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THE USE OF PEDOLOGICAL STUDIES IN INTERPRETING THE QUATERNARY HISTORY OF CENTRAL YUKON TERRITORY

A.E. Foscolos, N.W. Rutter and O.L. Hughes

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PREFACE

This study presents the results of detailed geomorphological, soil morphological, mineralogical and inorganic geochemical research work on soils and paleosols of central Yukon Territory. The aim was to combine soil morphology, clay mineralogy and soil chemistry within the framework set by the geomorphological data in order to further our knowledge of the type of Quaternary paleoclimate which existed during the interglacial periods in the area.

D.J. McLaren,
Director General,
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Ottawa, 1977

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THE USE OF PEDOLOGICAL STUDIES IN INTERPRETING THE QUATERNARY HISTORY OF CENTRAL YUKON TERRITORIES

Abstract

Soils and paleosols were investigated from pre-Reid (early Pleistocene), Reid (Illinoian or early Wisconsinan) and McConnell (classical Wisconsinan) surfaces in central Yukon. Paleosols on the pre-Reid surface indicate that it was subjected to two distinct climates, an initial one which was warm and subhumid with grassland-shrub vegetation and later a more temperate and humid climate characterized by the development of a Luvisol with a red, textural B horizon, in places over 190 cm (75 in) thick. Subsequently, the climate became colder, resulting in the Reid glaciation. Thermal contraction cracks developed in the pre-Reid deposits beyond the limit of Reid glaciation and were filled with eolian sand, as well as minor silt and clay, to form sand wedges. During the subsequent Reid-McConnell interglacial, a cool, subhumid climate prevailed as evidenced by the Brunisolic characteristics of paleosols on deposits of Reid age. This was followed by a cold period which climaxed with the advent of the McConnell glaciation. Sand wedges also formed in the deposits of the Reid glaciation; the wedges are shallower and narrower than those on the pre-Reid surface, suggesting a shorter cold period. During retreatal stages of the McConnell glaciation, a thin blanket of loess was deposited over McConnell, Reid and pre-Reid surfaces, covering the soils on the Reid and pre-Reid surfaces during post-glacial (Holocene) time. Finally, Brunisolic soils developed on the loess blanket and, locally, where the loess is very thin or lacking, on deposits of McConnell age.

Résumé

Les auteurs ont étudié les sols et les paléosols du centre du Yukon, à partir des surfaces pré-Reid (Pléistocène inférieur), des surfaces de l'avancée Reid (Illinoïen ou Wisconsin inférieur) et de l'avancée McConnell (Wisconsin classique). Les paléosols que l'on trouve à la surface du pré-Reid indiquent qu'ils ont été soumis à deux climats distincts, un premier chaud et subhumide (végétation d'herbes et broussailles), suivi plus tard d'un second climat, plus tempéré, humide et caractérisé par la formation d'un luvisol à horizon B de couleur rougeâtre, d'une épaisseur supérieure à 190 cm (75 po) par endroits. Par la suite, le climat s'est refroidi et a donné lieu à l'avancée glaciaire Reid. Des fissures dues à la contraction thermique se sont formées dans les sédiments pré-Reid, au-delà des limites de l'avancée Reid, et elles se sont remplies de sables éoliens, et accessoirement, de silts et d'argiles, pour finalement donner des coins de sables. L'époque interglaciaire Reid-McConnell qui a suivi, a été dominée par un climat frais et subhumide comme en témoignent d'ailleurs la nature brunisolique des paléosols que l'on trouve à la surface des moraines Reid. Cette époque fut suivie d'une période de refroidissement qui a culminé avec l'avancée McConnell. Des coins de sable se sont aussi formés dans les moraines de l'avancée Reid; mais comme ils sont moins profonds et plus étroits que ceux que l'on trouve à la surface pré-Reid, ils laissent croire à une période froide plus courte. Au cours des phases de retrait de la glaciation McConnell, une mince couche de loess s'est deposée sur les surfaces McConnell, Reid et pré-Reid, et elle a recouvert les sols des surfaces Reid et pré-Reid au cours de Post-glaciaire (Holocène). Finalement, des sols brunisoliques se sont formés sur la couche de loess et, sur des sédiments diâge McConnell, en certains endroits où le loess est très mince ou absent.

INTRODUCTION

Four major advances of the Cordilleran ice sheet in central Yukon Territory were first recognized by Bostock (1966). Although Bostock referred deposits at certain localities to the respective advances, the chronology is based primarily on geomorphic evidence, mainly moraines and ice-marginal features and their degree of preservation, rather than on stratigraphic evidence. By inference, there are three intervening interglacial intervals. Interglacial beds are known from a number of sections along major rivers of the region, but these are not firmly correlated yet with Bostock's morphostratigraphic chronology, and the flora and fauna of the beds and their paleoclimatic implications remain to be studied.

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In reconnaissance mapping it was found that, in going from the youngest to the oldest of the deposits of the respective advances, there is a marked increase in the depth of soil development, the thickness and redness of the B-horizon and the degree of weathering of rock clasts within the soil profile. Characteristics of the soils proved to be a useful adjunct to geomorphic criteria in distinguishing between deposits of the respective advances. These observations led to the present study, in which paleopedology is used to expand the rather meagre understanding of changing climates of central Yukon during the Quaternary.

Paleopedology, which is the study of ancient soils, has been used to assess changes in vegetation during the Quaternary Period (Bailey *et al.*, 1964; Jenny, 1941, 1958; Jungerius, 1969; Ruhe, 1969; Ruhe and Cady, 1969; Pettapiece, 1969; Smith *et al.*, 1950) and to evaluate paleoclimates (Janda and Croft, 1967; Birkeland and Janda, 1971). Birkeland (1969) has used clay mineralogy to decipher paleoclimates of the Sierra Nevada-Great Basin region of the southwestern United States. The present study thus follows well-established principles of paleopedology.

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REGIONAL PLEISTOCENE GEOLOGY AND CHRONOLOGY

The Pleistocene chronology of central and southern Yukon Territory can be considered in terms of the following four regions (Fig. 1). (1) The central and southern parts of Yukon Plateau, together with the flanks of the Coast Mountains to the southwest, and the flanks of the Selwyn Mountains to the east and northeast. This region was subjected to repeated glaciations by Cordilleran ice sheets that extended from the Interior Plateau region of British Columbia. (2) The east flank of St. Elias Mountains, together with Shakwak Trench and Ruby Range on the southwest fringe of Yukon Plateau. Large valley glaciers advanced repeatedly from St. Elias Mountains, and coalesced as a piedmont glacier in Shakwak Trench. Tongues of the piedmont glacier pushed into Ruby Range and into Wellesley basin north of the Ruby Range. Valley glaciers originating in the Ruby Range were in part coalescent with the piedmont glacier, and the piedmont glacier at times coalesced with the main Cordilleran ice sheet. (3) Ogilvie Mountains, which supported independent valley glaciers that moved southwestward toward and, locally, into Tintina Trench, and northward into the headwaters of the Peel River. (4) The unglaciated northwestern portion of Yukon Plateau (essentially the Klondike Plateau as defined by Bostock, 1964).

Soils described in this report are all from localities within the region covered by the main Cordilleran ice sheet, except for Locality 1 in Tintina Trench (Figs. 1, 2) where the Quaternary deposits are the product of alpine glaciers emanating from North and South Klondike valleys. These glaciers probably coalesced to form a piedmont glacier in Tintina Trench which may, in turn, have coalesced with a sub-lobe of the Cordilleran ice sheet that pushed northwestward along Tintina Trench beyond Stewart River.

Bostock (1966) found evidence for four advances of the Cordilleran ice sheet, which he named (from youngest to oldest) McConnell, Reid, Klaza and Nansen advances. The digitate outline of the Cordilleran ice-sheet margin at the maximum of the McConnell

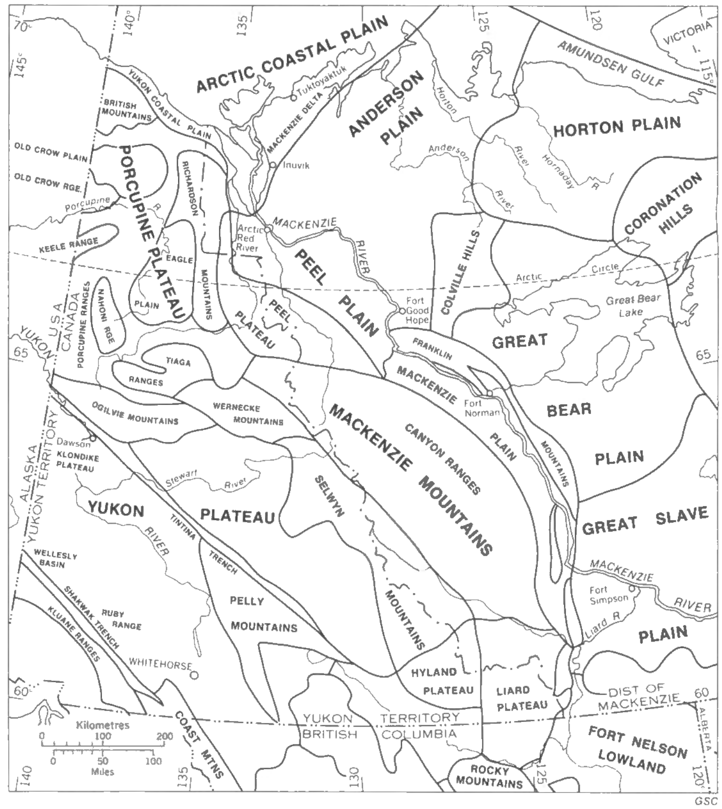

Figure 1. Physiographic map of Yukon Territory and western District of Mackenzie; after Map 1254A (Bostock *in* Douglas, 1970).

advance can be traced almost continuously from fresh moraines and other ice-marginal features (Hughes *et al.*, 1967). Where the ice sheet formed sub-lobes in major valleys, as at the type locality in Stewart Valley, broad outwash terraces extend several tens of kilometres down valley from the limit of the advance. Extensive ice-contact glaciofluvial deposits and retreatal outwash are found throughout the Yukon south and east of the McConnell limit.

Although moraines and other ice-marginal features of the earlier, more extensive Reid advance are subdued relative to those of the McConnell advance, they also can be traced almost continuously and outline the digitate margins of the former ice sheet. Outwash terraces can be traced also tens of kilometres along major valleys beyond the Reid limit, and extensive ice-contact glaciofluvial deposits and retreatal outwash of Reid age are found between the Reid and McConnell limits.

Evidence of still older, more extensive glaciations is found in the form of glacial erratics, outwash gravel and local till occurrences, as far as 80 km (50 miles) beyond the Reid limit. Moraines and other ice-marginal features have been obliterated, almost wholly, by weathering and erosion.

At least three advances of valley glaciers are recorded in Ogilvie Mountains (Vernon and Hughes, 1966; Ricker, 1968; Hughes *et al.*, 1972). The youngest relatively fresh moraines, judged to be

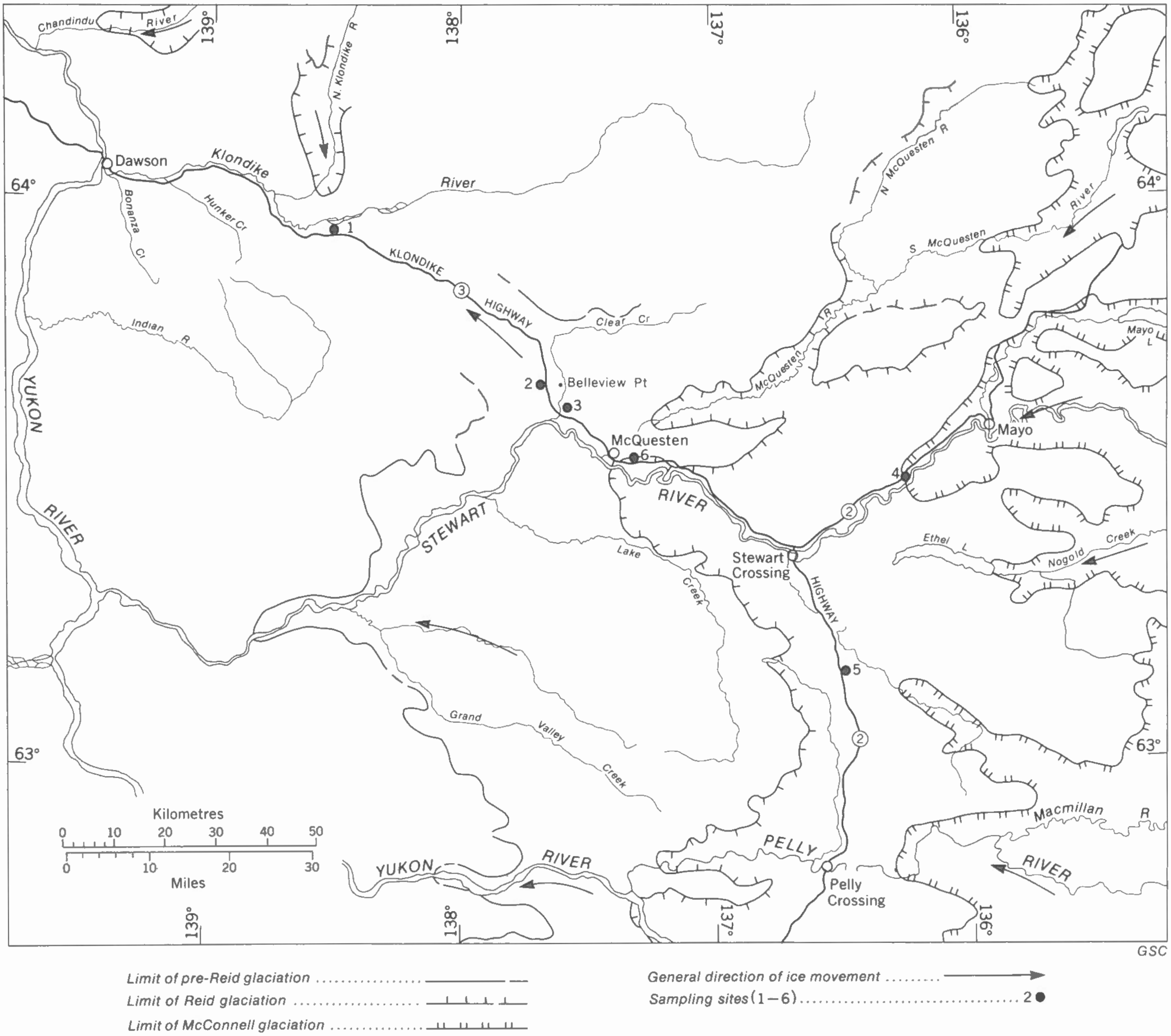

Figure 2. Location of soil sampling sites with respect to glacial limits. Glacial limits generalized from Hughes *et al.* (1969, Map 6-1968)

correlative with moraines of McConnell age, indicate a restricted advance of alpine glaciers in tributary valleys. In an earlier advance, glaciers of these tributary valleys merged to form trunk glaciers that occupied the larger valleys of Ogilvie Mountains. The trunk glaciers of North Klondike and Chandindu Valleys extended to Tintina Trench. Their limits are marked by moraines and other ice-marginal features that are judged, on the basis of geomorphic comparison, to be of Reid age. Glacial erratics and patches of very subdued moraine are found beyond moraines of presumed Reid age in the valleys of north-flowing rivers, indicating one or more pre-Reid glaciations. Beyond the presumed Reid limit of ice flowing from North Klondike Valley, Tintina Trench contains a sequence of glaciolacustrine, glacial and glaciofluvial sediments of pre-Reid age, named "Flat Creek beds" by McConnell (1905, p. 24B). The former extent of alpine ice in Tintina Trench during pre-Reid glaciation(s) has not been determined. Near its junction with North Klondike River (Fig. 2), Klondike River is deeply incised into the Flat Creek beds. The beds, considerably slumped, are exposed now only intermittently in cuts along an abandoned road that ascends the south wall of South Klondike Valley, and in shallow road cuts along the Klondike Highway. The lower beds are mainly glaciolacustrine silt and clay, and the upper beds comprise gravel with silty gravel beds that may be ablation till. Lack of a continuous section through the beds precludes any firm interpretation of whatever part of pre-Reid history is represented by the beds.

Deposits of alpine glaciations correlative with Nansen and Klaza advances, respectively, of the Cordilleran ice sheet may occur within the thick and poorly known sequence.

