CHEMICAL AND MINERALOGICAL CHARACTERIZATION AND COMPARISON OF AN ORTHIC BLACK, AN ORTHIC DARK GREY, AND AN ORTHIC GREY WOODED SOIL

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ABSTRACT

Three soil profiles from the Riding Mountain district of Manitoba were investigated in the field for morphological characteristics and in the laboratory for chemical and mineralogical properties. The soils studied were developed in well-drained glacial till; they differed from each other in some aspect of micro-climate and/or vegetation.

On the basis of their morphological characteristics, the three soils were classified as Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded. Morphologically these soils exhibited an increase in degree of horizon differentiation and depth to lime layer in going from Orthic Black to Orthic Grey Wooded. Particle size, mineralogical, and chemical data substantiated these differences in soil environment. Physical processes appeared to have been major factors in the genetic horizon differentiation.

The minerals present in the clay fractions included montmorillonoid, illite, vermiculite, chlorite, kaolinite, and a random 40:60 mixture of illite and montmorillonoid. Illite was found to be the dominant mineral in the coarse clay, while montmorillonoid was found to be the dominant mineral in the fine clay fraction of each horizon of the three profiles. The montmorillonoid species was found to be intermediate between beidellite and nontronite, tending towards the nontronite end of the continuous series. The mineralogical and the chemical characteristics of the three soil profiles substantiated that the glacial tills in which these soils have developed are similar in composition.

The chemical and mineralogical characteristics of the cutans, which were obtained from the "B" horizon of each profile, substantiated the differences in soil environment among these soils. Stress or diffusion cutans were found to be present in the Orthic Black and Orthic Dark Grey soils, while eluviation cutans were present in the Orthic Grey

Wooded soil. The cutans sample of each of the three profiles had a higher total nitrogen and extractable iron content than the soil horizon sample from which they were obtained. The organic matter and the clay content of the cutans as compared to the corresponding bulk sample were higher only in the cutans of the Orthic Grey Wooded soil. The nature and distribution of the clay minerals in the cutans was approximately similar to that of the respective bulk samples. More organic matter was found to be associated with the $< 5\mu$ material of the cutans samples as compared to the bulk samples.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

I INTRODUCTION

For agricultural purposes, the province of Manitoba can be divided into two main topographical regions. These regions have been referred to as the first and second steppe (21), and are located respectively, east and west of the Manitoba escarpment. The first steppe lies at a lower altitude than the land west of the escarpment, and has a smooth to almost flat topography. The second steppe lies above the 1300-1400 ft. contour; its altitudes ranging from 1300 to between 2400 and 2500 feet. The topography below the 1900 foot contour is undulating to rolling, but becomes hilly above this altitude. In these areas, the change in vegetation from grasses to forest occurs gradually with increase in altitude, which is reflected in the associated soil types. As a consequence, it is possible to study several soil types from a relatively small area.

This is a report of the study of the chemical and mineralogical characteristics of an Orthic Black, an Orthic Dark Grey, and an Orthic Grey Wooded soil from Manitoba. These three soils were selected from the Riding Mountain district of the province. Each one of these soils had developed on glacial till of mixed materials derived from shale, limestone, and granitic rock. The occurrence of this sequence of soils within a relatively small area provided an opportunity to study different soil profiles developed on similar parent materials and under similar macroclimatic conditions.

The principal objectives of this investigation were:

1. to describe and measure the features which serve to characterize the soil;

2. to assess the intensity of the processes which have resulted in the formation of these soils;
3. to determine the nature of the cutans present in the "B" horizon of each of the profiles under study;
4. to evaluate the mode of formation of these cutans.

II LITERATURE REVIEW

THE SOIL PROFILES

According to the National Soil Survey Committee classification of soils (46), Orthic Black and Orthic Dark Grey soils belong to the Chernozemic Order while Orthic Grey Wooded soils belong to the Podzolic Soil Order. Chernozemic soils are characterized (46) by the occurrence of dark coloured humus-mineral surface horizons (Ah or Aa) of high base saturation and with flocculated surface structures that do not become massive on wetting or drying. They are associated with a vegetation of xero- and meso-phyllic grasses and forbs or with transition grassland-forest vegetation. Podzolic soils are characterized (46) by the occurrence of light coloured eluvial (Ae) horizons, underlain by illuvial (B) horizons with accumulations of sesquioxides, organic matter, or clay, or any combination of these. They are associated with a forest or heath vegetation.

Orthic Black Soils

Orthic Black soils are the well-drained members of the Black Great Soil Group. By definition (46) Orthic Black soils have an Ah horizon of sufficient thickness to produce an Ap horizon 6 inches in thickness and having dry and moist Munsell Colour values (45) less than 3.5 and chromas less than 2.5. This "A" horizon is underlain by a colour Bm which is free from carbonates, or by a weakly textural Btj horizon. A lighter coloured horizon of carbonate concentration, Cca, is usually present but is not essential criterion. Orthic Black soils, and Chernozemic soils in general, are characterized principally by the high organic matter content and granular structure of the A horizon (9, 33).

The organic matter content in this horizon decreases gradually with increase in depth. The B horizon is usually prismatic in macro-structure, breaking to blocky or coarse granular aggregates; the latter tendency increasing with clay content (33). Orthic Black soils are usually neutral to mildly alkaline in reaction and free of an excess of soluble salts.

Orthic Black soils are usually, but not exclusively, associated with a mesophyllic vegetative cover of grasses and forbs, but may also occur under discontinuous tree cover. The general climatic conditions with which Black soils are associated include hot summers, cold winter, low humidity, rainfall deficiency, and sharp diurnal fluctuations in temperature (33). Orthic Black soils have developed on a great variety of geological materials (33).

The dominant soil forming process in the development of Chernozemic soils is referred to as calcification. According to Lutz and Chandler (35), calcification is "the process or processes of soil formation in which the surface soil is kept supplied with sufficient calcium to maintain the colloids in a high state of base saturation." These authors also indicate that the colloids are relatively immobile because of the high saturation of the soil with calcium. De Sigmond (17) stated that the principal feature of the processes of steppe soil formation is that the trivalent metal cations and the humus do not move downward, but that the bivalent cations (Mg and Ca) may move upward and downward, and that the univalent cations do move downward; the latter, (in particular sodium) frequently accumulating in the lower horizons. According to Buckman and Brady (9), the native vegetation-- which ranges from grasses to desert shrubs -- contributes actively to the process of calcification.

Grasses are particularly effective in returning bases to the surface of the soil, and as a result of their extensive root system, they also supply large amounts of organic matter.

Deep Chernozems (33) or Northern Chernozems (38) are the names used in Russia and in U.S.A., respectively, for Black soils comparable to those found in the Canadian prairie provinces. Northern Chernozems of eastern North Dakota, as described by McClelland et al (38), are well-drained soils on convex slopes or moderately well-drained soils on very gently concave or plane slopes. They have black, granular A horizons that are 5 to 14 inches in thickness and that have a pH ranging from 6.5 to 7.5. Sand grains are unstained and some are free of any adhering organic particles. The B horizon is usually a colour B but it may be a textural B with clay films on ped faces. Structurally, the B horizon is usually prismatic, breaking to blocky; its pH ranges from 6.5 to 8.0 or greater if lime occurs in the lower portion of the horizon. The thickness of the B horizon is usually about the same as that of the A horizon. This description is very similar to the one given by Ellis (21) for his group of Northern Black Earth soils in Manitoba.

Orthic Grey Wooded Soils

Orthic Grey Wooded soils are the well-drained members of the Grey Wooded Great Soil Group. According to the National Soil Survey Committee classification of soils (46), Orthic Grey Wooded soils have organic surface horizons (L - H), a light coloured eluvial horizon (Ae), and an illuvial horizon (Bt) in which clay is the main accumulation product. The Ae horizons contain the least amount of clay, bases, and sesquioxides. The B horizons often have a slight accumulation of total nitrogen and organic carbon as compared to the Ae horizons. An increase of free sesquioxides is usually associated with the accumulation of clay in the B horizon. In general, the base status of Grey Wooded soils is medium to high. The horizons above the calcareous horizons are usually slightly to moderately acid, the B horizons often being the most acid.

The best developed Grey Wooded soils are found where cool climatic conditions prevail; i.e. mean annual temperature of 40°F or less. Most of the Grey Wooded soils are found under boreal forest or under forest in the grassland-forest transition zone. They may also occur in somewhat warmer climates, under mixed forest vegetation. Grey Wooded soils have usually but not exclusively developed on basic parent materials. Some geological deposits which are not basic, but which decompose rapidly, also develop into good Grey Wooded soils (44, 46).

Grey Wooded soils are considered as being formed by the process of podzolization. There have been and still are two opinions concerning the essence of the podzolization process (16,23,33,49). Some authors consider that in podzolization there is removal of clay particles from the upper horizons of the soil without destruction of these particles. Other authors consider podzolization to be the destruction of clay particles in the upper part of the soil profile and removal of the product of this destruction. As a result of these two points of view, Cernescu (23), Duchaufour (16), and other authors proposed that podzolized soils be divided into two groups; the mode of clay movement being the differentiating criterion. This proposal has proven to be a very controversial issue. From the soil classification point of view, separation of Podzolic soils into two groups may not be justified, especially when the classification is based on broad genetic concepts (49).

From the point of view of soil genesis, on the other hand, the possibility of clay decomposing or altering in the profile must be examined closely; for instance, in view of sequential behaviour of soils (4,14,59).

Pawluk (50) studied the mineralogical composition of some Grey Wooded soils developed on glacial till, in Alberta. He concluded that Grey Wooded soils are pedogenically separable from Podzol soils. Evidence for this fact was obtained from analytical data, including low content of translocated sesquioxides, lack of severe chemical weathering of minerals, and enrichment of clay minerals in the B horizons.

Nygard _et_ _al_. (48), in describing the characteristics of some Podzolic, Brown Forest, and Chernozem soils of the Northern Lake States, compare the Grey Wooded soils to other podzolic types. These authors observed that, morphologically, Grey Wooded soils resemble Grey-Brown Podzolic soils more than the Podzols. The textural and structural characteristics were found to be very similar in these two soil types. According to these authors, Grey Wooded soils differed from Grey-Brown Podzolic soils by the thicker A_0 horizon, whiter A_2, virtual absence of A_3 and B_1, greater enrichment of silicate clays in the B, better developed and more stable blocky structure in the B, and higher pH and base status. Nygard _et_ _al_. suggested that the recognition of the Grey Wooded soils as distinct from the Podzols was warranted.

Stobbe (59) studied the Grey-Brown Podzolic and related soils of Eastern Canada. In the discussion of Grey-Brown Podzolic -- Grey Wooded intergrates, he stated that these soils do not differ significantly in the physical and chemical nature of the eluvial (A_2) and illuvial (B_2) horizons. They do differ marketly in the morphological nature of the A_0 and A_1 horizons; Grey Wooded soils invariably having an A_0 and lacking the mull-like A_1 horizon, characteristic of Grey-Brown Podzolic soils. Stobbe suggested that this difference is probably associated with differences in climate.

The genesis of Grey-Brown Podzolic soils has been discussed in a series of three papers by Cline and co-workers (14,22,37). According to these authors, Grey-Brown Podzolic soils are formed on calcareous parent materials. On non-calcareous parent materials, and under similar climatic conditions, only Brown Podzolic and Podzolic soils are formed. Cann and Whiteside (12), in their study of a Michigan soil profile, presented evidence that the B horizons are illuvial in nature. They observed that the upper B differed from the lower B in the nature of the illuviated materials. Tavernier and Smith (60) indicated that the illuvial characteristics of Grey-Brown Podzolic soils -- i.e. the accumulation of silicate clays -- is probably due to their flocculation by bivalent cations. It is Stobbe's opinion (59) that, considering the type of profile development and the resultant characteristics in the Grey-Brown Podzolic soils of Canada, these soils have not formed by the podzolization process. He suggested at a later date (17) that the term of decalcification be applied to "podzol-like" soils in their primary phase of weathering. The soil forming process or processes of decalcification would then imply that there is a depletion of bases in the solum, development of acidity, and the formation of an eluvial "A" horizon and an illuvial "B" horizon. Colloids and some trivalent cations are the principal soil constituents which are removed from the "A" horizon and are accumulated in the "B" horizon.

Orthic Dark Grey Soils

Orthic Dark Grey soils are the well-drained members of the Dark Grey Great Soil Group of the Chernozemic Order. By definition (46), Dark Grey soils have a Chernozemic A horizon (Munsell(45) colour value 3.5 - 5.0 when dry; less than 3.5 when moist) and have significant characteristics indicative of degradation or other modification resulting from the accumulation and decomposition of forest vegetation. These soils occur under a vegetation characteristic of transitional areas between grassland and forest; hence, they are associated with a mixed vegetation of trees, shrubs, forbs, and grasses. As a consequence, virgin Dark Grey soils possess both chernozemic and podzolic features.

Dark Grey soils were originally designated as Degraded or Wooded Chernozem by Canadian and U.S.A. pedologists (42,43,48,67). Most pedologists regard these soils as former grassland profiles which have been altered as a result of the effect of the invasion of trees (43); although some workers are undecided on this point (48). These altered profiles constitute a series of soils transitional between Chernozemic and Grey Wooded Podzolic soils. The degree of degradation expressed in the profiles determines whether they would be classed as Dark Grey or Dark Grey Wooded (46).

THE CLAY FRACTION OF SOILS

In soils, the clay fraction consists of all materials less than 2 microns in diameter, and includes both inorganic and organic constituents (25). The inorganic components of the clay fraction are chiefly clay minerals but include also amorphous and very poorly crystalline materials as well as some primary minerals. Most of the primary minerals which may be present in the clay fraction, such as quartz, micas, and iron oxides and hydroxides, tend to be concentrated in the coarse clay fraction (25,33). The organic constituents and the sesquioxides or hydroxides are often intimately associated with the clay minerals (25,57). Clay minerals are essentially hydrous aluminum silicates, in which isomorphous substitution may have taken place. Because of their crystalline nature, clay minerals can be separated and classified into several groups according to their basic structure (7,25).

The structures and properties of clay minerals have been described in detail by Grim (25) and other authors (7,15,36). Identification of clay minerals can be achieved by mineralogical, chemical, as well as by physical means; although no one method ensures absolute identification. Often the application of two or more methods is necessary to achieve this. Most prominent among the methods used for clay mineral investigation are X-ray diffraction analysis and differential thermal analyses. Details of most of the methods used in clay mineral studies have been presented by Jackson (27). Excellent monographs have been published, recently, pertaining to X-ray techniques (7) and to differential thermal analyses (36).

The relative abundance of clay minerals in soils varies with the five principal factors that govern soil formation; i.e. parent material, time, climatic, relief, and biotic factors. Each of these factors can have important independent effects on the clay mineral composition of soils, as has been shown by Jackson (28). The clay mineral composition of a soil at any one place is determined, however, by the product of the interaction of the soil forming factors; in other words, by the soil forming processes. Considerable work has been directed towards establishing the effect of soil forming processes on clay minerals. In some soils, colloidal clays present in the original materials may not be affected very much by weathering processes; in others it may result in translocation; or in still other soils it may cause alteration or breakdown into new products which may or may not in turn also undergo translocation. Jackson et al. (30,31,32) have shown that this alteration or breakdown of clay minerals in soils can be arranged into a weathering sequence. These authors claim that reversal of the weathering reactions can and does occur where potassium is present in the soil solution.

The kinds of clay minerals in soils of temperate climatic regions seem to depend more on the kind of parent material than on pedogenic factors. This is borne out by the frequency distribution of clay minerals in the soils of these regions (28). For Chernozemic soils the predominant minerals usually reported are montmorillonoid and illite, regardless of parent material (2,34,65,68). Thus, Ehrlich et al. (20), in Manitoba, found montmorillonoid and illite to be the dominant clay minerals in several Chernozemic soils as well as in their respective parent materials. These soils had developed on either moderately calcareous, strongly calcareous, or non-calcareous boulder till. Montmorillonoid and illite also seem to be the dominant clay minerals in the Podzolic soils of the temperate climatic region. Tedrow (61) found this to be true for three well-developed Podzols developed on grey acid sandstone glacial tills in eastern Pennsylvania. Moss and St. Arnaud (44), McCaleb and Cline (37), and others (17,20,50,58,68) obtained similar results for the clay mineral distribution in Grey Wooded and Grey-Brown Podzolic soils developed on calcareous parent material. With respect to the clay mineral species in soils of temperate climatic region, Parfenova and Yarilova (49) reported that montmorillonoid clay of the beidellite-nontronite series and illite were present in Chestnut, Chernozem, Solonetz, and Podzol soils of Russia. Warder and Dion (65) investigated the nature of the clay minerals in Saskatchewan soils -- the soils studied ranged from semi-arid Brown to Podzolic soils. They found that the clay minerals present were of the 2:1 layer lattice type, about 45 per cent of which was considered illite with the remainder montmorillonite-beidellite.

Soil forming processes operative in temperate climatic regions affect chiefly the distribution of clay minerals within the soil profiles. Bourne and Mortland (2) found that, in a Northern Chernozem with a weakly developed textural profile, the following important changes in the clay fraction due to pedogenesis had taken place:

1. a relative gain of illite in the A horizon and of montmorillonite in the B horizon, likely due to differential leaching;
2. a reconstruction of much of the clay in the A horizons to randomly, interstratified, mixed-layer forms, probably largely the result of K equilibrium reactions;
3. an increase of total clay by formation.

With respect to Grey Wooded soils, Pawluk (50) observed that clay transpositions within the soil sola involved primarily the less than 0.2 micron size fraction. This author found strong evidence that the coarse clay in the Ae horizon breaks down to the fine clay size prior to or during transposition.

A considerable number of investigations on the mineral composition of the clay fraction of Western Canadian soils are reported in the literature (6,13,20,50,51,52,65.) The earlier studies indicated relatively little change between the clay fractions of the profiles and that of their original parent materials. More recent investigations have shown that some differences do occur, although these are sometimes not very pronounced. Brown (6) observed the presence of a 14 Å mineral in the clay fractions of Grey Wooded soils from Saskatchewan and Alberta. Pawluk (50,51) noted the presence of this clay mineral in Grey Wooded and in Podzol soils of Alberta. He noted that in Podzol soils these 14 Å clay minerals were present in the B horizon only and that they appeared to be concentrated in the coarse (2.0 - 0.2u) clay fraction. According to this author, the 14 Å clay mineral is a modification of montmorillonite, its formation not resulting from the weathering of clay minerals, but from the weathering of less stable feldspars. (He proposes that the formation of this clay mineral is the result of the absorption of released hydrated alumina hydroxy ions from the weathered feldspars in the interlayer region of montmorillonite of fine clay size. This results in the formation of a clay mineral with 14Å d spacings and of coarse clay size). Clark _et al._ (13) reported that the clay fraction of the Concretionary Brown soils of southwestern British Columbia differs from that of its parent material. The surface soil clays of these soils consist of either heat stable chlorite or an interstratified complex of chlorite primarily, while montmorillonite, interstratified montmorillonite, chlorite, or chloritized vermiculite are the dominant clays of the lower horizons.

CUTANS

Cutans have been defined by Brewer (3) as: "a broad group of pedological features (including so-called clay-skins) associated with the surfaces of the skeleton grains, peds, and various kinds of voids within soil materials." The principal characteristics that enable differentiation between cutans are therefore: 1. the kind of surface with which they are associated, 2. the fabric of the cutans themselves, and 3. the mineralogical nature of the cutanic material. All three criteria can be investigated by micro-pedological means; the third differentiating characteristic also allows investigation by chemical and mineralogical methods.

Micro-pedological investigations (3,4) have shown that the mineralogical nature of the cutanic material can consist of: silica, soluble salts (carbonates, sulphates, chlorides, etc.); manganese oxide or hydroxides; sesquioxides; and/or clay minerals. The clay mineral cutans can be either pure clay minerals, clay minerals with iron oxides or hydroxides, or clay minerals with organic matter. Sawhney et al. (54) found that scrapings from the B3g horizon of a Brown Podzolic soil from central Connecticut contained more clay percentage-wise than the B3g horizon as a whole. Buol and Hole (10,11) investigated cutanic material by chemical means and provided further evidence for the complexity of the mineralogical nature of cutans. These authors observed that cutans contained relatively large amounts of N, C, P, Mn, free Fe, and clay as compared to the bulk sample.

The formation of cutans in soils may take place in several ways (10,11,41). They may be formed as a result of the migration of colloidal suspensions along the soil profile and subsequent concentration in the illuvial horizon in the form of crusts or incrustations on the walls of cracks and pores. They may also be formed in place as a result of weathering and soil formation, or as a result of stress or diffusion forces. Brewer (3) termed the cutans resulting from the latter mode of formation stress or diffusion cutans; those resulting from the former he termed eluviation cutans.

Cutans, or its synonyms, are mentioned in the descriptions of soil profiles of many great soil groups. Ehrlich and Smith (18) observed that the B horizons of Solonetz and Solodized-Solonetz soils in Manitoba were coated with clay skins. McClelland et al.(38) noted clay films on B-horizon-peds of a Northern Chernozem of eastern North Dakota. The occurrence of cutans in Grey-Brown Podzolic soils was noted by Brown and Thorp (8) and others (10,14,22). Frei and Cline (22) observed clay coatings in Brown Podzolic soils of New York; Schafer and Holowaychuk (55) observed them in Humic-Gley soils of Ohio. Thorp et al.(62), in their investigation of the role of leaching in soil genesis, were able to produce clay films on peds in the laboratory.

