Bt horizon. Strong fine granular; very firm when moist; neutral in reaction, pH 6.9. It has an abrupt smooth lower boundary.
BC	16 - 17	A strong brown (7.5 YR 5/6 dry, 7.5 YR 4/4 moist) loamy fine sand; weak medium granular; loose when moist; neutral in reaction; pH 6.7; it has an abrupt wavy lower boundary.
C1	17 - 36	A white (10 YR 8/2 dry, 10 YR 8/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.4; effervesces with dilute HCl; grades with a clear smooth lower boundary into .....
C2	36 - 66	A white (10 YR 8/2 dry, 10 YR 6/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.2; effervesces strongly with dilute HCl; grades with a diffuse smooth lower boundary into .....
C3	66 +	A white (10 YR 8/2 dry, 10 YR 6/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.4; effervesces with dilute HCl.

Profile No. 6 - Degraded Brown Wooded

Location - N.W. ¼ 34-12-10 East of the Principal Meridian.

Soil Condition - Dry to moist.

Parent Material - The parent material at this site is mainly fine sandy outwash. A discontinuous layer of limestone cobbles occurring at about 13 inches and a layer of medium sand at about 14 to 19 inches indicate the outwash nature of this deposit.

Elevation - Approximately 925 feet A.S.L.

Relief - This profile was sampled on a 0.5 per cent slope. The topography was undulating to gently rolling, the range being from about 0.5 to 5.0 per cent.

Drainage - Well drained internally; zero to slow runoff and rapid infiltration.

Stoniness - Slightly stony to moderately stony.

Vegetation - Jack pine predominates; roses and saskatoons are the main shrubs; bearberry, reindeer moss and some sedges occur.

Sampled by - G.F. Mills

Date - October 16, 1961.

Horizon	Depth(inches)	Description
L - H	0.5 - 0	An organic layer comprised of undecomposed and partially to well decomposed needles, twigs, bark and grasses; grades with a clear smooth boundary into.....

Figure 7.

Profile 6 - Degraded Brown Wooded.

Horizon	Depth(inches)	Description
Ah	0 - 2	A greyish brown (10 YR 5/2 dry, 10 YR 3/2 moist) fine sand; structureless; loose when moist; neutral in reaction; pH 6.6; grades with a gradual smooth lower boundary into .....
Ahe	2 - 4	A brown (10 YR 5/3 dry, 10 YR 3/4 moist) fine sand; structureless; loose when moist; neutral in reaction; pH 6.6; grades with diffuse smooth lower boundary into .....
Aej	4 - 11	A pale brown (10 YR 6/3 dry, 10 YR 5/8 moist) fine sand; structureless; loose when moist; slightly acid in reaction; pH 6.5; grades with a diffuse smooth lower boundary into the horizon below.
Btj	11 - 14	A light yellowish brown (10 YR 6/4 dry, 7.5 YR 4/4 moist) loamy fine sand containing a discontinuous layer of limestone cobbles. A considerable portion of this horizon appears to possess properties transitional to A and B with the main clay accumulation occurring around the limestone cobbles. Structureless; loose when moist; neutral in reaction; pH 6.6; it has a diffuse smooth lower boundary.
BC	14 - 19	A light yellowish brown (10 YR 6/4 dry, 10 YR 6/6 moist) medium sand; structureless; loose when moist; neutral in reaction; pH 6.7; grades with a diffuse smooth lower boundary into ....

Horizon	Depth(inches)	Description
C1	19 - 36	A very pale brown (10 YR 7/3 dry, 10 YR 6/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.2; effervesces with dilute HCl. It has an abrupt wavy lower boundary.
C2	36 - 66	A light grey (10 YR 7/2 dry, 10 YR 5/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.1; effervesces with dilute HCl; grades with a diffuse smooth lower boundary into....
C3	66 - 84	A white (10 YR 8/2 dry, 10 YR 6/3 moist) fine sand; structureless; loose when moist; moderately alkaline in reaction; pH 8.3; effervesces with dilute HCl.

LABORATORY PROCEDURE

Sample Preparation

When field sampling was completed, the samples were brought into the laboratory and spread out to air dry. These samples were then crushed with a wooden rolling pin, passed through a 2 mm sieve, and placed in covered cylindrical cartons. The material coarser than 2 mm was weighed and kept separate. All laboratory analysis were done on the<2 mm material.

Representative samples of limestone cobbles found in the profiles were ground in a mortar and pestle to pass a 60 mesh sieve. Particle size distribution, extractable iron, calcium carbonate equivalent and per cent calcite and dolomite were determined on the bulk sample.

X-ray diffractograms were obtained from the clay fraction ($<2u$).

Methods

pH Determination. The pH values were determined on saturated soil pastes using a Model 22 "Radiometer" pH meter. The wetted soil was allowed to equilibriate for one hour before the pH measurement was made.

Total Carbon. The total carbon content was determined in this study using a wet combustion method as modified by Ehrlich (11).

Inorganic Carbon. For this determination the apparatus and method used was a modified form of the Total Carbon apparatus as described by Ehrlich (11). Results are calculated as per cent calcium carbonate equivalent.

Organic Carbon and Organic Matter. The amount of organic carbon was calculated by subtracting the Inorganic Carbon from the amount of Total Carbon. The organic matter content was obtained by multiplying the organic carbon per cent by a factor of 1.724.

Calcite and Dolomite. Calcite and dolomite were determined by the manometric method as outlined by Skinner *et al.*(53).

Total Nitrogen. Total Nitrogen was determined by the macro-kjeldahl method (2).

Cation Exchange Capacity. The cation exchange measurement was determined by a method outlined by Atkinson *et al.*(2). One modification was found necessary. Due to the low exchange capacity of coarse textured soils the sample weight was increased to 50 gm.

Exchangeable Cations. Exchangeable calcium, magnesium, sodium, potassium and hydrogen were determined by procedures outlined by Atkinson *et al.*(2).

Extractable Iron. The procedure for the determination of free iron oxides was carried out during the preparation of the soil for x-ray diffraction analysis. The method for iron oxide removal is that of Aguilera and Jackson (1) as modified by Mehra and Jackson (31). The iron was determined by the potassium thiocyanate red colour method.

Particle Size Distribution. The particle size distribution was determined on the <2 mm soil material by the mineral fractionation procedure outlined by Jackson (23).

The size fractions employed for the particle size distribution analysis in this study are as follows:

Very coarse sand	2000 - 1000 µ
Coarse sand	1000 - 500 µ
Medium sand	500 - 250 µ
Fine sand	250 - 100 µ
Very fine sand	100 - 50 µ
Coarse silt	50 - 20 µ
Medium silt	20 - 5 µ
Fine silt	5 - 2 µ
Coarse clay	2 - 0.2 µ
Fine clay (medium and fine clay)	<0.2 µ

Mineralogical Analysis of the Fine Sand Fraction. The entire fine sand fraction obtained from the segregation procedure was separated into light and heavy mineral fractions according to a bromoform separation described by Milner (32). A further separation of the heavy minerals was made on the basis of their magnetic properties (32).

In order to facilitate the counting of the light minerals the mineral grains were stained according to a procedure by Reeder and McAllister (44). One modification was found necessary. The hydrofluoric acid treatment was reduced to 1 minute as it was found that some of the grains were being greatly reduced in size or dissolved completely. Following staining the light mineral grains were mounted in Caedex on microscope slides. A cover slip was placed over them and the slides were heated for 1 hour at 65°C. The temperature and time were critical in order to harden the Caedex without it becoming too brittle and cracking. These slides had to be left lying flat because even after the 1 hour cooking period the Caedex did not harden enough to prevent the grains from all flowing to one side of the slide.

The heavy minerals were mounted in Aroclor (R.I. - 1.66). A small chip of Aroclor was placed on the microscopic slide on a hot plate. The heavy minerals were sprinkled over an area equivalent to the surface of a cover slip. The cover slip was then lowered slowly over the minerals from one side, care being taken not to cause bubbles under the cover slip by dropping it too fast.

Representative slides were made of the magnetic minerals. Slides were not made for each horizon as the majority of these minerals were opaque.

For the light mineral analysis about 300 minerals were counted on each of duplicate slides under a petrographic microscope. About 180 to 220 heavy minerals from each horizon were counted and identified under the microscope. These slides were not duplicated. The representative slides of the magnetic minerals were studied under reflected light to determine which minerals were present. These minerals were not counted.

X-ray Diffraction Analysis. Samples for x-ray diffraction of the fine silt, coarse clay and fine clay fractions were prepared as described by Jackson (23). Only the major horizons of each profile were examined.

Two sets of slides for each horizon were prepared for diffraction analysis; the first being magnesium-saturated and the second potassium-saturated. Both sets of slides were solvated with glycerol.

Three sets of diffractograms were obtained from each horizon; the magnesium-saturated material, potassium-saturated material and one from the potassium-saturated material after it had been heated at 550°C for two hours. The goniometer was run from a 2θ of 2° to approximately 32°.

The x-ray analysis were carried out with a Philips x-ray diffractometer (Model 1051). All diffraction patterns were made with a cobalt tube and an iron filter at 36 K.V. and 9 m.a. All slides were x-rayed on the same scale and rate; counter: 32, rate meter: 4, time constant (Sec.): 16, and multiplier: 1, so that valid comparisons could be made.

IV RESULTS AND DISCUSSION

Soil Reaction

The pH values for the six profiles are shown in Table 1. In general the A horizons are medium to slightly acid. The B horizons are medium acid to neutral in reaction. The high pH in the B horizons of Profiles 2 and 5 can be attributed to the presence of particles of limestone. The C horizons show a wide variation in pH depending on whether or not the parent material is calcareous or non-calcareous.

Calcium Carbonate Equivalent

The $CaCO_3$ data presented in Table 1, with the exception of Profile 2, show low values in the Ae and B horizons. The $CaCO_3$ content is generally higher in the parent material, this being particularly so in Profiles 2, 3, 5 and 6. In Profiles 1, 2, 3, and 4 (Dencross area) the $CaCO_3$ content in the C horizons varies from 0.09 to 8.63 per cent whereas in Profiles 5 and 6 (Milner Ridge area) it is in the order of 23 per cent. These data suggest two distinct levels of calcium carbonate in the parent materials.

The depth at which free $CaCO_3$ occurs within the Dencross area is quite variable. It is noted in the section on Profile Descriptions (p.27) that free $CaCO_3$ was not detected at 110 inches in Profile 1 whereas in Profile 4 free $CaCO_3$ was found at 84 inches. Profiles 2 and 3 however, contained free lime at depths of 11 and 15 inches respectively. These differences can not be accounted for by leaching processes alone. According to Jackson et al.(21), $CaCO_3$ is one of the first constituents to be removed in the development of a soil. On porous well drained sandy sites, the $CaCO_3$ would be leached from the soil fairly rapidly.

TABLE 1

pH VALUES, PERCENT CALCIUM CARBONATE AND EXTRACTABLE IRON IN THE MAJOR HORIZONS OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	pH	Calcium Carbonate Equivalent %	Extractable Fe_2O_3 %
1. Orthic Grey Wooded	Ae	2 - 6	5.8	0.12	0.24
	Bt	15 - 19	5.6	0.38	0.51
	C1	23 - 48	6.0	0.13	0.14
	C2	48 - 110	6.6	0.23	
2. Orthic Grey Wooded	Ae	2 - 5	5.7	0.45	0.24
	Bt	7 - 11	7.3	3.68	0.89
	C1	15 - 21	7.8	0.77	0.18
	C2	21 +	7.9	5.28	
3. Degraded Brown Wooded	Aej	2 - 5	6.0	0.33	0.21
	Btj	9 - 15	6.2	0.48	0.25
	C1	19 - 37	7.8	8.63	0.11
	C4	64 +	7.8	3.00	
4. Degraded Brown Wooded	Aej	4 - 7	6.4	0.68	0.27
	Btj	7 - 14	5.6	0.25	0.35
	C1	22 - 54	7.3	0.47	0.29
	C4	84 +	7.2	0.09	
5. Orthic Grey Wooded	Ae2	4 - 12	5.8	0.12	0.31
	Bt	13 - 16	6.9	0.73	0.78
	C1	17 - 36	8.4	18.08	0.13
	C3	66 +	8.4	23.65	
6. Degraded Brown Wooded	Aej	4 - 11	6.5	0.18	0.33
	Btj	11 - 14	6.6	0.10	0.39
	C1	19 - 36	8.2	19.72	0.15
	C3	66 - 84	8.3	24.79	

Jenny (19) states that under humid conditions 5 to 10 per cent of the $CaCO_3$ had leached from a dune sand during the course of 250 to 300 years. As this area likely has been subjected to some duning action, the material that is moved by the wind would be from the surface of adjacent areas and as such would be leached of considerable amounts of $CaCO_3$. The lower $CaCO_3$ contents in Profiles 1 and 4 can be attributed to some duning action in addition to the leaching process.

Extractable Iron ("Free Iron")

The data for extractable iron in Table 1 show that iron has accumulated in the sola of these soils, with the highest quantity occurring in the B horizons and lower amounts in the parent materials and surface horizons. The increase in free iron oxide content in the A horizon as compared to the parent material suggests "in situ" release of iron from iron bearing minerals. The higher quantity of free iron in the B as compared to the A horizons suggests that some translocation of iron has occurred as well as the release of iron from iron bearing minerals.

The values for free iron in the C horizons of all profiles with the exception of Profile 4 are low. The higher free iron content in the C1 horizon of Profile 4 can be attributed to a possible iron accumulation transitional layer between the Btj horizon and the unaltered parent material. The colour notations for the C1 horizon in the section on Profile Descriptions (p.27) indicate that the unaltered parent material is first reached in the C2 horizon.

The accumulation of iron in the B horizons of Profiles 2, 3, 5 and 6 may be due, in part, to the mildly to moderately alkaline pH values of the C horizons. Wright and Levick (66) explain the precipitation of iron associated with chelating agents at this alkaline material as being due to increasing competition from hydroxyl ions with rising pH and increased concentration of the alkaline earths. They state that small amounts of calcium and/or magnesium can cause displacement of iron and its precipitation as the hydrated oxide.

Larger iron accumulations in the B horizons of Profiles 1, 2, and 5 can be attributed to organic matter and clay accumulations in these horizons. Results have been reported by Carroll (8) and by St. Arnaud and Whiteside (57) showing the close association between clay and free iron.

Organic Carbon, Organic Matter and Total Nitrogen

The results for organic carbon, organic matter, nitrogen and the C:N ratios are presented in Table 2. Very few conclusions can be drawn from these data. It is noted that there is very little variation in the organic carbon content among the profiles. Within profiles, the organic carbon content decreases with depth.

The data for total nitrogen show that in every profile the total nitrogen content is quite variable. The increase in nitrogen content in the B horizons of Profiles 2, 4 and 6 may be due to slight accumulations of organic matter and to an increase in ammonia-N fixed by the clay minerals. In general the C:N ratios decrease from the A to the B to the C horizons.