Northwestward along Klondike River to its junction with Yukon River, a high terrace of Klondike gravels (McConnell, 1905), consisting of quartzite, diabase and syenite derived from Ogilvie Mountains, appears to form a continuation of the upper surface of the Flat Creek beds. High terraces, underlain by quartzose White Channel gravel along Hunker, Bonanza and other north-flowing tributaries of Klondike River, merge with the Klondike gravel terrace (Fig. 2). McConnell (1905, p. 33B) considered the White Channel gravels to be at least as old as Pliocene. More recently, Hughes *et al.* (1972) have suggested that the uppermost part of the White Channel gravels, together with the Klondike gravels, are of early Pleistocene age. For the purpose of this study, however, the apparently correlative upper part of the Flat Creek beds, on which the paleosol of Locality 1 is developed, is assigned a pre-Reid age.

Flat Creek type deposits appear to underlie the gently undulant floor of Tintina Trench southeastward almost to Stewart River, where the deposits are the product of pre-Reid advances of the main Cordilleran ice sheet. At Belleview Point, on the west side of Clear Creek about 8 km (5 miles) north of its junction with Stewart River, till, regarded as belonging to the Klaza advance (Bostock, 1966, p. 8), overlies brown gravel. The gravel, part of the "brown drift" of Bostock, contains foreign pebbles derived from Ogilvie Mountains. Bostock (1966, p. 9) considered the brown drift to be part of the Flat Creek beds of McConnell, and correlated it with the Nansen drift. Locality 2 of this report is only 5 km (3 miles) west of Belleview Point; regional relationships suggest that surface deposits are of the same age (i.e. Klaza) at the two localities. Of the remaining localities (Fig. 2), 3 is on an outwash terrace of Reid age, 4 is on the crest of a moraine of McConnell age at the type locality, 5 is on ablation moraine of Reid age, and 6 is on an outwash terrace of McConnell age. Age assignments of these localities are considered to be extremely accurate because of their relationship to mapped glacial limits or to outwash terraces beyond the glacial limits.

RADIOCARBON DATING

Radiocarbon dates are inadequate to provide a firm chronology. In a section on the west bank of Stewart River, 12 km (7.5 miles) above the mouth of McQuesten River, till of Reid age overlies gravel that may be retreatal outwash of the Klaza glaciation, and is overlain by outwash of Reid age. A broad channel cut into the Reid outwash is filled with organic silt and sand with woody and peaty lenses. Wood from near the base of the fill has been dated as greater than 42 900 years old (GSC-524, Lowdon and Blake, 1968). Wood from beneath till of McConnell age in a section on the north bank of Stewart River 2.4 km (1.5 miles) downstream from Mayo has been dated as more than 46 580 years old (GSC-331, Dyck *et al.*, 1966). The dates suggest that the Reid glaciation ended, and the Reid-McConnell interglacial period began more (possibly considerably more) than 46 580 years ago, but do not fix the date of onset of the McConnell glaciation. There are no dates from above the McConnell drift. The correlative last advance of alpine glaciers in Ogilvie Mountains culminated sometime before 13 740 years ago (Hughes *et al.*, 1972, p. 36).

EOLIAN DEPOSITS

Thin loess deposits occur widely on flat or gently sloping surfaces in the glaciated parts of central Yukon Territory, commonly extending as a discrete, recognizable layer to about 300 m (1000 ft) above the floors of major valleys. Loess is disposed similarly in the unglaciated area adjacent to Yukon River and major tributaries such as Pelly, Stewart, Klondike and White Rivers that carried glacial meltwater beyond ice frontal positions during successive glaciations. Loess thickness is typically 30 to 60 cm (1-2 ft), locally 90 to 120 cm (3-4 ft) on surfaces of Reid age and older. On till surfaces of McConnell age, the thickness is typically 30 cm (1 ft) or less, and on outwash of the same age, 15 cm (6 in) or less. However, in both the glaciated and unglaciated areas, there are, locally, thicker deposits of organic silt that appear to be reworked loess concentrated from adjacent slopes. Such organic silt is common on the valley floors and low terraces of gold-producing creeks of the Klondike district, where silt may be 3 m (10 ft) or more in thickness, and commonly is overlain by several metres of woody, silty peat. The silt and peat, collectively, are termed "muck" by placer miners of the district. In the glaciated area, wedge-shaped accumulations of reworked loess, up to 3 m (10 ft) or more in thickness, are common along the toes of the slopes.

Loess of the region is believed to have been derived during successive glaciations from the broad outwash plains that extended down major valleys beyond the ice fronts. Outwash plains of McConnell age retain a braided channel pattern characteristic of glacial streams such as those of the upper reaches of present day Kaskawalsh, Slims, Donjek and White Rivers, which head in major glaciers of the St. Elias Range. One might expect that field studies of the oldest glacial deposits and adjacent unglaciated surfaces would reveal four-fold loess sequences related to the four regional glacial advances and containing paleosols developed during intervening non-glacial intervals. However, although organic reworked loessal silts in lower Hunker Creek in Klondike district have a radiocarbon age greater than 35 000 years [I(GSC) 181] and may be of Reid age or older, loess sequences with recognizable paleosols have not been found. At each of the localities reported herein, glacial or glaciofluvial deposits, ranging in age from probable early Pleistocene (Nansen) to classical Wisconsin (McConnell), are covered by a single thin loess layer. The soils developed in loess at the various localities are all essentially similar and are judged to have developed in post-McConnell time, and hence the loess at the various localities is of

McConnell age. Where then are the loess deposits of earlier glaciations?

The following three phenomena common to all of the pre-McConnell localities are considered as highly significant toward providing an explanation: 1) the loess lies directly on truncated paleosols; 2) ventifacts are common at the interface between the loess and the truncated paleosol; and 3) glacial or glaciofluvial deposits containing the paleosols are cut by sand wedges. These indicate severe climatic conditions in the immediate periglacial area during successive glaciations.

The wedges consist mainly of clean well-sorted sand with traces of silt and clay and contrast sharply in texture and colour to the paleosols in which they are developed. They range in width from 10 to 30 cm (4-12 in) at the top, terminating 1 to 1.5 m (3-5 ft) below the top of the paleosol. The wedges, therefore, are quite unlike fossil ice-wedges, which typically are filled with material sloughed from the sides of the former ice wedge, or material from an overlying stratum. They resemble sand wedges forming actively under polar desert conditions at McMurdo Sound area, Antarctica (Péwé, 1959, 1962, 1974; Berg and Black, 1966).

Sand wedges that form when seasonal thermal contraction cracks become filled with wind-blown sand are closely akin in origin to the much commoner ice-wedges of arctic regions. The wedges can grow by annual increments of a few millimetres to attain widths at the top of the wedge of 1 m (3 ft) (Péwé, 1974, p. 41). Whether sand wedges or ice wedges develop in an area where thermal contraction cracking takes place seasonally depends mainly on the presence or absence of surface water prior to closing of the cracks during the warm season. Sand wedge formation is favoured by low winter snowfall but, perhaps more particularly, by high evaporation potential prior to the main warm season, so that the snow is removed mainly by sublimation rather than melting. For the cracks to be filled with wind-blown sand, there must be a sand source, with vegetation sparse or lacking. In Antarctica and Greenland, the small quantity of sand required is derived from coarse glacial debris and coarse fan debris, respectively. It is of major significance to our interpretation of sand wedges in soils of central Yukon that actively forming sand wedges have been reported only from the immediate periphery of continental-size glaciers[1].

PEDOLOGICAL INVESTIGATIONS

MATERIALS

Morphological characteristics and soil classification

A sequence of six moderately well to very well drained soils located on drifts of pre-Reid to McConnell age was sampled. The site of each soil is presented in Figure 2. Each soil profile is derived from a paleosol and from a neosol, which has been developed on loess of McConnell age. The paleosols were developed on drifts ranging from pre-Reid to McConnell age. In order to use the morphological characteristics of each soil as an aid to elucidate the Quaternary history of the area, an effort was made to classify the neosols separately from the paleosol, whenever that was possible. The morphological characteristics of each soil are presented in the Appendix.

METHODS

Chemistry and mineralogy of soils

Soil samples were collected from each soil horizon, dried in the laboratory and passed through a 2 mm sieve. Subsequently, portions of the soil were subjected to the following analyses:

1. Detailed mechanical analysis following the A.S.T.M. method (1964), pH measurements as described by Peech (1965a, b) and total carbon and carbonates following the method of Foscolos and Barefoot (1970a). The results of these analyses were reported in the description of soils.

2. Per cent quartz in the very coarse, coarse, medium and fine sand fractions was determined following Jacksons' (1965) method in order to delineate the depth of the aeolian deposits in each soil (Barshad, 1955). Quartz and feldspars also were determined in the clay fraction in order to obtain the quantity of mica in each horizon of the paleosols from the K_2O content of the total elemental analysis of the <2μm fraction.

3. Elemental analysis of the <2mm and <2μm fraction was conducted using the $LiCO_3$:H_3BO_3 fusion method (Foscolos and Barefoot, 1970b).

4. Determination of oxalate extractable Fe and Al to aid in differentiating the soils (McKeague and Day, 1966).

5. Mineral identification on the whole rock and the <2μm fraction by X-ray diffraction using CoKα radiation, iron filter, setting of 40Kv-20ma, scanning speed of 1°/min/2Θcm, time constant 2 and range of 2° to 40°2Θ. The clay fraction, which was collected after sedimentation, was saturated with Ca^{2+} and K^+. X-ray diffractograms of Ca^{2+} saturated specimens were obtained using (a) an inert gas atmosphere (N_2) to induce 0 per cent relative humidity (R.H.); (b) 50 per cent R.H.; (c) glycerol solvation; and (d) heat treatment at 550°C for two and one-half hours. The K-saturated specimens were heated to 100°C for one hour and then analyzed under (a) an inert gas atmosphere (N_2) to induce 0 per cent R.H. and (b) 50 per cent R.H. Additional treatment on the clay size fraction was undertaken in order to differentiate between chlorite and kaolinite by X-rays. Warm dilute HCl was used to destroy chlorite thus enabling the identification

[1] An extensive summary of the origin of various types of frost-fissure fillings and criteria for their identification have been provided by Romanovskij (1973).

of kaolinite in the sample. Finally, the identification of discrete and mixed layered silicates was carried out following the criteria described in Brown (1961), Harward *et al.* (1968) and Kodama and Brydon (1968).

6. Differential thermal analysis was performed on Ca-saturated samples in order to obtain a semi-quantitative value for the ratio of 1:1+2:2 clay minerals against 2:1 layer silicates on the basis of crystal lattice water as discussed by Barshad (1965). Forty mg of sample were weighed and run from ambient temperature to 1000°C at a rate of 10°C/min using a R.L. Stone T.G.S.-5b unit for the thermal analysis.

RESULTS

Chemical analysis

The elemental analysis of the whole soil and the per cent quartz in four sand fractions from the studied sites are presented in Tables 1 to 6. These analyses indicate that the delineation of the paleosols on the basis of chemistry coincide with field observations. Elemental analysis was used also to study chemical trends within the paleosols. The data in Table 7 indicate that the SiO_2/R_2O_3[1] molar ratio varies considerably among the different paleosols. In the pre-Reid paleosols of site 1, the molar ratio of SiO_2/R_2O_3 is 0.5 in the II B horizon and increases to 1.0 in the II C horizon. In site 2, the II B horizon has a molar ratio of 0.7 which increases to 1.0 in the II C horizon. In the Reid paleosol, the II B horizon has a molar ratio of SiO_2/R_2O_3 of 0.8 which increases to 1.0 in the II Ck horizon. The same trend is obtained in the McConnell paleosol. Also, Table 7 illustrates that, regardless of the kind of parent material, the trend of SiO_2/R_2O_3 molar ratio is the same in both Reid and McConnell paleosols.

From elemental analysis of the <2μm fraction, after the removal of quartz and feldspars, the K_2O/SiO_2 ratio was used to quantitize the clay minerals and to assist in the interpretation of X-ray patterns. The data are presented in Tables 8 to 21. The results in Table 20 indicate that in the pre-Reid paleosol of site 1, the molar ratio of K_2O/SiO_2 ranges from 1.7×10^{-2} in the paleo B horizon to 2×10^{-2} in the paleo C horizon. In site 2, the pre-Reid paleosol exhibits a K_2O/SiO_2 molar ratio in the paleo B horizon of 3.5×10^{-2} and 3.6×10^{-2} in the paleo C horizon. In the Reid paleosol, the molar ratio of K_2O/SiO_2 ranges from 4.2×10^{-2} in the paleo B horizon to 5.0 in the paleo Ck horizon. A similar trend is observed in the McConnell paleosol. However, the paleosols of Reid and McConnell age developed on till show a substantial difference in the K_2O/SiO_2 ratio. In the Reid paleosol, the K_2O/SiO_2 molar ratio ranges from 2.8×10^{-2} in the paleo B horizon to 5.3×10^{-2} in the paleo C horizon whereas, in the McConnell paleosol, the K_2O/SiO_2 molar ratio ranges from 4.4×10^{-2} in the paleo B horizon to 5.0×10^{-2} in the paleo C horizon. These values of the McConnell paleosol developed on till are similar to those of the McConnell paleosol developed on outwash gravel. This implies that the weathering process during the Reid-McConnell interglacial period was more effective in the Reid paleosol developed on till than in the Reid paleosol developed on outwash gravel. However, weathering processes were unable to differentiate the paleosols developed on McConnell till from the paleosol developed on McConnell outwash gravel. This difference can be assigned to time as a soil-forming factor.

An effort was made also in this study to evaluate the per cent mica, expandables, and kaolinite and chlorite on the basis of chemical analysis of the <2μm fraction, after the removal of quartz and feldspars (Table 21). The aim was to assess the relationship, if any, between the type and concentration of different layer silicates with paleoclimate and/or age of paleosols. Thus, by assuming an average K_2O content of 8.5 per cent for mica (Barshad, 1965), the concentration of mica was obtained. Also, by assuming an average value of 4.65 per cent crystal lattice water for the 2:1 layer silicates at 400°C and an average value of 13.7 per cent crystal lattice water for kaolinite and chlorite at 400°C (Barshad, 1965), the concentration of expandables was obtained[2]. The concentration of layer silicates, including also the end members of the mixed layers, indicates that the mica concentration is low in the older paleosols and high in the younger paleosols. Specifically, the mica content ranges from 15 to 21 per cent in the pre-Reid paleosol of site 1, from 29 to 31 per cent in the pre-Reid paleosol of site 2, and from 34 to 41 per cent in the Reid paleosol developed on outwash gravel. The range of mica concentration of the paleosol developed on McConnell outwash gravel is similar to that of the Reid paleosol developed on outwash gravel. However, the paleosol developed on McConnell till has higher ranges of mica concentrations (38-47%), than the one developed on Reid till (25-39%).

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[1] $R_2O_3 = Al_2O_3 + Fe_2O_3$

[2] Example: Assuming that mica, expandables, kaolinite and chlorite minerals have been identified from the X-ray diffractograms of the <2μm fraction, and assuming that the elemental analysis yields a crystal lattice water value on a 400°C basis of 8.1%, then if x is assigned to all 2:1 layer silicates and y to kaolinite and chlorite we have:

$$0.0465x + 0.1370y = 0.081$$

$$x + y = 1.000$$

$$0.0465\ (1-y) + 0.1375y = 0.081$$

$$0.0465 - 0.0465y + 0.1375y = 0.081$$

$$0.091y = 0.0345$$

$$y = 0.0345/0.091 - 0.379$$ or 38% kaolinite + chlorite

Therefore, the 2:1 silicates are 100 - 38 ≃ 62%.

If mica has been valued on the basis of K_2O content at 21%, then 41% is the concentration of expandables.

Clay mineralogy

X-ray patterns of the <2μm specimen, of the soil and the paleosol horizons are presented in Figures 3 to 22.

Based on the clay minerals, the soils of this study can be placed into two groups. The first encompasses the Reid and McConnell paleosols, while the second includes the pre-Reid paleosols. Soils of the first group contain kaolinite, illite, chlorite, vermiculite and chloritic intergrades resulting from aluminum or iron interlayering of depotassified mica and vermiculite. Soils of the second group containing kaolinite, illite and montmorillonite-kaolinite mixed layers have been identified.