The presence of cutans in soil profiles has great significance with regard to the physical behaviour of the soil material (1), to profile development (62), and to plant growth (10,53). The importance of cutans in soil pedology is highly emphasized in the new soil classification system as proposed by the U.S.D.A. (64). According to this system, the presence of cutans in a soil horizon is indicative of translocated clay, provided that they occur on all sides of the peds.

III EXPERIMENTAL PROCEDURE

The soils selected for this project are well-drained soils belonging to the Newdale, the Erickson, and the Waitville associations (19). These soils developed from calcareous medium textured glacial till of mixed materials derived from shale, limestone, and granitic rock. The three soils are representative of the Orthic Black, Orthic Dark Grey and Orthic Grey Wooded soil types.

DESCRIPTION OF SOIL PROFILES

The description of soil profiles and notations on location, topography, drainage, stoniness, and vegetation are presented in summary form. Colours are those derived by comparing Munsell's (45) chart with actual soil colours. The colours given of the various horizons refer to the soil condition when sampled unless otherwise stated.

Newdale Clay Loam ....Orthic Black

Location: ....North Centre of 33-16-18 West of the Principal Meridian, Manitoba.

Vegetation: ....Oak, snowberry, prairie rose, wheatgrass, bluegrass, spear grass, yarrow, Canada thistle, and others.

Parent Material: ....Boulder till of mixed materials derived from shale, limestone, and granitic rock sediments.

Topography: ....About 5 per cent slope, facing southeast; undulating to rolling.

Drainage: ....Well-drained internally; medium run off.

Soil Condition: ....Moist.

Horizon	Depth (inches)	Description
L	2 - 1"	Undecayed organic material.
F - H	1 - 0"	Partially and fully decayed organic material.
Ah	0 - 5"	Black (10 YR 2/1) clay loam, very dark gray (10 YR 3/1) when dry; moderate, medium granular; very friable; pH 6.34; clear, smooth boundary.
Ahe̅j	5 - 9"	Black to very dark gray (10 YR 2.5/1) clay loam, very dark gray to dark gray (10 YR 3.5/1) when dry; moderate, medium granular; very friable; pH 6.09; clear boundary.
Btj	9 - 15"	Dark grayish brown to grayish brown (10 YR 4.5/2) clay loam, brown (10 YR 5/3) when dry; moderate, medium prismatic structure, breaking to moderate, medium subangular blocky; firm; pH 6.54; clear boundary.
BC	15 - 18"	Brown (10 YR 4.5/3) clay loam, brown (10 YR 5/3) when dry; weak, medium prismatic structure; friable; pH 7.02; weakly calcareous; clear boundary.

Horizon	Depth(inches)	Description
C	18 - 36 +"	Pale brown (10 YR 6/3) loam, pale brown to very pale brown (10 YR 6.5/3) when dry; weak, medium prismatic structure, slightly hard when dry; pH 7.65; strongly calcareous.

Erickson Clay Loam — Orthic Dark Grey

Location: .... North Centre of 33-16-18 West of the Principal Meridian, Manitoba.

Vegetation: .... Aspen are dominant -- undergrowth is hazel, dogwood, rose, vetch, and others.

Parent Material: .... Boulder till of mixed materials, derived from limestone, shale, and granitic rock sediments.

Topography: .... About 3 per cent slope, facing east-northeast; irregular, moderately sloping and marked by undrained depressions and shallow lakes.

Drainage: .... Moderately well drained internally; medium runoff.

Soil Condition: .... Moist.

Horizon	Depth (inches)	Description
L	3 - 2"	Undecayed organic material.
F	2 - 1"	Fermented organic material.
H	1 - 0"	Humus; altered organic material.

Horizon	Depth (inches)	Description
Ahej	0 - 5"	Black (10 YR 2/1) clay loam, very dark gray (10 YR 3/1) when dry; weak, fine granular; very friable; pH 6.3; gradual and irregular boundary.
Aeh	5 - 7"	Very dark gray (10 YR 3/1) clay loam, dark gray (10 YR 4/1) when dry; weak, fine subangular blocky structure; friable; pH 6.32; gradual and irregular boundary.
BA	7 - 10"	Very dark grayish brown (10 YR 3/2) clay loam, grayish brown (10 YR 5/2) when dry; moderate, fine subangular blocky structure; firm; pH 6.28; clear, wavy boundary.
Bt	10 - 14"	Very dark grayish brown (10 YR 3/2) clay loam, dark grayish brown (10 YR 4/2) when dry; strong, medium blocky structure; very firm; pH 6.96; gradual wavy boundary.
BC	14 - 18"	Very dark to dark grayish brown (10 YR 3.5/2) clay loam, grayish brown (10 YR 5/2) when dry; weak, fine subangular blocky structure; firm; pH 7.50; weakly calcareous; gradual, irregular boundary.
C	18 - 36 +"	Dark grayish brown (10 YR 4/2) clay loam, grayish brown to light grayish brown (10 YR 5.5/2) when dry; weak, medium to fine subangular blocky to granular structure;

Horizon	Depth(inches)	Description
		slightly hard when dry; pH 7.73, strongly calcareous.

Waitville Loam — Orthic Grey Wooded

Location: .... Riding Mountain National Park, about 400 feet off Highway No.10, on South-side of Road to the Forestry Station.

Vegetation: .... Chiefly aspen, intermixed with white birch and spruce; undergrowth consists of hazel, rose, cranberry, vetch, and grasses.

Parent Material: .... Boulder till of mixed materials, derived from shale, limestone, and granitic rock sediments.

Topography: .... Irregular, steeply sloping to hilly; numerous undrained depressions.

Drainage: .... Well-drained internally; medium runoff.

Soil Condition: .... Moist.

Horizon	Depth(inches)	Description
L	2 - 1"	Leaf litter.
F	1 - 0"	Partly decomposed organic material.
H	0 - 1"	Humus; altered organic material.
Ae	1 - 4"	Dark grayish brown to grayish brown (10 YR 4.5/2) loam, light gray to gray (10 YR 6/1) when dry; moderate, medium platy structure; very friable; pH 6.34; clear, smooth to wavy boundary.

Horizon	Depth(inches)	Description
BA	4 - 7"	Dark grayish brown (10 YR 4/2) clay loam, grayish brown (10 YR 5/2) when dry; moderate, fine subangular blocky structure; friable; pH 5.69; clear, smooth boundary.
Bt1	7 - 10"	Very dark grayish brown (10 YR 3/2) clay, dark grayish brown (10 YR 4/2) when dry; moderate, fine to medium blocky structure; firm; pH 5.66; clear, smooth boundary.
Bt2	10 - 13"	Very dark gray to very dark grayish brown (10 YR 3/1 - 3/2) clay, dark brown to dark grayish brown (10 YR 3/3 - 4/2) when dry; moderate, coarse prismatic structure, breaking to strong, medium to coarse blocky; very firm; pH 6.30; gradual, irregular boundary.
BC	13 - 17"	Dark grayish brown (10 YR 4/2) clay loam, brown to pale brown (10 YR 5/3) when dry; moderate, medium to fine subangular blocky structure; firm; pH 7.60; weakly calcareous; gradual, irregular boundary.
C1	17 - 34"	Brown to pale brown (10 YR 5/3) clay loam, brown to pale brown to light gray (10 YR 5/3 - 7/1) when dry; pseudo prismatic to crumbly structure; friable; pH 7.66; strongly calcareous, $CaCO_3$ appears to have accumulated along old root channels but is

Horizon	Depth (inches)	Description
		also found throughout the soil mass; diffuse boundary.
C2	34+"	Brown to pale brown to light gray (10 YR 5/3 - 7/1) loam when dry; pseudo-fragmentary to platy structure; hard when dry; pH 7.84; strongly calcareous, $CaCO_3$ appears to have accumulated along old root channels but is also found throughout the soil mass.

PREPARATION OF SOIL SAMPLES FOR ANALYSIS

The air-dry samples were crushed with a wooden rolling-pin, sieved through a 2 mm. sieve, weighed, and placed in cartons fitted with covers. The coarser material (>2mm) was also weighed in order that its comparative quantity in the profile could be estimated. All laboratory determinations were made on soil that was finer than 2 mm. Differential thermal analyses were conducted on material less than 5 microns in diameter, as obtained from the mineralogical separation experiment. Fusion analyses for total potassium content and specific surface determinations of the clay fractions were conducted on the coarse clay fractions (2 - 0.2µ) and on the fine clay fractions (less than 0.2µ). Fusion analyses for silicon, aluminium, and iron contents were made on the fine clay fractions (less than 0.2µ) only. For all other analyses, the 2 mm. material was considered sufficiently comminuted for the analyses to be conducted.

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The cutan study of this project was conducted on the dominant "B" horizon of each of the three soils. At the time of sampling, peds were selected from the Btj, the Bt, and the Bt2 horizon of the Orthic Black, the Orthic Dark Grey, and the Orthic Grey Wooded profile, respectively, and wrapped in "saran" paper to prevent air-drying. As soon as possible thereafter, the cutans on these peds were removed by lightly scraping with a knife. The cutans thus obtained were sieved with a 2 mm. screen, weighed, and placed in cartons fitted with covers. The floating technique for removing cutans as described by Buol and Hole (10) was tried but did not give any positive results. The analyses to which the cutans were subjected, were performed also on bulk samples of the selected peds. Preparation of these bulk samples for analysis was similar to that of the horizon samples.

METHODS

Soil Reaction

The pH values were obtained on soil pastes by means of a "Radiometer" pH meter.

Organic Matter

The organic matter content of the soils was determined by the Walkley-Black method, as modified by Walkley (26). This method involves the oxidation of readily oxidizable carbon of soils by chromic acid with sulphuric-acid-heat-of-dilution.

Total Nitrogen

Total nitrogen was determined by the macro-Kjeldahl method, employing the acid-base titration of distilled ammonia as modification (26).

Extractable Iron, Aluminium, and Silica.

Determination of these constituents was carried out on extracts, obtained in the procedure for preparation of the soil for X-ray diffraction analysis (27). Iron, aluminium, and silica were analyzed for on the sodium dithionite-citrate-bicarbonate extract; the latter two after the iron had been removed. Analyses for aluminium and silica were also made on the sodium carbonate extract of the afore-mentioned procedure. Iron was determined by the potassium thiocyanate red colour method; silicon by the ammonium molybdate yellow colour method; and aluminium by the aluminon method (26,27).

Cation Exchange Capacity

Cation exchange capacity measurements were obtained by leaching the soil with a 1 N NH_4OAc solution buffered at pH 7. The extract obtained from the leaching process was retained for the determination of exchangeable cations. The soil was then leached with ethanol to remove the excess salt and subsequently with 1 N NaCl to displace the ammonia from the exchange complex. The leachate was distilled whereupon the ammonia displaced was measured by titration against 0.1 N-NaOH (26).

Exchangeable Cations

Exchangeable Na and K were determined photometrically. An aliquot of the ammonium acetate extract was placed in a beaker and evaporated to dryness. To destroy the organic matter, 5 cc. of 1:1 H_2O_2 were added and the beaker plus contents were heated gently. Then 5 cc. of 1:1 HCl were added with subsequent heating to dryness to dehydrate the silica. The residue was taken up with 2 cc. concentrated HCl and placed in a 250 cc. volumetric flask. Upon addition of the proper amount of Li, the flask was filled to volume and the Na and K content was determined by means of a Beckman D.U. flame photometer.

Exchangeable (Ca + Mg) was determined as follows: an aliquot of the NH_4OAc extract was placed into an Erlenmeyer flask and diluted to 50 cc. with distilled water. Then 5 cc. of monoethanalamine buffer and about 30 mg. each of KCN and hydroxylamine hydrochloride were added. The flask was shaken until the solids dissolved, where upon about 0.2 mg. of Eriochrome Black T indicator was added. Titration of this solution with E.D.T.A. followed.

Exchangeable Ca was determined by placing an aliquot of the NH_4OAc extract in an Erlenmeyer flask and diluting it to 50 cc. with distilled water. Approximately 1 cc. of 6 N NaOH and 4 - 5 drops of Calcon indicator were then added. Upon subsequent stirring the solution was titrated with E.D.T.A.

Exchangeable Mg was obtained by difference.

Particle Size Distribution

The particle size distribution of the soil material less than 2 mm. in diameter was obtained by the mineral fractionation procedure as outlined by Jackson (27).

X-ray Diffraction Analysis

Samples for X-ray diffraction were prepared as described by Jackson (27). Only the dominant horizons of each profile were analyzed, since little information was expected to be obtained from the intermediate horizons. Two sets of slides were prepared from each horizon for X-ray diffraction analysis. The first set consisted of magnesium-saturated clay and the second of potassium-saturated clay; both sets were glycerol solvated. Diffractograms were obtained from the magnesium and from the potassium-saturated clays, and also from the potassium-saturated clays after they had been heated for two hours at 550°C.

The equipment used for the X-ray diffraction analyses consisted of a Philips P.W. 1010 generator, a Philips P.W. 1050 goniometer, and a Philips P.W. 1051 recorder. The unit was operated at 36 k.v., 8 m.a., and the recorder settings were: counter: 32, rate meter: 4, time constant (sec.): 16, and multiplier: 1.

Fusion Analyses

Fusion analyses were conducted to determine the total content of potassium, iron, silica, and aluminium in certain size fractions of the dominant soil horizons of the three profiles. The fusion methods employed were those outlined by the United States Geological Survey (56).

Total potassium of the coarse clay (2.0 - 0.2μ) and medium - fine clay (<0.2μ) fractions was determined photometrically by means of a Beckman D.U. flame photometer. Total iron, silica, and aluminium of the fine clay (<0.2μ) fractions were determined colorimetrically. Iron was determined according to the orthophenanthroline method, silicon according to the molybdenum blue colour method, and aluminium according to the Alizarin Red-S method.

Specific Surface Determination

Specific surface analyses were carried out on the 2.0 - 0.2 and the <0.2 micron clay fractions, according to the method of Kinter and Diamond, as modified by Mehra and Jackson (27). This method is based on sorption of one layer of glycerol between two surfaces of montmorillonite or vermiculite at 110°C.

Differential Thermal Analyses

Preparation of the samples for differential thermal analysis was done according to the procedure as described by Jackson (27). The analyses were conducted on soil material less than 5 microns in diameter; i.e. on mixtures of fine silt, coarse clay, and fine clay. The relative proportions of these fractions in each of the samples was according to their distribution in the soil sample proper. Each of the differential thermal analyses was done under controlled atmospheric conditions. The temperature range over which the samples were analyzed was from 0 to 600°C using an oxygen atmosphere, and from 0 to 1000°C using a nitrogen atmosphere.

The instrument used for the differential thermal analyses was a Stone, model D.T.A. -13 M. The unit was operated at 40 m.v. Small, vertical inflections signifying 100°C intervals were imposed automatically by the instrument on the thermograms.

EXPERIMENTAL RESULTS AND DISCUSSION

SOIL PROFILE INVESTIGATIONS

Soil Reaction

The pH values in Table I show that the organic horizons in each of the profiles are neutral to slightly acidic. The "A" and "B" horizons in each profile tend to be slightly acidic while the "C" horizons are moderately alkaline. Within profiles, the soil reaction varies most in the Orthic Grey Wooded and least in the Orthic Dark Grey profile. In general, however, there is little variation in pH values within and among the Orthic Black, the Orthic Dark Grey, and the Orthic Grey Wooded profiles. This lack of variation in pH indicates high base saturation as well as a certain uniformity in the chemical composition of the original parent material from which these soils developed.

Organic Matter, Organic Carbon, and Total Nitrogen

The results of the organic matter analyses are presented in Table I. These data show that the organic matter content of the organic soil horizons varies very little within and among the profiles. The organic matter content of the mineral soil horizons, on the other hand, varies considerably; i.e. within each profile it decreases with increase in depth. An exception to this general trend can be noted in the data for the Orthic Grey Wooded profile. In this profile, the organic matter content of the Ae horizon is considerably lower as compared to that of the underlying "B" horizons. This suggests that eluviation of organic material from the Ae horizon into the horizons below it has taken place. Considering these results and the environmental conditions at the respective soil locations, it can be concluded that eluviation and subsequent illuviation of organic

TABLE I

SOIL REACTION (pH); ORGANIC MATTER, ORGANIC CARBON, TOTAL NITROGEN, AND EXTRACTABLE IRON CONTENTS, AND C/N RATIOS OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED PROFILES

Soil	Horizon	pH	Organic Matter %	Organic Carbon %	Total Nitrogen %	C/N Ratio	Extractable Fe_2O_3 %
Orthic Black	L	6.6	41.92	24.24	1.37	17.7	
	F - H	7.3	45.40	26.29	1.26	20.8	
	Ah	6.3	4.00	2.31	0.20	11.6	1.00
	Ahe$\overline{j}$	6.1	3.17	1.84	0.16	11.5	0.95
	Btj	6.5	1.24	0.72	0.07	10.3	1.00
	BC	7.0	1.17	0.68	0.08	8.5	1.11
	C	7.7	0.76	0.44	0.05	8.8	0.95
Orthic Dark Grey	L	7.0	41.84	24.19	1.66	14.6	
	F	7.2	41.02	23.72	1.81	13.1	
	H	6.7	40.65	23.50	1.66	14.2	
	Ahe$\overline{j}$	6.3	6.90	3.99	0.34	11.7	0.84
	Aeh	6.3	3.66	2.11	0.18	11.7	0.85
	BA	6.3	1.17	0.68	0.07	9.7	1.00
	Bt	7.0	1.21	0.70	0.07	10.0	1.03
	BC	7.5	1.07	0.62	0.07	8.9	0.93
	C	7.7	0.69	0.40	0.06	6.7	0.96
Orthic Grey Wooded	L	6.1	42.14	24.37	1.44	16.9	
	F	6.5	41.69	24.10	1.61	14.9	
	H	6.4	39.74	22.98	1.36	16.9	
	Ae	6.3	1.04	0.60	0.05	12.0	0.62
	BA	5.7	1.59	0.92	0.09	10.2	1.19
	Bt1	5.7	1.40	0.81	0.08	10.1	1.15
	Bt2	6.3	1.57	0.91	0.08	11.4	1.18
	BC	7.6	1.33	0.77	0.07	11.0	1.14
	C1	7.7	0.48	0.28	0.05	5.6	0.84
	C2	7.8	0.37	0.21	0.03	7.0	1.23

matter is most intense in the Orthic Grey Wooded profile.

The total nitrogen content (Table I) in each of the profiles decreases with increase in depth. Exceptions to this general trend occur in the Ae and Bt2 horizons of the Orthic Grey Wooded profile. This trend as well as the exceptions are analogous to those observed for the organic matter content in these profiles. Hence, eluviation and subsequent illuviation of nitrogen, either in organic or inorganic form, is most intense in the Orthic Grey Wooded profile.

The C:N ratios, as shown in Table I, are as might be expected (53). Thus, when comparing similar horizons between profiles, the ratio is lower under neutral than under acid conditions. The decrease in C:N ratio with increase in depth may be due to variation in the constitution of the soil organic matter (5,47). Part of this apparent decrease may also be due to the inclusion of ammonium ions in the total nitrogen results. These ammonium ions were fixed in the soil by clay minerals (53).

Extractable Iron, Silica, and Alumina

The percentages of extractable iron are presented in Table I. These data show that iron oxide has accumulated in the "B" master horizon of each of the profiles. Furthermore, part or the whole "A" master horizon of each of these profiles is distinctly lower in iron oxide content than any one of the respective underlying B horizons. In the Orthic Black profile the difference between the free iron content of the Ahej and of the underlying Btj is quite small. This difference is of significant magnitude, however, to indicate that movement of iron out of the Ahej horizon has taken place. The high iron oxide content of the BC horizon of this profile suggests that free iron has accumulated in this horizon also. In the Orthic

Dark Grey profile the iron oxide content of both the Ahej and the Aeh horizons is considerably lower than that of any of the underlying B horizons. Accumulation of iron in this profile appears to have taken place in the BA and Bt horizons. In the Orthic Grey Wooded profile the iron oxide content of the Ae horizon is about half of that of the underlying B horizons. Illuviation of iron into each of these underlying B horizons appears to have occurred in about equal amounts.

From the data in Table I it can be concluded that eluviation of iron has taken place in all the profiles under study, and that the intensity of this process was greatest in the Orthic Grey Wooded and least in the Orthic Black profile. The results also show that the iron oxide content in the C horizons of the three soils is relatively high and is of about the same magnitude, except for the C2 horizon of the Orthic Grey Wooded profile. Considering the fact that the method used does not affect iron constituents in clay minerals, but removes only iron oxides and coatings, the relatively large amount of iron oxide in the C horizons suggests that the parent material on which these soils have developed does contain a high percentage of extractable iron. The nearly equal amounts of extractable iron in the C horizons of the profiles indicates that these soils have developed on similar parent material.