Cation Exchange Capacity and Exchangeable Cations

The results for the cation exchange capacity and the exchangeable cation analysis are presented in Table 3. Exchangeable cations and base saturation percentages were not calculated for the calcareous

TABLE 2

ORGANIC CARBON, ORGANIC MATTER, TOTAL NITROGEN AND CARBON-NITROGEN RATIOS OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	Organic Carbon %	Organic Matter %	Total Nitrogen %	C:N Ratio
1. Orthic	Ae	2 - 6	0.83	1.43	0.02	41.50
Grey	Bt	15 - 19	0.28	0.48	0.02	14.00
Wooded	C1	23 - 48	0.00	0.00	0.02	0.00
2. Orthic	Ae	2 - 5	0.81	1.38	0.02	40.00
Grey	Bt2	7 - 11	0.47	0.81	0.07	6.71
Wooded	C1	15 - 21	0.41	0.71	0.02	20.50
3. Degraded	Aej	2 - 5	0.97	1.67	0.02	48.50
Brown	Btj	9 - 15	0.55	0.95	0.01	55.00
Wooded	C1	19 - 37	0.28	0.48	0.04	7.00
4. Degraded	Aej	4 - 7	0.55	0.95	0.02	27.50
Brown	Btj	7 - 14	0.41	0.71	0.16	2.56
Wooded	C1	22 - 54	0.04	0.07	0.00	-
5. Orthic	Ae2	4 - 12	0.19	0.33	0.05	3.80
Grey	Bt	13 - 16	0.14	0.29	0.04	3.50
Wooded	C1	17 - 36	0.02	0.03	0.03	0.66
6. Degraded	Aej	4 - 11	0.21	0.36	0.02	10.50
Brown	Btj	11 - 14	0.19	0.32	0.05	3.80
Wooded	C1	19 - 36	0.04	0.07	0.00	-

TABLE 3

CATION EXCHANGE, EXCHANGEABLE CATIONS AND BASE SATURATION OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	Exchangeable Cations %					C.E.C. (me/100gm.)	% Base Saturation
			Ca	Mg	K	Na	H		
1. Orthic	Ae	2 - 6	39.4	24.4	1.8	0.9	33.5	2.1	66.5
Grey	Bt	15 - 19	60.3	14.7	2.1	1.0	21.9	3.4	78.1
Wooded	Cl	23 - 48	47.1	10.3	2.3	1.2	39.1	1.0	60.9
2. Orthic	Ae	2 - 5	58.7	12.9	2.2	1.1	25.1	2.0	74.9
Grey	Bt2	7 - 11	88.5	9.4	1.8	0.3	-	9.1	100.0
Wooded	Cl	15 - 21	-	-	-	-	-	0.8	-
3. Degraded	Aej	2 - 5	59.5	15.5	2.5	0.7	21.8	2.7	78.2
Brown	Btj	9 - 15	67.1	17.7	2.5	1.2	11.5	2.3	88.5
Wooded	Cl	19 - 37	-	-	-	-	-	0.6	-
4. Degraded	Aej	4 - 7	44.1	14.7	3.4	1.1	36.7	1.6	63.3
Brown	Btj	7 - 14	44.9	16.1	4.4	1.0	33.6	2.1	66.4
Wooded	Cl	22 - 54	69.2	7.7	1.9	2.9	18.3	0.8	81.7
5. Orthic	Ae2	4 - 12	50.9	17.5	2.6	1.1	27.9	2.4	72.1
Grey	Bt	13 - 16	86.0	11.8	1.9	0.3	-	8.7	100.0
Wooded	Cl	17 - 36	-	-	-	-	-	0.6	-
6. Degraded	Aej	4 - 11	54.7	21.8	1.5	0.7	21.3	3.7	78.7
Brown	Btj	11 - 14	71.8	25.5	1.9	0.8	-	4.5	100.0
Wooded	Cl	19 - 36	-	-	-	-	-	0.5	-

C horizons as the method used did not differentiate between calcium and magnesium obtained from the exchange complex and calcium and magnesium obtained from the relatively insoluble carbonates.

The values for total cation exchange capacity are closely related to the amounts of clay and organic matter present. All soils, with the exception of Profile 3, show an increase in total cations in the B horizons. This increase in cation exchange capacity can be attributed to the accumulation of organic matter and clay.

Calcium and magnesium are the dominant cations on the exchange complex of all the soils. Exchangeable hydrogen is present in the A horizon of all profiles and in the B horizon of Profiles 1, 3 and 4. The degree of unsaturation is highest in Profiles 1 and 4 which have exchangeable hydrogen in the C horizon. The percent base saturation values range from 60.9 to 100 per cent in the six profiles. These values are low as compared to values reported for Podzolic soils by other workers (29,54).

Particle Size Distribution

The particle size distribution data are presented in Tables 4 and 5. The data presented in Table 4 show that clay has accumulated in the B horizons of the six profiles. This higher clay content was detected in Profiles 1, 2, 5 and 6 in the field by hand texturing. The clay accumulations in the B horizons of Profiles 1, 2, 5 and 6 fit the limits of a "t" horizon as suggested by the National Soil Survey Committee of Canada (45). Profiles 3 and 4 show only a slight increase in clay content in

TABLE 4

TOTAL SAND, SILT AND CLAY CONTENT* OF THE MAJOR HORIZONS OF THE SIX SOIL PROFILES.

Profile No. and Soil Subgroup	Horizon	Depth in.	% Total Sand	% Total Silt	% Total Clay
1. Orthic	Ae	2 - 6	96.5	3.0	0.5
Grey	Bt	15 - 19	90.8	4.7	4.5
Wooded	C1	23 - 48	98.1	1.0	0.9
2. Orthic	Ae	2 - 5	92.6	5.7	1.7
Grey	Bt2	7 - 11	83.5	5.4	11.1
Wooded	C1	15 - 21	98.7	0.8	0.5
3. Degraded	Aej	2 - 5	94.8	2.4	2.8
Brown	Btj	9 - 15	94.7	2.4	2.9
Wooded	C1	19 - 37	98.3	0.6	1.1
4. Degraded	Aej	4 - 7	96.0	2.5	1.5
Brown	Btj	7 - 14	95.7	2.2	2.1
Wooded	C1	22 - 54	98.6	0.9	0.5
5. Orthic	Ae2	4 - 12	89.0	7.3	3.7
Grey	Bt	13 - 16	80.7	5.7	13.6
Wooded	C1	17 - 36	95.9	3.4	0.7
6. Degraded	Aej	4 - 11	91.5	5.5	3.0
Brown	Btj	11 - 14	88.7	5.7	5.6
Wooded	C1	19 - 36	95.7	3.6	0.7

* - Calculated on basis of recovered weight

TABLE 5
PARTICLE SIZE DISTRIBUTION OF THE MAJOR HORIZONS OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	%[1]					%				
			Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand[2]	Coarse Silt	Med. Silt	Fine Silt	Coarse Clay	Fine Clay
1. Orthic	Ae	2 - 6	0.3	3.0	21.2	70.2	5.3	1.7	1.1	0.2	0.2	0.3
Grey	Bt	15 - 19	1.3	5.9	24.8	64.0	4.0	2.4	1.7	0.6	1.6	2.9
Wooded	C1	23 - 48	0.0	0.0	4.2	91.0	4.8	0.6	0.3	0.1	0.3	0.6
2. Orthic	Ae	2 - 5	0.4	2.0	34.0	55.4	8.2	2.5	2.5	0.7	0.8	0.9
Grey	Bt2	7 - 11	1.2	14.5	36.4	45.0	2.9	1.7	2.5	1.2	3.9	7.2
Wooded	C1	15 - 21	0.0	0.7	36.5	59.4	3.4	0.4	0.3	0.1	0.1	0.4
3. Degraded	Aej	2 - 5	1.2	15.2	48.7	33.2	1.7	1.9	0.0	0.5	1.1	1.7
Brown	Btj	9 - 15	0.8	12.9	47.1	37.1	2.1	1.1	1.0	0.3	0.8	2.1
Wooded	C1	19 - 37	1.3	14.3	48.2	35.0	1.2	0.2	0.3	0.1	0.3	0.8
4. Degraded	Aej	4 - 7	0.1	6.4	49.7	41.5	2.3	0.9	1.3	0.3	0.5	1.0
Brown	Btj	7 - 14	0.1	7.1	51.5	38.9	2.4	0.8	1.1	0.3	0.8	1.3
Wooded	C1	22 - 54	0.6	17.3	48.7	31.5	1.9	0.4	0.4	0.1	0.3	0.2
5. Orthic	Ae2	4 - 12	2.3	3.7	9.4	76.7	7.9	2.7	3.7	0.9	1.6	2.1
Grey	Bt	13 - 16	3.1	5.0	11.7	76.1	4.1	1.8	3.0	0.9	3.4	10.2
Wooded	C1	17 - 36	0.1	0.1	2.0	91.1	6.7	2.3	1.0	0.1	0.3	0.4
6. Degraded	Aej	4 - 11	0.8	3.1	8.0	80.0	7.9	1.9	2.8	0.8	1.4	1.6
Brown	Btj	11 - 14	1.9	5.1	9.0	76.4	7.6	2.1	2.8	0.8	1.7	3.9
Wooded	C1	19 - 36	0.0	0.1	3.0	87.5	9.4	2.6	0.9	0.1	0.4	0.3

1. Sand fractions calculated as per cent of total sand.
2. Very fine sand obtained by difference.

the B horizon. These small amounts were not detected in the field.

The higher clay content in the B horizons can be attributed to translocation and to in situ release of clay minerals from limestone cobbles in the B horizons. The B horizons of all profiles with the exception of Profiles 3 and 4, contained fragments of limestone (Profile Descriptions, p.27). The profiles containing limestone cobbles in the B horizons show the largest clay accumulation, predominantly fine clay.

The total sand and silt contents for the C horizons in Table 4 show that Profiles 1 to 4, from the Dencross area have 98.1 to 98.7 per cent total sand and 0.6 to 1.0 per cent silt in the parent material. Profiles 5 and 6 from the Milner Ridge area have 95.9 and 95.7 per cent sand and 3.4 and 3.6 per cent silt in the parent material. This suggests that there are differences between the parent materials of the two areas and that within an area the parent material is fairly similar.

There is a slight increase in the coarse, medium and fine silt contents in the A and B horizons relative to the C horizon (Table 5). Similarily, the total sands decrease in the A and B horizon relative to the C horizon (Table 4). This redistribution in particle size can probably be attributed to physical weathering. St. Arnaud and Whiteside (56) working with soils ranging from Chernozems to Grey Woodeds in Saskatchewan found that physical breakdown of the coarser particles occurred in the A and B horizon relative to the parent material. They attributed this physical breakdown in large part to frost action.

Mineralogical Analysis of the Fine Sand Fraction (250 - 100u)

Light Mineral Fraction. The percentage of light minerals is fairly constant in all horizons of the six profiles constituting from

TABLE 6

PERCENT TOTAL LIGHT MINERALS, AND PERCENTAGES OF QUARTZ, K-FELDSPAR AND PLAGIOCLASE OF THE FINE SAND FRACTION OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	Light* Minerals %	** Quartz	** K Feldspar	** Plagio-clase
1. Orthic	Ae	2 - 6	99.1	86	2	12
Grey	Bt	15 - 19	98.7	89	4	7
Wooded	C1	23 - 48	99.4	92	3	5
2. Orthic	Ae	2 - 5	99.0	78	7	15
Grey	Bt2	7 - 11	98.6	77	6	17
Wooded	C1	15 - 21	98.8	74	7	19
3. Degraded	Aej	2 - 5	99.0	81	1	18
Brown	Btj	9 - 15	98.9	94	1	5
Wooded	C1	19 - 37	98.9	90	3	7
4. Degraded	Aej	4 - 7	98.7	71	4	25
Brown	Btj	7 - 14	98.5	73	6	21
Wooded	C1	22 - 54	98.6	73	6	21
5. Orthic	Ae2	4 - 12	98.3	68	9	23
Grey	Bt	13 - 16	97.9	72	8	20
Wooded	C1	17 - 36	98.3	63	10	27
6. Degraded	Aej	4 - 11	97.6	73	7	20
Brown	Btj	11 - 14	98.0	81	3	16
Wooded	C1	19 - 36	97.8	73	2	25

* Based on per cent of total fine sand fraction.

** Based on mineral counts of 300 grains.

97 to 99 per cent of the total fine sand fraction (Table 6). The analysis shows quartz to be the dominant mineral and that plagioclase feldspars predominate over the potash feldspars. When the light minerals were being counted it was apparent that the sodic members of the plagioclase series were more abundant than the calcic members. As the calcic plagioclases are low in the C horizon it is possible that the parent material was low in these minerals to start with. This can be attributed to strong weathering of the source material before deposition or else to the source material containing low amounts of calcic plagioclases.

Heavy Mineral Fraction. In general there is a higher percentage of heavy minerals in Profiles 5 and 6 than in Profiles 1 to 4 (Table 7). A higher percentage of magnetic minerals (primarily magnetite) can also be noted in Profiles 1 to 4 than in Profiles 5 and 6. These two differences in the heavy mineral fraction of the two areas suggest some differences in the origin of the parent materials.

The data for the heavy mineral composition of the six profiles are presented in Table 8. The dominant members of the heavy mineral suite in all profiles are the amphiboles with green hornblende being the dominant mineral. The hornblende grains are relatively unweathered. The abundance of hornblende minerals has been noted previously in mineralogical studies of other Manitoba soils (11,42). Minor amounts of tremolite and actinolite were also noted.

Garnet is next in abundance and occurs in all profiles. This series of minerals is quite resistant to both mechanical and chemical breakdown and so do not show signs of weathering. The garnets consist

TABLE 7

PERCENTAGE OF HEAVY AND MAGNETIC MINERALS IN THE FINE SAND FRACTION OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	Horizon	Depth in.	Heavy Minerals %	Magnetic Minerals* %
1. Orthic	Ae	2 - 6	0.9	14.5
Grey	Bt	15 - 19	1.3	26.3
Wooded	Cl	23 - 48	0.6	5.5
2. Orthic	Ae	2 - 5	1.0	13.6
Grey	Bt2	7 - 11	1.4	16.4
Wooded	Cl	15 - 21	1.2	13.7
3. Degraded	Aej	2 - 5	1.0	10.8
Brown	Btj	9 - 15	1.1	12.7
Wooded	Cl	19 - 37	1.1	7.2
4. Degraded	Aej	4 - 7	1.3	18.1
Brown	Btj	7 - 14	1.5	20.7
Wooded	Cl	22 - 54	1.4	15.0
5. Orthic	Ae2	4 - 12	1.7	8.2
Grey	Bt	13 - 16	2.1	9.8
Wooded	Cl	17 - 36	1.7	4.3
6. Degraded	Aej	4 - 11	2.4	8.6
Brown	Btj	11 - 14	2.0	7.7
Wooded	Cl	19 - 36	2.0	5.8

* Magnetic Minerals calculated as per cent of heavy mineral fraction.

TABLE 8
PERCENTAGE HEAVY MINERAL COMPOSITION IN THE FINE SAND FRACTION OF THE SIX SOIL PROFILES

Profile No. and Soil Subgroup	1. Orthic Grey Wooded			2. Orthic Grey Wooded			3. Degraded Brown Wooded			4. Degraded Brown Wooded			5. Orthic Grey Wooded			6. Degraded Brown Wooded		
Minerals / Horizon Depth	Ae 2-6	Bt 15-19	Cl 23-48	Ae 2-5	Bt2 7-11	Cl 15-21	Aej 2-5	Btj 9-15	Cl 19-37	Aej 4-7	Btj 7-14	Cl 22-54	Ae2 4-12	Bt 13-16	Cl 17-36	Aej 4-11	Btj 11-14	Cl 19-36
Hornblende (green)	44	38	43	42	42	41	40	39	35	44	39	20	37	35	33	44	31	43
Tremolite-Actinolite	3	5	4	3	6	7	5	6	5	7	5	4	7	5	4	4	7	3
Orthopyroxenes	2	-	-	1	1	-	3	2	1	1	3	2	-	1	6	1	3	6
Clinopyrenes	3	4	5	4	5	5	2	2	5	3	2	2	4	5	4	3	3	6
Garnets	7	7	5	7	5	6	2	3	8	7	7	5	7	10	4	8	10	3
Opaques(prim.Hematite)	2	10	4	7	5	5	7	7	3	11	15	31	5	1	3	2	3	3
Chlorite	6	7	4	6	6	7	4	7	8	4	3	5	5	7	4	2	6	4
Staurolite	6	6	7	4	3	7	6	3	7	4	6	2	8	5	3	7	7	4
Rutile	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-
Chromite	1	1	-	1	1	1	1	2	1	1	-	-	-	2	-	-	1	-
Epidote	-	1	-	-	1	-	1	1	-	1	1	-	1	-	1	-	-	-
Olivine	-	-	-	1	2	-	1	3	-	1	-	1	1	2	1	1	3	2
Miscellaneous (1)	5	3	6	2	4	3	5	3	5	1	3	6	2	4	5	4	5	2
Unidentified (2)	21	18	22	21	19	18	22	22	22	15	16	22	23	23	32	24	21	24

(1) Biotite, Muscovite, Quartz, Perthite, Leucoxene, Tourmaline.
(2) Strongly weathered.

primarily of the pale pink to colourless varieties known as grossularite. Some of the colourless garnet minerals exhibited zoning.

The opaque minerals consist predominantly of hematite with minor amounts of limonite and ilmenite. In general, the opaque mineral content follows the pattern of the magnetic minerals in relative abundance.

The orthopyroxenes identified are mainly hypersthene with traces of enstatite. The major clinopyroxene noted is augite with minor amounts of diopside in some of the horizons.

Chlorite and staurolite occur in all profiles in moderate amounts. Minor amounts of rutile and chromite are found in the six profiles. Both minerals are well rounded suggesting a detrital origin.

Other minerals noted were epidote, olivine, biotite, muscovite, quartz, perthite, tourmaline and leucoxene.

The minerals not identified were quite numerous in all profiles. The majority of these grains could not be identified because of severe weathering of the mineral surfaces. These minerals were generally colourless and non-pleochroic and are probably extremely well weathered amphiboles and pyroxenes.

X-ray Diffraction Analysis

Mineralogical analysis of the fine silt, coarse clay and fine clay fractions were determined by x-ray diffraction on each of the major horizons of the six profiles. The diffractograms of these fractions are shown in Figures 8 to 25. The diffraction patterns obtained from the non-heated K-saturated samples were omitted as they did not materially aid in identification.