Kaolinite has been confirmed from the d_{001} peak at 7Å after the removal of chlorite by warm dilute HCl. The specimen has been subjected to X-rays under an inert gas atmosphere in order to avoid any contribution to the d_{001} spacing of kaolinite from other concomitant clay minerals which are not destroyed by HCl, e.g. H-vermiculite (Brown, 1961). Figure 14 shows the diffraction patterns of an HCl treated specimen of <2μm soil clays under different X-ray conditions. Additional evidence for the presence of kaolinite also was obtained from the presence of the 3.57Å and 3.54Å double peaks representing the d_{002} and d_{004} planes of kaolinite and chlorite in the untreated <2μm clay samples (e.g. Fig. 3). This distinction is somewhat difficult when the sample is subjected to CuKα radiation and the use of Debye-Scherrer camera or when the diffraction patterns are recorded at a chart speed of 1°/cm/min. However, the separation of the doublet is possible when CoKα is used and the diffraction patterns are recorded at a chart speed of 2°cm/min and a scan speed of 1°2Θ/min. The presence of kaolinite was confirmed also by the disappearance of the 3.57Å peak upon heating the sample to 550°C for two and one-half hours. Thus, the presence of kaolinite has been verified in all diffractograms (Figs. 3-22).

Chlorite has been confirmed by the presence of d_{001} spacing at 14Å after heating the sample to 550°C for two and one-half hours. Thus chlorite has been ascertained in the loess deposits as well as in the paleosols of Reid and McConnell age (Figs. 3, 7, 11-22).

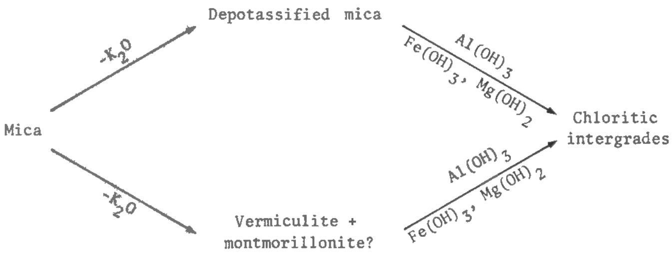
Mica has been identified in the presence of d_{001} spacing at 10Å in all Ca-saturated specimens which have been subjected to 50 per cent R.H. or glycerol solvation (Figs. 3-22). However, the intensity of the 10Å peak varies from the K_2O content presented in Tables 13 to 18. Thus, depotassification of mica seems to be related to the degree of weathering of the paleosol.

Vermiculite in the presence of illite, d_{001} 10Å, and chlorite, d_{001} 14Å, has been identified on the basis of the following mineralogical and chemical criteria. X-ray diffractograms obtained at 0 and 50 per cent R.H. and glycerol solvation indicate a simultaneous decrease in the 10Å peak intensity and an increase in the 14Å peak intensity on the same Ca-saturated <2μm specimen. At 0 per cent R.H., the d_{001} spacing at 10Å and 14Å has a given peak height. At 50 per cent R.H., the d_{001} spacing at 10Å decreases, whereas the d_{001} spacing of 14Å increases, indicating that an expandable mineral has shifted its d_{001} spacing from 10Å to 14Å. Upon glycerol solvation, the d_{001} spacing of 10Å and 14Å remains the same. This indicates that further expansion did not take place either from 10Å to 14Å, or to spacing higher than 14Å. This behaviour is typical of vermiculites since their maximum expansion is achieved with relatively low R.H. values, with little additional change for samples equilibrated at higher R.H. values, or by glycerolation (Harward *et al.*, 1968; Kodama and Brydon, 1968). Additional evidence for the presence of vermiculite was obtained by comparing the K-saturated <2μm specimens at different R.H. values with the Ca-saturated <2μm specimen at the same R.H. values. For the K-saturated specimens, the d_{001} peak intensity at 10Å and 14Å was constant regardless of the value of the relative humidity. However, by comparing the diffractograms of the Ca-saturated specimens versus the K-saturated ones at 50 per cent R.H., it was observed that, in the former, the peak intensity at 10Å decreases and the peak intensity of 14Å increases whereas, with the latter, the opposite is observed. This behaviour is attributed to the presence of vermiculite in the specimen (Harward *et al.*, 1968).

The presence of vermiculite seems to be related to the depotassification of mica because, wherever the mica increases in the soil profile, vermiculite seems to disappear from the X-ray patterns.

The presence of chloritic intergrades has been confirmed by the X-ray patterns [Figs. 3, 7, 11, 12, 13 (II BC horizon), 14-19, 21]. These intergrades seem to result from partial interlayering of hydroxy aluminum or hydroxy iron material in depotassified mica and vermiculite. The occurrence of partially interlayered phyllosilicates is suggested by the resistance to complete collapse to 10Å upon heating to 550°C. The possibility of having an expandable component in the chloritic intergrades is speculated from the behaviour of the Ca-saturated <2μm specimen when subjected to different relative humidities and glycerol solvation treatments. For example, in Figures 7 and 11, the chloritic intergrades in the Ca-saturated specimens occupy the region between 10Å and 14Å. At 0 per cent R.H., the chloritic intergrades tail off toward 14Å. At 50 per cent, the chloritic intergrades form a continuous plateau between 10Å and 14Å. Finally, upon glycerol solvation, the intergrades taper off toward the 10Å spacing. This continuous change of the plateau shape with different relative humidities and glycerol treatment implies that there is a mineral in the chloritic intergrades which expands to a certain point by absorbing water molecules, and expands even farther upon glycerol solvation, thus inducing changes in the shape of the X-ray patterns in the region between 10Å and 14Å. This behaviour can be attributed mainly to vermiculite because the expansion is limited between 10Å and 14Å. It is probable, however, that some montmorillonite also may be present. If vermiculite was the only expandable component of the intergrades, then the expansion or the change of the X-ray pattern between 10Å and 14Å should have been limited between 0 and 50 per cent R.H. because vermiculite reaches its maximum expansion at 50 per cent R.H. As a result, upon glycerol solvation of the <2μm specimen, the shape of the X-ray pattern between 10Å and 14Å should have stayed the same as it is under 50 per cent R.H. However, upon glycerolation the X-ray pattern changes, tailing off toward 10Å. This suggests that very small amounts of montmorillonite might be present also in the chloritic intergrades.

The overall reaction for the formation of intergrades can be summarized as follows:



The presence of excess aluminum and iron for the formation of chloritic intergrades can be verified from the chemical analysis (Tables 13-18). These analyses show high concentrations of Al_2O_3 and Fe_2O_3 in the studied paleosol.

In the pre-Reid paleosols, illite and kaolinite have been identified as previously described. Chlorite is absent and vermiculite also seems to be absent from the X-ray patterns of the <2μm specimen. Chloritic intergrades are present, though not as conspicuous as in the Reid and McConnell paleosols. For example, in Figure 3 the Ca-saturated <2μm specimen of the II Bt2 horizon treated at 550°C for two and one-half hours indicates resistance to complete collapse to 10Å for the 2:1 layer silicates. The latter is indicative of chloritic intergrades. For deeper horizons (II Bt1 and II BC; Figs. 4, 5), the presence of chloritic intergrades becomes less conspicuous and, finally, for the II C horizon (Fig. 4), the chloritic intergrades disappears completely. Again the explanation for the presence of chloritic intergrades in the pre-Reid paleosols lies probably in the depotassification of mica and the adsorption of hydroxy aluminum and hydroxy iron complexes.

Evidence for the presence of interstratified kaolinite-montmorillonite[1] is presented in Figures 4, 5 and 6. In Figure 5, the Ca-saturated <2μm specimen indicates that, upon increasing the R.H. from 0 to 50 per cent and upon glycerolation, there is a progressive movement of a poorly defined peak from 10Å to 15Å to 18Å. At 18Å, the peak has a leading tail toward the direction of lower angles. This behaviour of the interstratified clays indicates the presence of a montmorillonitic component in the mixed layer. Another line of evidence for the presence of a montmorillonitic component in the mixed layers is obtained by comparing the X-ray diffractograms of K-saturated <2μm specimen at 0 and 50 per cent R.H. In Figure 4, the II BC horizon of site 1 shows that the X-ray pattern of the K-saturated specimen at 50 per cent R.H. differs from the X-ray pattern of the same specimen at 0 per cent R.H. At 0 per cent R.H., all 2:1 layer silicates, upon K^+ saturation collapse, yield a well-defined 10Å peak. At 50 per cent, the same specimen exhibits a plateau from 11Å to almost 19Å. This differential behaviour is attributed to a montmorillonitic component in the interstratified clays. Evidence for the presence of the kaolinitic component in the interstratified clays is obtained from the Ca-saturated specimen at 0 per cent R.H., 50 per cent R.H., glycerol solvation and heat treatment at 550°C. In Figure 4, the Ca-saturated <2μm specimen of the II Bt2 horizon exhibits a plateau between 7Å and 10Å. Upon increasing the R.H. to 50 per cent, the plateau becomes more humpy, and upon glycerol solvation there is a hump with a maximum at 8.1Å. This hump, as well as the kaolinite, disappears upon heating to 550°C for two and one-half hours.

[1] The presence of the same mixed-layer clays in identical paleosols has been confirmed by Kodama *et al.* (1976).

The interstratified mixture of kaolinite-montmorillonite is identified in all pre-Reid paleohorizons of site 1 as well as in the clay fraction of the sand wedges of sites 1 and 2 (Figs. 5, 9). This type of interstratification, however, was less apparent in the pre-Reid paleohorizons of site 2.

DISCUSSION

GEOMORPHIC AND STRATIGRAPHIC EVIDENCE OF CLIMATIC FLUCTUATIONS

Climatic fluctuations in the region during the Quaternary, as inferred from stratigraphic and geomorphic evidence, can be summarized as follows:

1. Pre-Reid glaciation(s): The parent materials of the paleosols at Localities 1 and 2 were deposited during a glaciation which preceded the Reid glaciation. However, there is no firm geomorphic, stratigraphic or pedologic evidence by which the parent material can be assigned to either Klaza or Nansen glaciation, or correlative advances of alpine glaciers in the Ogilvie Mountains.

2. Pre-Reid interglacial: Geomorphic evidence, such as major deepening of Klondike River valley prior to the Reid glaciation, and virtual elimination of characteristic glacial landforms on pre-Reid deposits demonstrate that a major interglacial period preceded the Reid glaciation. No deposits of the interglacial have been found in the area, so that soil development on pre-Reid deposits at Localities 1 and 2 herein provide the first evidence of climatic conditions.

3. Reid glaciation: During the Reid glaciation, much of the Yukon Plateau was covered again by a Cordilleran ice-sheet. Glacial till was deposited over much of the region, and outwash was deposited beyond the ice front in major

valleys. Similarly, alpine glaciation was renewed in Ogilvie Mountains, with a trunk glacier extending down North Klondike Valley almost to the junction of North and South Klondike Rivers. There, terminal moraine and other ice-marginal features are inset in an inner valley below the pre-Reid surface. Restricted areas of pre-Reid deposits, with deep soils developed during a pre-Reid interglacial, remained ice-free but were subjected to an intense periglacial climate, significantly colder and drier than the present. Periglacial climatic conditions are inferred from the widespread occurrence of sand wedges that transect the paleosol developed on pre-Reid deposits, and from ventifacts at the upper surface of the paleosol. Sand forming the wedges probably was derived by deflation of the Ae horizon, now lacking, of the truncated paleosol. The sand is accompanied by minor amounts of the same pedogenetic clays as those found in adjacent paleosol, indicating local derivation of the sand filling. Deflation of the Ae horizon, transfer of the sand to the developing wedges, and development of ventifacts indicate that there could have been, at most, only sparse steppe vegetation.

During retreatal stages of the Reid, with increasing vegetation cover, loess may have been deposited widely over the region but, if so, it was removed by wind erosion during the subsequent McConnell glaciation.

4. Reid-McConnell interglacial: Non-glacial deposits are known from beneath till of the McConnell advance and from above Reid glacial deposits that lie beyond the McConnell limit; these are being studied currently. To date, however, soil development on Reid deposits (*see* below) provides the only evidence as to climatic conditions during the Reid-McConnell interglacial.

5. McConnell glaciation: During the McConnell glaciation, much of Yukon Plateau was covered again by the Cordilleran ice sheet. Areas of Reid drift beyond the ice margin were subjected to a cold dry climate, with resultant development of sand wedges, deflation of the A horizon of the Brunisol soil and development of ventifacts on quartz and quartzite pebbles. Sand wedges that transect the paleosol developed on parent materials of Reid age are narrower than those in pre-Reid drift, suggesting either that the periglacial climate was less intense or of shorter duration (or both) during the McConnell glaciation than during the Reid.

   Sand wedges of McConnell age were not identified in soils developed on pre-Reid parent material, although our interpretation of climatic history suggests that they should be present. They may have been lacking, locally, at the sites (1 and 2) selected for study, or were not distinguished from older wedges.

   Deposition of McConnell loess on pre-Reid, Reid and newly exposed McConnell drift probably took place in waning stages of the McConnell glaciation when, with climatic amelioration, vegetation was sufficient for entrapment of loess.

   There are no palynological or other paleobotanical data from the study area from which climate during the McConnell glaciation can be inferred. However, in a pollen sequence from southwestern Yukon (Rampton, 1971), the lowermost zone (Zone 1), dated about 31 000 years B.P. or possibly somewhat older, indicates either fell-field (rock desert) or sedge-moss tundra vegetation. The fell-field interpretation, which best fits our data, would indicate a cold dry climate comparable to that of the high arctic (Rampton, 1971, p. 970, Fig. 7). The remainder of the sequence shows a warming, a reversal to colder and drier, and then general warming to the present.

6. Post-McConnell: As with the McConnell glaciation, there are no palynologic data from the study-area from which post-McConnell climate can be inferred. Rampton's palynologic data do not indicate a hypsithermal warming; however, in the same region, radiocarbon dates on logs indicate that the tree line, and hence summer temperature, fluctuated above present levels between 6000 and 1200 years B.P. (Rampton, 1971, p. 959). Soils on McConnell drift were developed, therefore, under climatic conditions the same as or somewhat warmer than those of the present. The same conclusion has been reached from the study of shelled invertebrates in the Richardson Mountains area, north of the studied area (Delorme *et al.*, 1975).

INTERGLACIAL CLIMATES AS INFERRED FROM PEDOLOGIC EVIDENCE

The geomorphic and stratigraphic evidence summarized above established an alternation of glacial intervals in which parent materials were deposited, and interglacial intervals (including the present Holocene) in which paleosols and the neosol on the youngest (McConnell) deposits were developed. Except for the present interglacial interval, however, there is no evidence, except what can be derived from the paleosols themselves, as to the duration of the interglacial soil-forming intervals or the climate prevailing during these intervals. Were the climates of the interglacials, which gave rise to strikingly different soils, markedly different to that of the present, or is the difference in soil development attributable to progressively longer interglacial intervals as we go back in time? Examination of moisture and temperature requirements for formation of the older soils indicates that differences in climate rather than duration of the interglacials were the dominant factors.

In the Appendix it is indicated that soils developed on sites 1 and 2 (Fig. 2) are classified as truncated Luvisols[1]. It is shown, also in the Appendix, that soils developed on Reid and McConnell

[1] These soils can, conceivably, be classified as Red-Yellow podzols.

drifts as well as on loess deposits are Brunisols. However, the Brunisols developed on McConnell drifts, sites 4 and 6, and on loess deposits are markedly thinner than those developed on Reid drifts, sites 3 and 5 (Fig. 2).

Evidence for the difference in climate between the pre-Reid and the Reid-McConnell interglacial periods is obtained from the depths at which pedogenetic clays are encountered in the pre-Reid and Reid paleosols. Montmorillonite-kaolinite mixed layers are identified beyond 190+ cm depth in the pre-Reid paleosols of site 1, whereas vermiculite and chloritic intergrades are found in Reid paleosol of site 3 to the depth of 93 cm. Since water must be considered for both the depth of weathering and for either the clay translocation or the generation of clays, then it is possible to calculate the amount of water needed to reach these depths, using the equation which describes the water movement in unsaturated material. This equation, which is presented by Birkeland (1974), is as follows:

$$d = \frac{Pw}{100} \times P_b \times D$$

where d is the amount of water in cm; Pw is the difference between field capacity (F.C.) and permanent wilting point (P.W.P.) (in this case it represents the water-holding capacity per horizon expressed in cm^3 H_2O/g soil); P_b is the bulk density in g/cm^3; and D is the depth of water penetration in cm.