The extractable silica and alumina results presented in Table II are difficult to interpret. Very little information is present on the form or forms of silicon or aluminium which are extracted by the methods used. With respect to silicon, McKeague and Cline (39,40) found that silica in soil solutions was in monomeric form -- presumably as Si $(OH)_4$ -- and that this compound is absorbed on soil particles, the process being strongly pH dependent. Thus, the silica extracted by the sodium citrate

TABLE II

SODIUM-CITRATE EXTRACTABLE AND SODIUM CARBONATE EXTRACTABLE SILICA AND ALUMINA CONTENTS OF THE ORTHIC BLACK, THE ORTHIC DARK GREY AND ORTHIC GREY WOODED PROFILES

Soil	Horizon	Na-Citrate Extraction		Na_2CO_3 Extraction	
		% SiO_2	% Al_2O_3 (x 10^2)	% SiO_2 (x 10^3)	% Al_2O_3 (x 10^2)
Orthic Black	Ah	0.935	12.2	12.96	0.14
	Ahej	0.860	12.6	11.37	0.07
	Btj	0.813	9.9	12.00	0.3
	BC	0.973	9.2	12.53	0.2
	C	1.010	7.0	13.06	0.8
Orthic Dark Grey	Ahej	1.251	24.0	11.31	2.0
	Aeh	1.165	23.1	10.33	1.6
	BA	1.369	20.1	7.03	1.2
	Bt	1.347	17.7	7.85	0.9
	BC	1.262	22.7	8.36	2.1
	C	1.245	17.3	22.50	0.3
Orthic Grey Wooded	Ae	1.834	14.8	4.89	2.3
	BA	2.240	17.0	6.84	1.5
	Bt1	2.552	16.5	12.48	1.4
	Bt2	2.561	20.1	17.43	1.0
	BC	0.791	11.9	7.19	0.8
	C1	0.898	7.1	12.81	0.6
	C2	0.807	6.1	14.54	0.4

method as well as by the sodium carbonate method must come, in part, from silica coatings on soil particles. With respect to aluminium, this may, in part, have come from the exchange complex. Pawluk (50), in his paper on Grey Wooded soils, observed that sodium carbonate extractable silica attained its highest concentration in the "C" horizons, while extractable alumina appeared to accumulate in the "B" horizons. Similar observations can be made from the data presented in Table II, although the trends are far from obvious.

Cation Exchange Capacity and Exchangeable Cations

The results from the analyses for cation exchange capacity and for exchangeable cations are presented in Table III. Only the dominant horizons of the profiles were investigated. The exchangeable cations are expressed in per cent of the exchange capacity. Exchangeable cations, base saturation percentages and Ca:Mg ratios have not been calculated for the "C" horizons, as the method employed does not differentiate between cations obtained from the exchange complex and those obtained from the relatively insoluble carbonates.

The results show that the cation exchange capacity in the Orthic Black and in the Orthic Dark Grey profile decreases with increase in depth. No such trend is present in the Orthic Grey Wooded profile. The different behaviour of the exchange capacity in the latter profile as compared to the former two profiles can be attributed to differences in organic matter and/or clay content of the various horizons. From Table I (p.29) and Table IV (p35) can be seen that the difference in exchange capacity between the "A" and "B" horizons of the Orthic Black as well as of the Orthic Dark Grey profile must be due to organic matter. This influence of organic matter is particularly

TABLE III

CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATION DATA FOR THE MAJOR HORIZONS OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED PROFILES

Soil	Horizon	Cation Exchange Capacity (me/100 gm)	Exchangeable Cations (%)				Ca:Mg Ratio	% Base Saturation.
			K	Na	Ca	Mg		
Orthic Black	Ah	26.88	5.54	---	69.27	14.43	4.80	89.25
	Btj	24.64	4.71	---	73.05	23.86	3.06	101.62
	C	13.65						
Orthic Dark Grey	Ahej	31.57	5.32	0.09	65.73	14.67	4.48	85.84
	Bt	25.11	3.48	---	71.17	26.40	2.70	101.95
	C	17.92						
Orthic Grey Wooded	Ae	5.99	2.84	0.53	68.61	25.04	2.74	96.99
	Bt2	27.30	2.60	---	65.93	32.97	2.00	101.50
	C2	9.95						

evident in the Orthic Dark Grey profile, where the much lower clay content of the "A" horizon as compared to the "B" is not indicated in the exchange capacity. In the Orthic Grey Wooded profile, on the other hand, the lower exchange capacity of the Ae horizons as compared to the Bt2 horizon is due to differences in clay content. The cause of the large difference in cation exchange capacity between the Ae and Bt2 horizons of this profile must be attributed to soil-forming processes.

The data in Table III show that, in each of the profiles, exchangeable potassium has accumulated in the surface horizon, rather than moved downward in the profile. Deposition of this cation by vegetation and liberation through weathering may be responsible for this apparent accumulation. The exchangeable calcium and magnesium content increases with increase in depth within each profile. An exception to this general trend can be noted in the Orthic Grey Wooded soil. The calcium content of the Ae horizon of this profile is higher than that of the Bt2 horizon. The Ca/Mg ratios are lower in the "B" than in the "A" horizons of the soils. On comparing profiles, the difference in ratio between the "A" and "B" horizons is smallest in the Orthic Grey Wooded soil. The base saturation of the three profiles is high for both the "A" and "B" horizons.

Particle Size Distribution

The particle size distribution data are presented in Table IV and in Table V. As may be noted from Table V, the average texture of the profiles under study is clay loam. This table also shows that the difference in total clay content between the "A" and "B" horizons increases progressively from the Orthic Black to the Orthic Grey Wooded

TABLE IV

TOTAL SAND, SILT, AND CLAY CONTENT, AND FINE SILT, COARSE CLAY, AND FINE CLAY CONTENT OF THE HORIZONS OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED SOILS

Soil	Horizon	% Total Sand	% Total Silt	% Total Clay	% Fine Silt	% Coarse Clay	% Fine Clay
Orthic Black	Ah	36.3	33.6	30.0	3.4	9.8	20.3
	$Ah\overline{ej}$	36.2	33.5	30.2	3.2	9.5	20.7
	Btj	22.9	43.1	34.0	3.4	9.8	24.2
	BC	18.3	47.7	34.0	3.7	11.1	22.9
	C	35.8	43.5	20.7	2.5	6.9	13.9
Orthic Dark Grey	$Ah\overline{ej}$	33.6	37.3	29.1	4.4	9.8	19.3
	Aeh	35.0	34.8	30.2	3.8	9.5	20.6
	BA	29.8	31.2	39.0	4.4	10.9	28.1
	Bt	33.7	30.2	36.0	4.2	11.2	24.8
	BC	37.6	32.8	29.5	3.8	10.8	18.7
	C	32.7	34.3	33.0	5.2	13.8	19.2
Orthic Grey Wooded	Ae	51.1	38.1	10.8	4.5	6.2	4.6
	BA	33.0	31.0	36.0	3.6	11.6	24.4
	Bt1	31.4	24.3	44.3	3.1	11.5	32.8
	Bt2	31.1	24.4	44.5	2.8	11.8	32.7
	BC	35.8	32.2	31.9	3.6	11.7	20.2
	C1	36.2	34.3	29.5	3.6	12.0	17.5
	C2	40.6	35.1	24.2	3.7	9.6	14.6

TABLE V

SAND AND SILT CONTENT OF THE HORIZONS OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED PROFILES

Soil	Horizon	% Very Coarse Sand	% Coarse Sand	% Med. Sand	% Fine + Very Fine Sand	% Coarse Silt	% Medium Silt
Orthic Black	Ah	2.3	4.2	7.7	22.2	17.0	13.2
	Ahej	2.5	3.7	7.3	22.8	17.3	13.1
	Btj	0.7	2.0	4.5	15.7	22.5	17.1
	BC	1.0	1.4	2.8	13.1	23.9	20.0
	C	2.5	4.2	7.2	21.9	26.4	14.5
Orthic Dark Grey	Ahej	2.9	4.6	6.5	19.5	16.5	16.4
	Aeh	2.4	4.3	7.4	20.8	16.4	14.6
	BA	2.1	3.9	6.3	17.4	12.9	13.8
	Bt	2.6	4.1	6.9	20.1	12.9	13.1
	BC	2.9	4.9	8.7	21.0	15.9	13.0
	C	2.5	4.0	8.0	18.2	13.0	16.1
Orthic Grey Wooded	Ae	4.7	6.2	9.3	30.9	18.2	15.4
	BA	1.8	3.7	5.9	21.4	15.1	12.3
	Bt1	2.1	3.2	5.4	20.6	11.6	9.6
	Bt2	1.9	3.2	5.5	20.4	12.1	9.5
	BC	2.3	3.3	5.6	24.6	15.1	13.5
	C1	2.6	3.9	6.1	23.6	17.7	13.1
	C2	3.7	5.7	7.8	23.5	17.9	13.5

profile. This trend is logical as these soils have developed on similar parent material but under the influence of different environmental conditions. It illustrates that clay movement among these profiles is most intense in the Orthic Grey Wooded soil.

The data in Table IV also show the distribution of the fine silt, coarse clay, and fine clay fractions in the soils. Of these fractions, the fine clay is the largest in amount in every horizon of each of these profiles, except for the Ae horizon of the Orthic Grey Wooded soil. In all three profiles, accumulation of coarse and fine clay in the "B" horizon is apparent. No such trend is evident for the fine silt. The accumulation of clay in the "B" horizon must be attributed mainly to the process of illuviation. From the data in Table IV it is thus apparent that the fine clay fraction is principally affected by these processes.

The data for the various sand fractions and for the coarse and fine silt fractions of the horizons in the profiles are presented in Table V. These data are quite variable, so that it is difficult to attribute any of the differences which occur within and among profiles to pedogenic processes.

INVESTIGATIONS ON THE CLAY FRACTION

X-ray Diffraction Analyses

The diffractograms of the fine silt and clay fractions, as shown in Figures 1 to 9, have been arranged according to profile sequence. Only the dominant horizons of each profile were analyzed. The diffraction patterns obtained from the non-heated potassium treated samples of the coarse and the fine clay fractions have not been recorded, since they were of no material aid in mineral identification.

<u>Fine Silt Fractions (5 - 2µ)</u> The diffractograms of the fine silt fractions of the Orthic Black, the Orthic Dark Grey, and the Orthic Grey Wooded profile are shown in Figures 1, 2, and 3 (Appendix, p.96), respectively. The most prominent reflections (4.2 and 3.3 Å) are indicative of quartz. Reflections characteristic of chlorite and/or vermiculite (14.0 and 7.0Å) and for illite or micas (10.0 and 5.0Å) can also be observed. The intensity of these reflections does not seem to vary much among horizons within the profiles nor among the profiles. As may be noted, the characteristic first order* montmorillonoid** reflection at 17.7Å is not present in any of the patterns obtained for the magnesium treated samples. In some instances, however, such as in the C horizon of the Orthic Black profile, a faint indication of this reflection may be observed. It is apparent, therefore, that very little if any montmorillonoid is present in the fine silt fraction. This was to be expected, since the average size of montmorillonoid clays is less than 2 microns (25).

<u>Coarse Clay Fractions (2.0 - 0.2µ)</u> The diffraction patterns of the coarse clay fractions of the Orthic Black, the Orthic Dark Grey, and the Orthic Grey Wooded soils are presented in Figures 4, 5, and 6, respectively. The reflections indicative of quartz, at 4.2 and 3.3Å, are

* The term "order" is used throughout this discussion to explain the basal reflections only; it is not necessarily the order which corresponds to the unit cell.

** The term "montmorillonoid" refers in this discussion to the clay mineral group; the term "montmorillonite" refers to the clay mineral species.

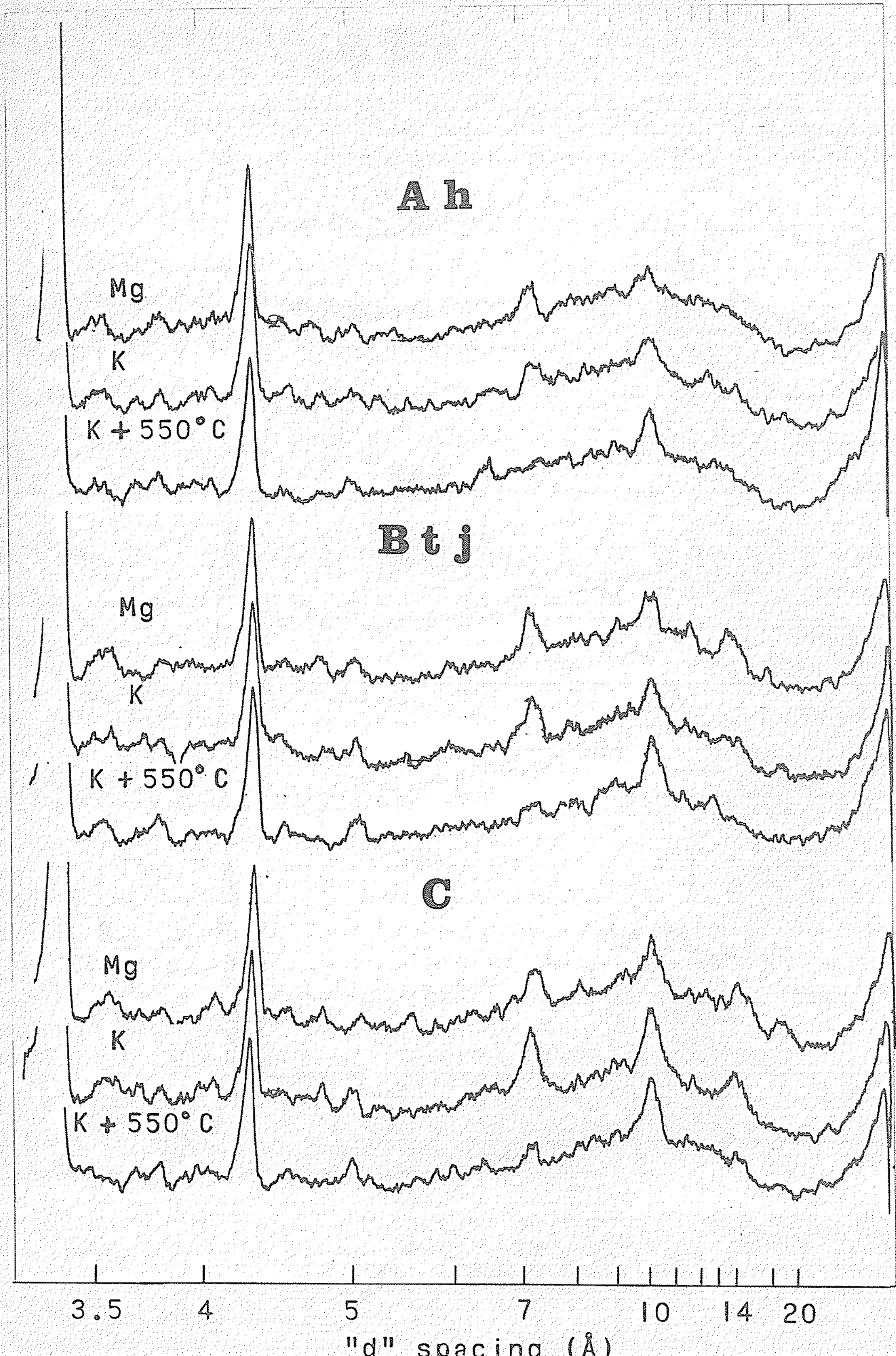

Figure 1. X-ray diffraction patterns of the fine silt fractions of the Orthic Black profile.

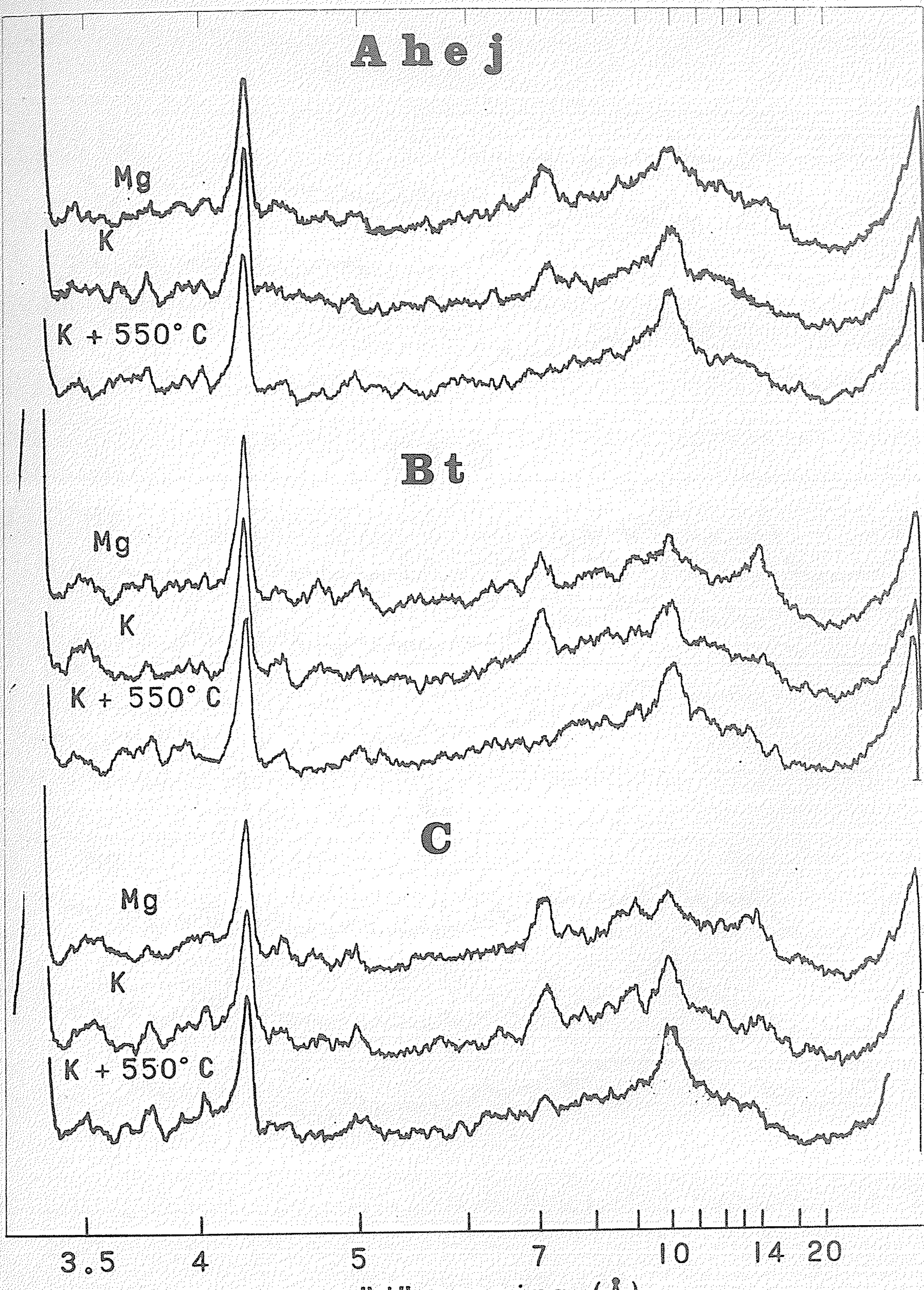

Figure 2. X-ray diffraction patterns of the fine silt fractions of the Orthic Dark Grey profile.

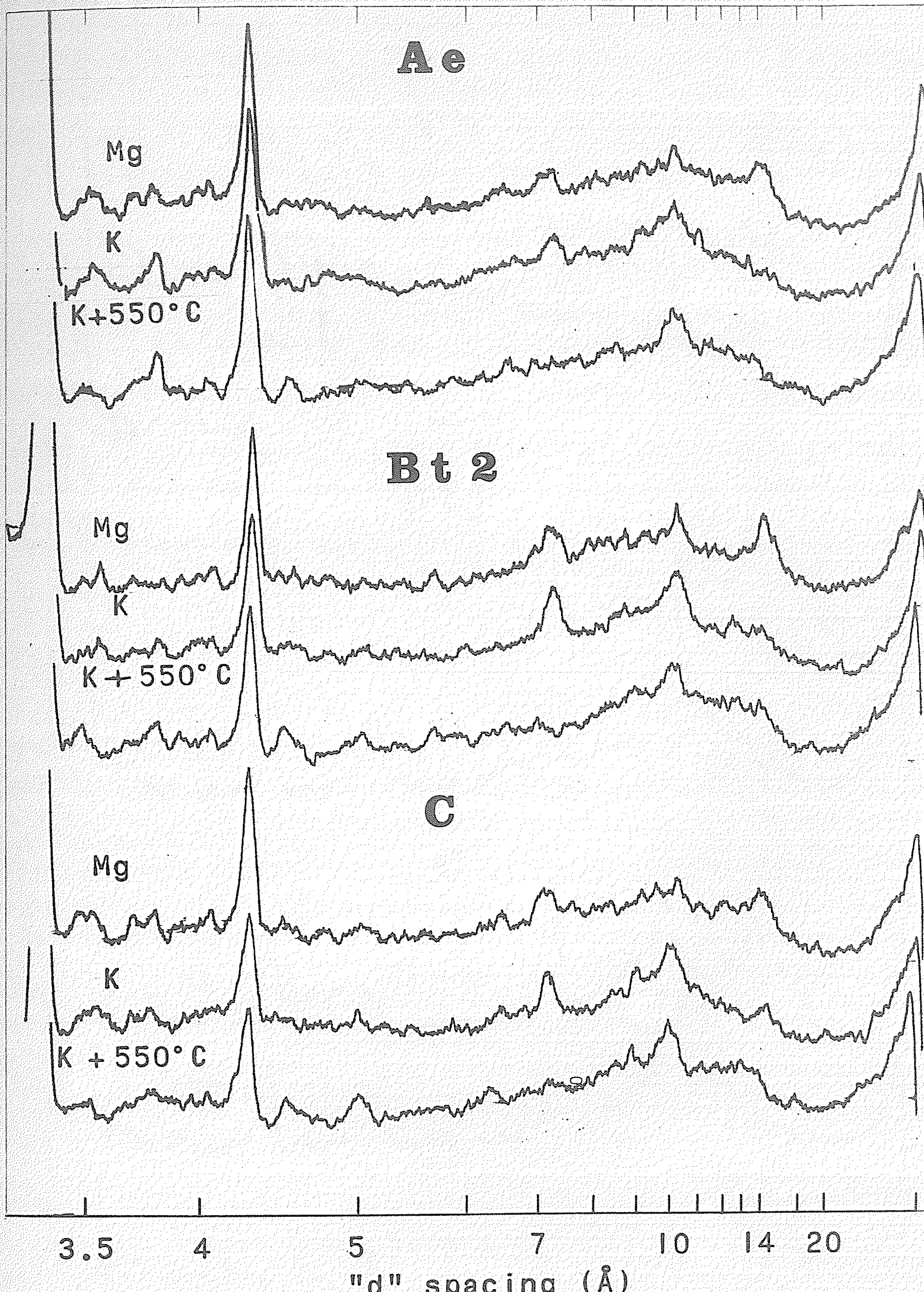

Figure 3. X-ray diffraction patterns of the fine silt fractions of the Orthic Grey Wooded profile.