Fine Silt Fraction (5 - 2u). The x-ray diffractograms for the fine silt fraction of the six profiles are presented in Figures 8 to 13.

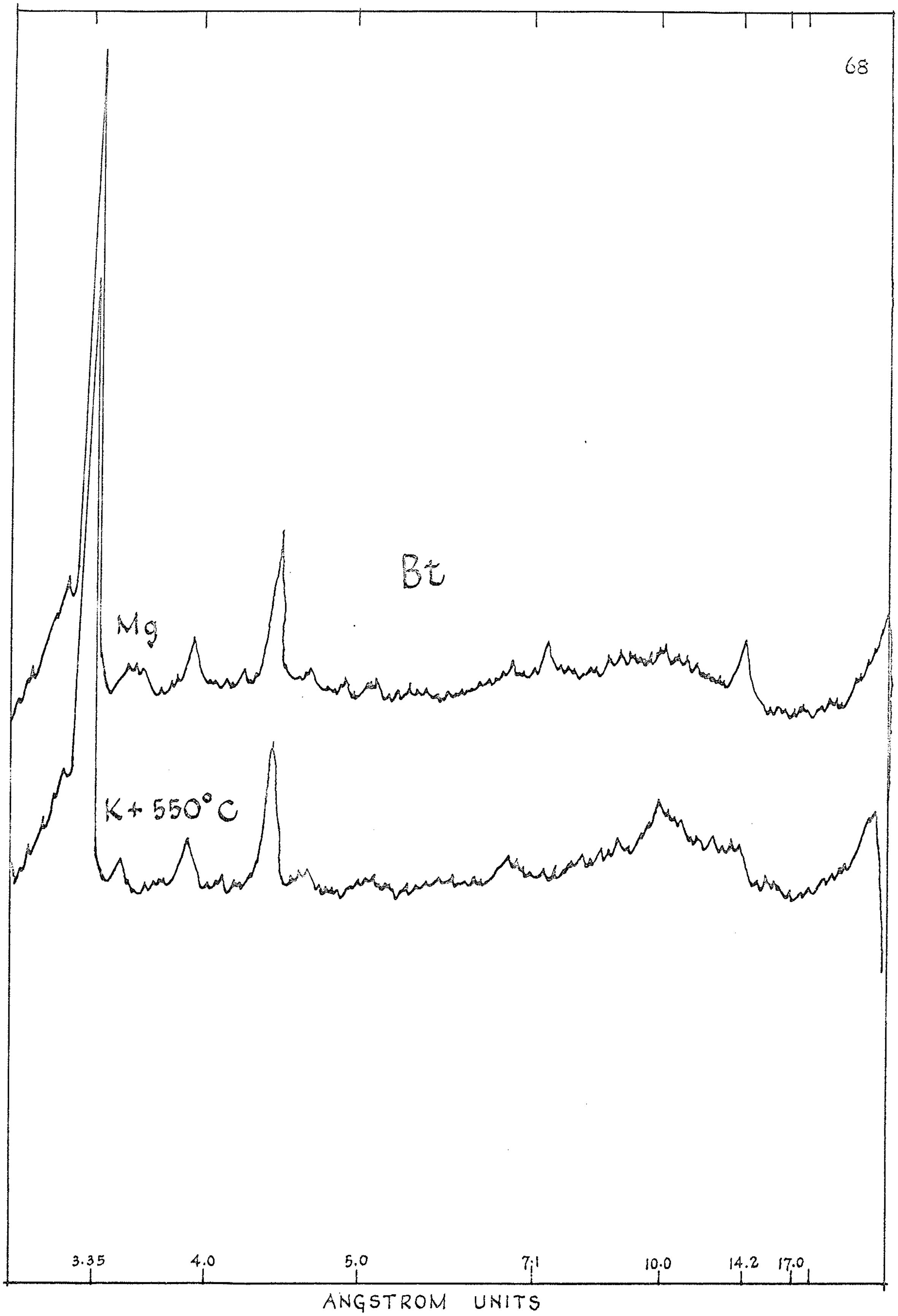

Figure 8. Profile 1. X-ray diffraction patterns for the fine silt fractions.

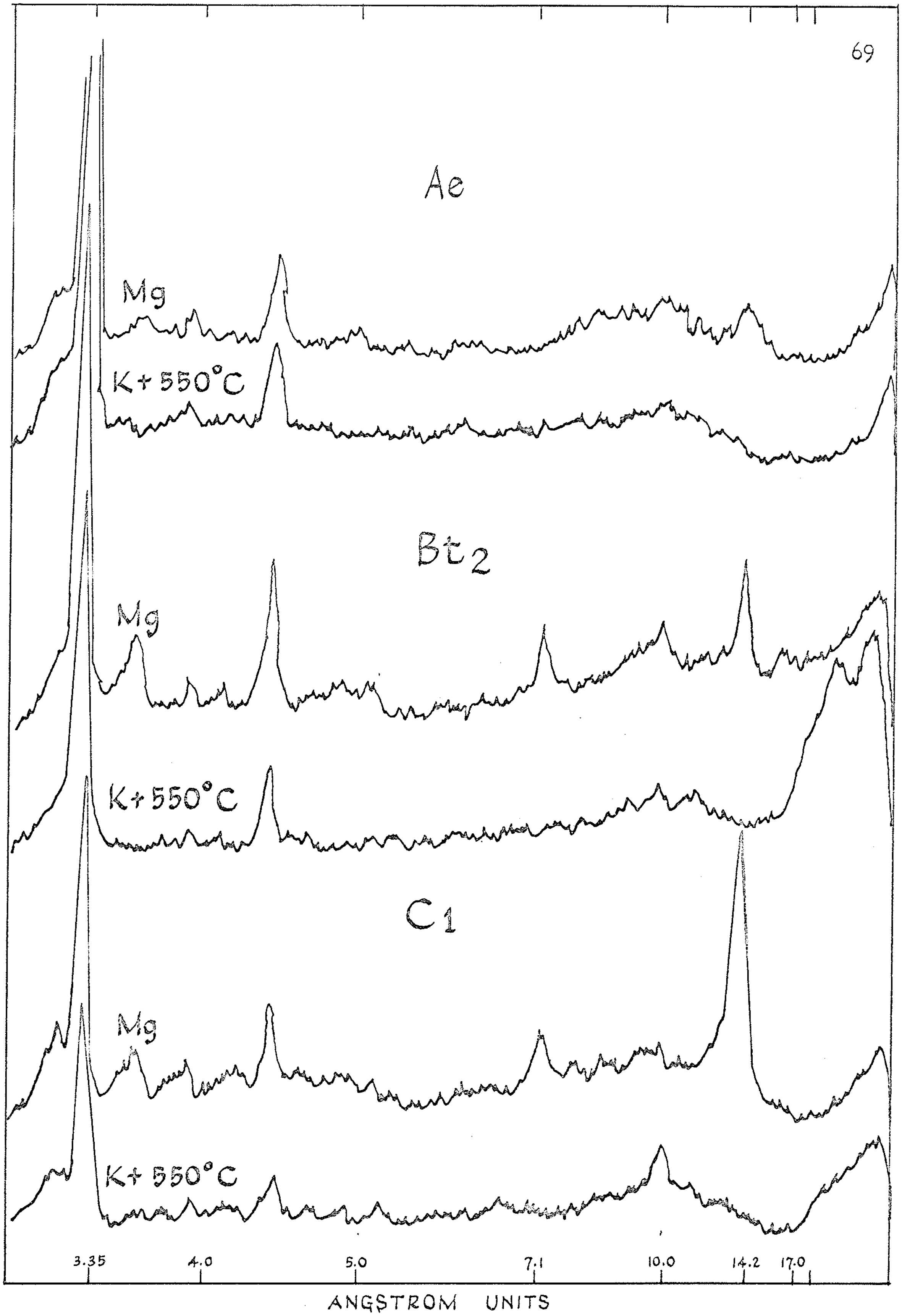

Figure 9. Profile 2. X-ray diffraction patterns for the fine silt fractions.

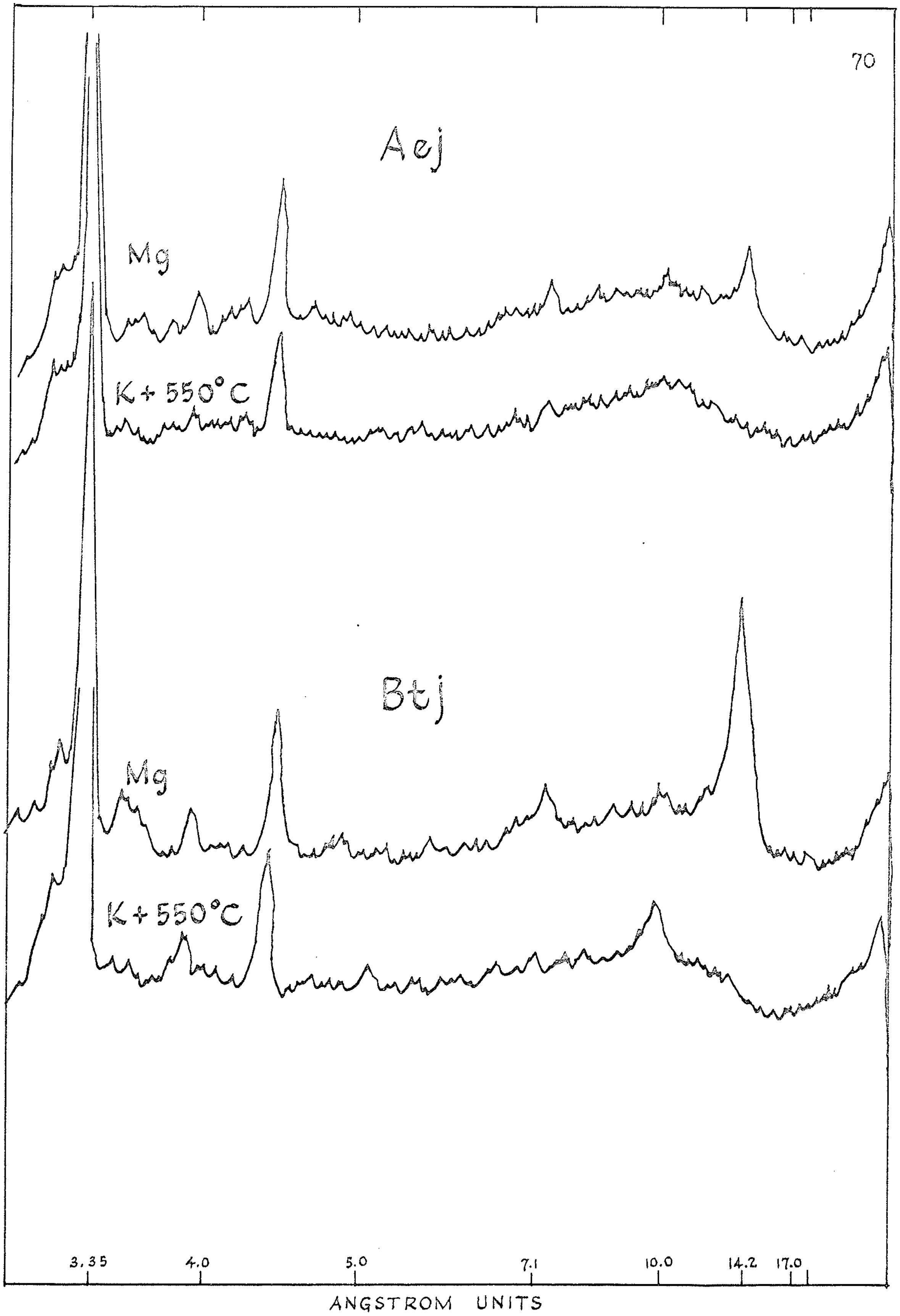

Figure 10. Profile 3. X-ray diffraction patterns for the fine silt fractions.

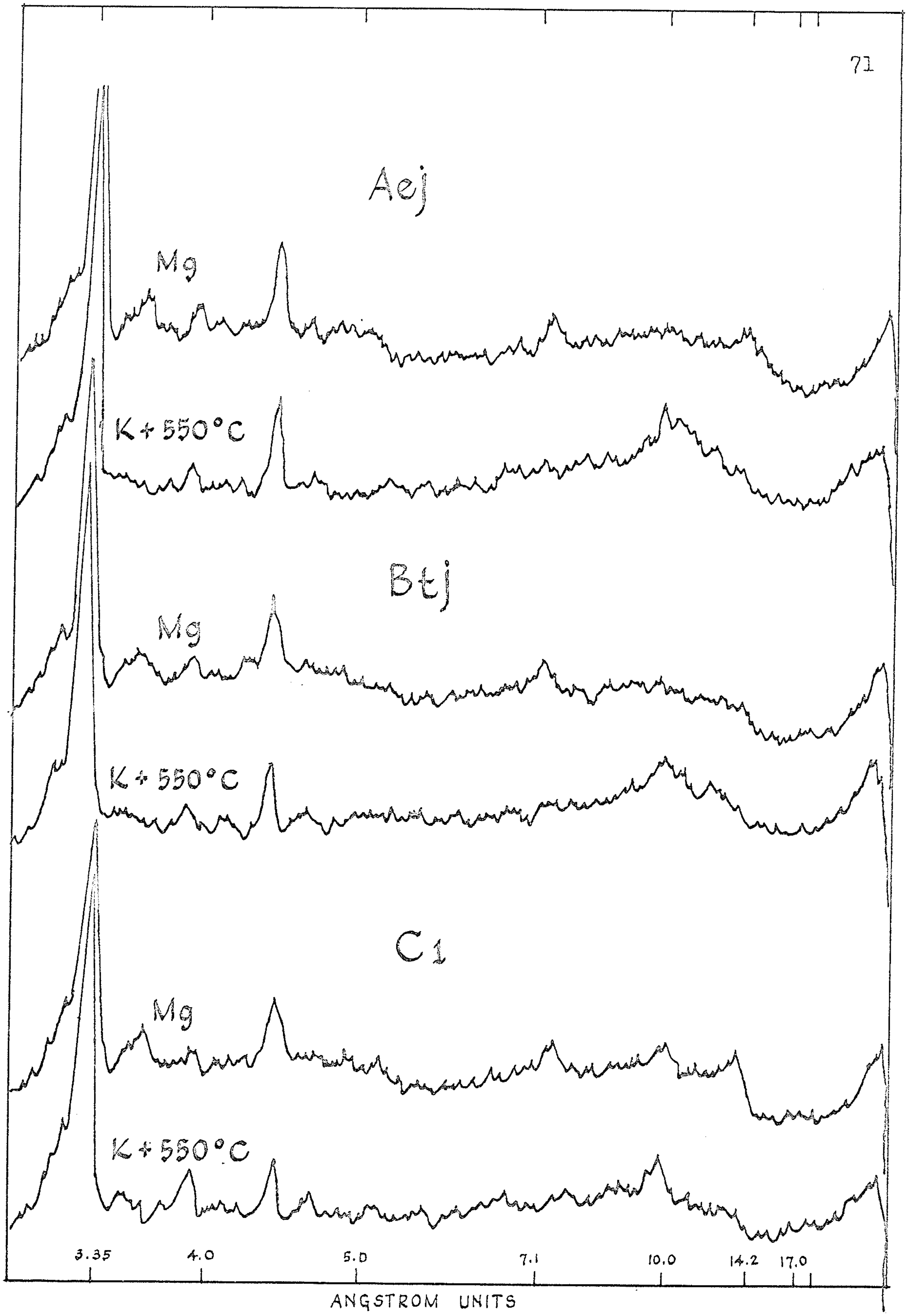

Figure 11. Profile 4. X-ray diffraction patterns for the fine silt fractions.