On the basis of studies by Kelly *et al.* (1946), who have published solid phase suction-water retention curves for a number of California soils, it can be assumed that a sandy, clayey loam soil has a Pw value around 15 per cent and a loamy sand or a sandy loam soil has a Pw value around 10 per cent. Assuming a bulk density of 1.5 g/cm^3, then the amount of water needed for the pre-Reid paleosol at 190+ cm depth is:

$$d = \frac{15}{100} \times 1.5 \times 117^* + \frac{10}{100} \times 1.5 \times (190 - 117)$$

$$= 36.4 \text{ cm or } 364 \text{ mm.}$$

For the Reid paleosol, the obtained amount of water to reach the 93 cm depth of weathering is:

$$d = \frac{10}{100} \times 1.5 \times 93 = 14 \text{ cm or } 140 \text{ mm.}$$

These calculations assume that water (or rainfall) has been precipitated at once and that evapotranspiration and water runoff are zero. What the calculations indicate is that the climate during the pre-Reid interglacial period was much more humid or that the water regime for the development of pre-Reid soils was of a higher magnitude than that responsible for the development of Reid soils.

From the type of pedogenetic clay minerals encountered in the paleosols, another hint concerning the climatic differences between pre-Reid-Reid and Reid-McConnell interglacial periods is obtained. Montmorillonite in soils developed on acid or basic igneous parent material is found under low precipitation, Mean Annual Precipitation (M.A.P.) of less than 100 cm and Mean Annual Temperature (M.A.T.) of 12° to 18°C (Barshad, 1966), or under higher M.A.P. and higher M.A.T. (Sherman, 1952). To transform montmorillonite to kaolinite, as it is encountered in pre-Reid paleosols, a high degree of leaching should have been taking place.

Thus, the type of clay minerals in the pre-Reid soils in conjunction with the red colour of the textural B horizon suggests that initially the climate in the pre-Reid era should have been warm and dry to induce the formation of montmorillonite, and thereafter it became more humid.

Was the climate which existed in the Reid-McConnell interglacial period similar to today's climate? The answer again seems to be no. On the basis of climatological data (Thomas, 1953), today's climate in central Yukon is characterized by a M.A.T. of 15° to 20°F (-7° to -10°C) and M.A.P. (snow + rain) of 10 to 15 inches (25-37.5 cm). Furthermore, soils are frozen for 7 to 8 months, thus being pedogenetically inactive for this period of time. Considering, therefore, the rainfall of 5 inches (12.7 cm) which precipitates in spring, summer and fall in the area, and dividing this precipitation into three equal portions of 1.7 inches (4.25 cm) for the three seasons, the maximum depth of water penetration on the basis of the previously described equation of water movement in unsaturated media assuming no evapotranspiration, a Pw of 15 per cent and P_b of 1.5, is as follows:

$$D = \frac{d \times 100}{Pw \times P_b} \simeq 19 \text{ cm.}$$

The depth of water penetration of 19 cm is inadequate to explain the pedogenetic formation of clays at a depth of 93 cm found in the pre-Reid paleosol on Reid outwash at site 3. Therefore, though the soil developed post-glacially on McConnell deposits and those developed during the Reid-McConnell interval have the same type of clay minerals, and both are classified as Brunisols, it is concluded that the moisture regime during the Reid-McConnell period was much higher than that of today. The suggested transition is from a subhumid climate during the Reid-McConnell interglacial period to the subarctic-semiarid climate of today.

From the preceding discussions, it is apparent that today's climate can neither explain the genesis of the thick, reddish-brown, textural B horizons, nor the type of clay minerals encountered in the pre-Reid paleosols. If time is the missing element to convert the McConnell Brunisols to pre-Reid Luvisols, then we should have seen some similarities between Reid, which has the same type of clay minerals as McConnell paleosols, and pre-Reid paleosols. Birkeland (1974), summing up the work of many scientists, states that clay minerals formed in soils from parent materials low in clay content, as is the case in this study, probably form mineral assemblages stable in that environment and, therefore, variation in the minerals with age is not found and not expected. As a result, it seems that dissimilar climates existed between the interglacial periods. Work by Zoltai and Tarnocai (1974), in the plains

* Up to 117 cm depth the texture is sandy clayey loam.

east of this report-area and by Pettapiece and Zoltai (1974) in the subarctic of northwestern Canada indicate climatic changes even during the last post-glacial period. The same conclusion has been reached from the study of shelled invertebrates (Delorme *et al.*, 1975). The latter have been used as paleoclimatic indicators in the southern Richardson Mountains, which are north of the investigated area. Indeed, a climate that is more humid and with somewhat higher temperatures than those of today must be considered to explain the low pH values of 4.9 and 5.2 encountered at a depth of 48 cm and 67 cm respectively in the soil developed on till of McConnell age. Today's rainfall is inadequate to penetrate to such a depth. Therefore, these pH values mark a progression to a colder and drier climate which preserved the morphogenetic characteristics of the paleosols.

QUATERNARY CLIMATES OF CENTRAL YUKON TERRITORY

The combining of geological studies with soil morphology, clay mineralogy and clay chemistry of the paleosols and neosols together with evidence from other research studies suggests the following sequence of Quaternary climates for the area studied.

Pre-Reid paleosols were subjected to two climates. The initial one was warm and subhumid with grassland-shrub vegetation, favourable for the generation of montmorillonite (Strakhov, 1967). An area in the Klondike district adjacent to the study-area which had a grassland environment during some part of the Quaternary is well documented from fossil remains of large grazing herbivores (Harington and Clulow, 1973). The age of the fossil assemblages relative to the chronology of the present study-area has not been established, and it is not our intent to suggest a correlation with the pre-Reid interglacial. The fossil evidence, however, does lend credence to the interpretation, from pedologic evidence, of a former grassland environment in a region now occupied by boreal forest. Subsequently, a more temperate and humid climate appeared which induced the degradation of montmorillonite to kaolinite through the intermediate step of mixed-layer montmorillonite-kaolinite. In addition, this type of climate was responsible for the development of the Luvisols with the red, very thick, textural paleo B horizon to a depth of 190+ cm. Later, the climate became colder with the onset of the Reid glaciation. The very cold climate induced thermal contraction cracks in soils, which were filled progressively with sand plus minor amounts of silt and clay to form sand wedges. The sand was derived locally by deflation of the Ae horizon of the previously formed Luvisol.

During the subsequent Reid-McConnell interglacial period, it seems that a cool, subhumid climate prevailed. This climate was responsible for the development of the Brunisolic characteristics encountered in the paleosols developed on deposits of Reid age. A cold period ensued resulting in the McConnell glaciation. This period must have been severe but shorter than the Reid as deduced from the presence of narrower and shallower sand wedges in the Reid paleosols. In the waning stages of the McConnell glaciation, loessal silt derived from extensive outwash trains was deposited as a thin blanket over the truncated paleosols of the pre-Reid and Reid surfaces and over newly uncovered McConnell surfaces. The transition from deflation and truncation of the earlier formed paleosols to loess deposition indicates a significant increase in vegetative cover that stabilized the soil surface and served to trap the loess.

Finally, the post-glacial climate has imparted to McConnell deposits and the overlying loess the characteristics of a Brunisol soil. Today's subarctic-semiarid climate is different from that occurring during the retreat of McConnell ice and shortly after. Evidence presented by Zoltai and Tarnocai (1974) and Delorme *et al.* (1975) in areas adjacent to the area investigated suggest that the climate was somewhat warmer and more humid than it is today, probably a subarctic-subhumid type of climate.

REFERENCES

American Society for Testing and Materials
1964: Grain size analysis of soils in the 1964 book of A.S.T.M. Standards, 4th ed., p. 95-106.

Bailey, L.W., Odell, R.T. and Boggers, W.R.
1964: Properties of selected soils developed near the forest-prairie border in east-central Illinois; Soil Sci. Soc. Am. Proc., v. 28, p. 256-263.

Barshad, I.
1955: Soil development *in* Chemistry of the soil, F.E. Bear, ed. in chief; Reinhold Publishing Corp., New York, p. 1-52.

1965: Thermal analysis techniques for mineral identification and mineralogical composition *in* Methods of soil analysis, C.A. Black, ed. in chief; Am. Soc. Agronomy, pt. 1, p. 699-742.

1966: The effect of a variation in precipitation on the nature of clay mineral formation in soils from acid and basic igneous rocks; Proc. Internatl. Clay Conf., v. 1, p. 167-773.

Berg, T.E. and Black, R.F.
1966: Preliminary measurements of growth of non-sorted polygons, Victoria Land. Antarctica. Antarctic soils and soil forming processes; Am. Geophysical Union, Antarctic Res. Ser., v. 8, p. 61-108.

Bostock. H.S.
1948: Physiographic subdivisions of the Canadian Cordillera north of the fifty-fifth parallel *in* Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel; Geol. Surv. Can., Mem. 247, Map 922A.

Bostock, H.S.
1966: Notes on glaciation in central Yukon Territory; Geol. Surv. Can., Paper 65-36.

Birkeland, P.W.
1969: Quaternary paleoclimate implications of soil clay mineral distribution in a Sierra Nevada-Great Basin transect; J. Geol., v. 77, p. 289-302.

1974: Pedology, weathering and geomorphological research; Oxford University Press, New York.

Birkeland, P.W. and Janda, R.L.
1971: Clay mineralogy of soils developed from Quaternary deposits of the eastern Sierra Nevada, California; Bull. Geol. Soc. Am., v. 82, p. 2495-2514.

Brown, G.
1961: X-ray diffraction and crystal structure of clay minerals, 2nd ed.; Mineralogical Soc., London.

Delorme, L.D., Zoltai, S.C. and Callas, L.L.
1975: Shelled invertebrates as indicators of paleoclimate in N.W. Canada during the late glacial period; Intern. conf. on global scale paleolimnology and paleo-climate, Kioto, Japan.

Douglas, R.J.W., ed.
1970: Geology and economic minerals of Canada; Geol. Surv. Can., Econ. Geol. Rept. No. 1.

Dyck, W., Lowdon, J.A., Fyles, J.G. and Blake, W, Jr.
1966: Radiocarbon dates V; Geol. Surv. Can., Paper 66-48.

Fitzpatrick, E.A.
1971: A systematic approach to soil pedology science; Oliver and Boyd, Division of Longman Group Ltd.

Foscolos, A.E. and Barefoot, R.R.
1970a: A rapid determination of total, organic and inorganic carbon in shales and carbon-ates. A rapid determination of total sulphur in rocks and minerals; Geol. Surv. Can., Paper 70-11.

1970b: A buffering and standard addition technique as an aid in the comprehensive analysis of silicates by atomic absorption spectroscopy; Geol. Surv. Can., Paper 70-16.

Flint, R.F.
1970: Glacial and Quaternary geology; John Wiley and Sons, New York.

Harington, C.R. and Clulow, F.V.
1973: Pleistocene mammals from Gold Run Creek, Yukon Territory; Can. J. Earth Sci., v. 10, no. 5, p. 697-759.

Harward, M.E., Carstea, D.D. and Sayegh, A.H.
1968: Properties of vermiculites and smectites: Expansion and collapse; Clays and Clay Min., v. 16, p. 437-447.

Hughes, O.L.
1969: Distribution of open-system pingos in central Yukon Territory with respect to glacial limits; Geol. Surv. Can., Paper 69-34.

Hughes, O.L., Campbell, R.B., Muller, J.E. and Wheeler, J.O.
1969: Glacial map of Yukon Territory, south of 65 degrees north latitude; Geol. Surv. Can., Paper 68-34, Map 6-1968.

Hughes, O.L., Rampton, V.N. and Rutter, N.W.
1972: Quaternary geology and geomorphology, southern and central Yukon; XXIV Intern. Geol. Congr., Montreal 1972, Field Excursion A-11.

Jackson, M.L.
1965: Free oxides, hydroxides, and amorphous aluminosilicates *in* Methods of soil analysis, C.A. Black, ed. in chief; Am. Soc. Agronomy, p. 1, p. 578-603.

Jackson, M.L., Hseung, Y., Corey, R.B., Evans, E.J. and Vanden Heuval, R.C.
1952: Weathering sequence of clay-size minerals in soils and sediments: II. Chemical weathering of silicates; Soil Sci. Soc. Am. Proc., v. 16, p. 3-6.

Janda, R.J. and Croft, M.G.
1967: Stratigraphic significance of a sequence of noncalcic brown soils formed on Quaternary alluvium in the north-eastern San Joaquin Valley, California *in* Quaternary soils, R.B. Morrison and H.E. Wright, Jr., eds. in chief; Intern. Assoc. Quaternary Res., VII Cong., Proc. 9, p. 151-196.

Jenny, H.
1941: Factors of soil formation; McGraw-Hill, New York.

1958: Role of plant factor in the pedogenic functions; Ecology, v. 39, p. 5-16.

Jungerius, P.D.
1969: Soil evidence of postglacial tree line fluctuations in the Cypress Hills area, Alberta, Canada; Arctic and Alpine Res., v. 1, p. 235-245.

Kelly, O.J., Hunter, A.S., Haise, H.R. and Hobbs, C.H.
1946: A comparison of methods of measuring soil moisture under field condition; J. Am. Soc. Agron., v. 38, p. 759-784.

Kodama, H. and Brydon, J.E.
1968: A study of clay minerals in podzol soils in New Brunswick, eastern Canada; Clay Minerals; Bull. 7, p. 295-309.

Kodama, H., Miles, N., Shimoda, S. and Brydon, J.E.
1976: Mixed-layer kaolinite-montmorillonite from soils near Dawson, Yukon Territory; Can. Min., v. 14, p. 159-163.

Lowdon, J.A. and Blake, W., Jr.
1968: Radiocarbon dates VII; Geol. Surv. Can., Paper 68-2, pt. B.

McConnell, R.G.
1905: Report on the Klondike gold fields; Geol. Surv. Can., Ann. Rept. (Misc.), v. XIV (1901), pt. B, p. 1-71. (Also separate Publ. No. 884).

McKeague, J.A. and Day, J.H.
1966: Dithionate and oxalate-extractable Fe and Al as aids in differentiating various classes of soils; Can. J. Soil Sci., v. 46, p. 13-22.

Morrison, R.B.
1967: Principles of Quaternary stratigraphy *in* Quaternary soils, R.B. Morrison and H.E. Wright, Jr., eds. in chief; Intern. Assoc. Quaternary Res., VII Cong., Proc. 9, p. 1-69.

Morrison, R.B. and Frye, J.C.
1965: Correlation of the Middle and Late Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains and eastern midwest areas; Nevada Bur. Mines, Rept. 9, p. 1-45.

Nichols, R.L.
1969: Geomorphology of Inglefield Land, North Greenland; Medd. om Grønland, Bd. 188, Nr. 1, p. 109.

Peech, M.
1965a: Exchange acidity *in* Methods of soil analysis, C.A. Black, ed. in chief; Am. Soc. Agronomy, pt. 2, p. 905-913.

1965b: Hydrogen-ion activity *in* Methods of soil analysis, C.A. Black, ed. in chief; Am. Soc. Agronomy, pt. 2, p. 914-926.

Pettapiece, W.W.
1969: The forest grassland transition *in* Pedology and Quaternary Research, S. Pawluk, ed. in chief; Univ. Alberta Printing Dept., Edmonton, p. 103-113.

Pettapiece, W.W. and Zoltai, S.C.
1974: Soil environment in the western Canadian subarctic *in* Quaternary Environment, W.C. Mohoney, ed.; Proc. Intern. Symp., Toronto, Univ. Toronto Press, York Univ. Series, Geographical Monograph, v. 5, p. 279-292.

Péwé, T.L.
1959: Sand-wedge polygon (Tesselations) in the McMurdo Sound region, Antarctica. A progress report; Am. J. Sci., v. 257, p. 545-552.

1962: Age of moraines in Victoria Land, Antarctica; J. Glaciology, v. 4, p. 93-100.

1974: Geomorphic processes in polar deserts *in* Polar deserts and modern-man, T.L. Smiley and J.H. Zumberge, eds.; Univ. Arizona Press, Tucson.

Rampton, V.
1971: Late Quaternary vegetational and climatic history of the Snag-Kluttan area, southwest Yukon Territory, Canada; Bull. Geol. Soc. Am., v. 82, p. 959-978.

Romanovskij, N.N.
1973: Regularities in formation of frost-fissures and development of frost-fissure polygons; Proc. Intern. Symp. of the Commission on Periglacial Morphology of the I.G.U. and Subcommission on Paleogeographical Maps and Atlases of the INQUA, Yokutsk-Moscow, 1969; Biuletyn Peryglacjalny, no. 23.

Ricker, K.E.
1968: Quaternary geology in the southern Ogilvie Ranges, Yukon Territory; M.Sc. dissertation, Dept. Geology, Univ. British Columbia.

Ruhe, R.V.
1969: Soils, paleosols and environment *in* Pleistocene and Recent environments of the central Great Plains, W. Dort, Jr. and J.K. Jones, Jr., eds.; Univ. Press of Kansas, Lawrence, p. 37-52.