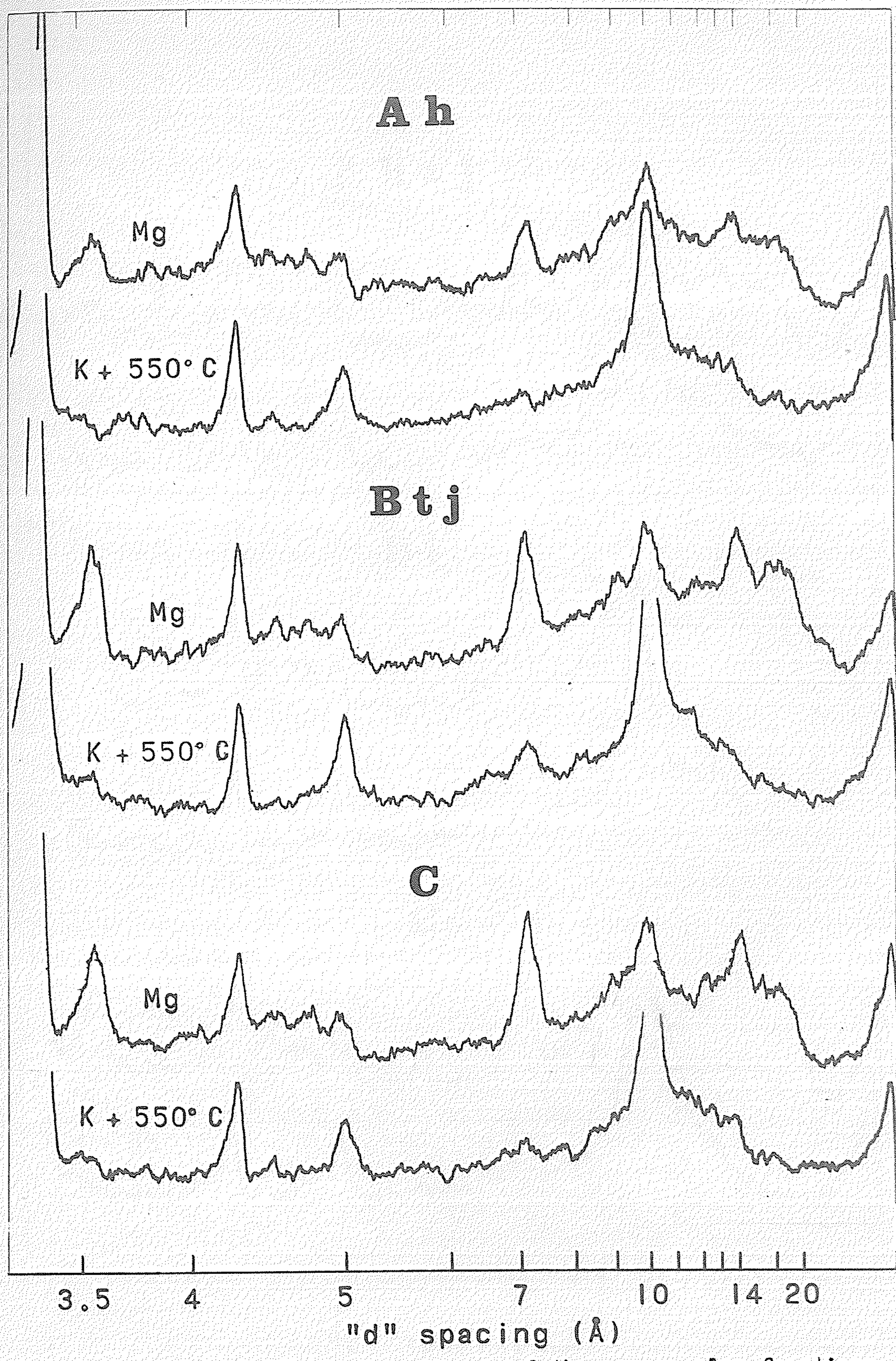

Figure 4. X-ray diffraction patterns of the coarse clay fractions of the Orthic Black profile.

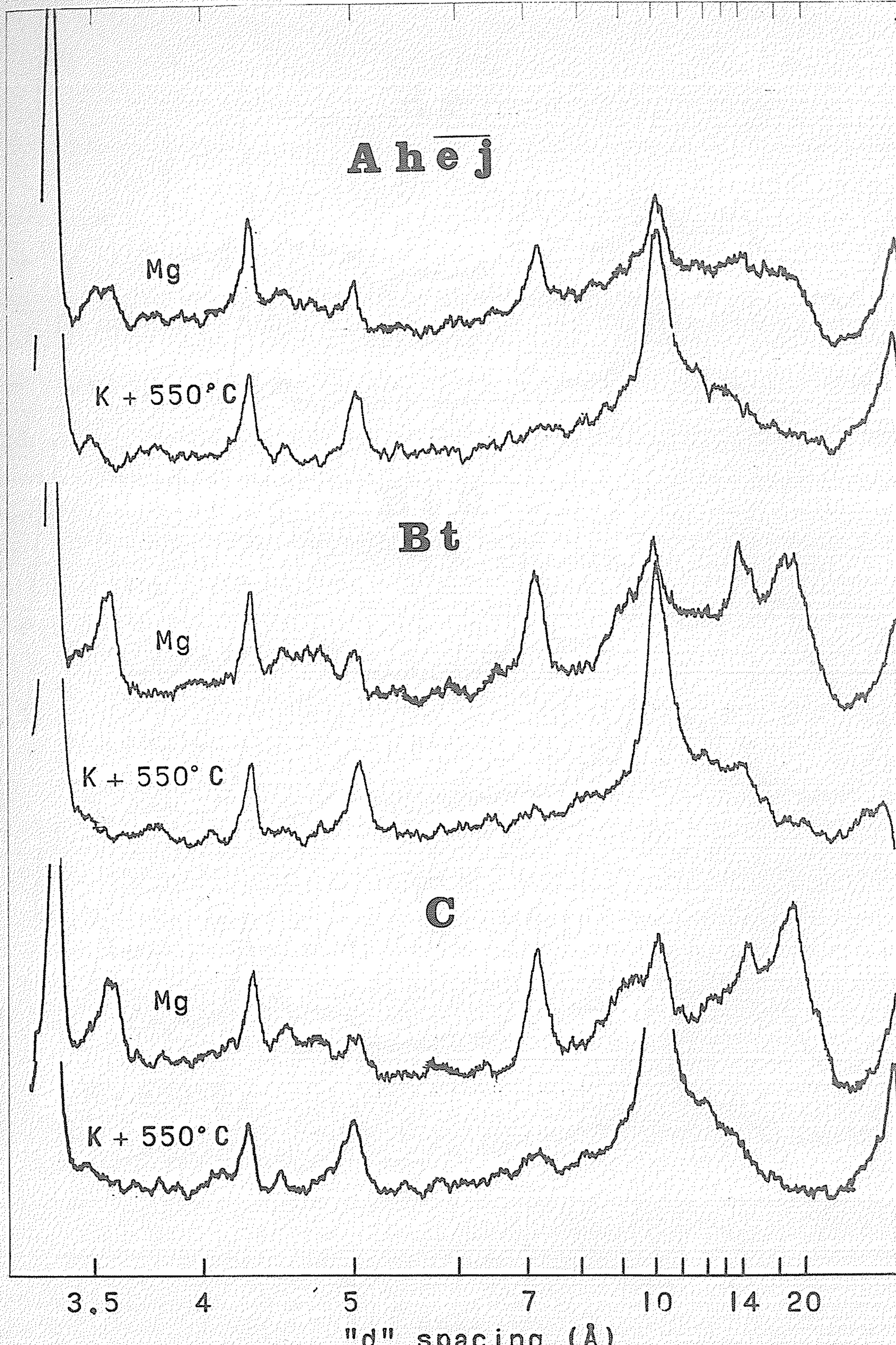

Figure 5. X-ray diffraction patterns of the coarse clay fractions of the Orthic Dark Grey profile.

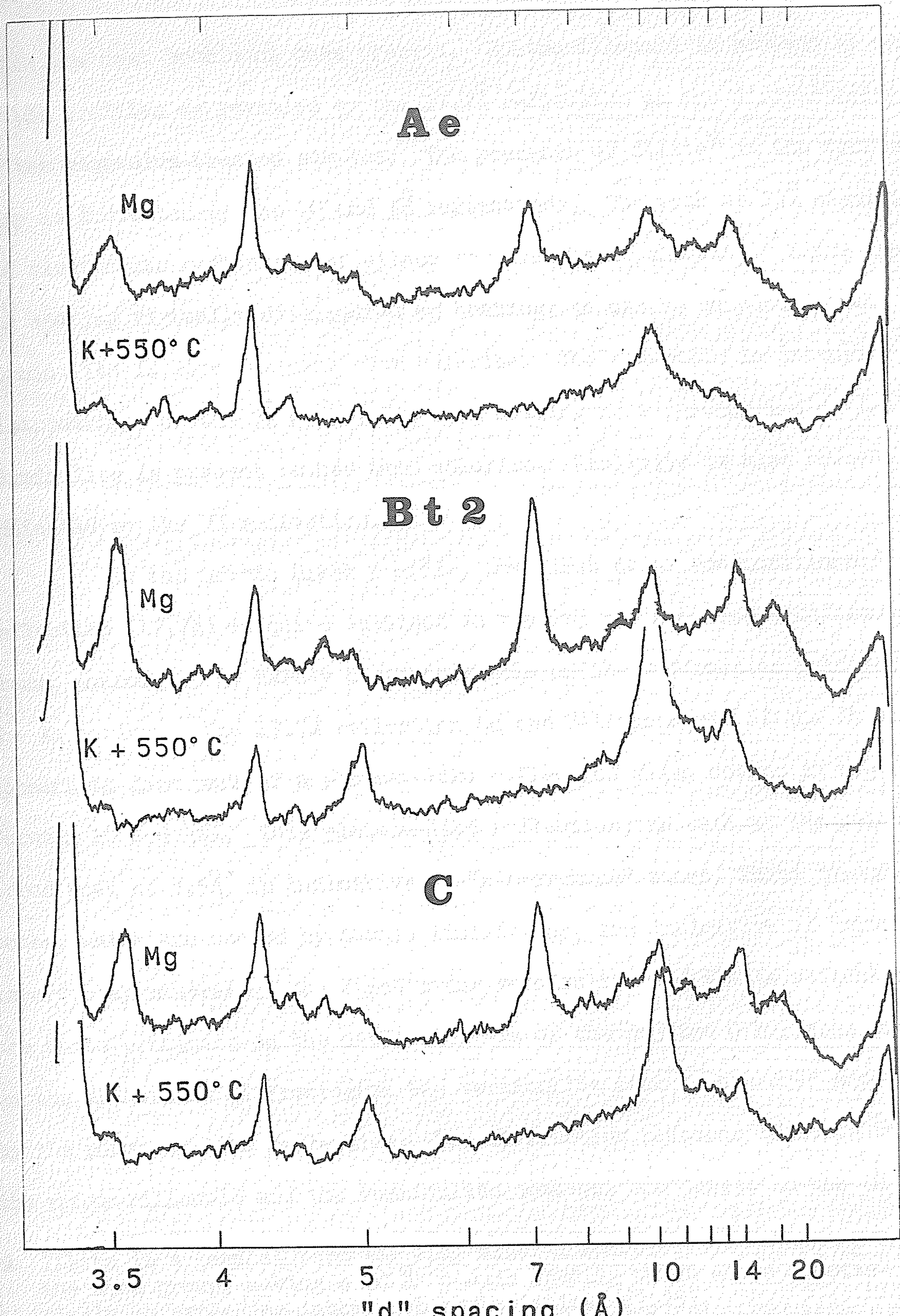

Figure 6. X-ray diffraction patterns of the coarse clay fractions of the Orthic Grey Wooded profile.

again the most prominent ones present. Montmorillonoid is present in each of the profiles as revealed by the 17.7Å reflection on the diffractograms of the magnesium-treated samples. The presence of illite* in the coarse clay is indicated by the 10 and 5Å reflections. The peak at 14Å signifies the first order reflection of either vermiculite or chlorite. Since the 14Å spacing virtually disappeared on heating, it can be concluded that vermiculite is more dominant than chlorite. The reduction in intensity or disappearance of the 7Å reflection upon heating is a further indication that vermiculite is present rather than chlorite. Kaolinite is also present as indicated by the 7Å reflection.

In the Orthic Black profile, the first order montmorillonoid reflection (17.7Å) is quite distinct on the Btj and C horizons diffractograms, whereas it is hardly distinguishable on the diffraction patterns of the Ah horizon. The 17.7Å reflection on the diffractogram of the Ah horizon appears to form part of a plateau-like reflection which occurs in the region between 10 and 18Å. This plateau-like reflection, as well as the relatively broad peak at 3.5Å, is indicative of "x-amorphous" zones. These "x-amorphous" zones, which are caused by z-axis limitations, are indicative of "mixed-layer" clay minerals. The first order vermiculite and illite reflections are quite prominent on the diffractograms of the Btj and C horizons whereas on the Ah horizon diffractogram the vermiculite peak is obscured somewhat by the pleateau-like reflection. The diffraction patterns indicate that the montmorillonoid and the vermiculite contents are lowest in the Ah

* Illite is a general term for clay mineral constituents belonging to the mica group, having a 10 Å c-axis spacing which shows substantially no expanding-lattice characteristics. (7,25).

horizon. The illite content in each of the horizons of this profile is approximately similar and appears to be greater than the montmorillonoid and vermiculite content.

In the Orthic Dark Grey profile (Fig.5), the first order montmorillonoid and vermiculite reflections are hardly distinguishable on the diffraction pattern of the Ahej horizon. These reflections are prominent, however, on the diffractograms of the Bt and C horizons. Analogous to the Orthic Black profile, the diffraction pattern of the Ahej horizon can only be explained as being due to the presence of mixed-layer clay minerals. With respect to the distribution of the clay minerals in the Orthic Dark Grey profile, the montmorillonoid content appears to increase with depth. The vermiculite content is lowest in the Ahej, and of about equal amount in the Bt and C horizons. The illite content remains constant down the profile.

In the Orthic Grey Wooded profile (Fig.6), montmorillonoid does not appear to be present in the Ae horizon, but is prominent in the Bt2 and C horizons. The vermiculite content appears to increase slightly with depth, while the illite content remains constant. The 7Å peak in the diffractograms obtained from the Mg-treated samples suggests that an appreciable amount of kaolinite is present, in particular in the Bt2 and C horizons. A 14Å peak may be observed in the Bt2 and C horizons diffractograms obtained from the heat-treated samples. This reflection may signify the presence of a clay mineral with a 14Å d-spacing, similar to the ones noted in the B horizon of podzolized soils of Alberta and Saskatchewan. (6,50,51) The characteristic periodic ordering of the peaks of this mineral (51) is however, not evident on these diffractograms.

Among profiles, the diffraction patterns obtained from the heated mounts are quite similar in general appearance. Irregularities occur with respect to the 7.1Å reflections which may be present or absent in any of the diffraction patterns, and with respect to the 14Å reflection which is distinct only on the diffractograms of the Bt2 and C horizons of the Orthic Grey Wooded profile. The diffraction patterns obtained from the Mg-treated samples are characteristic for each profile, although some similarities can be observed. Concerning the clay mineral distributions in each of the three profiles, it can be seen that the "A" horizons appear to contain the least amount of montmorillonoid and vermiculite. The relative amount of illite seems to remain constant within and among the profiles.

Among profile horizons, the relative intensities of the illite reflections do not seem to vary appreciably. For the other clay minerals, variations in relative content do seem to be present, in particular between "A" horizons. With respect to this horizon, the montmorillonoid content (17.7Å peak) progressively decreases from the Orthic Black to the Orthic Grey Wooded profile. The first order vermiculite reflection (14Å) in these "A" horizons is small in the Orthic Black, absent in the Orthic Dark Grey, and quite prominent in the Orthic Grey Wooded profile. Analogous to this is the relative increase in "x-amorphous" zones on the diffractogram of the Orthic Dark Grey profile to that of the Orthic Black profile, and its subsequent absence on the pattern of the Orthic Grey Wooded profile. These trends can be explained in terms of weathering conditions: with a slight increase in weathering conditions, interstratification of clay minerals results. When weathering becomes intensive, however, the interstratified complex breaks up either as a result of differential decomposition of its components or as a result of differential movement due to size and shape of the minerals.

The diffraction patterns of the "B" horizons of the profiles are fairly similar in general appearance, except for minor variations of the first order montmorillonoid reflections. The stronger 17.7Å reflection in the "B" horizon of the Orthic Dark Grey as compared to that of the Orthic Black soil appears to be due to differences in the montmorillonoid content of the parent materials. The 17.7Å reflection in the "B" horizon of the Orthic Grey Wooded profile is weak compared to that on the "B" horizon of the Orthic Black profile. This weak first order montmorillonoid reflection and the strong 7.1Å reflection in the diffraction pattern of this horizon, and the montmorillonoid distribution in the profile, are considered as evidence that illuviation has taken place in this profile.

<u>Fine Clay Fraction (<0.2u)</u> The diffractograms of the fine clay fraction of the dominant horizons from the Orthic Black, the Orthic Dark Grey, and the Orthic Grey Wooded profile, are shown in Figures 7, 8, and 9, respectively. Montmorillonoid is the dominant clay mineral in this size fraction, as revealed by the intensity of its first order reflection at 17.7Å. The next most prominent reflection on the diffractograms of the Mg-treated samples occurs at 9.2Å. This reflection signifies a random 40:60 mixture of illite and montmorillonoid.(27) Illite, as a pure clay mineral, does not occur in this size fraction. Vermiculite is present, but in much smaller amounts. Its presence is indicated by the plateau-like reflection between the 17.7 and 9.2Å peaks, and also by the occurrence of the 7.1Å reflection. An interesting feature in the diffraction patterns of each of these profiles is that the sharpness of the respective reflections increases with increase

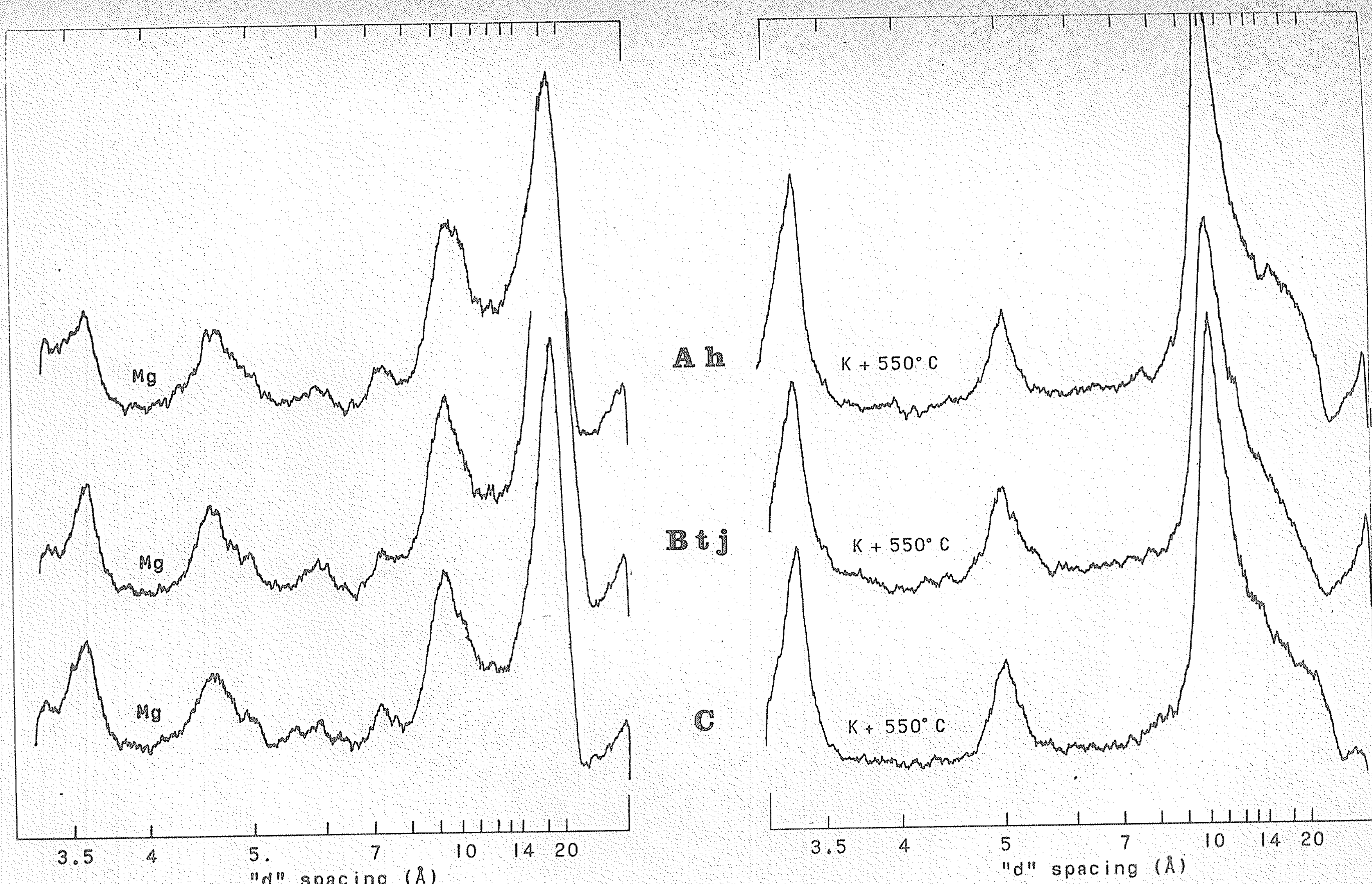

Figure 7. X-ray diffraction patterns of the fine clay fractions of the Orthic Black profile.