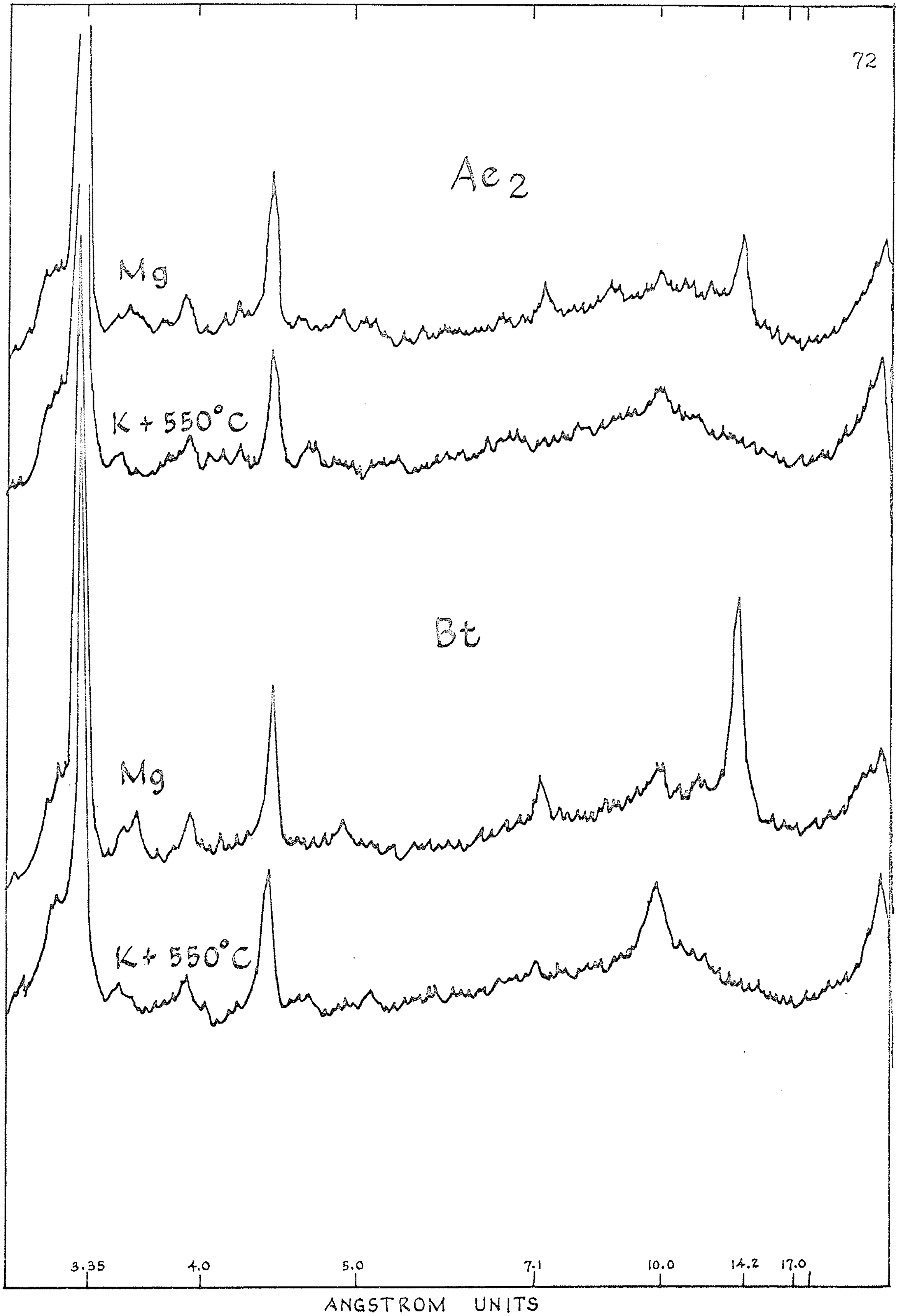

Figure 12. Profile 5. X-ray diffraction patterns for the fine silt fractions.

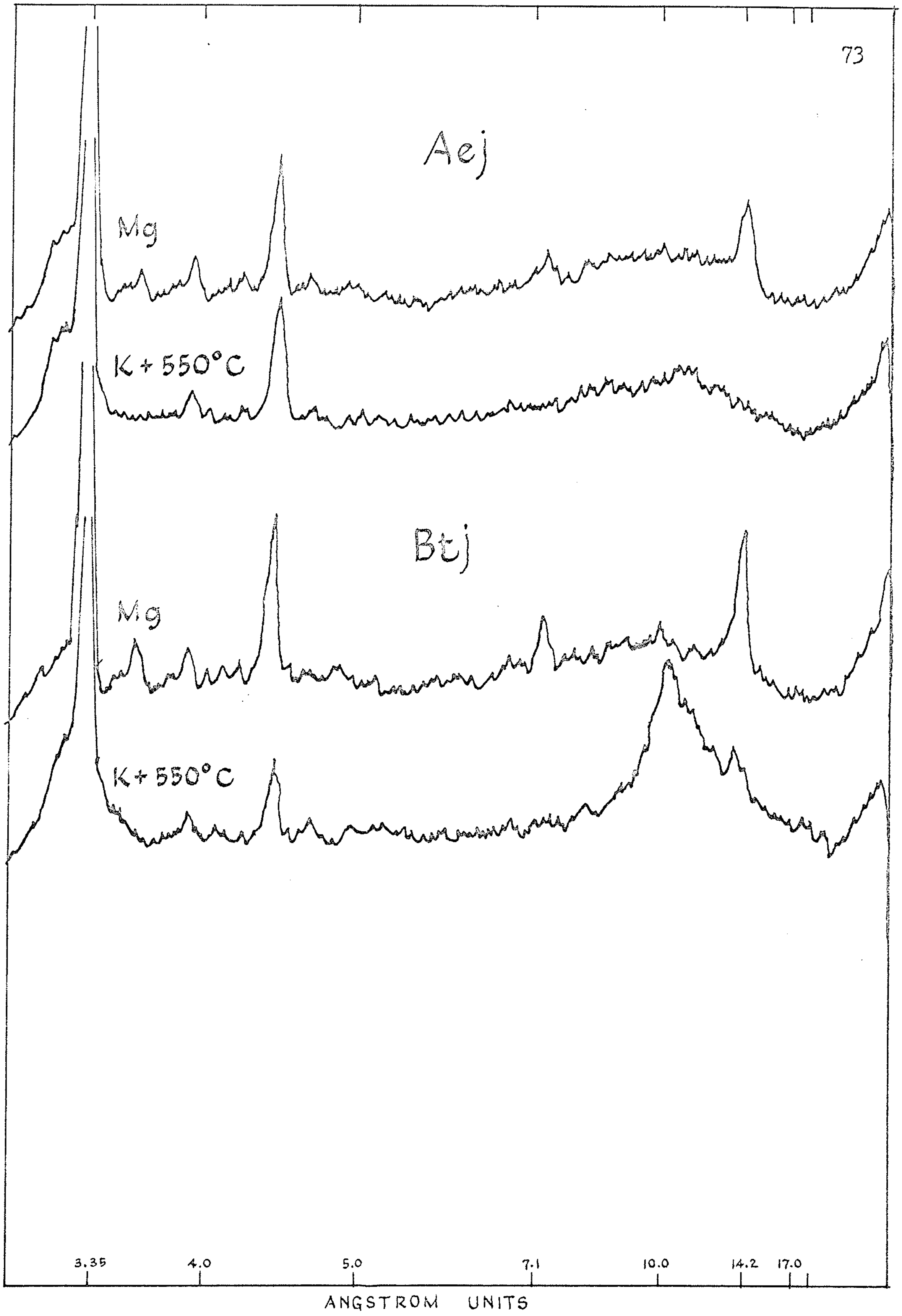

Figure 13. Profile 6. X-ray diffraction patterns for the fine silt fractions.

The diffractograms for one or two horizons in Profiles 1, 3, 5 and 6 are absent as there was not enough fine silt to make a slide.

The most prominent reflections on the diffractograms of all horizons of the six profiles are those for quartz in the 4.2 and 3.3Å positions. The intensity of these reflections varies very little among profiles, indicating approximately equal amounts of quartz in the fine silt fraction of the soils.

All profiles contain some vermiculite as is indicated by the 14Å spacings on the diffractograms of the Mg-saturated samples, and the partial collapse of these spacings when the samples were heated to 550°C. The weak 14Å peaks which remain after the heat treatment indicate traces of chlorite in some of the profiles (Figures 8,10,11 and 13).

The weak 10 and 5Å reflections on the diffractograms of the Mg-saturated samples in some profiles are indicative of illite and/or micas. The relatively broad nature of some of the 10Å peaks is indicative of a fine grained poorly developed illite rather than a fine grained muscovite, which has a relatively narrow sharp peak (63). In general, illite appears to be more abundant in the B and C horizons, than in the A horizons. The characteristic 17.7Å reflection of the montmorillonite minerals does not appear in the diffractograms of the fine silt fractions.

There is evidence for mixed-layer minerals in the 10 to 14Å and 14 to 18Å regions on the diffractograms of the Mg-saturated samples. The diffractograms of the heated K-saturated samples show weak non differentiated peaks between 10 and 14Å which suggest random interstratification of illite, vermiculite and chlorite. This kind of diffraction pattern is the result of a random interstratification, in which the number of diffracting planes of minerals with 10 and 14Å spacings occurring in each uninterrupted zone, is approaching the minimum number for x-crystallinity (22). Such x-amorphous zones are interstratified too coarsely to show intermediate Hendricks-Teller spacings (23).

Due to lack of diffractograms for the A and C horizons of some profiles it is only possible to compare the profiles on the basis of the diffractograms of the B horizons. Qualitatively, with the exception of Profile 4, the diffractograms are quite similar as to clay mineral composition. Quantitatively, vermiculite varies from trace amounts in Profile 4 to moderate to large amounts in the other five profiles. Illite occurs in moderate amounts in Profiles 2, 3, 5 and 6 and in trace amounts in Profiles 1 and 4. Mixed-layer minerals appear to be present in equal amounts in all horizons.

Coarse Clay Fractions (2.0 - 0.2u). The diffractograms for the coarse clay fraction of the six profiles are presented in Figures 14 to 19. In each of the six profiles the strong peaks at 4.2 and 3.3Å are indicative of quartz. However, the peaks are less pronounced than those of the fine silt fraction, indicating that quartz is present in smaller amounts.

The 14Å peaks on the diffractograms of the Mg-saturated samples are more pronounced in all profiles than on the diffractograms of the fine silt fractions. This can be attributed to an increase in the vermiculite content as well as to the presence of chlorite. The partial collapse of the 14Å spacing to 10Å and the disappearance of the 7Å second order vermiculite reflection on the diffractograms of the heated K-saturated samples confirms the presence of vermiculite. In general, the peak intensities for vermiculite increase progressively from the A to the B to the C horizons in all profiles. The weak 14Å reflections on the diffractograms of the heated K-saturated samples are indicative of chlorite.

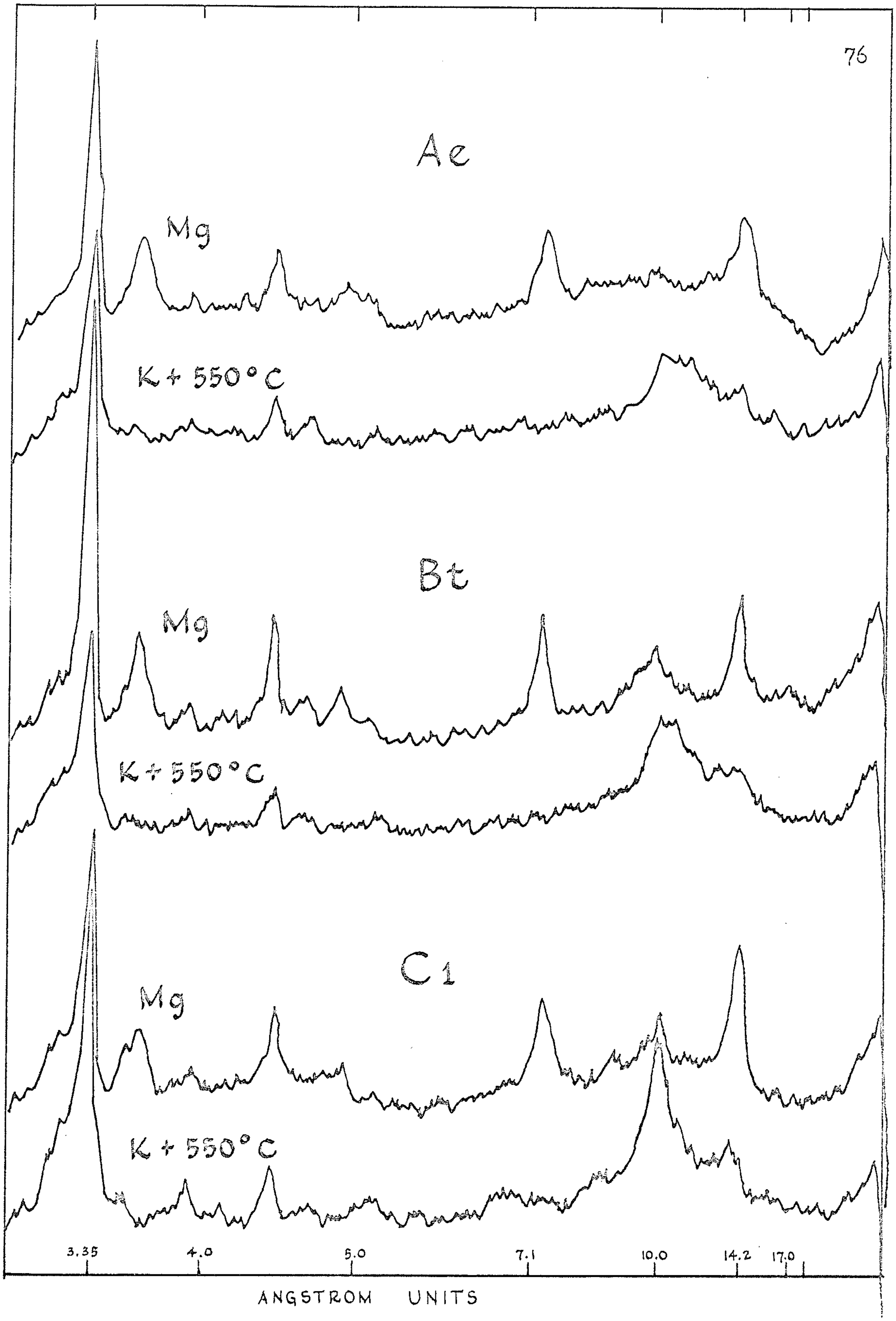

Figure 14. Profile 1. X-ray diffraction patterns of the coarse clay fractions.

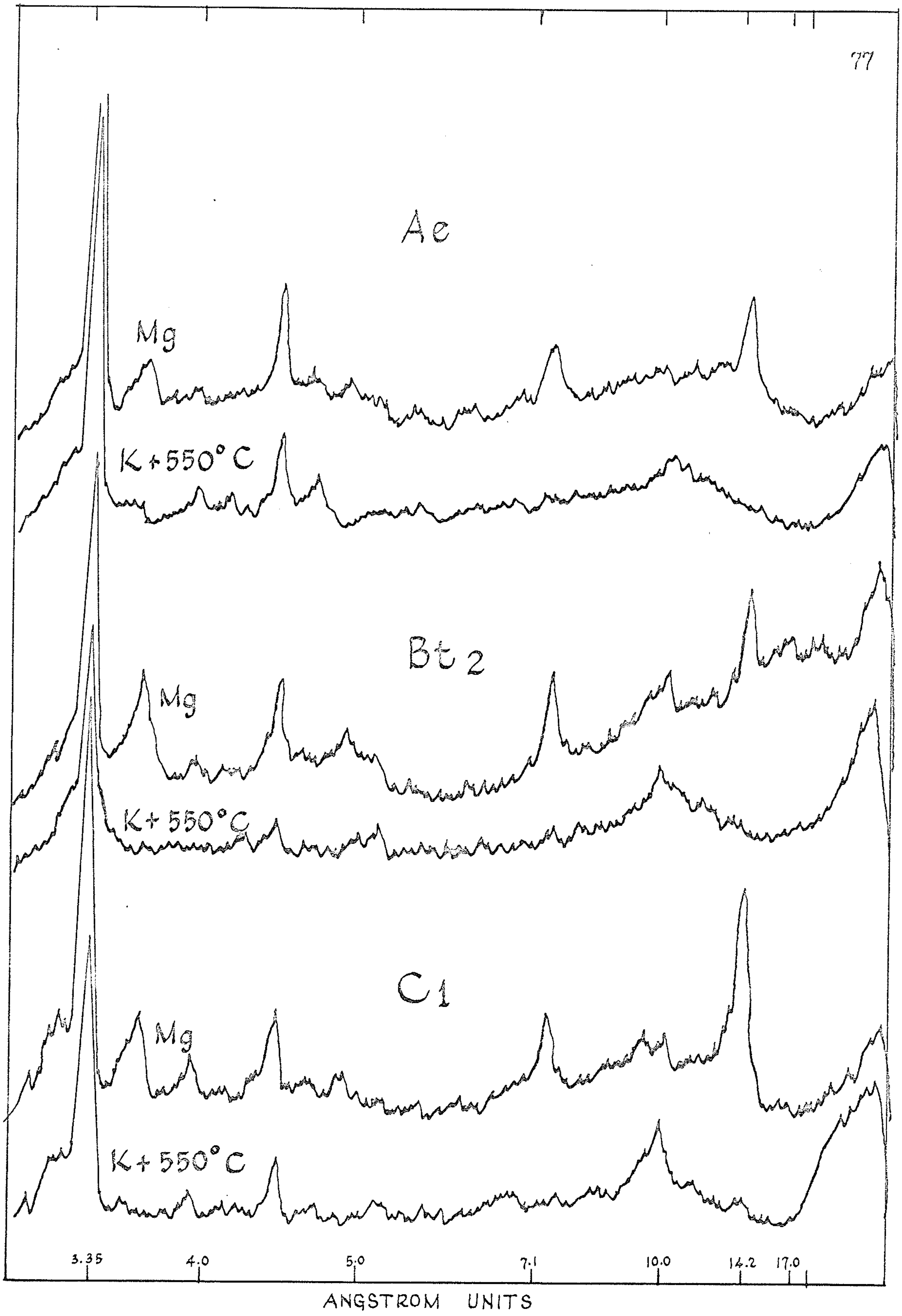

Figure 15. Profile 2. X-ray diffraction patterns of the coarse clay fractions.