Ruhe, R.V. and Cady, J.C.
1969: The relation of Pleistocene geology and soils between Bentley and Adair in southwestern Iowa; U.S. Dept. Agric. Tech. Bull., v. 1349, p. 1-92.

Sherman, G.D.
1952: The genesis and morphology of the alumina-rich laterite clays *in* Problems of clay and laterite genesis; Am. Inst. Mining Metal. Eng., p. 154-161.

Smith, G.D., Alloway, W.H. and Riecken, F.F.
1950: Prairie soils of the upper Mississippi Valley; Advances in Agron., v. 2, p. 157-205.

Strakhov, N.M.
1967: Principles of lithogenesis; Oliver and Boyd Ltd., Edinburgh, v. 1.

Thomas, M.K.
1953: Climatological Altas of Canada; Publications of the Division of Building Research N.R.C. and Meteorological Division, Department of Transport Canada, N.R.C. No. 3151, D.B.R. No. 41.

Vernon, P. and Hughes, O.L.
1966: Surficial geology, Dawson, Larsen Creek and Nash Creek map-areas, Yukon Territory; Geol. Surv. Can., Bull. 136.

Zoltai, S.C. and Tarnocai, C.
1974: Perenially frozen peatlands in the western Arctic and subarctic of Canada; Can. J. Earth Sci., v. 12, p. 28-43.

APPENDIX

DESCRIPTION OF SOIL PROFILES

SOIL PROFILE IN SITE 1: This site is located on a well- to moderately well drained pre-Reid outwash surface with a slope of ≈2°. A sand wedge extends between depths of 13 and 117 cm. The vegetation consists predominantly of poplar with some white spruce and with a ground cover of clump grass and some Labrador tea. The neosol is classified as a Brunisol (Eutric) and the paleosol, which has been developed on the pre-Reid drift, as a Luvisol.

Horizon	Depth (cm)	Description
H	3.5-0	Very dark greyish brown (10 YR 3/2, d); very dark brown (10 YR 2/2, m); extremely decomposed, humified organic matter; plentiful fine roots, clear wavy boundary; 3-5 cm thick; pH = 5.4
Ahe	0-13	Brownish-yellow (10 YR 6/6, d); dark yellowish brown (10 YR 4/4, m); silt loam; compacted; single grain; very friable; few fine roots; gradual, smooth boundary; 12-15 cm thick; pH = 4.9; O.M. = 0.7%
BM	13-18	Yellowish-brown (10 YR 5/4, d); brown (7.5 YR 4/4, m); silt loam; weak, fine granular structure; friable, very few fine roots; very few pebbles; abrupt, clear boundary; 5-7 cm thick; pH = 5.0; O.M. = 0.5%
II Bt1	18-40	Reddish-brown (5 YR 5/5, d); reddish-brown (5 YR 4/5, m); sandy clay loam; medium, granular structure, friable; clear, irregular boundary; 15-25 cm thick; no roots; plentiful shattered and weathered stones; pH = 4.9; O.M. = 0.3%
II Bt2	40-117	Brown (7.5 YR 5/2, d); dark brown (7.5 YR 4/4, m); sandy clay loam; single grain; abundant medium-size pebbles with thin weathering rinds; ph = 5.2; O.M. = 0.2%
II BC	117-190	Yellowish-brown (10 YR 5/6, d); dark yellowish brown (10 YR 4/4, m); sandy loam, single-grained; abundant medium-size pebbles with weathering rings; pH = 6.1; O.M. = 0.2%
II C	190+	Yellowish-brown (10 YR 5/6, d); dark yellowish brown (10 YR 4/4, m); loamy sand; single grain; abundant, medium and large gravels with some weathering rings; pH = 6.1; O.M. = 0.1%

SOIL PROFILE IN SITE 2: The site is located on a very gently sloping, moderately well drained pre-Reid outwash surface. A sand wedge extends between depths of 40 and 103 cm. The vegetation consists of white spruce, balsam poplar? and black spruce with a ground cover of clump grass. The neosol is classified as a Brunisol (Eutric?) and the paleosol as a Luvisol.

L-H	2.5-0	Very dark brown (10 YR 2/2, d); black (10 YR 2/1, m); partially decomposed organic matter; abundant fine and medium roots; abrupt, smooth boundary; pH = 6.1
Ah	0-2.5	Dark brown (10 YR 3/3, d); very dark greyish brown (10 YR 3/2, m); sandy loam; single grain; friable; plentiful fine roots; clear, wavy boundary; 2-3.5 cm thick; pH = 4.8; O.M. = 8.6%
Bm1	2.5-15	Yellowish-brown (10 YR 5/4, d); brown (10 YR 4/3, m); loam; amorphous, friable; few fine and very fine roots; few fine and very fine pores; very few small-size stones; gradual, wavy boundary; 12-14 cm thick; pH = 5.4; O.M. = 3.4%
Bm2	15-40	Pale brown (10 YR 6/3, d); brown (10 YR 5/3, m); silt loam; amorphous; friable; very few fine and very fine roots; clear boundary; O.M. = 1.0%
Bgj	40-65	Yellowish-brown (10 YR 5/6, d); strong brown (7.5 YR 5/6, m); sandy loam; some yellowish-brown mottles; amorphous structure that breaks down into subangular blocky fragments across natural surfaces of weakness; very firm (m); soft (d); very few fine roots; some stones; diffuse boundary; pH = 6.7; O.M. = 0.5%

Horizon	Depth (cm)	Description
II Bt	45-68	Yellowish-brown (10 YR 5/6, d); brown (7.5 YR 5/4, m); sandy loam; subangular blocky structure; very firm (m), soft (d); very few fine roots; some pebbles; diffuse boundary; pH = 6.7; O.M. = 0.5%
II BC	68-103	Yellowish-brown (10 YR 6/6, d); brown (7.5 YR 5/4, m); loamy sand; single grain; friable; some stones; diffuse boundary; pH = 6.7; O.M. = 0.3%
II C	103-123	Yellowish-brown (10 YR 5/6, d); dark yellowish brown (10 YR 4/4, m); loamy sand; single grained; friable; no visible soil accumulations; pH = 6.6; O.M. = traces
III C	123+	Yellowish-brown (10 YR 5/6, d); dark yellowish brown (10 YR 4/4, m); sand; single grained; friable; pH = 6.8

SOIL PROFILE IN SITE 3: This site is located on a flat-lying, well-drained, gravelly outwash terrace of Reid age. The vegetation consists of spruce and poplar with a ground cover of clump grass. A sand wedge extends between depths of 22.5 and 93 cm. The neosol as well as the paleosol are classified as Brunisols (Eutric).

L-H	2.5-0	Very dark brown (10 YR 2/2, d); partially decomposed organic matter; fibrous; predominantly moss; abundant fine and medium roots; abrupt, smooth boundary; 2.3-3.0 cm thick; pH = 6.3
Bm1	0-14.5	Reddish-brown (5 YR 5/4, d); reddish-brown (5 YR 4/4, m); silt loam; single grained; friable; few, fine and very fine roots; gradual boundary; smooth, 13-16 cm thick; pH = 5.9; O.M. = 1.7%
Bm2	14.5-30	Dark yellowish brown (10 YR 4/4, d); dark yellowish brown (10 YR 3/4, m); loam, single grained; friable; few, fine and very fine roots; gradual boundary; smooth, 7-9 cm thick; pH = 6.0; O.M. = 1.0%
II Bm1	30-49	Yellowish-brown (10 YR 5/4, d); brown (10 YR 4/3, m); sandy loam; fine, weak crumb; very friable; very few fine roots; no pores; no stones; smooth abrupt boundaries, except in presence of small sand wedges; 6-10 cm thick; pH = 6.4; O.M. = 0.7%
II Bm2	49-68	Yellowish-brown (10 YR 5/4, d); brown (10 YR 4/3, m); very gravelly sandy loam; single grained; friable; no roots, no pores; abrupt smooth boundary; 6-10 cm thick; pH = 6.4; O.M. = 0.4%
II BC	68-93	Light olive-brown (2.5 YR 5/4, d); olive-brown (2.5 YR 4/4, m); very gravelly sandy loam; single grained; friable; no roots; no pores; diffuse boundary; abundant gravel; pH = 6.9; O.M. = traces
II Ck	93+	Light olive-brown (2.5 Y 5/4, dry); olive-brown (2.5 Y 4/4, m); very gravelly sandy loam; single grain; friable; no root; no pores; abundant gravel; pH = 7.1; moderately calcareous; no O.M.

SOIL PROFILE IN SITE 5: The site is located on well- to imperfectly drained till, of Reid age, on a 1 to 2° west-dipping slope to the west. There are some small sand wedges extending from 17 cm to a maximum of 27 cm. The vegetation consists of lodgepole pine and poplar with a ground cover of grasses and moss. The neosol and paleosol are classified as Brunisols (Dystric).

L-H	5-0.0	Very dark greyish brown (10 YR 3/2, d); partially decomposed fibrous organic material; plentiful fine and few medium roots; abrupt, irregular boundary; 4.0-7.0 cm thick; pH = 4.8
Ahe	0-2.5	Yellowish-brown (10 YR 5/4, d); brown (10 YR 4/3, m); silt loam, single grained; friable; few fine roots; clear, smooth boundary; 2.0-3.0 cm thick; pH = 4.5; O.M. = 3.4%
Bm	2.5-17	Yellowish-brown (10 YR 5/4, d); dark yellowish brown (10 YR 4/4, m); silt loam; weak, fine, platy structure; slightly sticky; very friable; few very fine roots; few fine and very fine root canals; abrupt, wavy, boundary over ventifact disconformity; 14-18 cm thick; pH = 5.0; O.M. = 1.0%

Horizon	Depth (cm)	Description
II Bm	17-40	Light olive-brown (2.5 Y 5/4, d); olive-brown (2.5 Y 4/4, m); gravelly loam; very weak, fine, platy structure; very friable; many weathered stones; pH = 5.1; O.M. = traces
II BC	40-66	Light olive-brown (2.5 Y 5/4, d); olive-brown (2.5 Y 4/4, m); very stony sandy loam; single grained to amorphous (m); diffuse smooth boundary; 14-18 cm thick; pH = 5.3
II C	66+	Light olive-brown (2.5 y 5/4, d); olive-brown (2.5 Y 5/4, d); olive-brown (2.5 Y 5/4, m); very stony sandy loam; single grained; very friable; pH = 6.3

SOIL PROFILE IN SITE 4: This site is very well drained, located on a level ground on top of a moraine of McConnell age, 30 m (100 ft) wide. Natural vegetation is a second growth (≈10 years old) white spruce and poplar. Both neosol and paleosols are classified as Dystric Brunisols.

F-H	6	Very dark greyish brown (10 YR 3/2, d); very dark brown (10 YR 2/2, m); partially decomposed fibrous; organic matter; abundant medium and fine roots; abrupt slightly wavy boundary; 5-7 cm thick; pH = 6.4
Ah	0-5	Greyish-brown (10 YR 5/2, d); dark greyish brown (10 YR 4/2, m); sandy loam; weak fine crumb; plentiful fine rootlets; few fine vesicular pores; gradual smooth boundary
Bm	5-20	Yellowish-brown (10 YR 5/4, d); greyish-brown (10 YR 4/3, m); sandy loam; mostly fine granular to weakly developed, medium subangular blocky; friable; few rootlets; clear, wavy boundary except where broken by irregularly shaped small sand wedges; 13-20 cm thick; pH = 5.0; O.M. = 0.5%
II Bm	20-48	Yellowish-brown (10 YR 6/4, d); brown (10 YR 5/3, m); sandy loam; amorphous; friable very fine roots; few fine and medium pores; abundant stones; clear, smooth boundary; 17-20 cm thick; pH = 4.9; O.M. = 1.0%
II BC	48-67	Greyish-brown (10 YR 5/2, d); dark grey (10 YR 4/1, m); sandy loam; amorphous, firm; very gravelly; diffuse boundary; 18-20 cm thick; pH = 5.4; O.M. = traces
III C	67+	Greyish-brown (10 YR 5/2, d); dark grey (10 YR 4/1, m); sandy loam; amorphous; very firm; very stony; pH = 6.4

SOIL PROFILE IN SITE 6: The site is located on a well-drained, flat-lying McConnell outwash surface. The natural vegetation consists of spruce and poplar. Both neosol and paleosol are classified as Dystric Brunisols.

F-H	2.0-0.0	Dark brown (10 YR 3/3, d); very dark brown (10 YR 2/2, m); partially decomposed organic matter; fibrous; abundant medium and fine roots; clear, wavy boundary; 3-5 cm thick; pH = 5.8
Bm	0.0-12.5	Yellowish-brown (10 YR 5/4, d); dark yellowish brown (10 YR 4/4, m); loamy sand; single grained to amorphous (m); friable; few fine roots; gradual boundaries; smooth, 11-14 cm thick; pH = 4.9; O.M. = 2.2%
II Bm	12.5-21	Yellowish-brown (10 YR 5/4, d); dark yellowish brown (10 YR 4/4, m); loamy; sandy; single grained; friable; very few fine roots; abrupt, clear boundary; 5-7 cm thick; pH = 5.4; O.M. = 0.9%
II C	21-42	Dark greyish brown (10 YR 4/2, d); very dark greyish brown (10 YR 3/2, m); very stony loamy sand; single grained; clear, smooth boundary; 18-24 cm thick; very stony; pH = 6.2; O.M. = 0.5%
III C	42+	Dark greyish brown (10 YR 4/2, d); very dark greyish brown (10 YR 3/2, m); very stony loamy sand; single grained; pH = 6.2; O.M. = traces

ILLUSTRATIONS

Tables 1-21, Figures 3-22

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Ahe	0.0-13.5	5.25	79.06	8.69	0.66	0.03	3.68	2.00	0.71	1.01	0.88	3.02	99.82	0.48	0.30	0.78
Bm1	13.5-18.5	3.85	76.02	9.88	0.65	0.03	4.08	2.00	0.71	1.04	0.91	3.17	98.49	0.29	0.38	0.67
II Bt 1	18.5-46.0	26.02	83.12	7.08	0.33	0.03	3.57	0.71	0.57	0.43	0.25	3.30	99.39	0.20	0.28	0.48
II Bt 2	46.0-117	31.26	84.15	6.57	0.31	0.03	3.43	0.57	0.61	0.42	0.26	3.11	99.46	0.23	0.16	0.39
II BC	117-190	25.24	87.04	5.30	0.17	0.02	2.57	0.55	0.60	0.38	0.27	2.37	99.27	0.15	0.12	0.27
II C	190+	26.08	89.23	4.01	0.17	0.02	1.97	0.61	0.58	0.28	0.20	1.88	98.95	0.11	0.10	0.21
sand wedge		3.85	78.53	9.83	0.51	0.02	3.85	2.05	0.79	0.93	0.84	2.67	100.02	0.33	0.22	0.52

GSC

TABLE 1. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed on pre-Reid outwash gravel, site 1

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Ah	0.0- 2.5	9.90														
Bm1	2.5-15.0	9.90	79.84	8.46	0.49	0.04	3.56	1.92	0.90	0.88	0.95	2.82	99.87	0.31	0.30	0.61
Bm2	15.0-40.0	7.03	78.19	9.28	0.48	0.03	3.58	1.98	0.89	0.99	0.97	3.09	99.48	0.22	0.15	0.37
II Bgj	40.0-45.0	26.48	84.29	6.47	0.50	0.04	2.93	1.43	0.91	0.74	0.75	1.59	99.65			
II Bt	45.0-68.0	28.49	85.15	5.07	0.33	0.04	2.78	1.28	1.05	0.48	0.37	2.08	98.63	0.19	0.20	0.39
II BC	68.0-103	28.08	87.81	5.34	0.29	0.02	1.84	0.95	1.08	0.31	0.19	1.43	99.26	0.20	0.12	0.32
II C	103-123	26.74	88.06	5.31	0.30	0.02	1.57	0.97	1.19	0.28	0.17	1.09	98.96	0.13	0.09	0.22
III C	123+	35.57	87.12	6.30	0.33	0.02	1.87	1.09	1.21	0.36	0.24	1.47	100.01	0.17	0.07	0.24
sand wedge		8.59	76.06	11.97	0.67	0.02	3.99	1.38	0.83	0.85	1.16	1.72	98.65	0.10	0.20	0.30

GSC

TABLE 2. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed on pre-Reid outwash gravel, site 2