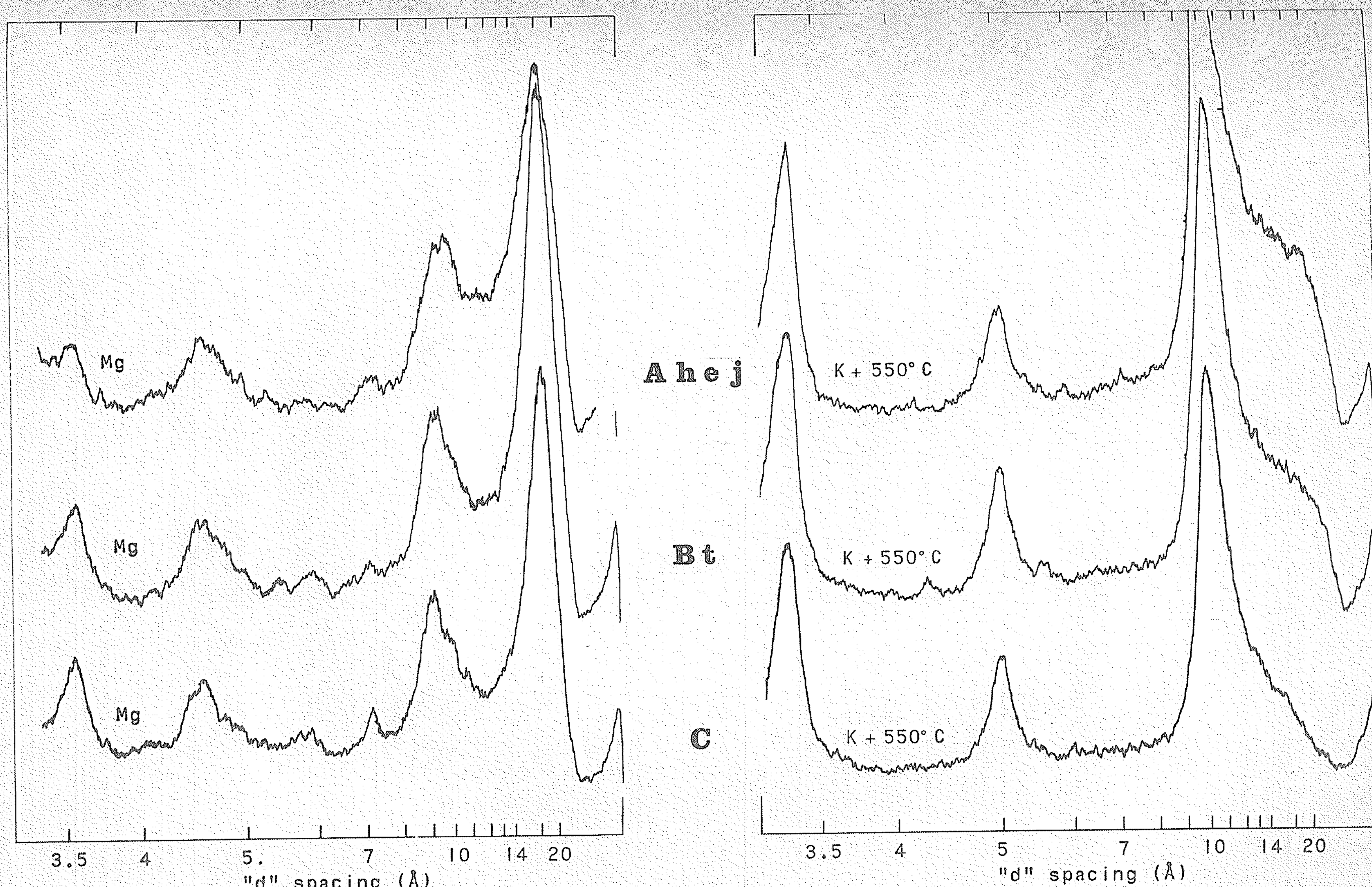

Figure 8. X-ray diffraction patterns of the fine clay fractions of the Orthic Dark Grey profile.

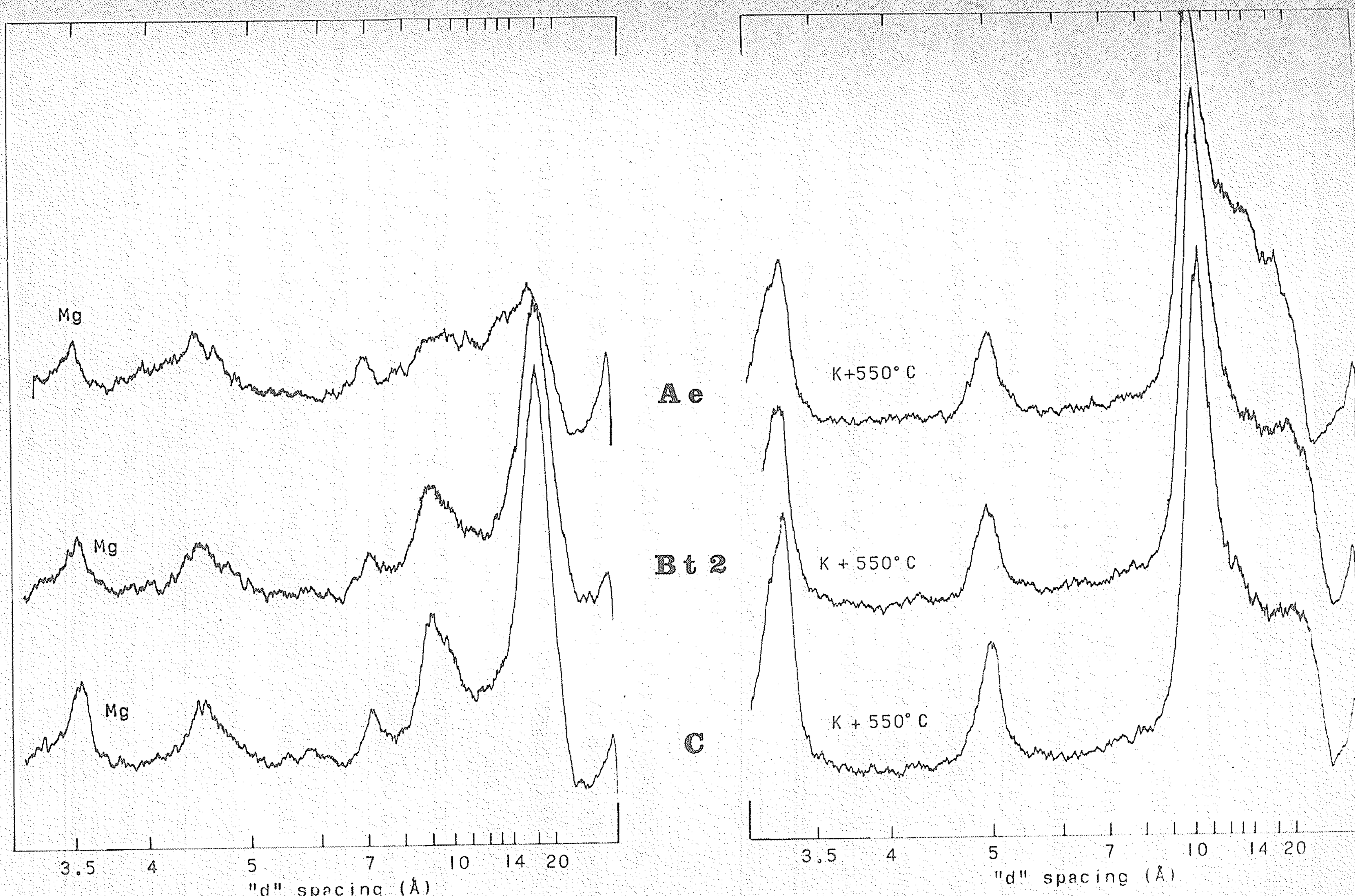

Figure 9. X-ray diffraction patterns of the fine clay fractions of the Orthic Grey Wooded profile.

in depth of the profile. Since the sharpness of a peak is a reflection of the crystalline state of the material, this feature may be very useful in indicating the intensity of the weathering conditions.

In the Orthic Black profile (Fig.7), the diffractograms of the various horizons are fairly similar in general appearance. The accumulation of montmorillonoid clay in the Btj horizon, as well as the even distribution of the random mixture and vermiculite down the profile are quite well noticeable. Of interest is the reflection occurring at 5.9Å; a slight accumulation of its material in the Btj horizon may be noted. The material responsible for this reflection could only be identified as being composed of layer silicates. This is indicated by the disappearance of the 5.9Å peak upon heating. The most likely explanation for the occurrence of this reflection is that it is the "average" spacing of a certain order of interstratified layer silicates.

In the Orthic Dark Grey profile (Fig.8), the accumulation of montmorillonoid clay in the Bt horizon is very apparent, and so is the even distribution of the random mixture down the profile. The vermiculite content appears to be lower in the Bt horizon than in the Ahe$\overline{\text{j}}$ or the C horizon, as is indicated by the lesser intensity of the 7.1Å reflection. With respect to the 5.9Å reflection, this is nearly absent in the Ahe$\overline{\text{j}}$, but indicates accumulation of material in the Bt horizon.

In the Orthic Grey Wooded profile (Fig.9), a very small amount of montmorillonoid is present in the Ae horizon, as compared to that of the Bt2 or C horizons. The vermiculite content appears to be about evenly distributed in the profile, while the random mixture increases with depth. The 5.9Å reflection is absent in the Ae horizon, faint in the Bt2 horizon, and distinct in the C horizon. Possibly associated with the absence of the

5.9Å reflection in the pattern of the Ae horizon is the occurrence of a plateau-like region between 15 and 9Å. This plateau may be the result again of z-axis limitations; and, if so, interstratified material is present in this horizon. Unlike the interstratified material of the 5.9Å reflection, however, this material is interstratified too coarsely to show intermediate Hendricks-Teller spacings.(27).

Among profiles, the diffractograms obtained from the heated mounts do show close similarity in the relative intensities of the various reflections. The patterns obtained from the Mg-treated samples of the Orthic Black and of the Orthic Dark Grey soil are nearly identical down the profile, and are quite unlike those of the Orthic Grey Wooded soil. In each of the profiles, the montmorillonoid content appears to be higher in the "B" and "C" horizons than in the "A" horizon. The random illite-and-montmorillonoid mixture content and the vermiculite content do not seem to vary appreciably between horizons in each profile.

Among profile horizons, most variation can be observed among "A" horizons, and least among "C" horizons. With respect to the "A" horizons, the relative montmorillonoid and random mixture contents decrease progressively from the Orthic Black to the Orthic Grey Wooded profile. Analogous to this is the behaviour of the 5.9Å reflection; it is relatively strong on the Ah horizon diffractogram of the Orthic Black profile, but is absent on the Ae horizon pattern of the Orthic Grey Wooded profile. Comparable to the behaviour of the coarse clay of the "A" horizons, these trends can be explained in terms of weathering conditions. With respect to the "B" horizons, most noticeable is the decrease in sharpness of the reflections on going from the Orthic Black to the Orthic Grey Wooded profile. This trend in the crystallinity of the clay minerals in these profiles is a further indication that weathering processes are most intense in the Orthic Grey Wooded, and least in the Orthic Black profile. The "C" horizon diffractograms are very similar in appearance, in particular with respect to the intensity and sharpness of the reflections.

Fusion Analyses of the Clay Fractions

The results of the fusion analyses on clay fractions are shown in Table VI. These analyses were carried out: a) to obtain a more accurate estimate of the illite content; and b) to identify the montmorillonoid species in the soils under study.

Illite Content of the Clay Fractions. According to Gieseking (24) and Whittig *et al.*(66), an estimate of the amount of mica-like minerals in clays can be obtained by assuming that these minerals contain an average of 6 per cent K_2O. In order to justify this assumption, the chemical analyses of a number of illite samples are presented in Table VII. These analyses were compiled from Table D, page 372 of "Clay Mineralogy" by Grim (25) and from Table 5, pages 16-18, of "Rock Forming Minerals: Sheet Silicates" by Deer, Howie, and Zussman (15). The average K_2O content obtained in this way agreed closely with that suggested by Gieseking and by Whittig *et al.*. Since illite is a general term for the argillaceous constituents belonging to the mica group, the assumption that the illite in the soils under study contains 6 per cent K_2O may or may not apply. This depends on the source material and on the degree of chemical substitution that has taken place. Furthermore, St. Arnaud (58) has shown that about one quarter of the total potassium content of the coarse clay fraction may come from primary minerals.

The data in Table VI show that the illite content is considerably

TABLE VI

TOTAL POTASSIUM AND CALCULATED ILLITE CONTENT OF THE COARSE AND FINE CLAY FRACTIONS, AND TOTAL IRON, SILICON, AND ALUMINIUM CONTENT OF THE FINE CLAY FRACTIONS OF THE DOMINANT HORIZONS OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED PROFILES

Soil	Horizon	Coarse Clay		Fine Clay				
		% K_2O	% Illite	% K_2O	% Illite	% Fe_2O_3	% Al_2O_3	% SiO_2
Orthic Black	Ah	2.17	33.17	1.80	30.03	18.96	16.57	45.77
	Btj	2.46	41.02	1.14	19.08	23.92	19.43	47.50
	C	2.79	46.43	1.66	27.66	20.66	16.05	48.79
Orthic Dark Grey	Ahej	2.93	48.78	1.41	23.43	21.26	19.72	46.78
	Bt	2.95	49.23	1.57	26.16	19.70	18.92	48.79
	C	1.82	30.33	1.41	24.42	19.34	16.17	47.21
Orthic Grey Wooded	Ae	2.70	45.07	1.69	28.18	---	---	---
	Bt2	3.72	61.93	1.53	25.48	18.66	19.61	47.35
	C2	2.32	38.67	1.35	22.43	20.44	19.15	51.08

TABLE VII

TOTAL CHEMICAL ANALYSES OF A NUMBER OF DIOCTAHEDRAL ILLITE SAMPLES [1].

element \ sample	1.	2.	3.	4.	5.	Average
SiO_2	51.26	56.91	52.23	51.22	51.65	52.65
TiO_2	0.05	0.81	0.37	0.53	-----	0.44
Al_2O_3	30.15	18.50	25.85	25.91	21.67	24.42
Fe_2O_3	2.36	4.99	4.04	4.59	6.20	4.44
FeO	0.59	0.26	-----	1.70	1.24	0.98
MnO	0.04	-----	-----	-----	-----	0.01
MgO	1.37	2.07	2.69	2.84	4.48	2.69
CaO	0.00	1.59	0.60	0.16	0.00	0.49
Na_2O	0.13	0.43	0.33	0.17	0.31	0.29
K_2O	7.77	5.10	6.56	6.09	6.08	6.05
H_2O +	6.28	5.98	7.88	7.14		
H_2O −	0.00	2.86	-----	-----	-----	
P_2O_5	-----	-----	-----	-----	-----	
TOTAL	100.00	99.50	100.55	100.35	98.07	

1 Sample Source, Analyst, and Reference.

Sample #1. Light greenish yellow soft scales of illite, on decomposed granite, Ballater, Aberdeenshire, Mackensie, et al, 1949. Min. Mag. 28: 704 (15).
Sample #2. Illite, Fithian, Illinois. Kerr, et al, 1950 (15)
Sample #3. Illite, Alexander County, Illinois. Grim and Rowland, 1941, Amer. Min. 27: 746-761. (25)
Sample #4. Illite, Fithian, Illinois. Grim and Rowland, 1941. Amer. Min. 27: 746-761.(25)
Sample #5. Geoschwitz, Germany. Maegdefrau, E. and Hofmann, U., 1937, Z. Krist. 98: 31-59. (25).

higher in the coarse clay than in the fine clay in each of the profiles. In the Orthic Black profile, the illite content of the coarse clay increases down the profile. The amount of illite in the fine clay fractions of this profile is nearly the same for the Ah and C horizons; the Btj horizon being lower in illite content. In the Orthic Dark Grey profile, the illite content of the coarse clay is lowest in the C horizon. The amount of illite in the fine clay is fairly constant down the profile; a slight increase may be noted in the Bt horizon. In the Orthic Grey Wooded profile, the illite content of the coarse clay indicates accumulation in the Bt2 horizon. The illite content of the fine clay shows a slight decrease with depth.

Among profiles, neither the distribution of illite in the coarse clay, nor that in the fine clay seems to indicate any weathering trend. With respect to the fine clay fractions, the similarity in illite content as well as in illite distribution may be noted. This is in agreement with the observations made from the x-ray diffraction patterns for the random 40:60 mixtures of illite and montmorillonoid.

<u>The Montmorillonoid Species</u>. The investigations for the determination of the montmorillonoid species present in the soils were carried out on the fine clay fractions. Fusion analyses were made in order to determine the total oxides of iron, aluminium and silicon, the results of which are presented in Table VI. From these results, and with the aid of the total potassium data, the montmorillonoid composition was calculated the results of which are shown in Table VIII. In order to calculate this, it was assumed that only illite and montmorillonoid clay minerals were present in the fine clay fractions.

The results in Table VIII show that the montmorillonoid clay present in each of the soils has a relatively high content of silica, alumina, and iron. The latter element suggests that the nontronite species

TABLE VIII

THE COMPOSITION OF THE MONTMORILLONITE FRACTION AS CALCULATED FROM THE RESULTS PRESENTED IN TABLE VI, p 51.

Soil	Horizon	% Illite in Sample	Amount of oxide attributable to Illite			% Montmorillonoid in sample	Amount of oxide remaining			Amount of oxide in 100% montmorillonoid		
			$\%Fe_2O_3$	$\%Al_2O_3$	$\% SiO_2$		$\% Fe_2O_3$	$\%Al_2O_3$	$\%SiO_2$	$\%Fe_2O_3$	$\%Al_2O_3$	$\% SiO_2$
Orthic Black	Ah	30.03	1.33	7.33	15.81	69.97	17.63	9.24	29.96	25.20	13.21	42.82
	Btj	19.08	0.85	4.66	10.05	80.92	23.07	14.77	37.45	28.51	18.25	46.28
	C	27.66	1.23	6.75	14.56	72.34	19.43	9.30	34.23	26.86	12.86	47.32
Orthic Dark Grey	Ahej	23.43	1.04	5.72	12.34	76.57	20.22	14.00	34.44	26.41	18.28	44.98
	Bt	26.16	1.16	6.39	13.77	73.84	18.54	12.53	34.02	25.11	16.97	47.43
	C	24.41	1.08	5.96	12.85	75.58	18.26	10.21	34.36	24.16	13.51	45.46
Orthic Grey Wooded	Ae	28.18				71.82						
	Bt	25.48	1.13	6.22	13.42	74.52	17.53	13.39	33.93	23.52	17.97	45.53
	C2	22.43	1.00	5.48	11.81	77.57	19.44	13.69	39.27	25.06	17.65	50.63

Agenda: % Illite in sample: see Table VI
% Montmorillonoid in sample = 100 --% Illite.
% Oxide attributable to illite - %average oxide (Table VII) x $\frac{\text{\% illite in sample}}{\text{100\% illite.}}$

Amount of oxide remaining = Total oxide (Table VI) - Amount of oxide attrib. to illite.

Amount of oxide in 100% montmorillonite = amount of oxide remaining x $\frac{\text{100\% montmorill}}{\text{\% Mont. in sample.}}$

of the montmorillonoid group occurs in these soils. In order to verify this, the total chemical analyses of a number of nontronite samples were compiled from the literature and are presented in Table IX. Comparison of the data in Table VIII with those in Table IX shows that the silica and iron content of the montmorillonoid clay corresponds closely to that of pure nontronite. However, the alumina content obtained is considerably higher than can be attributed to pure nontronite, which suggests that some beidellite is present (see Table IX for beidellite composition). Considering the suggestion that montmorillonite-beidellite-nontronite form a continuous series (15), it is concluded that the montmorillonoid species present in the soils is intermediate between beidellite and nontronite, tending towards the nontronite end of the series.