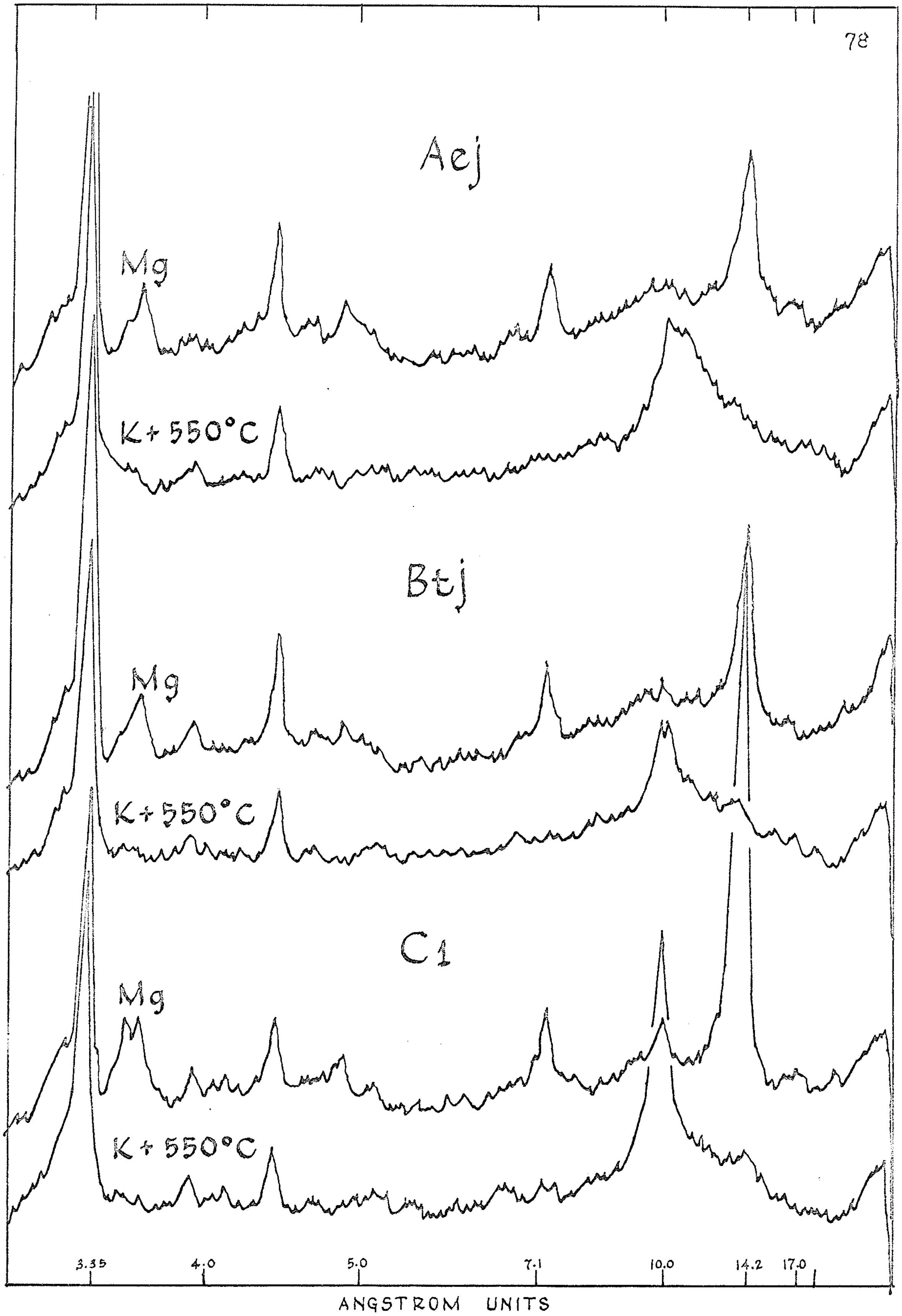

Figure 16. Profile 3. X-ray diffraction patterns of the coarse clay fractions.

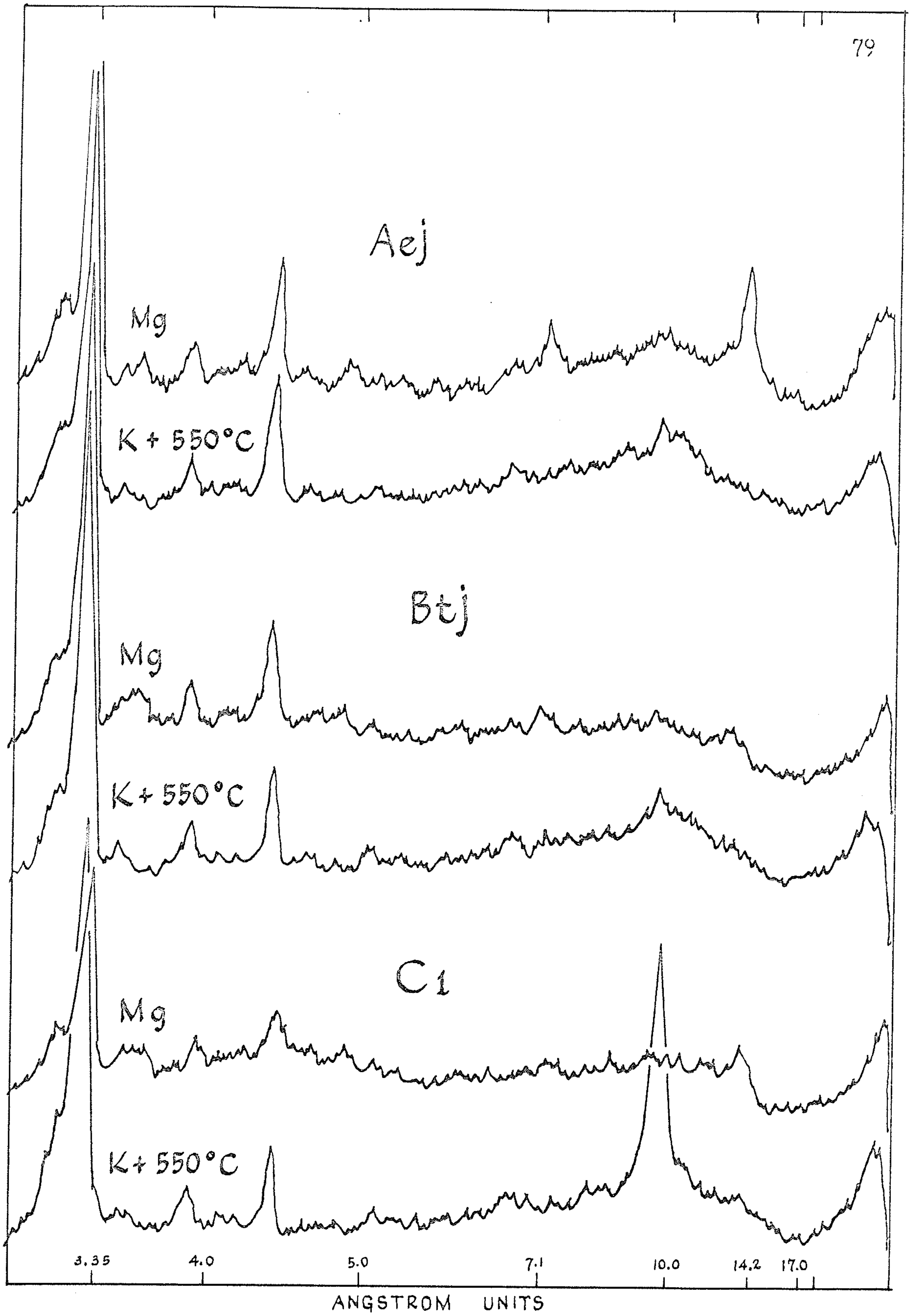

Figure 17. Profile 4. X-ray diffraction patterns of the coarse clay fractions.

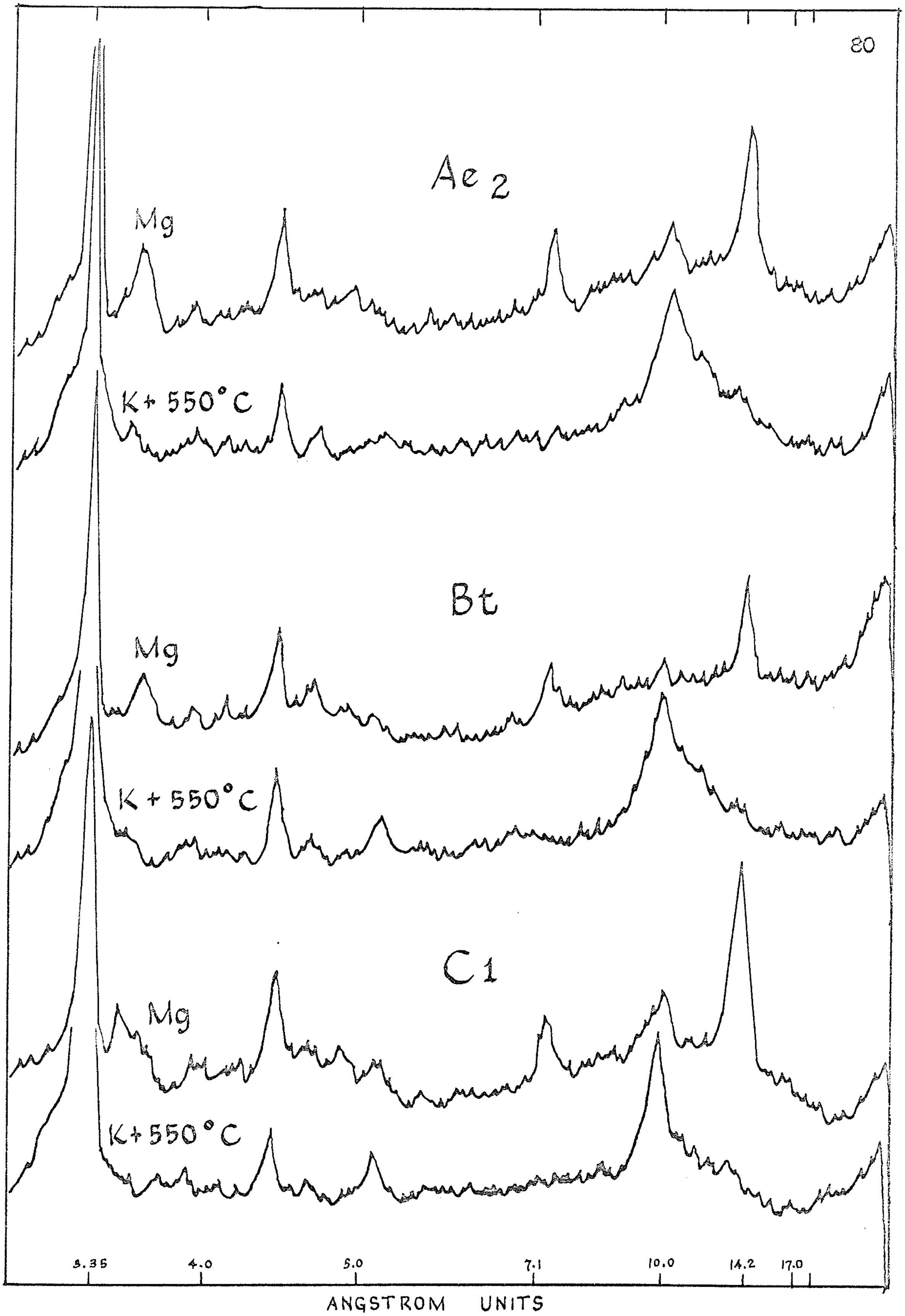

Figure 18. Profile 5. X-ray diffraction patterns of the coarse clay fractions.

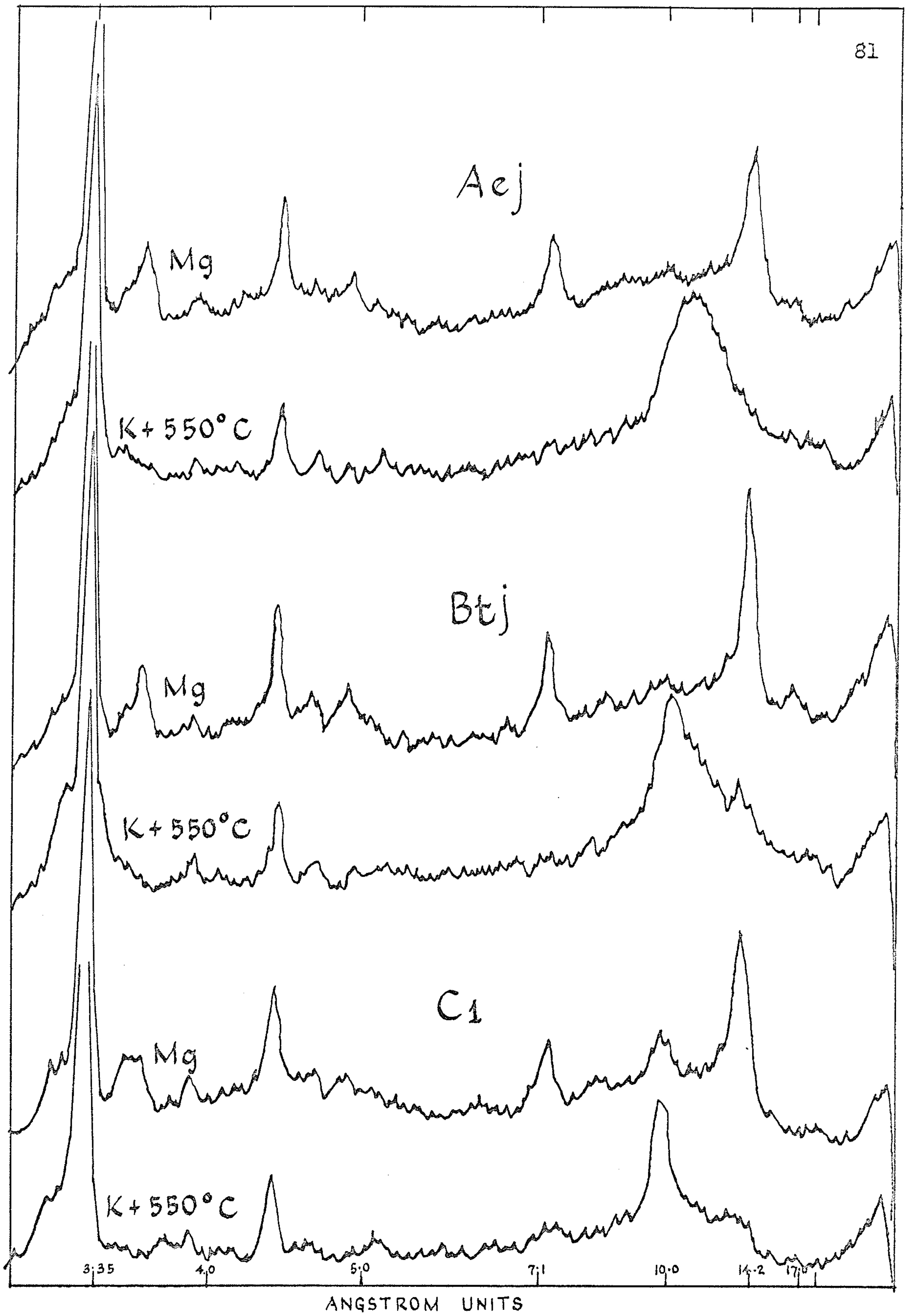

Figure 19. Profile 6. X-ray diffraction patterns of the coarse clay fractions.

This 14Å peak in some instances is part of the plateau-like reflection extending from 10 to 14Å.