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Bm1	0.0-14.5	8.24	80.17	7.62	0.48	0.07	3.68	1.53	0.61	0.79	0.91	2.98	98.84	0.74	0.28	1.01
Bm2	14.5-30.0	8.69	80.97	7.09	0.50	0.06	4.34	1.35	0.74	0.86	0.78	2.50	90.19	0.98	0.28	0.76
II Bm1	30.0-49.0	38.46	83.96	5.14	0.49	0.06	3.71	1.48	0.65	0.71	0.68	2.16	99.04	0.23	0.15	0.38
II Bm2	49.0-68.0	33.94	86.52	5.01	0.27	0.03	2.85	1.04	0.60	0.66	0.59	1.81	99.38	0.28	0.19	0.47
II BC	68.0-93.0	32.20	86.78	4.31	0.33	0.02	2.71	1.94	0.58	0.50	0.24	1.80	99.21	0.39	0.32	0.71
II Ck	93.0+	37.36	87.04	4.20	0.28	0.05	2.69	1.97	0.57	0.58	0.45	1.47	99.30	0.20	0.12	0.32

GSC

TABLE 3. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed in Reid outwash gravel, site 3

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Ahe	0.0-2.5	3.84	76.53	9.17	0.51	0.03	3.92	2.29	0.81	0.91	1.03	3.98	99.18	0.50	0.16	0.66
Bm	2.5-17.0	3.37	75.51	10.63	0.66	0.03	3.79	2.30	0.88	1.11	1.17	3.47	99.55	0.49	0.10	0.59
II Bm	17.5-40.0	20.76	76.06	10.17	0.48	0.02	4.99	2.38	0.95	0.98	0.81	2.62	99.46	0.32	0.16	0.46
II BC	40.0-66.0	15.77	79.26	8.33	0.39	0.03	4.00	2.36	0.91	0.86	0.75	2.09	98.98	0.41	0.20	0.61
II C	66.0+	17.47	78.94	8.97	0.38	0.06	3.71	2.23	0.87	1.12	1.23	2.08	99.59	0.20	0.08	0.28

GSC

TABLE 4. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed on Reid till, site 5

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Ah	0-5	58.55	90.31	3.23	0.31	0.01	1.29	1.33	0.41	0.32	0.37	2.08	99.66	0.29	0.11	0.40
Bm	5-20	51.22	89.32	3.62	0.33	0.01	1.89	1.24	0.50	0.41	0.37	1.79	99.48	0.21	0.09	0.30
II Bm	20-48	19.99	89.69	3.89	0.36	0.02	1.94	1.01	0.55	0.48	0.30	1.53	99.77	0.23	0.14	0.37
II BC	48-67	23.23	87.48	4.19	0.37	0.03	2.55	1.25	0.58	0.55	1.16	1.41	99.55	0.29	0.13	0.42
III C	67+	42.25	88.29	3.99	0.37	0.03	2.69	1.27	0.57	0.46	0.67	1.30	99.64	0.22	0.07	0.29

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TABLE 5. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed on McConnell till, site 4

Horizon	Depth in cm	Total Quartz	Elemental Analysis in Per Cent											Per cent Oxalate Extractable		
			SiO_2	Al_2O_3	TiO_2	MnO	Fe_2O_3	Na_2O	K_2O	MgO	CaO	L.O.I.	Total	Fe	Al	Σ (Al + Fe)
Bm	0-12.5	20.50	84.26	6.19	0.50	0.03	3.43	1.04	0.59	0.68	0.49	2.68	99.89	0.17	0.23	0.40
II Bm	12.5-21.0	40.60	88.03	4.16	0.27	0.02	3.15	0.84	0.54	0.51	0.32	1.72	99.50	0.17	0.07	0.24
II C	21.0-42.0	40.63	89.17	3.98	0.15	0.02	2.28	1.03	0.54	0.45	0.25	1.10	98.97	0.19	0.09	0.28
III C	42.0+	43.33	89.32	3.68	0.17	0.03	1.85	0.89	0.62	0.50	0.95	1.37	99.38	0.18	0.05	0.23

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TABLE 6. Elemental analysis, per cent quartz in four sand fractions (2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and 0.250-0.125 mm) and oxalate extractable iron and aluminum of a soil profile developed on McConnell outwash gravel, site 6

PARENT MATERIAL	AGE OF PALEOSOLS							
	Pre-Reid Site 1		Pre-Reid Site 2		Reid		McConnell	
	Horizon	SiO_2/R_2O_3 of Horizon / SiO_2/R_2O_3 of p.m.	Horizon	SiO_2/R_2O_3 of Horizon / SiO_2/R_2O_3 of p.m.	Horizon Reid	SiO_2/R_2O_3 of Horizon / SiO_2/R_2O_3 of p.m.	Horizon	SiO_2/R_2O_3 of Horizon / SiO_2/R_2O_3 of p.m.
GRAVEL	II Bt1	0.5	II Bgj	0.7	II Bm1	0.8		
	II Bt2	0.6	II Bt	0.8	II Bm 2	0.8	II Bm	0.8
	II Bc	0.7	II BC	1.0	II BC	1.0	II C	0.9
	II C	1.0	II C	1.0	II Ck	1.0	III C	1.0
TILL					II Bm	0.8	II Bm	1.1
					II Bc	1.0	II BC	1.1
					II C	1.0	III C	1.0

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TABLE 7. Ratio of SiO_2/R_2O_3 of the horizon to SiO_2/R_2O_3 of parent material in the $<2\mu m$ fraction of the paleosols developed on gravel and till surfaces of pre-Reid, Reid and McConnell ages

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Ahe	0.0-13.5	43.03	19.43	11.45	1.30	0.35	0.05	2.03	1.41	0.35	1.10	0.45	5.00	4.50	5.90	98.35
Bm1	13.5-18.5	44.86	20.15	11.77	1.70	0.28	0.06	2.05	1.70	0.35	1.10	0.45	4.30	4.80	5.50	99.07
II Bt1	18.5-46.0	44.85	20.63	12.62	1.50	0.14	0.04	1.32	0.26	1.57	1.70	0.22	2.60	4.60	6.90	98.95
II Bt 2	46.0-117	44.82	19.92	12.01	1.20	0.16	0.06	1.31	0.31	1.54	1.20	0.22	3.20	5.60	7.20	98.75
II BC	117-190	46.01	19.81	12.04	1.20	0.16	0.06	1.33	0.25	1.59	1.40	0.22	3.40	4.80	6.80	99.07
II C	190+	46.07	19.89	12.33	1.00	0.18	0.06	1.42	0.25	1.67	1.40	0.33	3.60	4.60	7.40	100.20
sand wedge		44.01	18.92	11.72	1.30	0.20	0.05	1.91	1.60	0.19	1.70	0.11	5.90	3.40	7.50	98.51

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TABLE 8. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on pre-Reid outwash gravel, site 1

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Bm1	2.5-15.0	44.61	19.42	10.31	1.20	0.24	0.04	2.31	2.33	0.30	1.60	0.78	2.90	6.60	7.30	99.94
Bm2	15.0-40.0	45.43	18.95	12.03	1.20	0.13	0.06	2.53	2.10	0.32	2.20	0.78	3.00	5.00	5.50	99.20
II Bgj*	40.0-45.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
II Bt	45.0-68.0	45.44	20.17	13.27	1.00	0.08	0.08	1.75	1.52	0.34	2.20	0.45	2.90	3.60	6.30	99.10
II BC	68.0-103	44.65	19.52	12.68	0.84	0.09	0.06	1.52	1.50	0.14	2.20	0.33	4.70	4.00	6.10	98.43
II C	103-123	45.01	20.43	12.65	0.67	0.08	0.06	1.54	1.70	0.14	2.40	0.33	3.00	4.10	6.50	98.61
III C	123+	44.63	18.31	14.07	0.84	0.18	0.11	2.45	1.80	0.27	2.20	0.67	4.00	4.20	4.70	98.43
sand wedge		46.83	20.62	10.30	1.30	0.02	0.03	3.50	1.30	1.76	1.80	0.45	3.00	2.80	6.00	99.76

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TABLE 9. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on pre-Reid outwash gravel, site 2

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Bm1	0.0-14.5	45.61	19.02	11.74	0.84	0.06	0.12	2.22	2.03	0.24	1.30	0.67	3.40	5.10	5.90	98.25
Bm2	14.5-30.0	44.83	19.43	14.32	0.84	0.04	0.11	2.23	1.95	0.22	1.70	0.78	2.20	5.30	5.60	99.55
II Bm1	30.0-49.0	42.22	19.47	16.93	0.84	0.11	0.22	2.35	1.52	0.59	3.10	1.00	2.70	4.00	4.00	99.05
II Bm2	49.0-68.0	45.24	20.68	11.25	0.84	0.18	0.07	3.16	1.34	0.27	2.80	0.56	2.10	3.70	6.20	98.39
II BC	68.0-93.0	45.83	20.32	11.47	0.84	0.18	0.08	3.12	1.21	0.22	3.00	0.56	4.00	3.00	5.10	98.93
II Ck	93.0+	43.85	20.41	12.90	0.67	0.20	0.15	2.74	1.28	0.24	3.20	0.56	3.30	4.00	5.80	99.30

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TABLE 10. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on Reid outwash gravel, site 3

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Ahe	0.0-2.5	45.22	18.33	12.01	1.80	0.11	0.08	2.32	4.52	1.10	1.10	0.45	4.40	4.00	3.70	99.04
Bm	2.5-17.0	43.49	19.65	13.84	1.70	0.35	0.09	2.34	1.86	0.35	1.20	0.45	2.70	7.90	3.10	99.02
II Bm	17.0-40.0	43.28	20.19	12.65	1.30	0.27	0.08	23.9	1.54	0.30	2.00	0.45	2.60	4.80	6.30	98.15
II BC	40.0-66.0	44.45	20.58	11.49	0.84	0.26	0.08	2.35	1.18	0.35	2.20	0.45	3.40	4.40	6.30	98.34
II C	66.0+	44.43	20.11	13.44	0.75	0.23	0.11	2.51	1.01	0.41	3.10	0.45	2.70	4.40	6.40	100.05

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TABLE 11. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on Reid till, site 5

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Ah	0.0-5.0	58.51	16.92	6.71	1.70	0.11	0.05	1.81	2.20	0.40	1.50	0.84	2.50	2.10	4.60	99.95
Bm	5.0-20.0	56.23	16.44	8.33	1.50	0.23	0.05	2.33	1.20	0.86	1.70	1.12	2.60	2.70	4.10	99.39
II Bm	20.0-48.0	49.25	19.16	10.94	1.00	0.32	0.06	2.12	1.10	0.35	2.80	0.78	2.20	3.90	4.90	98.88
II BC	48.0-67.0	52.83	17.73	9.72	1.00	0.30	0.08	2.14	1.20	0.73	3.20	0.78	2.10	3.10	5.10	100.01
III C	67+	57.02	16.35	8.61	1.30	0.40	0.10	2.15	0.50	0.59	3.40	0.78	0.20	1.90	6.10	99.40

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TABLE 12. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on McConnell till, site 4

Horizon	Depth in cm	Elemental Analysis in Per Cent												Loss on ignition		Total
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	105°–350°C	350°–1000°C	
Bm	0.0-12.5	48.22	13.41	8.67	1.20	0.20	2.20	2.11	5.40	1.00	1.20	3.23	1.50	3.40	7.50	99.24
II Bm	12.5-21.0	60.03	13.43	8.92	0.50	0.72	0.06	1.97	3.30	0.67	2.20	1.12	1.00	2.90	3.10	99.92
II C	21.0-42.0	45.86	18.92	12.31	0.50	0.72	0.50	2.13	1.50	0.43	2.80	1.23	0.60	4.50	6.30	98.30
III C	42.0+	46.23	18.96	12.34	0.33	0.69	0.52	1.94	1.70	0.38	2.80	1.45	0.80	5.70	4.60	98.44

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TABLE 13. Elemental analysis of the Ca-saturated <2μm fraction of a soil profile developed on McConnell outwash gravel, site 6

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Ahe	0.0-13.5	45.08	24.22	14.58	1.72	0.45	0.06	2.61	1.81	0.28	1.10	0.59	7.50	100.00
Bm	13.5-18.5	44.73	24.79	14.43	2.07	0.35	0.08	2.53	2.20	0.25	1.00	0.57	7.00	100.00
II Bt1	18.5-46.0	45.63	23.67	14.76	1.84	0.16	0.05	1.54	0.33	1.86	1.80	0.26	8.10	100.00
II Bt2	46.0-117.0	48.21	22.95	13.74	1.46	0.19	0.08	1.56	0.40	1.77	1.30	0.24	8.10	100.00
II BC	117.0-190.0	48.50	22.96	13.83	1.37	0.22	0.08	1.35	0.40	1.84	1.50	0.15	7.80	100.00
II C	190+	48.93	22.64	13.77	1.33	0.18	0.07	1.52	0.28	1.80	1.50	0.18	7.80	100.00
sand wedge		49.34	22.02	13.60	1.10	0.20	0.07	1.61	0.27	1.80	1.40	0.39	8.20	100.00

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TABLE 14. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on pre-Reid drift, site 1

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Bm1	2.5-15.0	45.11	22.99	13.65	1.48	0.24	0.05	2.82	2.80	0.28	1.60	0.98	8.00	100.00
Bm2	15.0-40.0	43.08	22.97	15.55	1.45	0.17	0.08	3.22	2.70	0.30	2.40	0.98	7.10	100.00
II Bgj*	40.0-45.0													
II Bt	45.0-68.0	43.25	23.96	16.27	1.13	0.10	0.10	2.17	2.00	0.29	2.50	0.53	7.70	100.00
II BC	68.0-103.0	45.21	23.64	15.68	0.92	0.11	0.07	1.89	2.00	0.17	2.50	0.31	7.50	100.00
II C	103.0-123.0	46.30	23.48	14.89	0.71	0.09	0.07	1.84	1.90	0.16	2.60	0.36	7.60	100.00
III C	123.0+	44.51	22.39	16.24	0.96	0.23	0.14	3.06	1.30	0.33	2.50	0.74	7.60	100.00
sand wedge		48.08	22.98	11.82	1.38	0.14	0.03	4.02	0.36	2.01	1.80	0.48	6.90	100.00

*Analysis was not carried out

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TABLE 15. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on pre-Reid drift, site 2

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Bm1	0.0-14.5	46.86	22.46	14.49	1.01	0.07	0.15	2.73	2.50	0.26	1.40	0.77	7.30	100.00
Bm2	14.5-30.0	43.12	22.17	17.14	1.06	0.05	0.13	2.65	2.30	0.23	3.00	0.85	6.70	100.00
II Bm1	30.0-49.0	44.52	23.98	13.17	1.03	0.19	0.18	3.46	2.10	0.33	2.90	0.84	7.30	100.00
II Bm2	49.0-68.0	47.29	23.54	11.70	0.98	0.21	0.08	3.62	1.50	0.20	3.00	0.58	7.30	100.00
II BC	68.0-93.0	47.83	22.40	12.76	1.04	0.20	0.09	3.51	1.40	0.08	3.20	0.59	6.90	100.00
II Ck	93.0+	44.52	23.37	15.20	0.79	0.24	0.18	3.25	1.40	0.10	3.50	0.65	6.80	100.00

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TABLE 16. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on Reid outwash gravel, site 3

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Ahe	0.0-2.5	44.79	24.07	15.18	1.32	0.44	0.10	2.96	2.70	1.20	1.00	0.54	5.70	100.00
Bm	2.5-17.0	41.35	24.73	19.07	1.33	0.48	0.12	3.22	2.40	0.22	1.20	0.58	5.30	100.00
II Bm	17.0-40.0	46.26	22.26	14.73	1.57	0.32	0.09	2.73	1.80	0.27	2.00	0.57	7.40	100.00
II BC	40.0-66.0	44.18	24.76	14.16	1.06	0.32	0.10	2.92	1.40	0.38	2.40	0.52	7.80	100.00
II C	66.0+	39.37	23.28	17.51	1.59	0.29	0.14	3.41	1.80	0.42	3.30	0.59	8.30	100.00

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TABLE 17. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on Reid moraine, site 5

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Ah	0.0-5.0	55.86	19.44	7.54	2.16	0.14	0.06	2.34	2.80	0.80	1.60	1.06	6.20	100.00
Bm	5.0-20.0	52.04	20.16	10.26	1.87	0.30	0.06	2.46	2.80	0.91	1.90	1.04	6.20	100.00
II Bm	20.0-48.0	46.87	23.19	13.46	1.54	0.39	0.07	2.67	1.30	0.38	3.20	0.93	6.00	100.00
II BC	48.0-67.0	47.17	22.13	12.52	1.28	0.39	0.10	2.73	1.50	0.81	3.80	0.97	6.60	100.00
III C	67.0+	51.08	19.52	10.78	1.59	0.50	0.12	2.62	0.60	0.61	4.00	0.98	7.60	100.00