Specific Surface Determination of Clay Minerals

The purpose of this experiment was to obtain additional information concerning the montmorillonoid + vermiculite content in these soils. Although this method provides an easier way to estimate these minerals than can be done from x-ray diffraction patterns, its accuracy is debatable. The critical factor in the determination of the percent montmorillonoid + vermiculite by this method is the determination of the specific planar surface. In order to calculate this, one must know which species of minerals are present in the soil. Furthermore, one must know the a and b unit cell dimensions for each of these species as well as their unit cell weight. What makes the specific planar surface a still more variable quantity is the fact that the mineral species usually are part of a continuous series. Thus, there is usually some Mg in octahedral co-ordination in beidellite

TABLE IX

TOTAL CHEMICAL ANALYSES OF A NUMBER OF NONTRONITE AND ONE BEIDELLITE SAMPLE [1]

Mineral	Nontronite							Beidellite
sample / element	1	2	3	4	5	6	Average	1
SiO_2	39.92	40.25	40.54	41.38	46.06	44.0	42.03	59.30
TiO_2	0.08	0.03	---	---	0.84	0.32		
Al_2O_3	5.37	5.50	5.19	9.84	12.22	3.6	6.41	36.11
Fe_2O_3	29.46	29.44	31.24	27.47	18.54	29.0	27.52	0.50
FeO	0.28	0.00	0.39	tr?	0.28		0.32	
MnO	---	---						
Zno	---	---						
MgO	0.93	0.53	0.06	tr?	1.62	2.1	1.05	0.10
CaO	2.46	2.29	1.92	tr?	1.66	---	2.08	0.02
Na_2O	tr	0.00	0.14				0.05	3.98
K_2O	tr	0.00	0.24	tr?	---	---	0.06	0.11
H_2O -	---	7.25	6.00	9.25	17.26	18.7		
H_2O -	14.38	15.09	14.75	12.10				
TOTAL	99.88	100.38	100.47	100.04	98.48	97.4		100.12

1. Sample Source, Analyst, and Reference.

<u>Sample #1</u>: Green-yellow nontronite, joint fillings in diabasic basalt, Garfield, Washington, U.S.A. Kerr, P., <u>et al</u>, Prelim. report #7. Reference Clay Minerals. Amer. Petrol.Inst., Res. Proj. 49: 1950. (15)
<u>Sample #2</u>: Yellow-green nontronite in veins associated with weathered basalt, Colfax, Whitman County, Washington, U.S.A. Allen, V.T., and Scheid, V.E., Amer. Min. Vol.31, p.294: 1946. (15)
<u>Sample #3</u>: Manito, Washington, U.S.A.; Kerr, P.F., <u>et al</u>, Report #7, Amer. Petroleum Instit., Res.Proj. 49: 1950. (25).
<u>Sample #4</u>: Sandy Ridge, North Carolina; <u>Sample #5</u>: Spokane, Washington; <u>Sample #6</u>: Nontron, France; Ross, C.S., and Hendricks, S.B., U.S. Geol.Survey, Profess. Paper 205 B (1945) (25).
<u>Beidellite</u>: Weir, A.H. and Green-Kelley, R., American Mineralogist 47: 137-146, 1962.

TABLE X

SPECIFIC SURFACE DATA FOR THE COARSE AND FINE CLAY FRACTIONS OF THE DOMINANT HORIZONS OF THE ORTHIC BLACK, ORTHIC DARK GREY AND ORTHIC GREY WOODED PROFILES.

Soil	Size Fraction	Horizon	Specific External Surface (m^2/gm)	Specific Interlayer Surface (m^2/gm)	Specific Planar Surface (m^2/gm)	% Montmorillonite + Vermiculite
Orthic Black	Coarse Clay	Ah	23.49	132.55	152.13	20.02
		Btj	21;39	143.25	161.08	21.29
		C	17.95	145.16	160.12	21.07
Orthic Dark Grey		Ahe$\overline{j}$	20.44	154.71	170.33	22.41
		Bt	38.39	198.26	230.25	30.30
		C	66.09	156.62	211.70	27.86
Orthic Grey Wooded		Ae				
		Bt2	22.16	137.90	156.37	20.58
		C2				
Orthic Black	Fine Clay	Ah	122.05	467.57	569.28	74.91
		Btj	139.62	530.22	646.57	85.06
		C	151.08	445.03	570.93	75.12
Orthic Dark Grey		Ahe$\overline{j}$	154.71	377.80	506.73	66.68
		Bt	143.82	348.00	467.85	61.56
		C	95.31	542.82	622.25	81.88
Orthic Grey Wooded		Ae				
		Bt2	118.04	414.47	512.84	67.48
		C2	101.99	483.99	568.98	74.87

and in nontronite, so that montmorillonite-beidellite-nontronite appear to form a continuous series (15). As a result of the previous considerations it was calculated that the average planar surface was 760 m^2/gm. The parameters used to calculate the specific planar surface for nontronite were: $b_o = 9.12Å$ and $a_o = 5.25Å$ (15,25,27), while the specific planar surface values for montmorillonite, beidellite, and vermiculite were obtained from Jackson (27).

The results obtained from this experiment are presented in Table X. These data show that the percent montmorillonoid + vermiculite in the coarse clay fractions is far less than that in the fine clay fractions. This trend agrees closely with the observations made from the x-ray diffraction patterns, and it is opposite to the trend observed for the illite content. A striking example of the correlation between these results and those obtained by x-ray diffraction is the relatively high montmorillonoid content in the coarse clay of the Orthic Dark Grey profile, as compared to that of the Orthic Black and Orthic Grey Wooded profiles. Correlation with the x-ray diffraction results can further be noted, when adding the illite content data (Table VI, p.51) to those of montmorillonite + vermiculite (Table X, p.54). This adds up to about 100 per cent for each of the fine clay fractions. For the coarse clay fraction, the illite + vermiculite + montmorillonite content constitutes from 60 to 75 per cent of the fractions. The remaining one-third to one-fourth of the fraction appears to be composed of primary minerals chiefly, in particular quartz, and of small amounts of chlorite and/or kaolinite.

CUTAN INVESTIGATIONS

Chemical and mineralogical analyses were conducted on the cutans and on bulk samples of the selected peds. The analyses on the bulk samples were included for comparison purposes. The results obtained were expected to have been affected by the following factors: 1. considerable contamination of the cutans may have taken place, due to the scraping method employed; 2. as a result of the dynamic nature of soils, new surfaces become exposed and old ones covered, so that the cutans obtained may have constituted only a small part of the total present. On considering these conditions, it was concluded that even minor variations in the results should be considered as significant.

Organic Matter, Organic Carbon, and Total Nitrogen

The results obtained from these analyses are presented in Table XI. It may be noted that for each of the profiles more total nitrogen is present in the cutans than in the bulk samples. The organic matter and, consequently, the organic carbon contents are higher only in the cutans of the Orthic Grey Wooded profile. This different behaviour of the organic matter content in the Orthic Grey Wooded as compared to that in the Orthic Black and Orthic Dark Grey samples may have been brought about by their mode of formation. According to Brewer (3), eluviation cutans, stress cutans, and diffusion cutans have been recognized. The latter two types signify in situ formation, while the former is the result of eluviation. Considering the organic matter results, these suggest that the "B" horizon cutans of the Orthic Black and those of the Orthic Dark Grey profiles have formed in situ. The accumulation of organic matter in the cutans of the Bt2 horizon of the Orthic Grey Wooded profile, on the other hand, suggests that they are eluviation cutans.

TABLE XI

ORGANIC MATTER, TOTAL NITROGEN, AND EXTRACTABLE IRON CONTENT, AND C/N RATIOS OF THE CUTANS AND BULK SAMPLES OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED SOILS.

Soil	Horizon	% Organic Matter	% Organic Carbon	% Total Nitrogen	C/N Ratios	% Extractable Fe_2O_3
Orthic Black	Btj	1.41	0.81	0.071	11.4	0.964
	Cutans	1.22	0.71	0.092	9.2	1.277
Orthic Dark Grey	Bt	1.31	0.75	0.085	8.8	1.153
	Cutans	1.10	0.63	0.095	6.6	1.392
Orthic Grey Wooded	Bt2	1.41	0.81	0.079	11.4	1.296
	Cutans	1.68	0.97	0.106	7.7	1.758

With respect to the accumulation of total nitrogen in the Orthic Black and in the Orthic Dark Grey cutans, this may have been brought about by:

a) seasonal fluctuations of the nitrogen distribution in soils; and

b) ammonium fixation by clay minerals.

The accumulation of total nitrogen in the cutans of the Orthic Grey Wooded profile is, most probably, associated with the presence of the eluviated organic matter.

Extractable Iron

The data in Table XI show that more extractable iron is present in the cutans than in the bulk samples of each of the three profiles. This trend is analogous to the one observed for the total nitrogen content in these samples. Approximately similar amounts of extractable iron have accumulated in the cutans of the Orthic Black and of the Orthic Dark Grey profile. This suggests that the cutans in these two profiles have been formed by similar processes. The amount of extractable iron accumulated in the cutans of the Orthic Grey Wooded soil is considerably higher than that in the cutans of the Orthic Black and Orthic Dark Grey profiles. This high extractable iron content of the cutans of the Orthic Grey Wooded profile may be associated with the presence of the eluviated organic matter. If so, this would indicate that the cutans in this profile have been formed by illuviation. In general, the results indicate that the cutans of each of these profiles consist, in part, of sesquioxides.

Cation Exchange Capacity and Exchangeable Cations

The results of the cation exchange capacity and of the exchangeable cations experiments are shown in Table XII. The exchange capacity results follow the same trend as that observed for organic matter; i.e. the cutans have a higher exchange capacity only in the case of the Orthic

TABLE XII

CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS OF THE CUTANS AND THE BULK SAMPLES OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED SOILS.

Soil	Horizon	Cation Exchange Capacity (m.e./100 gm)	Exchangeable Cations (m.e./100 gm)						% Base Saturation
			K	Na	Ca	Mg	Ca-Mg	Total	
Orthic Black	Btj	26.57	1.24	0.03	18.50	5.37	23.87	25.14	94.62
	Cutans	25.84	1.17	0.17	18.00	5.00	23.00	24.34	94.20
Orthic Dark Grey	Bt	28.60	1.26	0.25	20.88	6.37	27.25	28.76	100.52
	Cutans	27.72	0.90	0.06	19.60	6.60	26.20	27.16	97.98
Orthic Grey Wooded	Bt2	28.97	0.61	---	18.28	9.15	27.43	28.04	96.79
	Cutans	31.99	0.74	0.34	20.00	9.20	29.20	30.28	94.65

Grey Wooded soil. This may have been brought about by the higher amount of organic matter in these cutans as well as by the fact that this organic matter has been eluviated. The latter reason is quite important, since translocated organic matter usually has a lower carbon content, so that it is relatively more active in cation exchange reactions than surface soil organic matter. The difference in exchange capacity between cutans and bulk samples of the Orthic Black and of the Orthic Dark Grey soil is fairly small.

The exchangeable cations data show that calcium and magnesium are the dominant cations in the bulk and in the cutans samples. In terms of percent calcium on the exchange complex, this is approximately the same for the cutans and their bulk samples within each profile. Magnesium, the next most prominent exchangeable cation, behaves similar to calcium. The bulk sample of the Orthic Black and of the Orthic Dark Grey soil has a higher exchangeable potassium content than their respective cutans sample. The reverse is true for the Orthic Grey Wooded soil. The cutans as well as their bulk samples have a high base saturation. The lower base saturation of the cutans, as compared to their respective bulk samples, suggests that the former have more exchangeable hydrogen on the exchange sites.

Particle Size Distribution

The results obtained from this experiment are presented in Table XIII. These data show that the cutanic material and the bulk sample of the Orthic Grey Wooded soil are of a clay texture. The texture of the bulk and the cutans samples of the other two soils is clay loam. It may be noted that only the cutans of the Orthic Grey Wooded profile have a higher clay content than its Bt2 bulk sample. Further-

TABLE XIII

PARTICLE SIZE DISTRIBUTION DATA OF THE CUTANS AND BULK SAMPLES OF THE ORTHIC BLACK, ORTHIC DARK GREY, AND ORTHIC GREY WOODED SOILS

Soil	Sample	% very coarse sand	% coarse sand	% medium sand	% fine - very fine sand	% coarse silt	% med. silt	% fine silt	% coarse clay	% fine clay
Orthic Black	Btj	2.31	2.68	4.40	16.08	22.04	15.67	3.95	9.17	23.67
	Cutans	0.71	3.31	6.11	18.83	20.25	14.91	3.21	8.85	23.82
Orthic Dark Grey	Bt	2.36	4.02	6.22	19.52	12.29	13.90	4.57	10.99	26.16
	Cutans	0.82	4.93	8.21	20.83	12.40	11.69	4.03	10.38	26.70
Orthic Grey Wooded	Bt2	1.95	3.23	5.41	21.89	11.48	11.26	3.50	11.05	30.20
	Cutans	1.47	4.23	5.99	21.22	10.37	8.99	2.91	10.34	34.46

more, this higher clay content may be attributed to the increase in the fine clay fraction. As was noted from Table IV,(p35) clay eluviation had taken place in the Orthic Grey Wooded soil, and the clay fraction affected mostly by the eluviation processes was the fine clay. The conclusion may be drawn, therefore, that the cutans of the Orthic Grey Wooded soil are, in part, clay in nature. The lack of clay accumulation in the cutans of the Orthic Black and of the Orthic Dark Grey soil indicates that these cutans have not been formed as the result of eluviation.

With respect to the various sand and silt fractions, the amount of each of these fractions in the cutans and in their respective bulk sample do vary. These variations are small and, likely, of no pedogenic significance.

X-ray Diffraction Analyses

The diffractograms obtained from this experiment are arranged in such a way as to obtain maximum comparability between the bulk and the cutans samples. The diffractograms for each horizon are arranged according to treatment.

The diffraction patterns of the respective fine silt fractions are shown in Figure 10 . Very little variation can be noted between the patterns of the cutans and those of the respective bulk samples of any one profile. Similarly, there is little variation among the soils.

The diffractograms of the coarse clay fractions of the Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded profiles are shown in Figures 11, 12, and 13, respectively. In general, the diffraction patterns are very similar for the bulk and cutans samples. Montmorillonoid, illite,

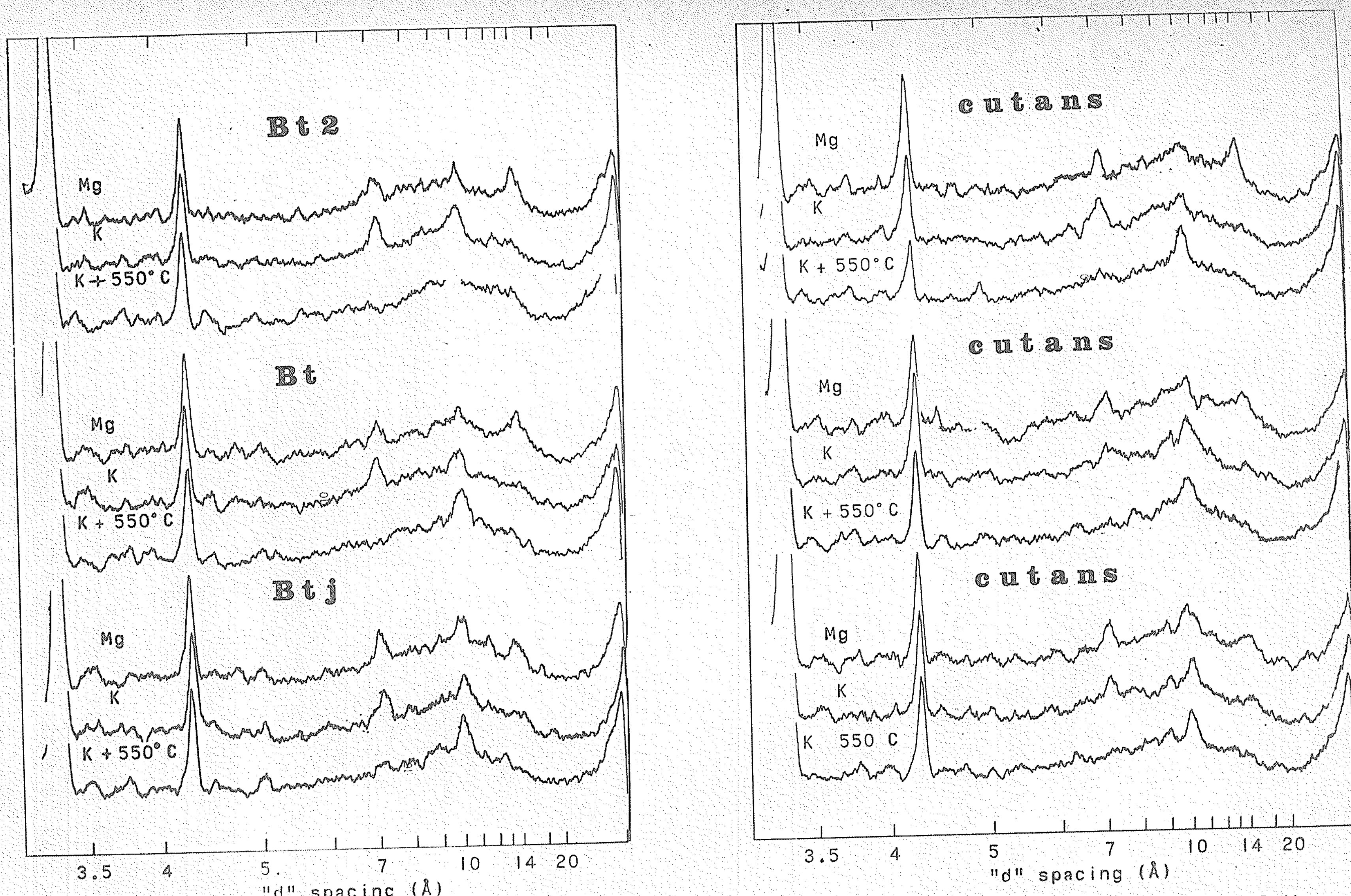

Figure 10. X-ray diffraction patterns of the fine silt fraction of the bulk and cutans samples of the Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded soils.

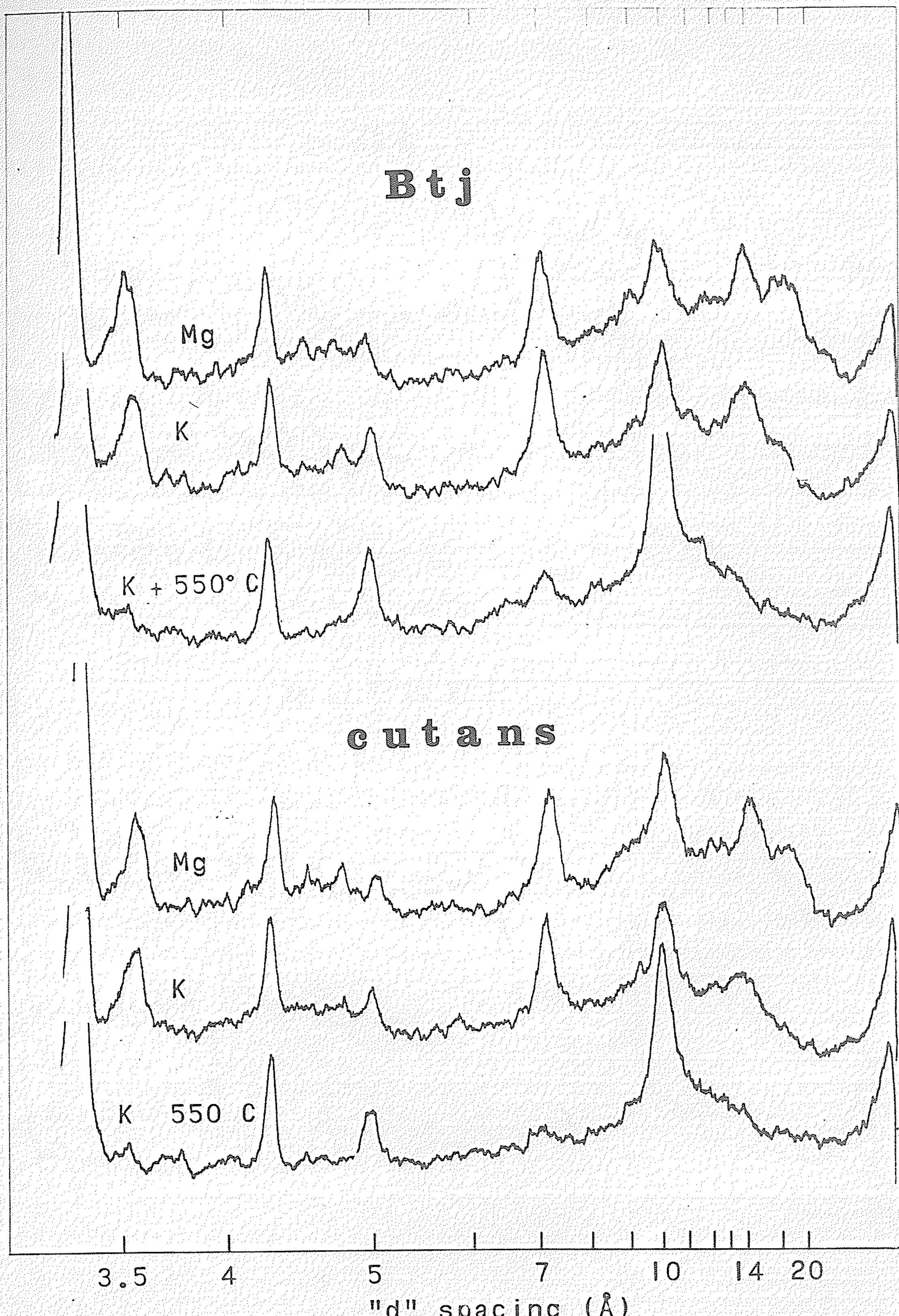

Figure 11. X-ray diffraction patterns of the coarse clay fraction of the bulk and the cutans sample of the Orthic Black soil.