The diffractograms of the Mg-saturated samples show distinct 10Å reflections indicative of illite. These reflections appear only in the diffractograms of the B and C horizons, being more pronounced in the C than in the B horizons. Minor amounts of illite occur in the A horizon of Profile 5 and trace amounts are found in the A horizons of the other profiles. As in the fine silt fractions, the relatively broad 10Å reflections indicate a fine grained poorly developed illite rather than a mica (63). The 17.7Å montmorillonite reflection is weak on the Mg-diffractograms of all horizons of the six profiles with the exception of the Bt2 horizon of Profile 2 and the Btj horizon of Profile 6.

Two plateaux in the 10 to 14Å and 14 to 18Å regions on the diffractograms of the Mg-saturated samples suggest the presence of random mixed-layer minerals. These plateaux consist of weak non-differentiated peaks and indicate that a portion of the interstratified material is of such a coarse nature that the various layer silicates are too inextensive in one sequence (fewer than 10 to 30 layers) to result in an x-ray diffraction peak (23). The diffractograms of the heated K-saturated samples show a series of weak non-differentiated peaks in the 10 to 14Å region which suggest random interstratification of illite, vermiculite and chlorite (22). The random mixed-layer minerals occur in all horizons of the six profiles in approximately equal amounts.

The Mg-diffractograms of the C horizons of all profiles with the exception of Profile 4 show reflections for discrete layer silicate minerals as well as randomly interstratified minerals. The diffraction patterns of the heated K-saturated samples of the C horizons of all profiles show a large 10Å peak which is due to the collapse of expanded layer silicates to a common spacing. However, the diffraction pattern obtained from the heated K-saturated sample of the C horizon of Profile 4 is attributed ohly to the presence of random ternary or more complex mixtures. Somewhat similar results have been obtained by Whittig and Jackson (64). The occurrence of a binary interstratified mixture is precluded by the lack of average spacings noted for such mixtures before heating. Jackson (23) states that ternary or more complex interstratified mixtures appear not to give the intermediate Hendricks-Teller spacings noted for binary mixtures. If z-axis limitation was involved, broadened peaks and plateaux would have appeared rather than the low background found. In the absence of discrete montmorillonite and vermiculite this kind of response to heating indicates quaternary interstratification as montmorillonite, vermiculite, illite, chlorite sequences.

In general, all profiles contain quartz, vermiculite, chlorite, illite, montmorillonite and mixed-layer minerals. Profile 4 contains only small to trace amounts of discrete clay minerals. Quantitatively, the diffractograms show that the intensity of the characteristic peak for vermiculite increases from the A to the B to the C horizons in all profiles. This can be attributed to better crystallinity of vermiculite due to less intense weathering, and to a larger amount of this mineral. In general, the amount of illite in relation to vermiculite is least in the A horizon and increases with depth. This probably indicates that some illite has weathered to vermiculite. The alteration of the basic mica structure to vermiculite has been reported by several workers (9,22,46).

Fine Clay Fraction (< 0.2u). The x-ray diffractograms for the fine clay fraction of the six profiles are presented in Figures 20 to 25. The diffractograms show that quartz is absent in the fine clay fractions. Weak 14Å reflections on the diffractograms of the Mg-saturated samples and the partial collapse of these peaks on heating to 550°C indicate that some vermiculite is found in most of the horizons of the six profiles.

The diffractograms of the Mg-saturated samples show that the 10Å reflection characteristic of illite is present in all horizons of the six profiles. The relatively broad peaks indicate that the illite is a fine grained poorly developed crystal. In general, the illite peaks are best defined in the C horizons. This can be attributed to the presence of well crystalline illite and also to less interstratification of other minerals with illite.

The 17.0 and 17.7Å peaks on the diffractograms of the Mg-saturated samples indicate that montmorillonite is present in all profiles. The Mg-diffractograms of the A and B horizons of Profiles 1, 2 and 3 show strong lines for montmorillonite whereas in Profile 4 montmorillonite is present only in the A horizon. In general, the 17.7Å reflection is absent in the x-ray patterns of the C horizons of these profiles. The diffractograms for Profiles 5 and 6 show that montmorillonite is present in all horizons.

Traces of chlorite are indicated in all profiles by the occurrence of weak 7.2Å reflections on the diffractograms of the Mg-saturated samples together with a weak 14Å reflection which remains on the diff-

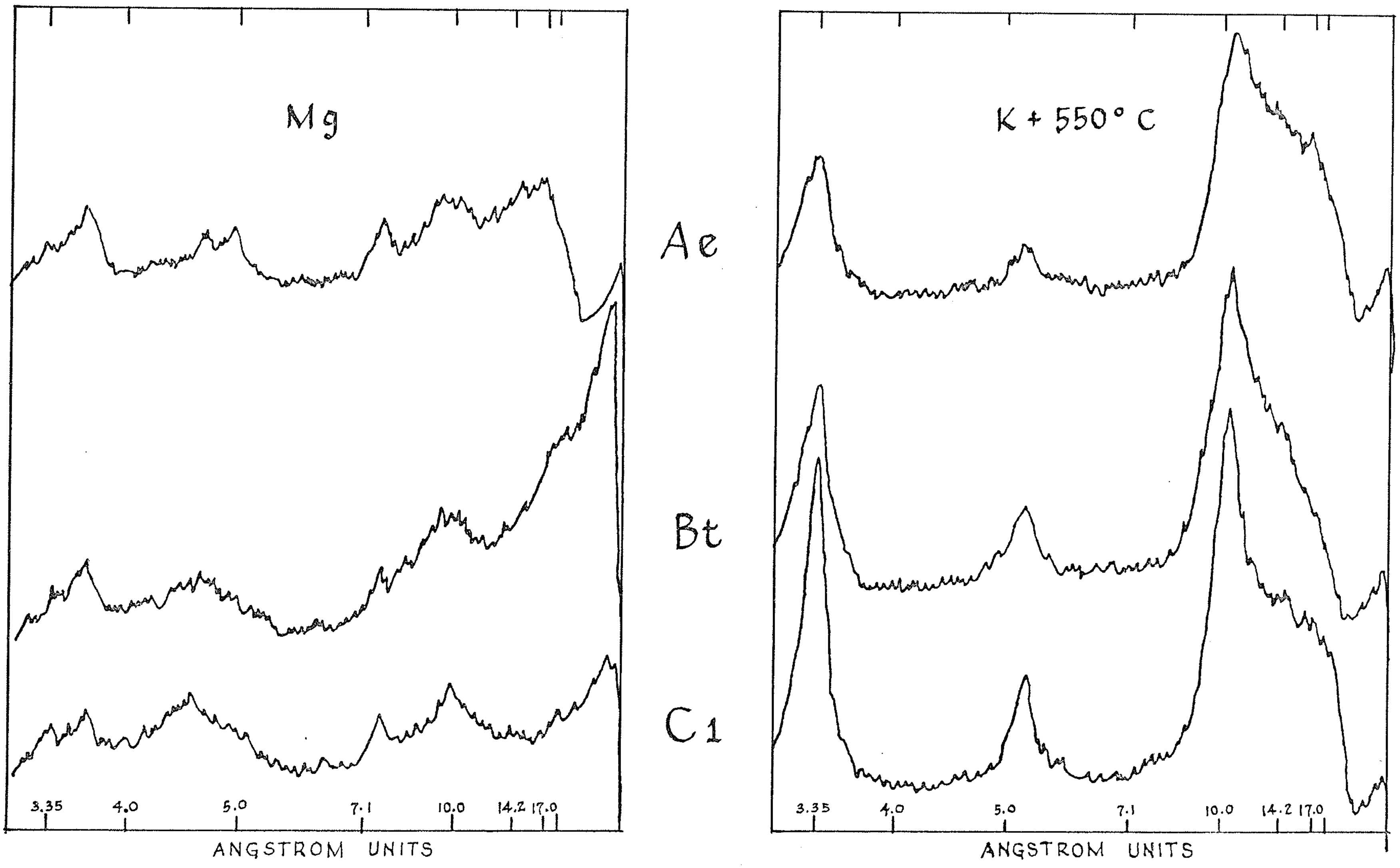

Figure 20. Profile 1. X-ray diffraction patterns of the fine clay fraction.

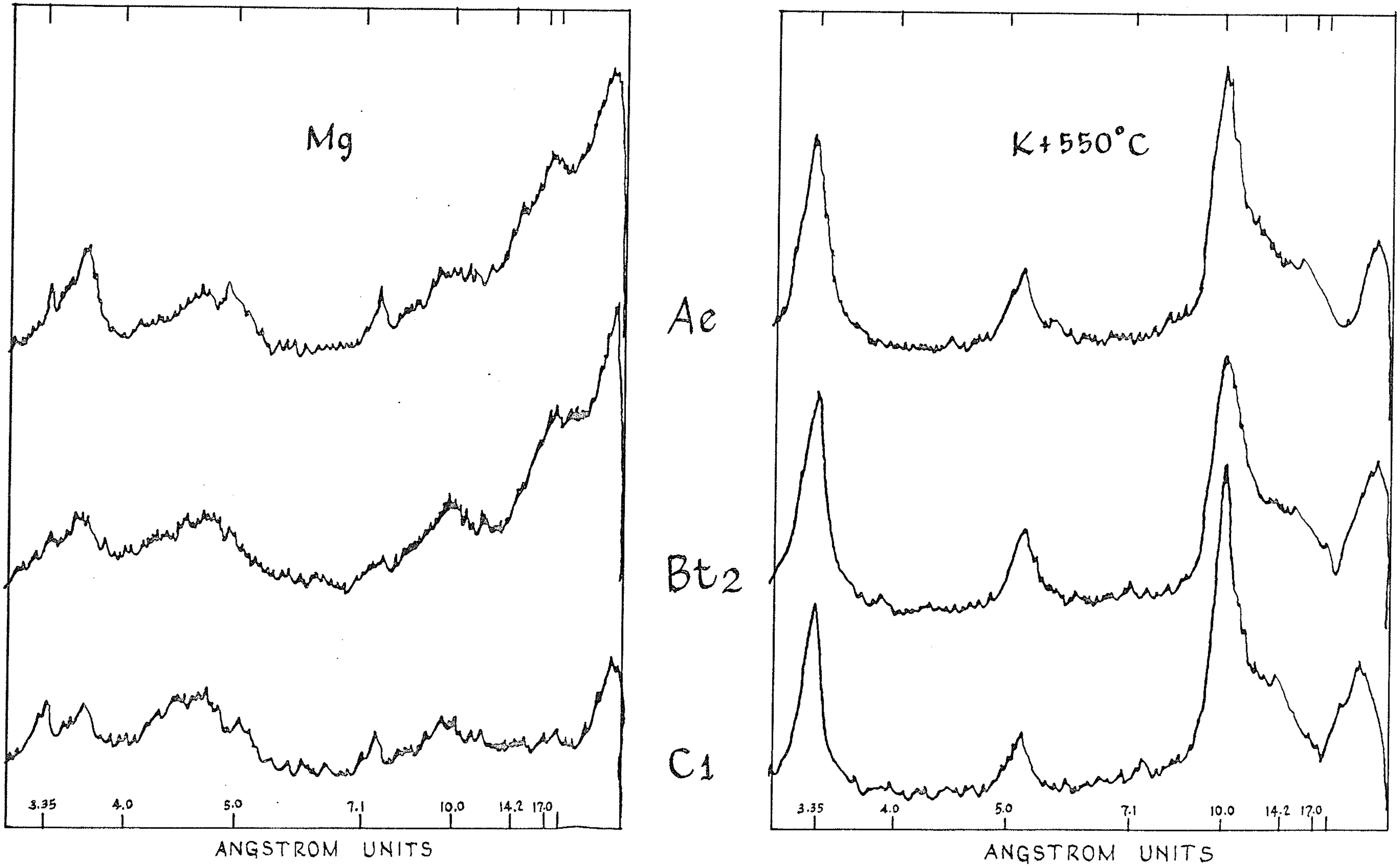

Figure 21. Profile 2. X-ray diffraction patterns of the fine clay fraction.

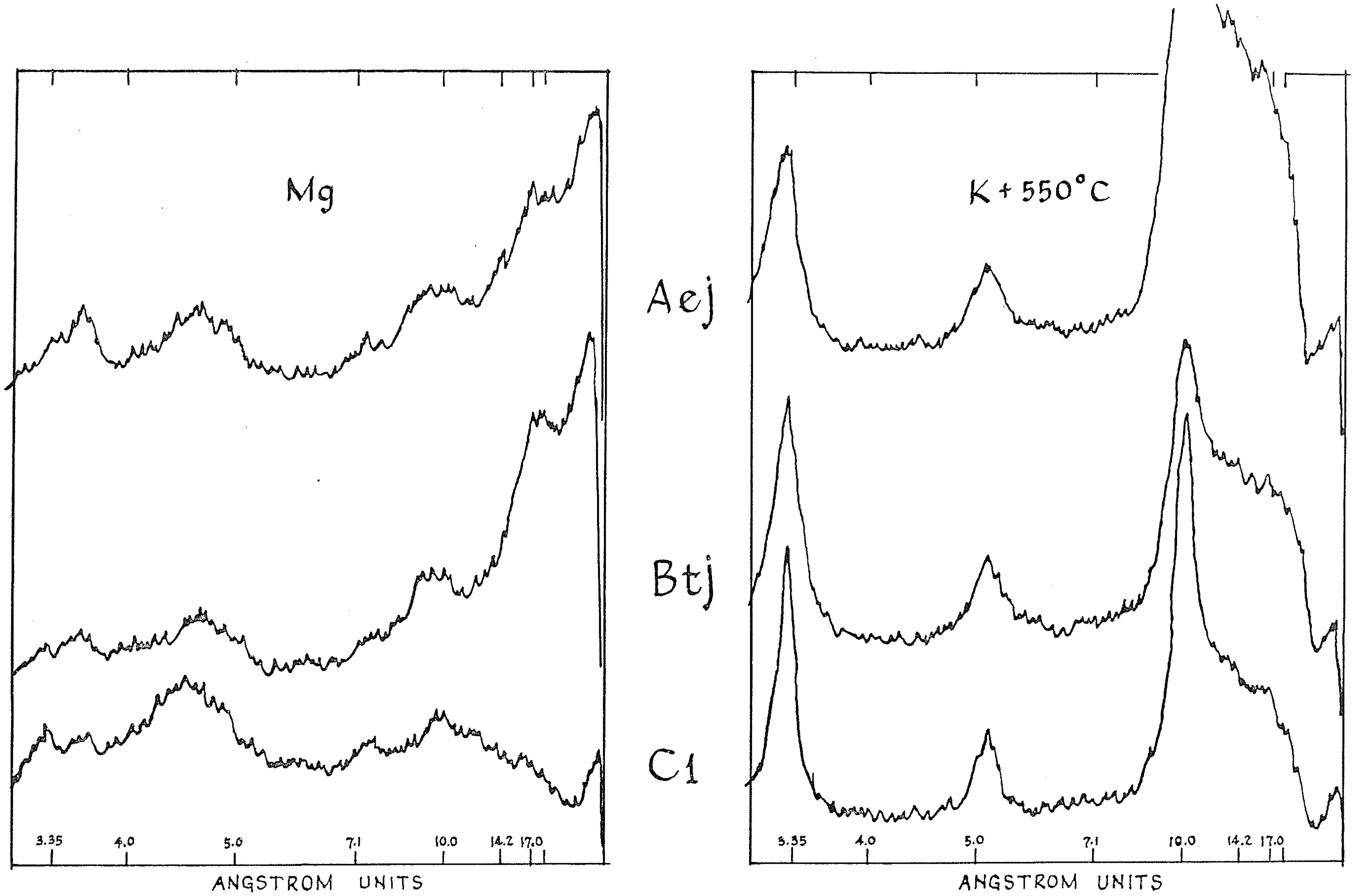

Figure 22. Profile 3. X-ray diffraction patterns of the fine clay fraction.