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TABLE 18. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on McConnell till, site 4

Horizon	Depth in cm	Elemental Analysis												
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	MgO	CaO	Na_2O	K_2O	BaO	H_2O^+	Total
Bm	0.0-12.5	49.84	15.76	14.07	1.43	0.23	1.59	2.56	2.66	1.12	1.20	2.74	6.80	100.00
II Bm	12.5-21.0	48.63	17.07	15.64	0.76	1.09	0.09	2.66	2.40	0.42	3.10	1.44	6.70	100.00
II C	21.0-42.0	40.87	23.53	15.51	0.90	1.46	0.24	2.63	2.20	0.49	3.20	1.27	7.70	100.00
III C	42.0+	42.78	22.75	14.90	0.61	0.88	0.61	2.62	1.80	0.47	3.40	1.48	7.70	100.00

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TABLE 19. Elemental analysis of the <2μm fraction at 400°C after the removal of quartz and feldspars of a soil profile developed on McConnell outwash gravel, site 6

PARENT MATERIAL	AGE OF PALEOSOLS							
	Pre-Reid Site 1		Pre-Reid Site 2		Reid		McConnell	
	Horizon	K_2O/SiO_2 x10^{-2}	Horizon	K_2O/SiO_2 x 10^{-2}	Horizon	K_2O/SiO_2 x 10^{-2}	Horizon	K_2O/SiO_2 x 10^{-2}
GRAVEL	II Bt 1	2.5	II Bgj		II Bm 1	4.2		
	II Bt 2	1.7	II Bt	3.5	II Bm 2	4.3	II Bm	4.1
	II BC	2.0	II BC	3.6	II Bc	4.3	II C	5.0
	II C	2.0	II Ck	3.6	II Ck	5.0	III C	5.1
TILL					II Bm	2.8	II Bm	4.4
					II BC	3.5	II BC	5.1
					II C	5.3	III C	5.0

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TABLE 20. Ratio of K_2O/SiO_2 in the <2μm fraction at 400°C after the removal of quartz and feldspars of paleosols developed on gravel and till surfaces of pre-Reid, Reid and McConnell ages

PARENT MATERIAL	AGE OF PALEOSOLS															
	Pre-Reid Site 1				Pre-Reid Site 2				Reid				McConnell			
	Horizon	Mica	Expand	Kaol + Chl	Horizon	Mica	Expand	Kaol + Chl	Horizon	Mica	Expand	Kaol + Chl	Horizon	Mica	Expand	Kaol + Chl
GRAVEL	II Bt	21	41	38	II Bgj				II Bm	34	37	29				
	II Bt	15	47	38	II Bt	29	39	32	II Bm	35	36	29	II Bm	36	41	23
	II BC	18	47	35	II BC	31	37	32	II BC	38	37	25	II C	38	29	33
	II C	18	47	35	II Ck	29	38	33	II Ck	41	35	24	III C	41	25	34
TILL									II Bm	23	46	31	II Bm	38	47	15
									II BC	28	38	34	II Bc	45	34	21
									II C	39	21	40	III C	47	23	30

GSC

TABLE 21. Per cent mica, kaolin + chlorite and expandable clay minerals in the <2μm fraction at 400°C after the removal of quartz and feldspars of paleosols developed on gravel and till surfaces of pre-Reid, Reid and McConnell ages

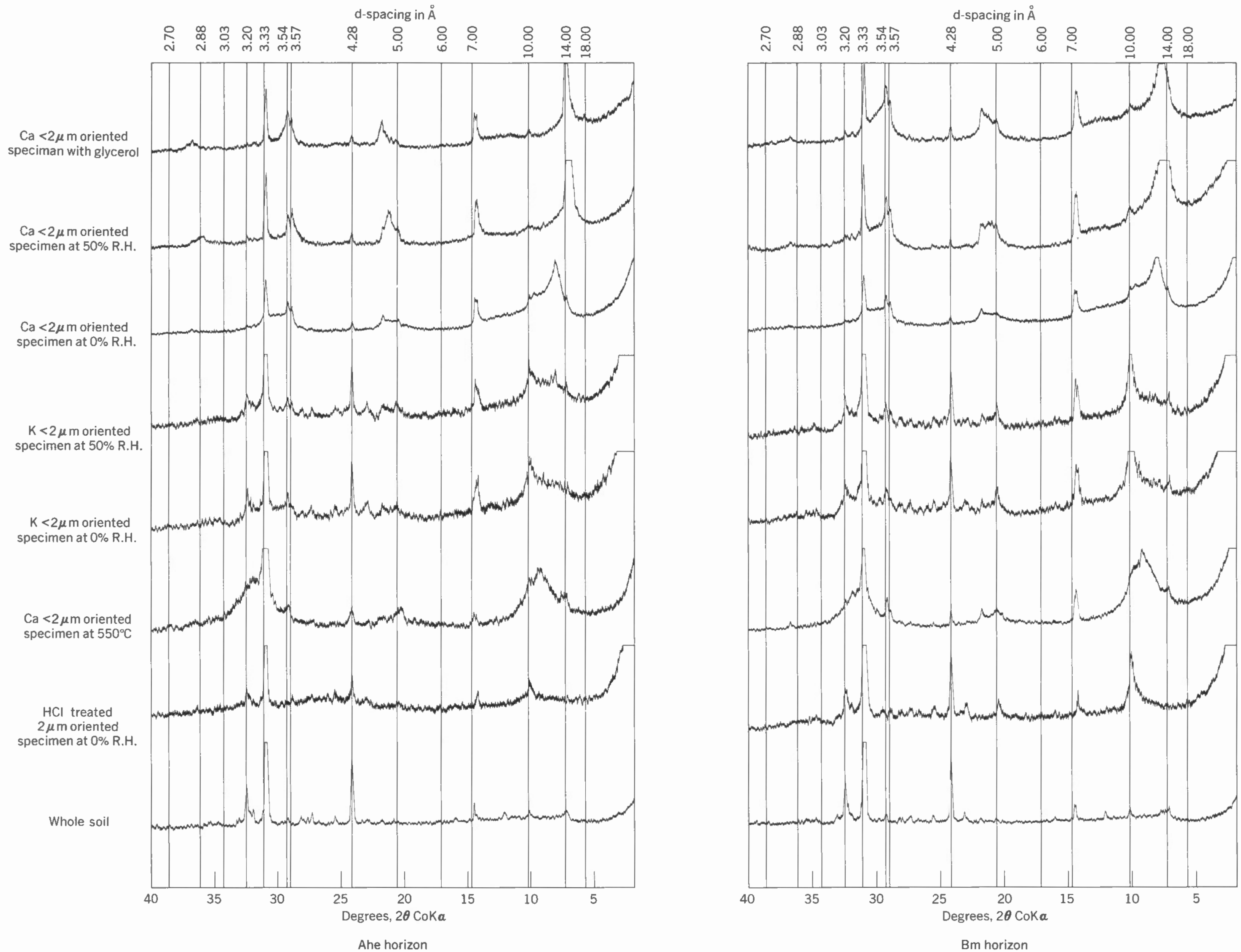

Figure 3. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, Ahe and Bm horizons, site 1.

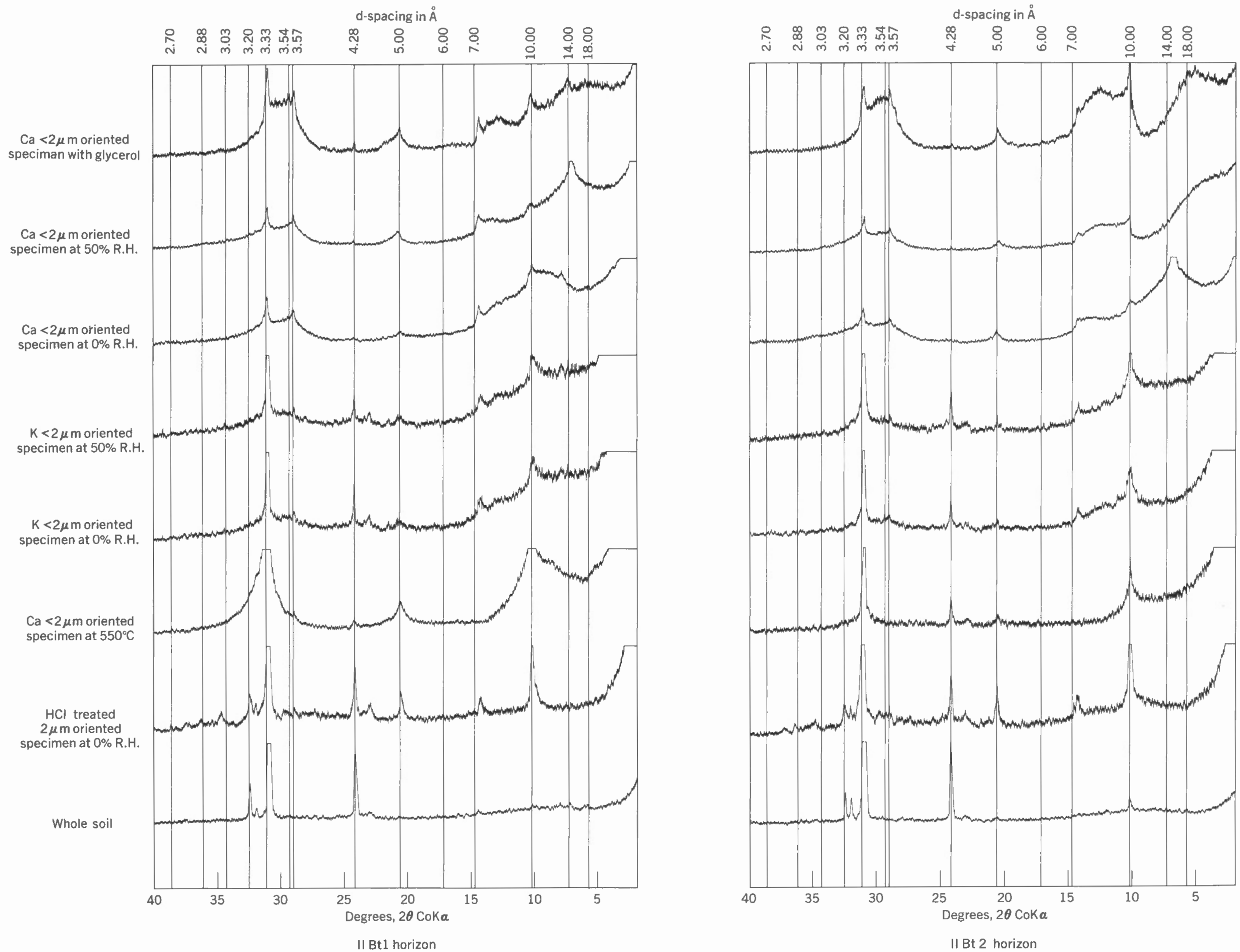

Figure 4. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, II Bt1 and II Bt2 horizons, site 1.

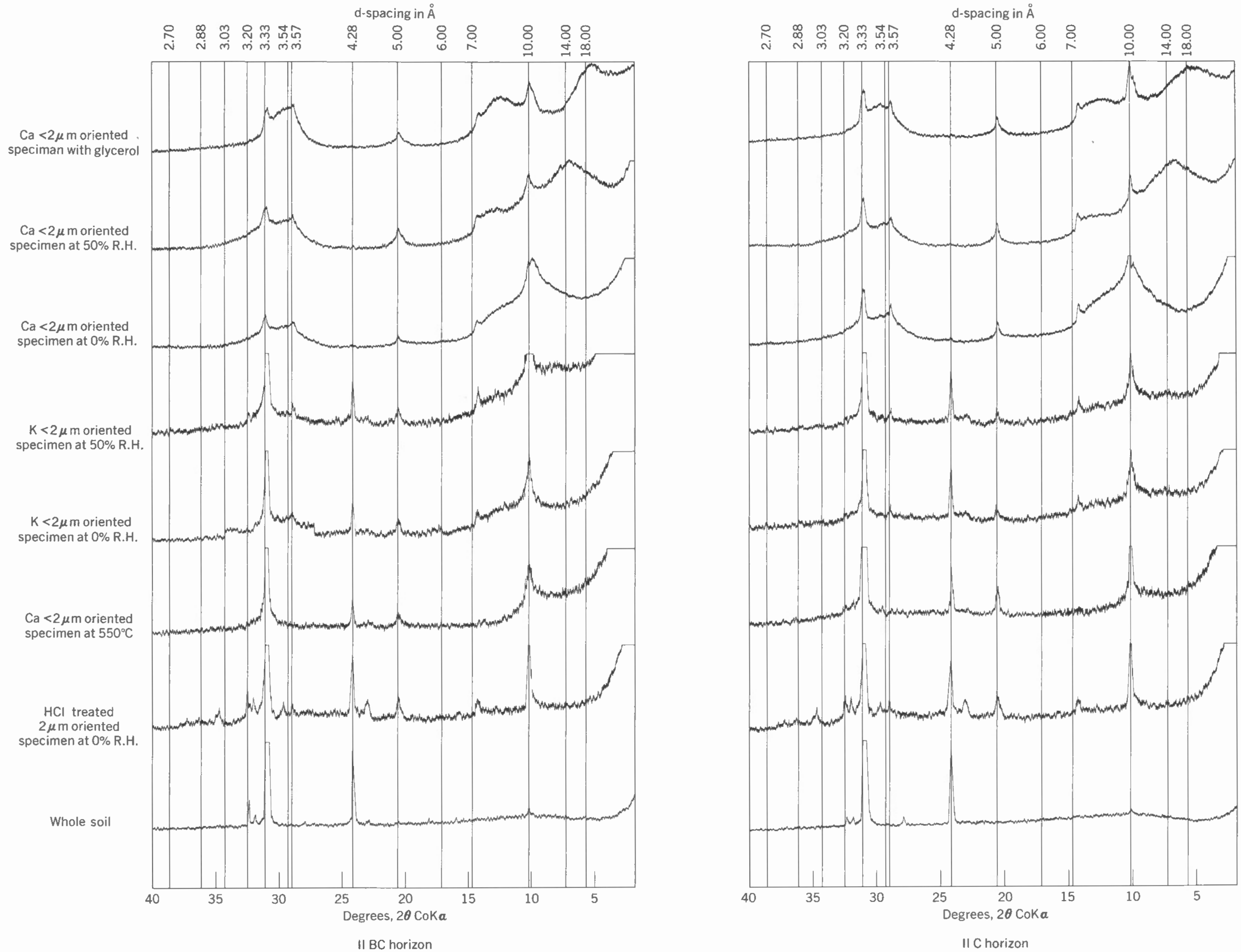

Figure 5. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, II BC and II C horizons, site 1.