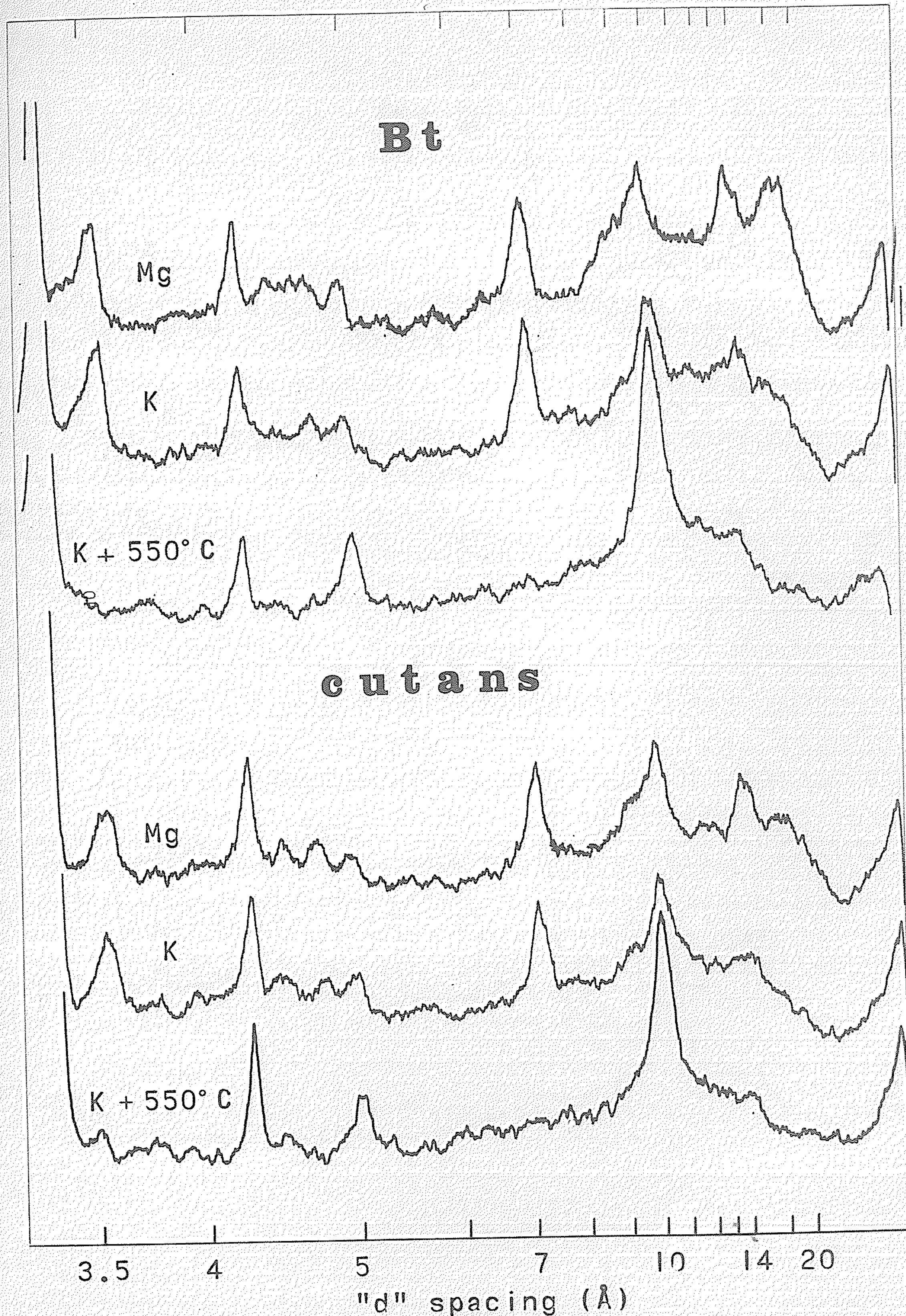

Figure 12. X-ray diffraction patterns of the coarse clay fraction of the bulk and the cutans sample of the Orthic Dark Grey soil.

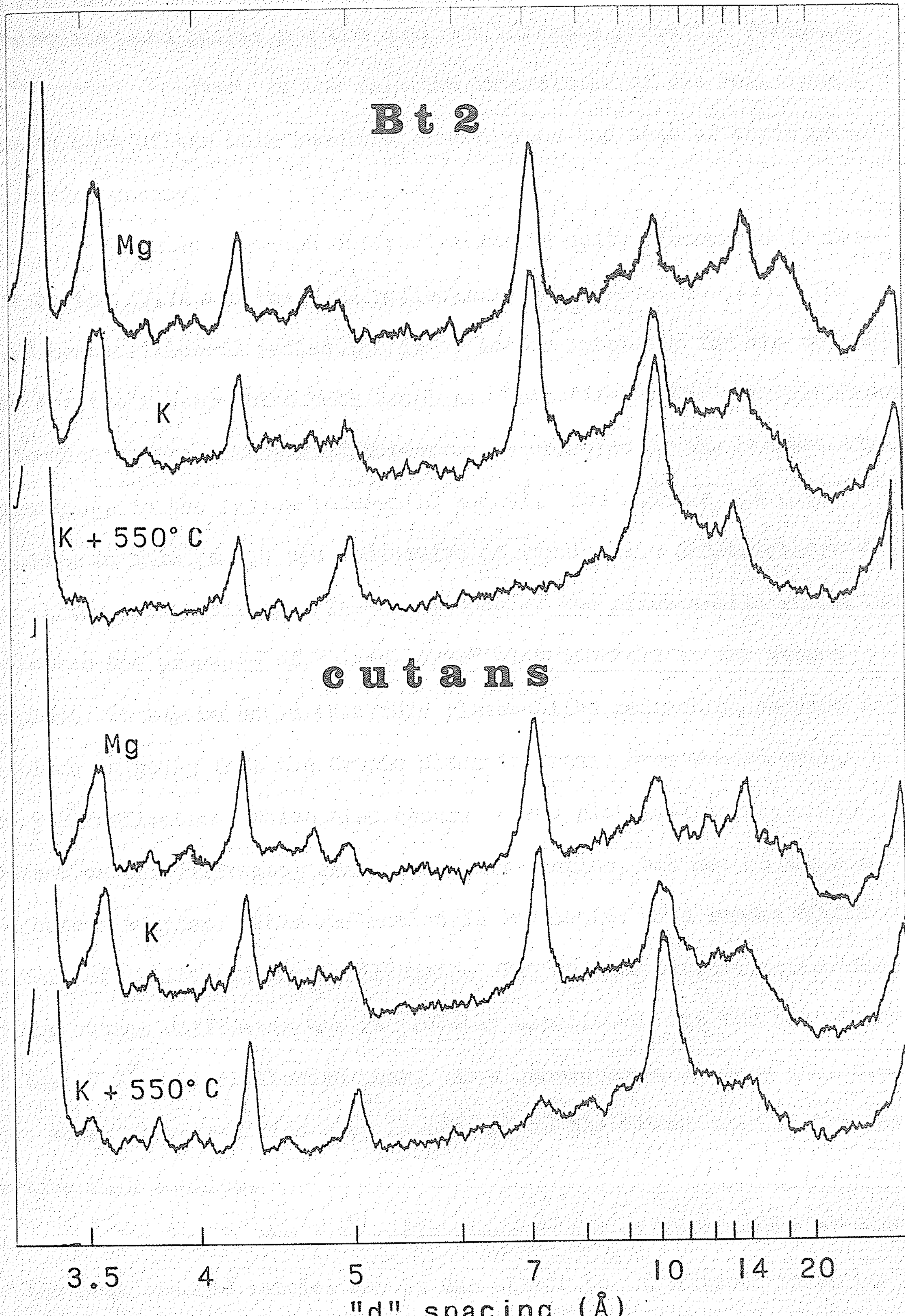

Figure 13. X-ray diffraction patterns of the coarse clay fraction of the bulk and the cutans sample of the Orthic Grey Wooded soil.

vermiculite, and quartz are the dominant minerals present. Variation can be noted, however, in the relative intensities of the reflections between each of the bulk sample diffractograms and that of their corresponding cutans.

Variation between diffractograms is quite pronounced in respect to the 17.7Å and the 9.2Å reflections (Mg-treated mounts). The 17.7Å montmorillonoid reflection is of lesser intensity for the cutans than for their respective bulk samples. This first order montmorillonoid reflection on the cutans diffractograms is obscured by the plateau-like reflection, in the region between 18 and 9Å. The 14Å and 10Å peaks occurring in this region are indicative of vermiculite and/or chlorite and illite, respectively. The occurrence of the plateau-like reflection indicates the presence of "mixed-layer" clay minerals in the cutans samples. It may be noted that this plateau-like reflection becomes less distinct on going from the Orthic Black to Orthic Grey Wooded soil. The 9.2Å reflection, which also occurs in the plateau-like region is present on the diffractograms of the bulk samples, but not on those of the cutans samples. This reflection is indicative of a random 40:60 mixture of illite and montmorillonoid. The absence of this reflection on the cutans diffractograms is probably associated with the near-absence of the 17.7Å montmorillonoid peak. As a consequence, it does indicate that more interstratified clay is present in the cutans than in the respective bulk samples.

The 14, 7, and 3.5Å reflections on the diffractograms of each of the heat treated samples may be due either to chlorite or to an unnamed 14Å clay mineral (51). The latter appears to be present in the bulk sample of the Orthic Grey Wooded soil only, as is indicated by the lowering of the Ångstrom spacing when heated and by the mode of formation of this mineral. The presence of chlorite in the bulk samples is most noticeable in the diffractogram of the Btj horizon of the Orthic Black soil. Its presence in the cutans samples is most evident in the cutans diffractogram of the Orthic Grey Wooded profile. This trend in the chlorite content as well as the trend in the distinctiveness of the plateau-like reflection on the cutans diffractograms may be indicative of the mode of formation of the cutans. Thus, the absence of chlorite on the diffractogram of the K-treated + heated mount from the bulk sample of the Orthic Grey Wooded profile, and the presence of it as well as the broken up pattern of the plateau-like region on its cutans diffractogram suggest that these cutans are eluviation cutans. The distinct presence of chlorite in these cutans indicates, furthermore, that mechanical eluviation is prominent in the Orthic Grey Wooded soil. In the Btj horizon samples of the Orthic Black soil, chlorite is distinctly present in the bulk sample diffractogram. Its absence, as well as the smooth appearance of the plateau-like region on the cutans sample diffractogram suggest that the cutans in the Orthic Black soil are stress or diffusion cutans. In the Orthic Dark Grey soil, chlorite does not seem to be present on the diffractograms of either the bulk or the cutans sample. The smooth plateau-like region on the cutans diffractogram may suggest, however, that these cutans have formed in situ.

The diffraction patterns for the fine clay fractions are shown in Figures 14, 15, and 16. Analogous to the diffraction patterns obtained from the coarse clay fractions, there is little variation between the pattern of the cutans and that of their bulk samples. Most noteworthy is that the diffractograms of the cutans samples from the Orthic

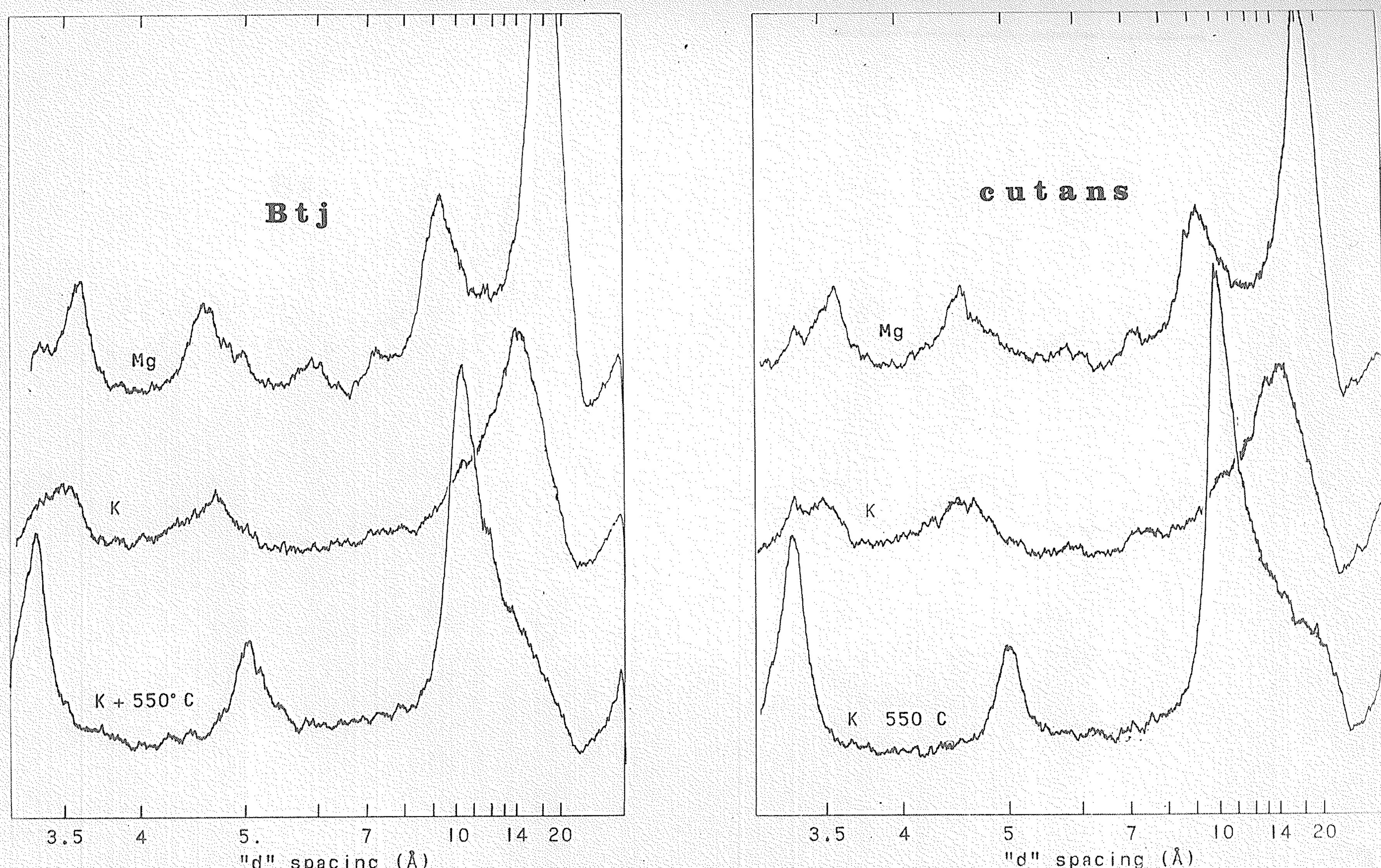

Figure 14. X-ray diffraction patterns of the fine clay fraction of the bulk and the cutans sample of the Orthic Black soil.

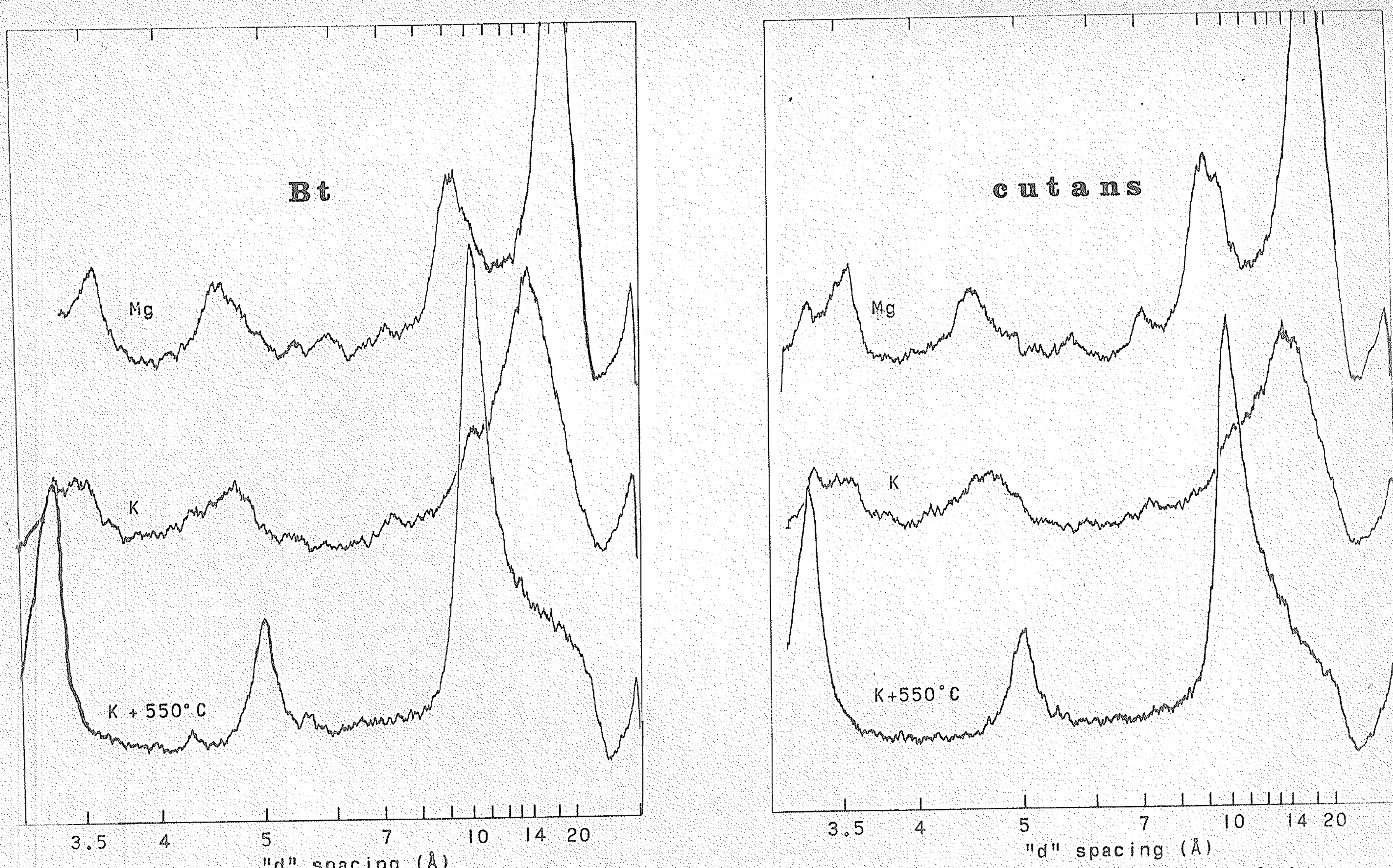

Figure 15. X-ray diffraction patterns of the fine clay fraction of the bulk and the cutans sample of the Orthic Dark Grey soil.

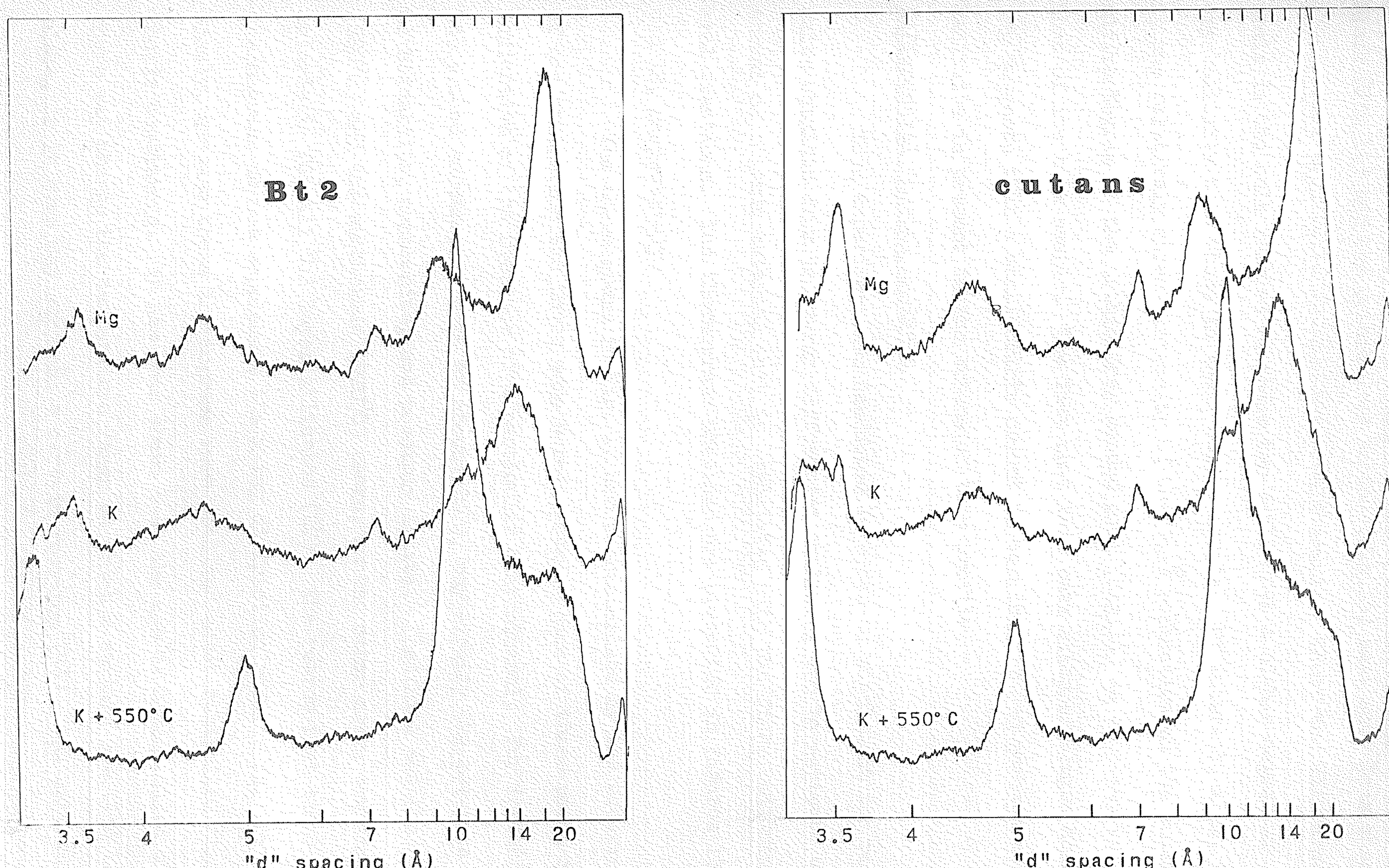

Figure 16. X-ray diffraction patterns of the fine clay fraction of the bulk and the cutans sample of the Orthic Grey Wooded soil

Black (Fig.14) and the Orthic Grey Wooded (Fig.15) soil show less sharp reflections than their corresponding bulk sample. Thus, the clay minerals in the bulk samples of these two soils have a higher degree of crystallinity than those in their cutans sample. Of interest, also, is the relatively strong intensity of the 7.1Å reflection on the cutans diffractogram of the Orthic Grey Wooded soil (Fig.16) as compared to that of its bulk sample. The fact that this peak disappears upon heating suggests that a considerable amount of vermiculite and perhaps some kaolinite is present in the cutans of this profile.