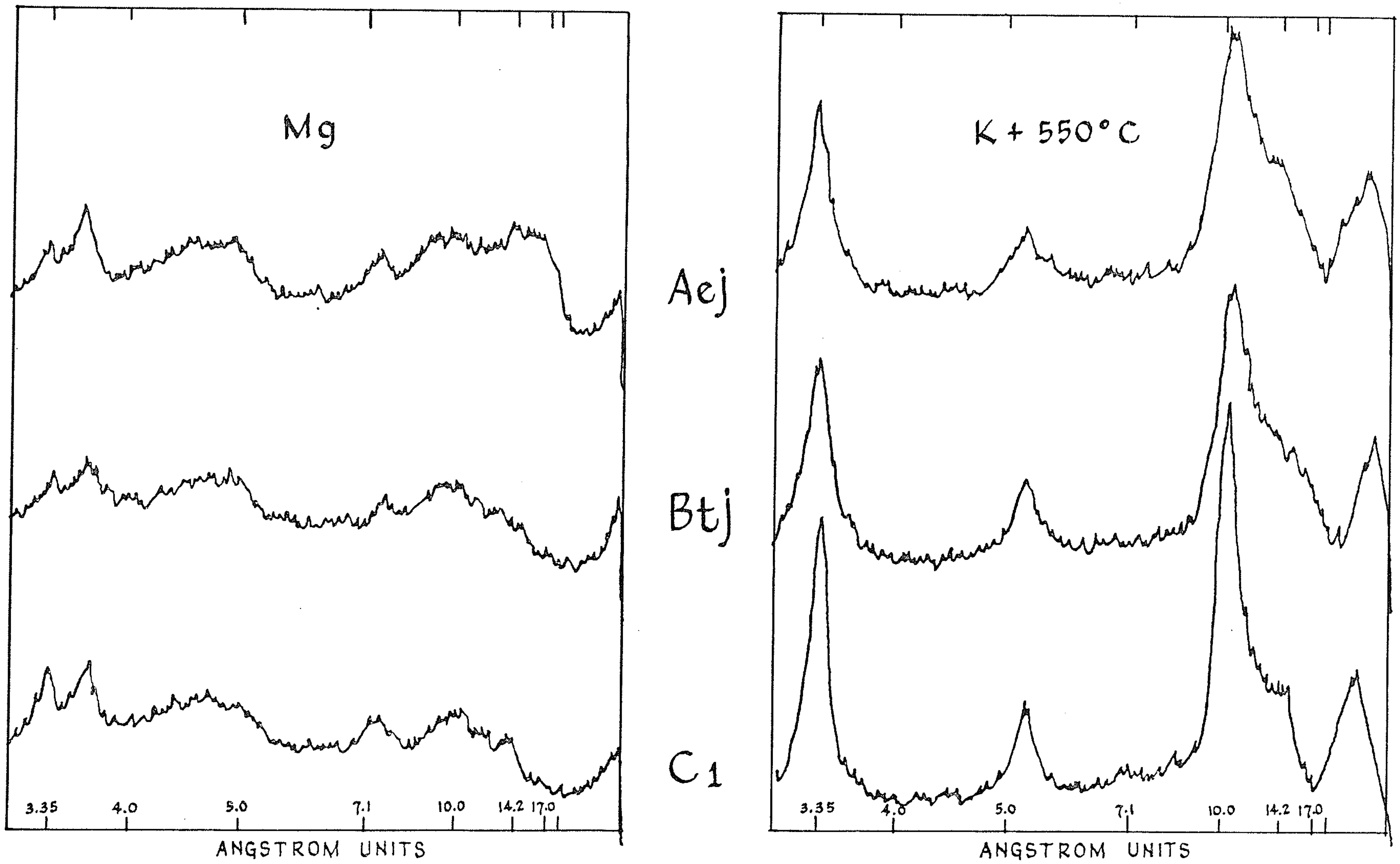

Figure 23. Profile 4. X-ray diffraction patterns of the fine clay fraction.

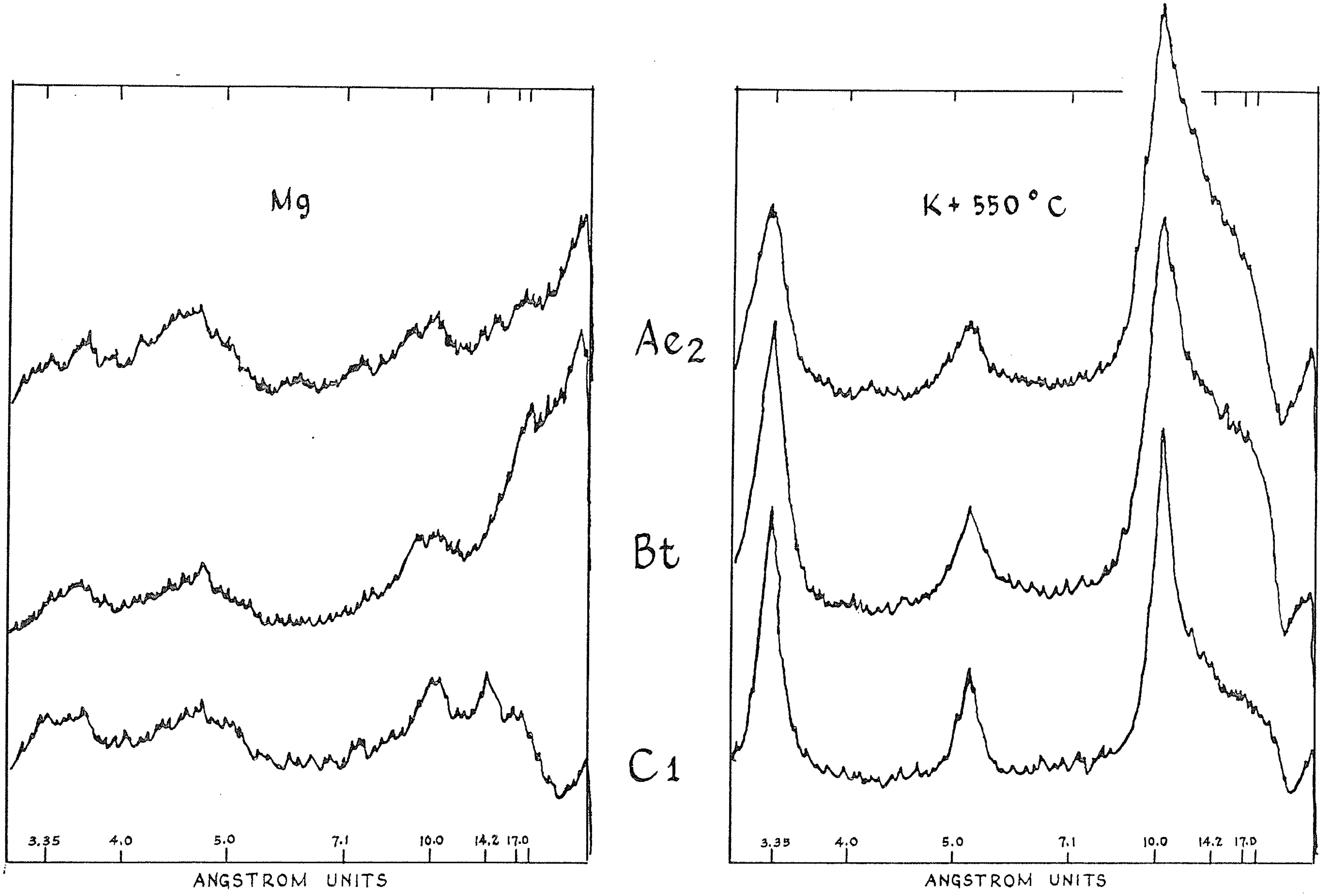

Figure 24. Profile 5. X-ray diffraction patterns of the fine clay fraction.

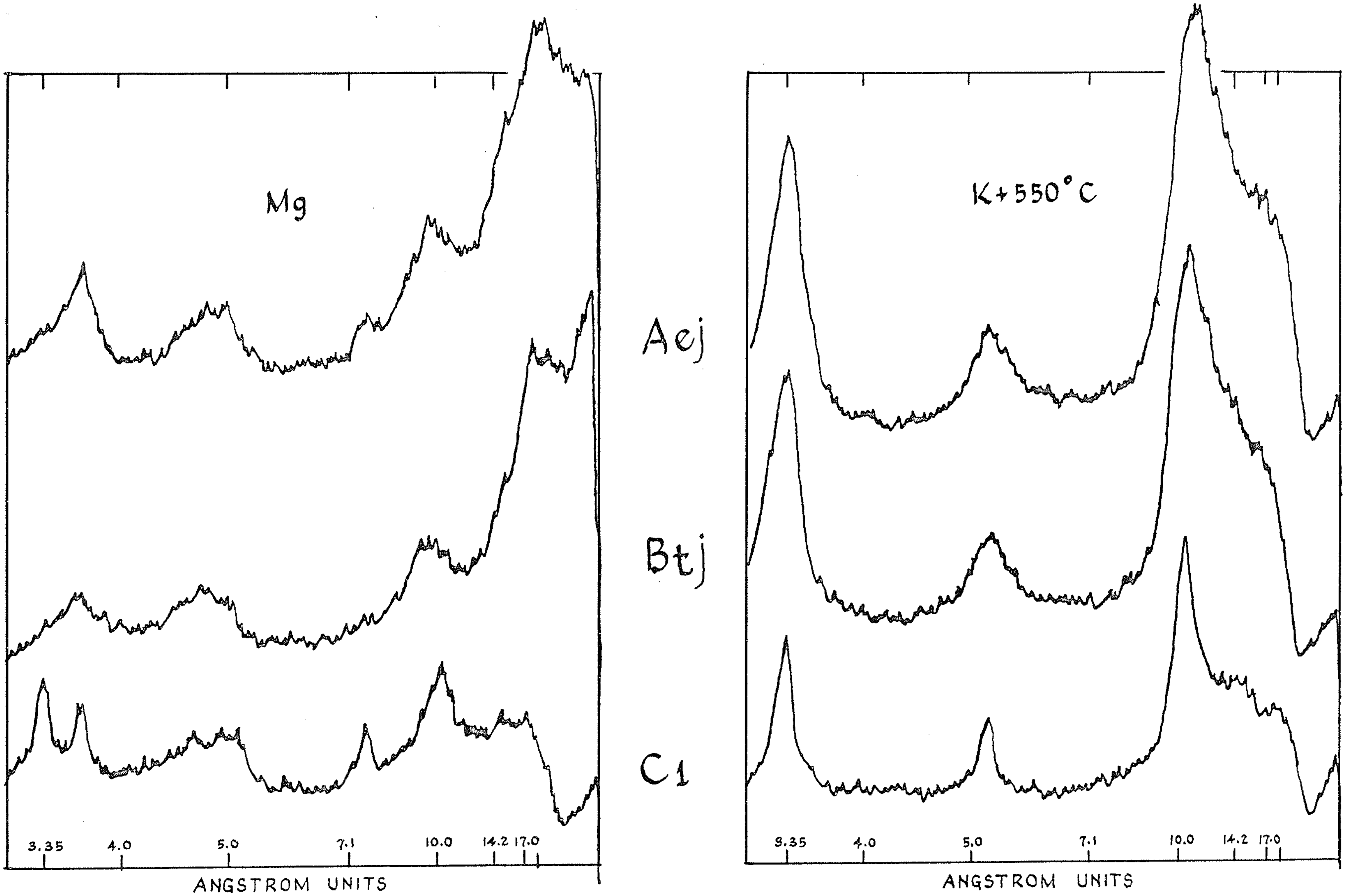

Figure 25. Profile 6. X-ray diffraction patterns of the fine clay fraction.

ractograms of the heated K-saturated samples.

Random mixed-layer clay minerals are present in all six profiles. The diffractograms of the Mg-saturated samples indicate that the mixed-layer minerals occur in larger amounts in the A and B than in the C horizons. The high background in the low angle region of most diffractograms and a broad peak at 3.5Å is indicative of minerals with intermediate spacing in the 10 to 18Å region(23). The presence of a large 10Å peak on the diffractograms of the heated K-saturated samples together with the absence of distinct Hendricks-Teller spacings on the diffractograms of the Mg-saturated samples indicate that the interstratification is a ternary or more complex mixture of minerals (64). The identification of small amounts of discrete illite, vermiculite, chlorite and montmorillonite suggests that most of the interstratified mixed-layer minerals consist of these components.

The mixed-layer minerals occur in larger amounts in the A and B horizons than in the C horizons. The presence of mixed-layer minerals in much greater amounts in the sola than in the parent materials suggests that they are of authigenic origin. Similar results have been obtained by Pawluk (38). Authigenic formation of mixed-layer minerals can be attributed to alteration of illite (46).

All profiles contain vermiculite, illite, montmorillonite, chlorite and random mixed-layer minerals, but quantitatively there is some variation within profiles. In general the montmorillonite and mixed-layer minerals occur in the A and B horizons and are absent in the C horizon. Illite is more abundant in the C horizon than in the A and B horizon. The amounts of chlorite and vermiculite do not show any observable trends.

Limestone Samples. It is noted in the Profile Descriptions, (p.27) that the B horizons of Profiles 1, 2, 5 and 6 contain limestone cobbles. As the B horizon of Profile 3 did not contain any cobbles, a limestone fragment from the C horizon was analyzed. Limestones were not encountered in Profile 4. Some chemical, physical and mineralogical data for the limestone samples are presented in Table 9, p.109 in the Appendix.

The x-ray diffractograms of the limestone samples from the five profiles are presented in Figures 26 and 27. The size fraction analyzed was less than 2 microns.

The most prominent reflections in the diffractograms of the limestones are those for quartz at the 4.2 and 3.3Å spacings. There is very little variation in the intensity of these reflections between samples indicating approximately equal amounts of quartz.

Illite is present in all the limestones as indicated by the 10Å reflection in the diffractograms of the Mg-saturated samples. The broad nature of this peak indicates a fine grained poorly developed illite crystal similar to that identified in the x-ray diffractograms of the soil profiles. The occurrence of a weak 14Å reflection on the diffractograms of the heated K-saturated samples provides evidence that chlorite is present. Montmorillonite and vermiculite as discrete minerals are absent in all limestone samples. In the diffractograms of the Mg-saturated samples there are plateaux in the 10 to 18Å region consisting of small non-differentiated peaks which can be attributed to random interstratification of chlorite, vermiculite and illite. As in the coarse clay samples this interstratification is of such a coarse nature that there are no distinct x-ray diffraction peaks formed.

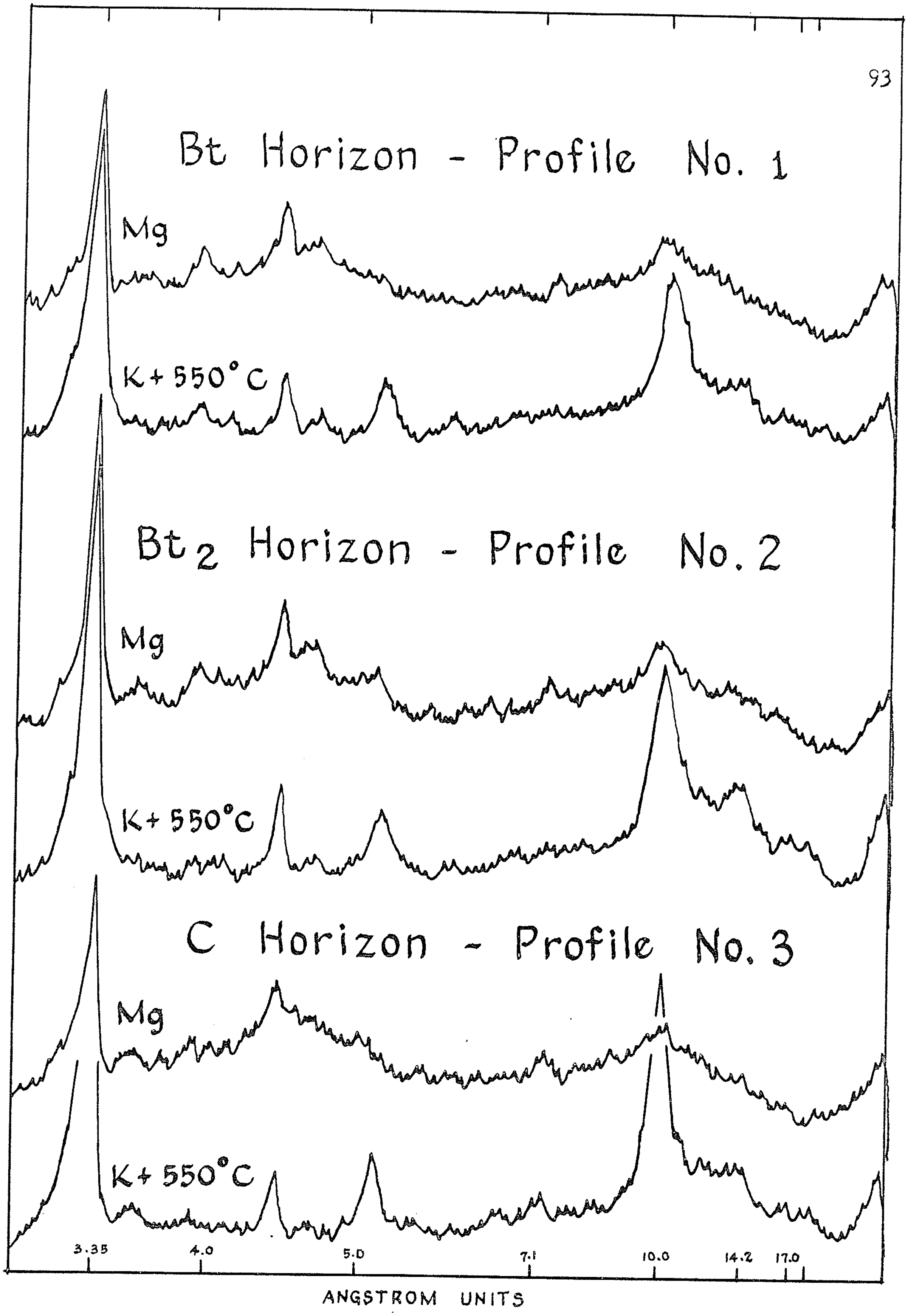

Figure 26. X-ray diffraction patterns of the limestone samples of Profiles 1, 2 and 3.