Differential Thermal Analyses

This experiment was conducted in order to supplement the results obtained from the x-ray diffraction analyses, and to estimate the amount of organic material that is associated with the finer soil mineral fractions. The thermograms obtained are presented in Figures 17 and 18, respectively.

The thermograms in Fig. 17 are characterized by the occurrence of one exothermic and three endothermic peaks. None of these peaks is indicative of the presence of a particular clay mineral. For instance, the second endothermic peak at about 520°C, may signify the presence of beidellite, nontronite, and possibly illite. The third endothermic (880°C) and the exothermic (920°C) peaks, on the other hand, are characteristic for all 2:1 layer silicates (27). The reason that these thermograms do not supplement the x-ray diffraction results is, most likely, because these thermograms were obtained under controlled atmospheric conditions. It has been shown that the use of a controlled atmosphere may change the temperature range at which a certain reaction takes place, or it even may suppress a certain reaction (36). The only informa-

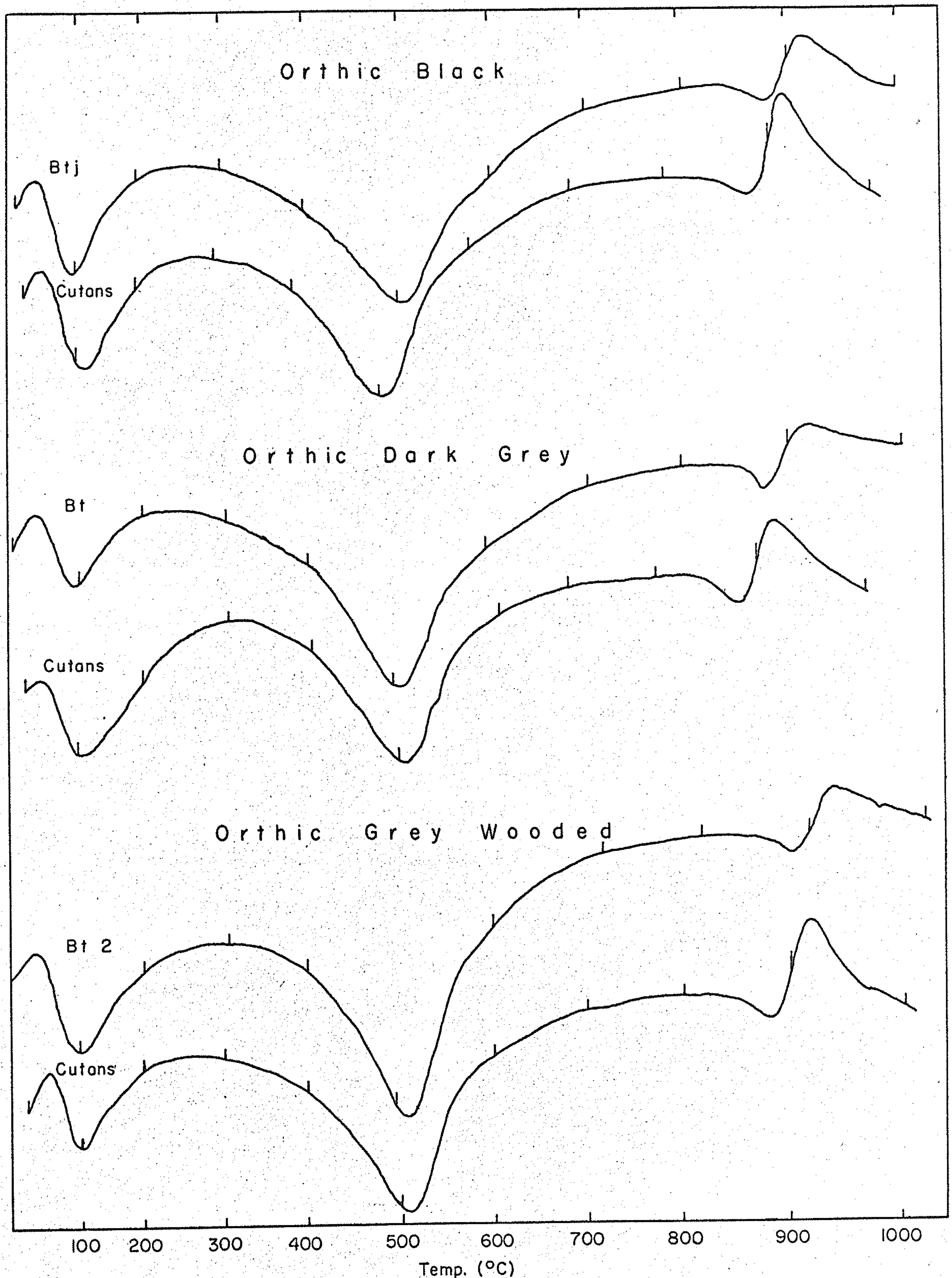

Figure 17. Differential thermograms of the <5μ fraction of the bulk and cutans samples of the Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded soils.

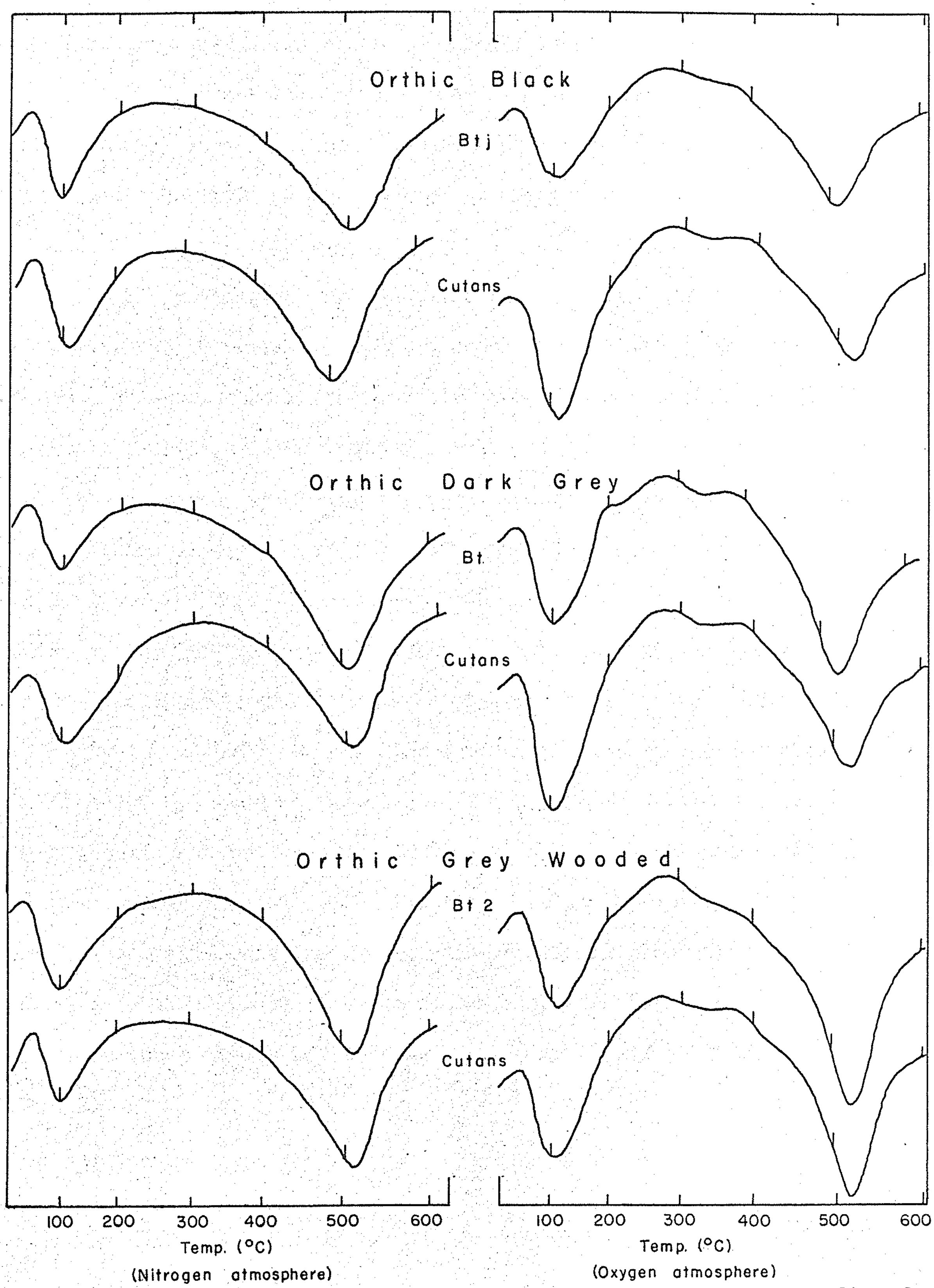

Figure 18. Differential thermograms of the <5µ fraction of the bulk and cutans samples of the Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded soils.

tion on these thermograms that supplements the x-ray diffraction results is the similarity in shape of the cutans thermograms to that of their bulk samples. It may be noted, also, that the 880°C endothermic and the subsequent 920°C exothermic peak are more pronounced on the thermograms of the cutans than on those of the bulk samples.

The thermograms obtained for estimation of the amount of organic material in these samples are shown in Figure 18. In order to obtain a means of comparison for this, two analyses were made; in the first one a nitrogen atmosphere was employed and in the second an oxygen atmosphere was used. The nitrogen atmosphere was used to suppress the oxidation of organic matter. From the thermograms in Figure 18 it can be seen that more organic matter is associated with the $<5\mu$ material of the cutans samples than with that of the respective bulk samples. This is indicated by the stronger exothermic peak in the range of 300 to 500°C, and also by the stronger intensity of the endothermic peak at about 100°C. Only in the case of the Orthic Grey Wooded soil do these results confirm the observations made from the organic matter analyses (Table XI, p.57). With respect to the cutans of the Orthic Black and of the Orthic Dark Grey soil, this experiment shows that organic matter is a constituent of these cutans. The incorporation of organic matter in these cutans is probably the result of stress or diffusion action.

SUMMARY

1. The Orthic Black, Orthic Dark Grey, and Orthic Grey Wooded soils exhibited marked variations in morphology in the field. The following gradations were noted in going from Chernozemic Black to Podzolic Grey Wooded:

    a) an increase in the thickness of the solum;

    b) a decrease in the thickness of the Ah horizon and in the expression of granular structure within the A horizons;

    c) an increase in the degree of leaching as exhibited by the development of platy structure and by the change from darker to lighter colours in the Ah$\overline{ej}$, Aeh, and Ae horizons;

    d) a change from weak to strong subangular blocky structures in the B horizons;

    e) an increase in the degree of development of the textural B horizon.

2. In general, the organic matter and total nitrogen contents in the profiles decrease with increase in depth. A slight accumulation of organic matter and of total nitrogen occurs in the B horizon of the Orthic Grey Wooded profile. This, and the low organic matter content in the Ae horizon of the former, suggests that weathering is most intense in the Orthic Grey Wooded profile. The C/N ratios conform to the normal, i.e. for similar horizons of different profiles, the ratio is higher under acid than under neutral conditions. These results reflect also that the surface organic matter is different in composition from that of the subsoil.

3. Extractable iron has accumulated in the "B" horizon of each of the profiles under study. The amount of free iron accumulated increases from Orthic Black to Orthic Grey Wooded soil, thus suggesting that weathering is most intense in the latter profile. The free iron oxide content in the C horizons of each of these soils is relatively high and of about equal magnitude. This is considered as an indication that the parent materials on which these soils have developed are similar in composition. The translocation of iron within all three soils appears to be closely associated with clay movement.

4. The cation exchange capacity of the Orthic Black and Orthic Dark Grey profiles decreases with increase in depth. No such trend is present for the Orthic Grey Wooded profile. All three soils are highly base saturated, calcium and magnesium being the dominant cations on the exchange complex. The Ca/Mg ratio is smaller in the "B" than in the "A" horizons. Comparison among profiles shows that the difference in ratio between the "A" and "B" horizons is smallest in the Orthic Grey Wooded profile. The amount of leaching within the profiles is seen to have increased in intensity on going from Orthic Black to Orthic Grey Wooded soil, as evidenced by the decrease in solum pH values.

5. Accumulation of clay in the "B" horizon is evident in each of the soils under study and is principally due to fine clay movement. The difference in clay content between "A" and "B" horizons increases progressively from Orthic Black to Orthic Grey Wooded soil.

6.a) Little or no montmorillonoid is present in the fine silt fraction (5 - 2μ) in the three profiles. This fraction contains vermiculite, illite, primary minerals, and some chlorite and kaolinite.

The intensities of the clay mineral reflections on the "A" horizon diffractograms are, in general, weaker than those on the diffractograms of the "B" and "C" horizons.

b) The coarse clay fraction (2.0 - 0.2μ) contains montmorillonoid, vermiculite, and quartz. Traces of chlorite and kaolinite are also present. Montmorillonoid is the most variable mineral in the coarse clay fraction. It is present in lesser amounts than illite in any of the horizons analyzed and is present in least amount in the "A" horizon of each profile. Mixed-layer clay minerals occur in the diffraction patterns of the "A" horizon of the Orthic Black and Orthic Dark Grey profile, but not in that of the Orthic Grey Wooded profile. These mixed-layer minerals are most pronounced in the "A" horizon of the Orthic Dark Grey profile. This trend is considered to be a reflection of the weathering conditions; i.e. a slight increase of weathering causes interstratification of clay minerals; this interstratified complex disintegrates when weathering becomes more intense. A 14Å clay mineral, other than chlorite, appears to be present in the "B" horizon of the Orthic Grey Wooded soil.

c) Montmorillonoid is the dominant mineral in the fine clay fraction (<0.2μ). Vermiculite and a random 40:60 mixture of illite and montmorillonoid occur in lesser amounts. Illite, as a pure clay mineral does not occur in this size fraction. A 5.9Å reflection, possibly due to coarsely interstratified material, is present on most of the diffractograms of the three profiles. Within each profile, this reflection is most pronounced on the "B" horizon diffractogram. On comparing "A" horizons, it is seen that this reflection is most prominent in the Orthic Black soil and is absent in the Orthic Grey Wooded soil. The degree of crystallinity of the clay minerals present increases with depth within each profile and decreases from Orthic Black to Orthic Grey Wooded soil, as is evidenced by the degree of sharpness of the reflections. Further evidence that the amount of leaching within the profiles increases in intensity from Orthic Black to Orthic Grey Wooded soil is found in the decrease in montmorillonoid and random mixture contents in the respective "A" horizons.

7. Clay minerals constitute approximately 60 - 75 per cent of the coarse clay fraction and about 100 per cent of the fine clay fraction. The illite content of the coarse clay is higher than that of the fine clay. The ratio of illite to montmorillonoid in the former is approximately 2:1. The total potassium data show that the ratio of illite to montmorillonoid in the fine clay is approximately 1:4.

8. The montmorillonoid species present in these soils is intermediate between beidellite and nontronite, tending towards the nontronite end of the series.

9. The cutans of all three profiles have a higher free iron and total nitrogen content than their corresponding bulk samples. Organic matter content and cation exchange capacity are higher only in the cutans of the Orthic Grey Wooded soil. These results are taken as an indication that the cutans in the Orthic Black and Orthic Dark Grey soils were formed from local material, while those in the Orthic Grey Wooded soil were formed from eluviated material.

10. The mechanical composition of the cutans is similar to that of

their respective bulk samples in the Orthic Black and Orthic Dark Grey profile. In the Orthic Grey Wooded profile the cutans contain a higher percentage of fine clay than the bulk samples. This suggests that these cutans are partly composed of clay.

11. The mineralogical composition of the cutans is similar to that of the corresponding bulk samples. The dominant clay minerals are montmorillonoid, illite, and vermiculite. In the coarse clay fraction, the diffractograms of the cutans differ from those of their bulk samples by the occurrence of a plateau-like reflection between 18Å and 9Å, and by the absence of a 9.2Å reflection. This plateau-like reflection, signifies the presence of "mixed-layer" clay minerals. The mixed-layer mineral content decreases on going from Orthic Black to Orthic Grey Wooded soil. Trace amounts of chlorite occur in the cutans as well as in the bulk samples. A 14Å clay mineral, other than chlorite, appears to be present in the bulk sample of the Orthic Grey Wooded soil. The most notable difference between the fine clay fraction of the cutans and bulk samples is that the degree of crystallinity of the clay minerals in the cutans is less than in their bulk sample.

12. The differential thermal analyses of the $<5\mu$ material shows that more organic matter is associated with the $<5\mu$ material of the cutans than with that of the corresponding bulk samples. In all three soils, the third endothermic (880°C) and the exothermic (920°C) peak are more pronounced on the thermograms of cutans than on those of the bulk samples.

CONCLUSIONS

1. Calcification is the dominant process active in the formation of Orthic Black soils, as is evidenced by:
   (a) the accumulation of organic matter in the "A" horizon and the granular structure of this horizon;
   (b) the "mellowed" nature of the Btj horizon; i.e. excess salts have been removed and little or no accumulation of organic matter, iron and clay has taken place;
   (c) the high base saturation of the solum, and the occurrence of maximum calcium and potassium content in the "A" horizon;
   (d) the similarity in clay mineral composition and distribution between horizons.

2. The Orthic Dark Grey soil shows evidence of the activity of both the calcification and decalcification processes. Evidence that the calcification process is active in this soil is found in:
   (a) the accumulation of organic matter in the "A" horizon;
   (b) the removal of excess salts from the B horizon;
   (c) the high base status of the solum and the occurrence of maximum calcium and potassium content in the "A" horizon.

   The activity of the decalcification process is evidenced by:
   (a) the presence of the partly leached Aeh horizon;
   (b) the development of subangular-blocky structure in the solum;
   (c) the accumulation of small amounts of organic matter, nitrogen, iron, and clay in the "B" horizon;
   (d) the variation in clay mineral composition and distribution between the A horizon and the B and C horizon.

3. Evidence that the Orthic Grey Wooded soil has formed by the decalcification process of soil formation is found in:

   (a) the presence of a leached Ae horizon, which has a platy structure, is light in colour, has a low clay content, and has a low cation exchange capacity;

   (b) the accumulation of organic matter, nitrogen, iron and clay in the "B" horizon, and the occurrence of well-developed subangular to blocky structure in this horizon;

   (c) the change in clay mineral composition and distribution down the profile.

4. The clay fractions have undergone small but significant changes as a result of pedogenic processes. Reconstruction of clay to randomly interstratified, mixed-layer forms has taken place in the "A" horizon of the Orthic Black and of the Orthic Dark Grey soil. The formation of a 14Å clay mineral appears to have occurred in the "B" horizon of the Orthic Grey Wooded soil.

5. Physical processes appear to have been major factors in the genetic horizon differentiation, as is indicated by the particle size and the mineralogical data.

6. These soils have developed on similar parent materials, as is evidenced by:

   (a) the free iron content in the C horizon of all three soils is of about equal magnitude;

   (b) the high base saturation of the C horizons;

   (c) the dominance of illite clay in the coarse clay fractions and of montmorillonoid clay in the fine clay fractions of each of these soils;

(d) the montmorillonoid species in all three soils is intermediate between beidellite and nontronite, tending towards the nontronite end of the series.

7. The cutans of the Btj horizon of the Orthic Black and those of the Bt horizon of the Orthic Dark Grey soil are stress or diffusion cutans. Eluviation cutans are present in the Orthic Grey Wooded soil only.

8. The cutans of the "B" horizon of all three soils are composed of organic matter, nitrogen, iron, clay minerals, and possibly other constituents, regardless of their mode of formation.

9. The cutans of the "B" horizon of each of the soils under investigation reflect the process by which the soil has formed:

(a) the slight accumulation of total nitrogen and extractable iron in the cutans of the Btj horizon of the Orthic Black soil are reflective of the calcification process by which this soil has formed;

(b) the larger accumulation of extractable iron in the cutans of the Bt horizon of the Orthic Dark Grey soil as compared to that of the Orthic Black suggest the simultaneous occurrence of the podzolization and the calcification processes in the Orthic Dark Grey soil;

(c) the very significant accumulation of extractable iron, organic matter, total nitrogen, and fine clay content in the cutans of the Bt2 horizon of the Orthic Grey Wooded profile are reflective of the podzolization process by which this soil has formed.

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