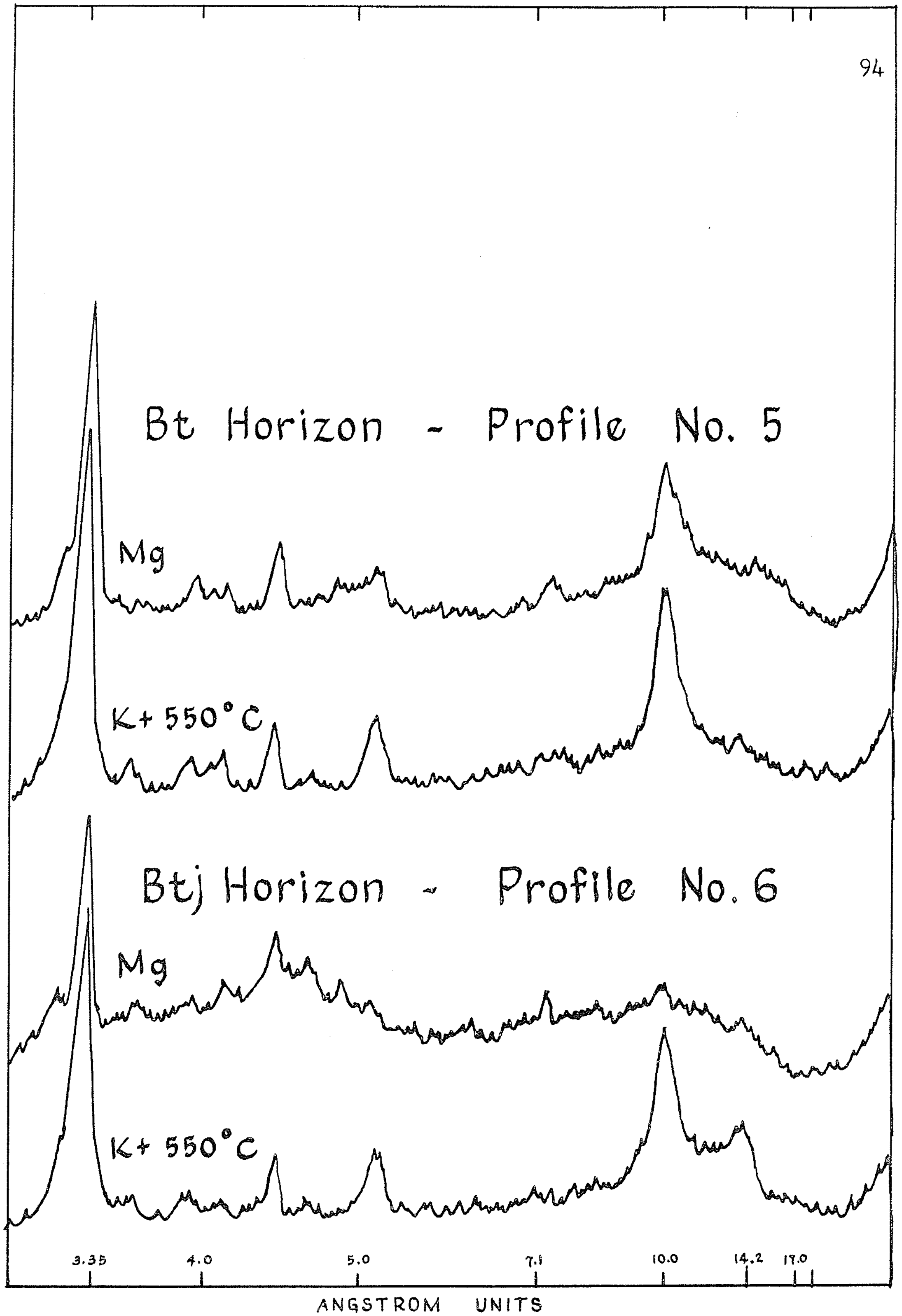

Figure 27. X-ray diffraction patterns of the limestone samples of Profiles 5 and 6.

A strong 10Å peak is evident on the diffractograms of the heated K-saturated samples of all the limestones. A similar reflection was obtained from the diffractogram of the heated K-saturated sample of the coarse clay fraction in Profile 4 (Fig.17,p.79) and also on all the heated K-diffractograms of the fine clay fraction. This peak confirms the presence of the ternary interstratified mineral identified in the Mg-saturated samples (64).

All limestone samples contain quartz, illite, chlorite, and mixed-layer minerals. Chlorite is present in only trace amounts.

SUMMARY

Orthic Grey Wooded and Degraded Brown Wooded soils developed on glacio-fluvial and aeolian deposits in Eastern Manitoba were studied both in the field and laboratory to: (1) characterize and classify the two main profile types, and (2) study the formation of a B horizon in these soils, and in particular to determine the relationship between the clay accumulation and the limestone cobbles in some of the B horizons.

Two profiles of each type were sampled from the Dencross area (Twp. 15, Rge. 7 E.) and one profile of each type was sampled from the Milner Ridge area (Twp. 12 and 13, Rge. 10 E.). All profiles were of similar texture and drainage and developed under similar climatic and biotic conditions.

1. The main difference in morphology between the two soil profile types is associated with the degree of development of the B horizons. The formation of the Bt horizon appears to be related directly to the presence of limestone cobbles. In the Orthic Grey Wooded profile the limestone cobbles form approximately a continuous layer and in this profile type a well developed Bt occurs around and between the cobbles. In the Degraded Brown Wooded profile the limestone cobbles are discontinuous or absent and hence the textural B horizon is weakly developed or lacking.

2. All profiles show the effects of varying degrees of leaching as the pH values of the sola range from medium acid to neutral in reaction. In general the $CaCO_3$ contents are closely related to

the pH values.

3. Accumulation of extractable iron is evident in the sola of all profiles. Amounts of free iron are greater in the B than in the A and C horizons, suggesting both in situ release of iron and some translocation of iron. The translocation of iron in all soils appears to be associated with clay and organic matter movement.
4. Slight accumulations of organic matter occur in the B horizons. In general the C:N ratios decrease from the A to the B to the C horizons.
5. The cation exchange capacity is closely related to the amounts of clay and organic matter present. Calcium and magnesium are the dominant cations on the exchange complex of all the soils. The high degree of unsaturation typical of Podzolic soils is not evident in these profiles.
6. Accumulation of clay has occurred in the B horizons of all profiles. The largest increase appears to be in the fine clay fraction. The B horizons with the larger clay contents are characterized by the presence of limestone cobbles from which the in situ release of clay minerals has occurred. There is evidence of redistribution in particle size of the total sand and the silt fractions in the sola relative to the parent materials. This redistribution is attributed to physical weathering.
7. The mineralogical analysis of the fine sand fraction indicates that quartz is the dominant mineral in the light mineral fraction.

The plagioclase feldspars predominate over the potash feldspars in all the profiles. In the heavy mineral suite, hornblende is the dominant mineral, with garnet and the opaque minerals being next in abundance. Various other minerals are present in minor amounts. Some of the more resistant minerals are well rounded which suggests that they are of detrital origin.

8. (a) The fine silt fraction contains quartz, vermiculite, chlorite, illite and mixed-layer clay minerals. Illite appears to be more abundant in the B and C than in the A horizon. The mixed-layer minerals are randomly interstratified.

   (b) The coarse clay fraction of all profiles contains quartz, vermiculite, chlorite, illite, montmorillonite and random mixed-layer clay minerals. Illite and vermiculite contents increase with depth, with vermiculite showing a greater increase than illite.

   (c) In general, the reflections on the diffractograms of the Mg-saturated samples of the fine clay fraction are less distinct or are non-existent as compared to the diffractograms of the coarse clay fraction. The fine clay fraction of all profiles contains some vermiculite, illite, montmorillonite and chlorite, with random mixed-layer clay minerals predominating. The reflections for montmorillonite and mixed-layer minerals are most pronounced in the A and B horizons. As in the other fractions, the illite content appears to increase with depth.

9. The limestone samples contain quartz, illite, traces of chlorite and randomly interstratified clay minerals.

10. In general, the parent materials of the two areas appear to be similar as indicated by:

   (a) similar free iron contents,
   (b) similarity in the heavy mineral suite.
   (c) similar clay mineral composition.

11. Some differences in origin of the parent material of the two areas are indicated by:
    (a) two distinct levels of $CaCO_3$, varying from 0.09 to 8.63 per cent in the Dencross area, and in the order of 23 per cent in the Milner Ridge area,
    (b) the higher silt content and lower sand content in the parent material of the Milner Ridge area as opposed to the parent material of the Dencross area.
    (c) the higher heavy mineral content and lower magnetic mineral content in the parent material of the Dencross area as compared to the parent material of the Milner Ridge area.

12. Mineralogical and chemical data indicate a certain degree of uniformity of parent material in each area. Some differences however, do appear in the particle size distribution within the sand size fraction.

13. The x-ray analysis of the coarse and fine clay fractions of the A, B, and C horizons of the two profile types suggests some weathering sequences among the various clay minerals. The absence of illite in the coarse clay of the A horizons suggests that it was first altered to mixed-layer minerals and then to vermiculite, or else directly to vermiculite. In the fine clay fraction illite is more abundant in the C horizon than in the A and B horizon. This indicates that illite has been altered in the latter two horizons to random mixed-layer minerals and montmorillonite. The increase in random mixed-layer

minerals in the fine clay fraction of the A and B horizons can be attributed also to reduction in size of mixed-layer minerals of the coarse clay fraction. The increase in montmorillonite in the fine clay fraction of these horizons can be attributed to reduction in size of vermiculite with alteration to montmorillonite, together with alteration of mixed-layer minerals of the fine clay fraction.

14. Weathering of the limestone cobbles results in the release of illite and random mixed-layer minerals which can enter the above mentioned weathering sequence. A schematic diagram showing possible paths of weathering, eluviation of the clay minerals, and the effect on the Bt horizon of the release of clay minerals from the limestone cobbles is shown in Figure 28.

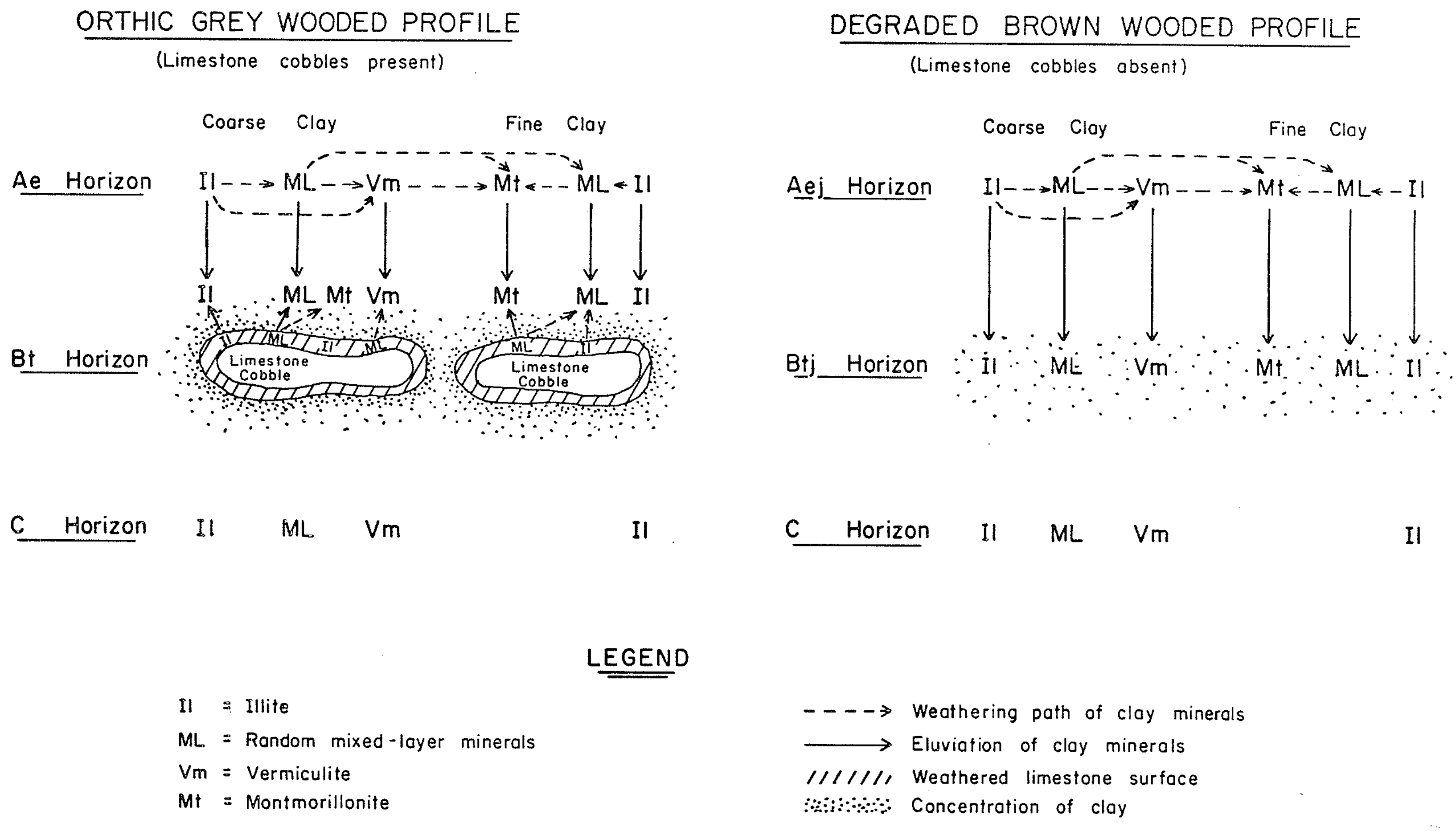

Figure 28. Schematic Diagram Showing Possible Paths of Weathering, Eluviation of the Clay Minerals, and the Effect on the Bt Horizon of the Release of Clay Minerals From the Limestone Cobbles.

CONCLUSIONS

1. Chemical and physical data indicate that decalcification has been the dominant process in the formation of the Orthic Grey Wooded and Degraded Brown Wooded profile types. The main changes have been:
   - (a) removal of free $CaCO_3$ from the sola;
   - (b) partial depletion of bases from the sola with the degree of unsaturation in the sola being approximately 25 to 30 per cent;
   - (c) accumulation of small amounts of organic matter and sesquioxides in the B horizons;
   - (d) accumulation of clay, (particularly fine clay) has occurred in all profiles, being most pronounced in the Bt horizon of the Orthic Grey Wooded profiles.
2. In general the main morphological, chemical and physical differences between the two profile types can be attributed to the limestone cobbles. In the Orthic Grey Wooded profile there has been in situ release of clay minerals from the limestone cobbles as well as precipitation of downward moving clay around and between the cobbles. In the Degraded Brown Wooded soils, which lack the limestone cobbles, downward moving clay is diffused through a larger zone and so is not detected as a "t" horizon. Such Btj horizons also lack the clay minerals released in situ from the decomposing limestone.

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APPENDIX

TABLE 9

SOME CHEMICAL, PHYSICAL AND MINERALOGICAL DATA
OF THE LIMESTONE SAMPLES OCCURRING IN SOME HORIZONS

Profile No. and Soil Subgroup	Horizon	Depth in.	% Total Sand	% Total Silt	% Total Clay	Solution Loss %	Calcium* Carbonate Equivalent %	% Calcite	% Dolomite	Extractable Fe_2O_3 %
1. Orthic Grey Wooded	Bt	15 - 19	29.2	39.0	7.6	24.2	-	-	-	0.49
2. Orthic Grey Wooded	Bt2	7 - 11	19.5	53.9	3.8	22.8	74.60	19.56	49.86	0.57
3. Degraded Brown Wooded	C	66 +	11.7	68.6	8.3	11.5	99.61	2.72	89.68	0.61
5. Orthic Grey Wooded	Bt	13 - 16	0.1	3.2	2.8	93.9	90.52	47.76	39.38	0.37
6. Degraded Brown Wooded	Btj	11 - 14	15.1	20.1	13.5	51.3	89.15	90.06	0.00	0.65

* Per Cent Calcium Carbonate Equivalent is calculated from weight of inorganic CO_2.