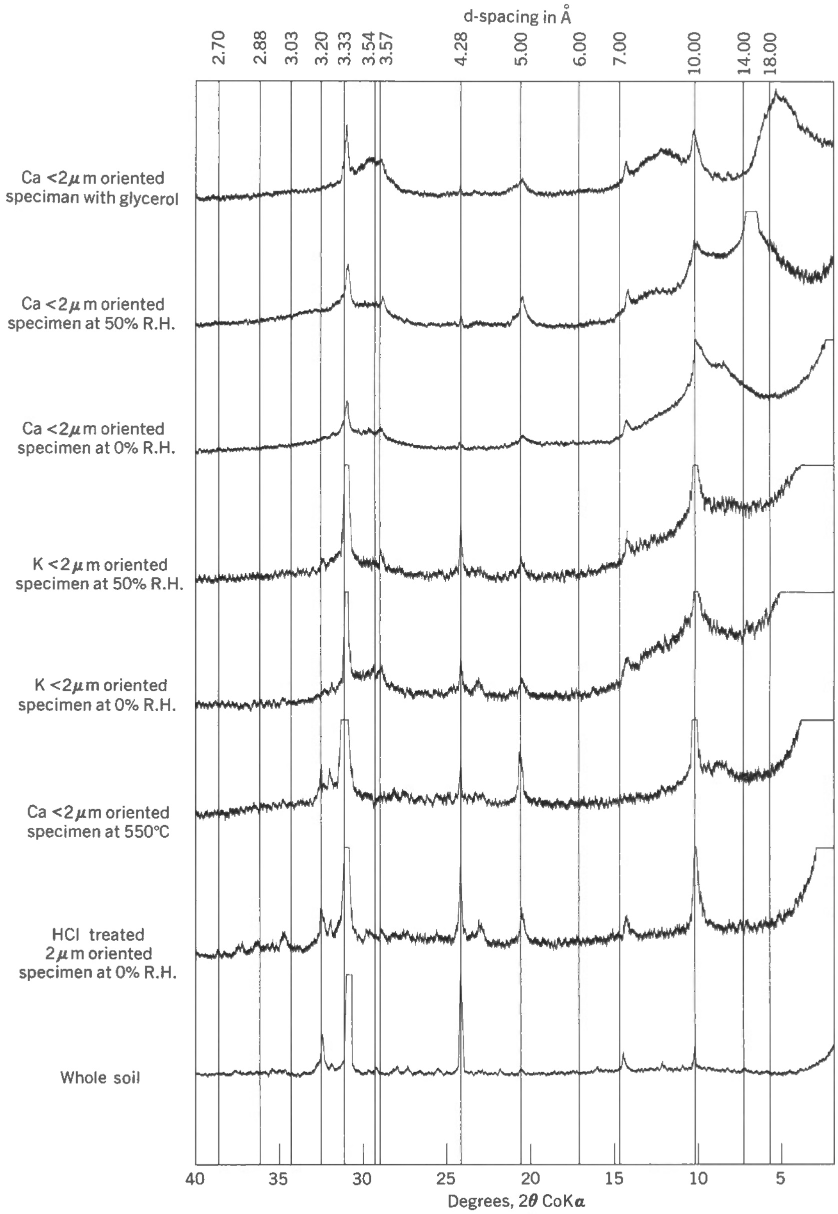

Figure 6. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a sand wedge located in a soil developed on pre-Reid outwash gravel surface, site 1.

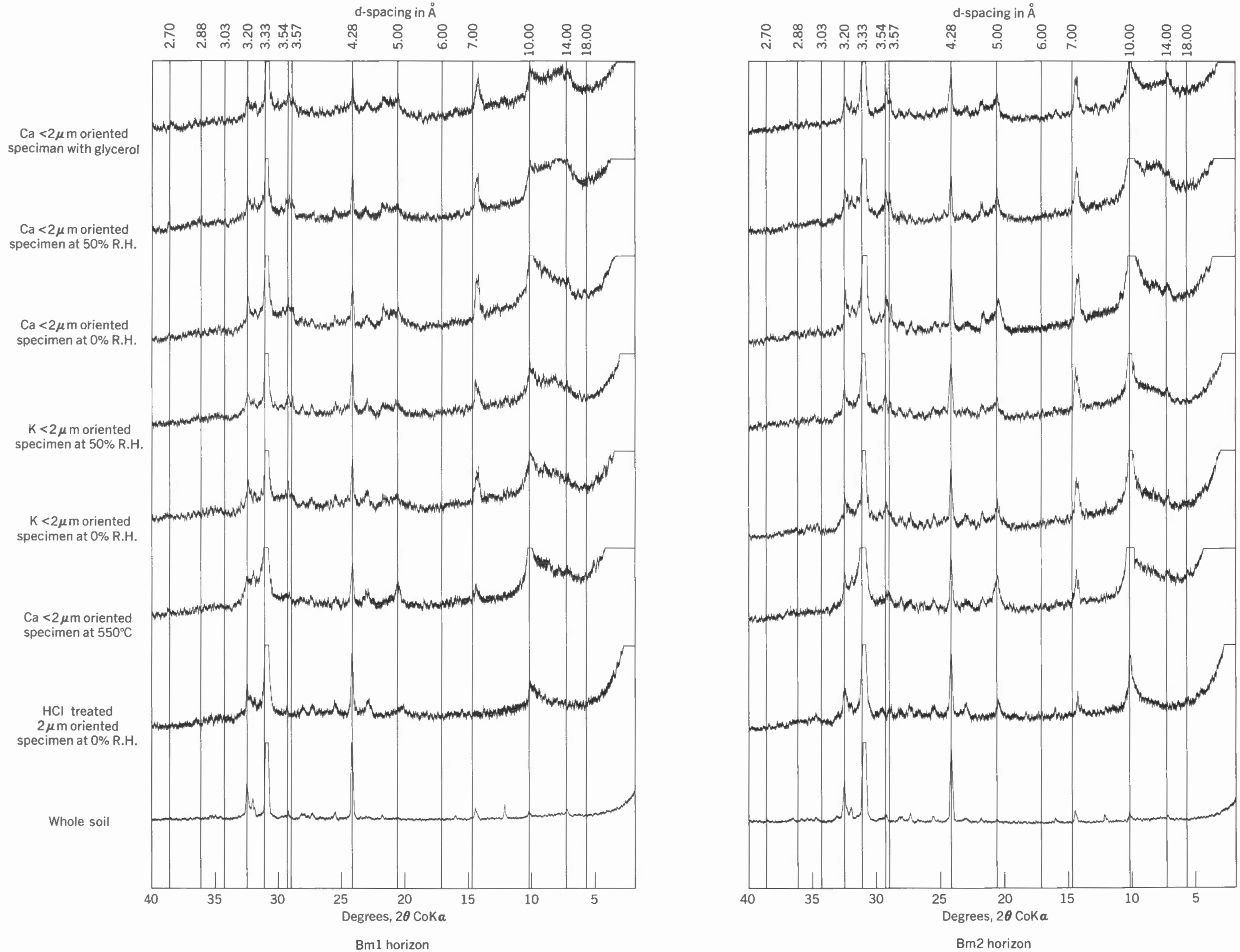

Figure 7. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, Bm1 and Bm2 horizons, site 2.

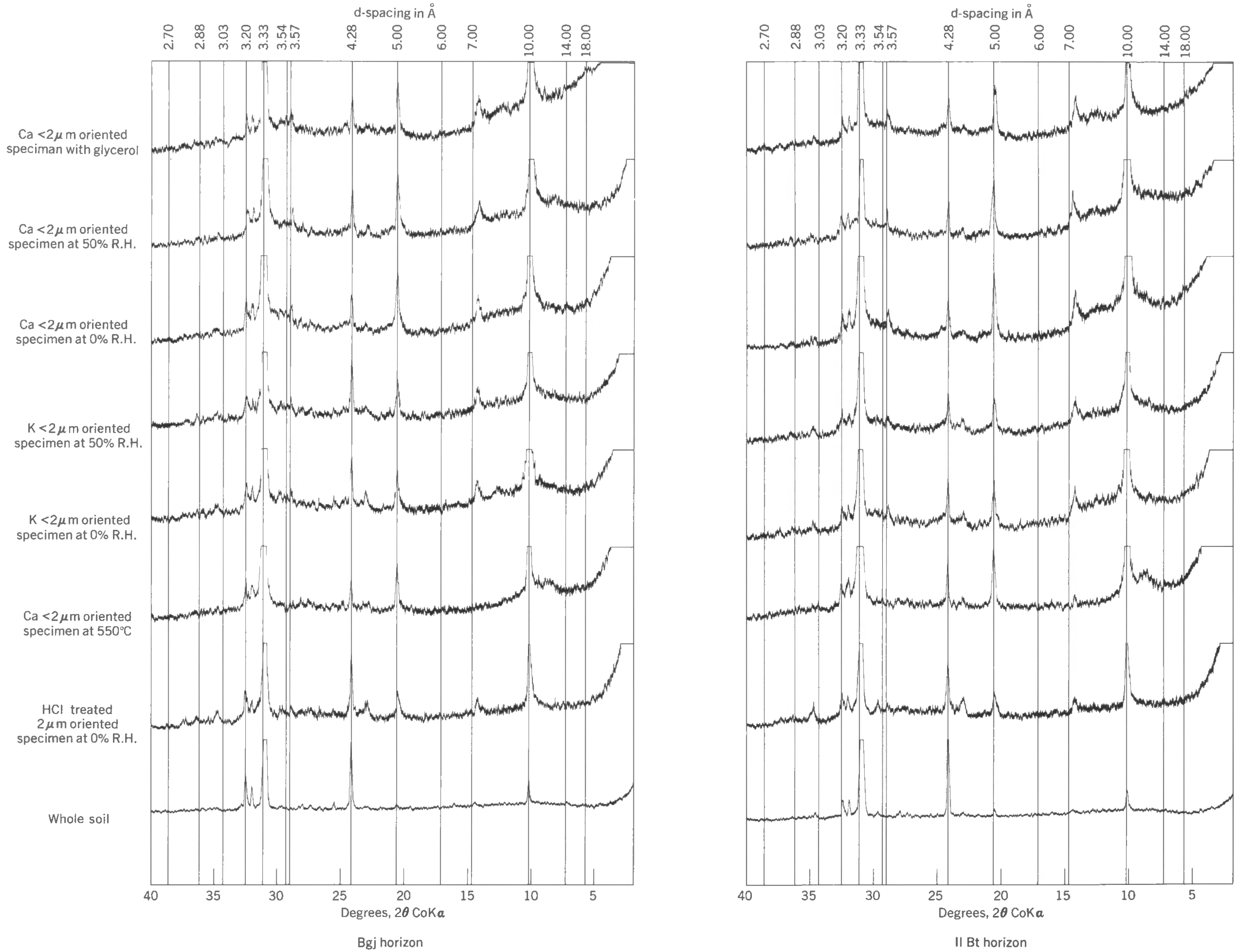

Figure 8. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, Bgj and II Bt horizons, site 2.

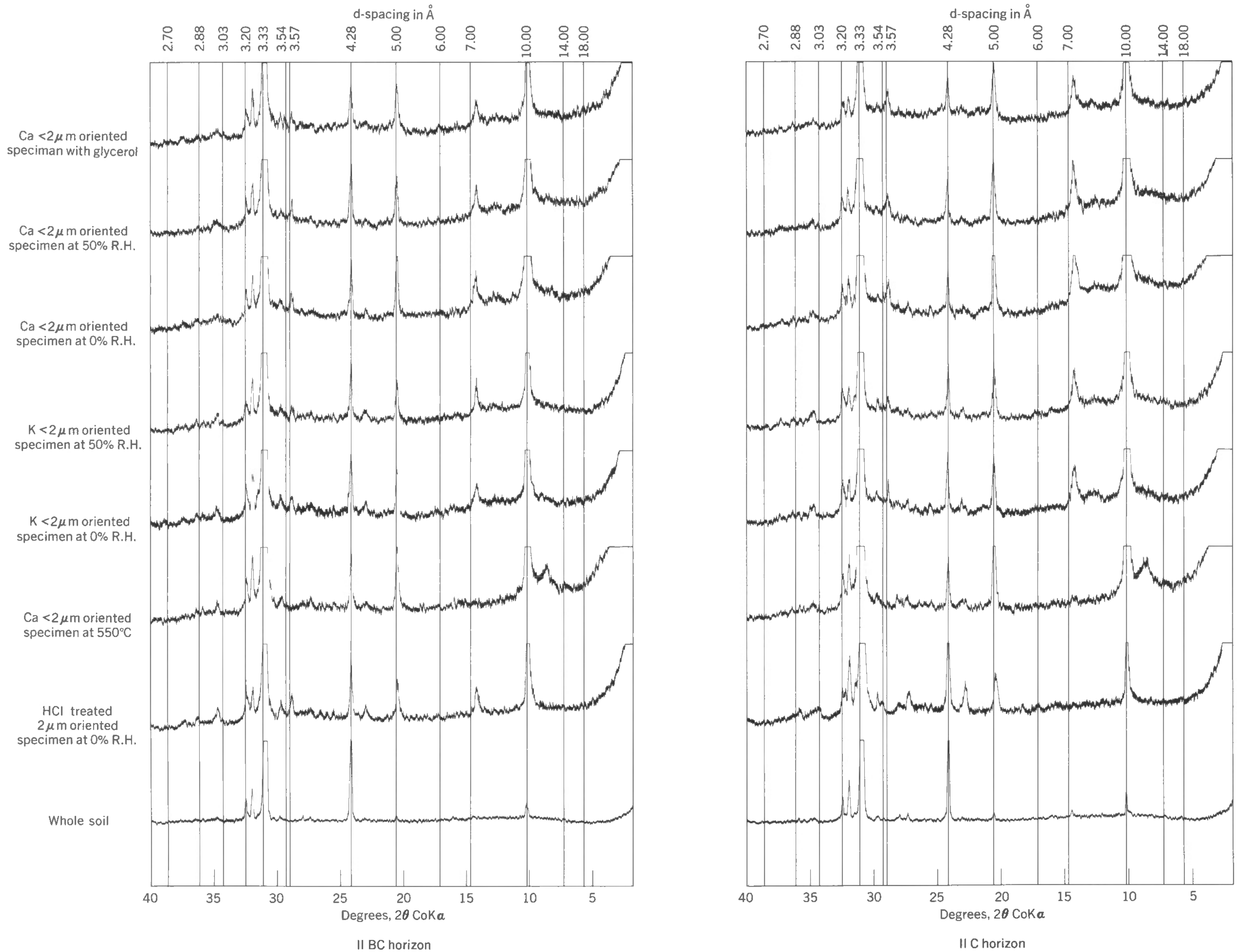

Figure 9. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on a pre-Reid outwash gravel surface, II BC and II C horizons, site 2.

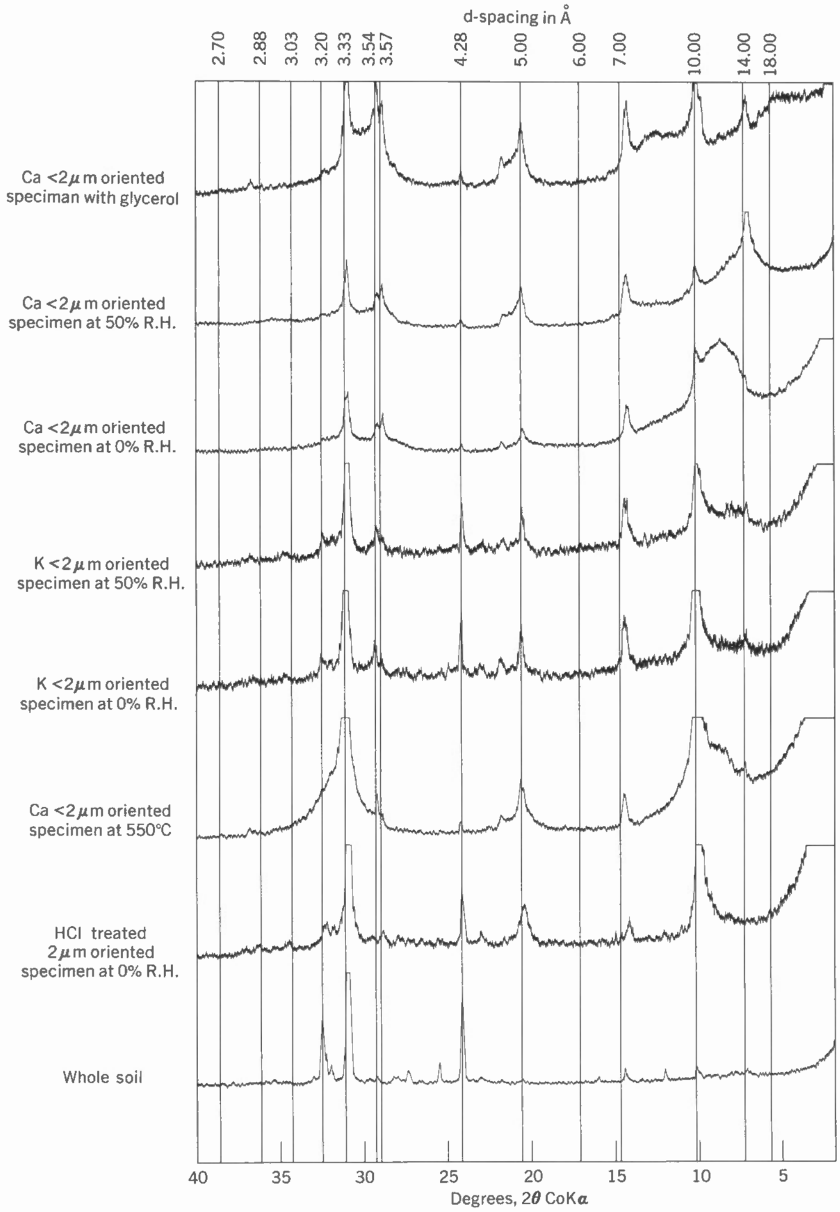

FIGURE 10. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a sand wedge located in a soil developed on pre-Reid outwash gravel surface, site 2

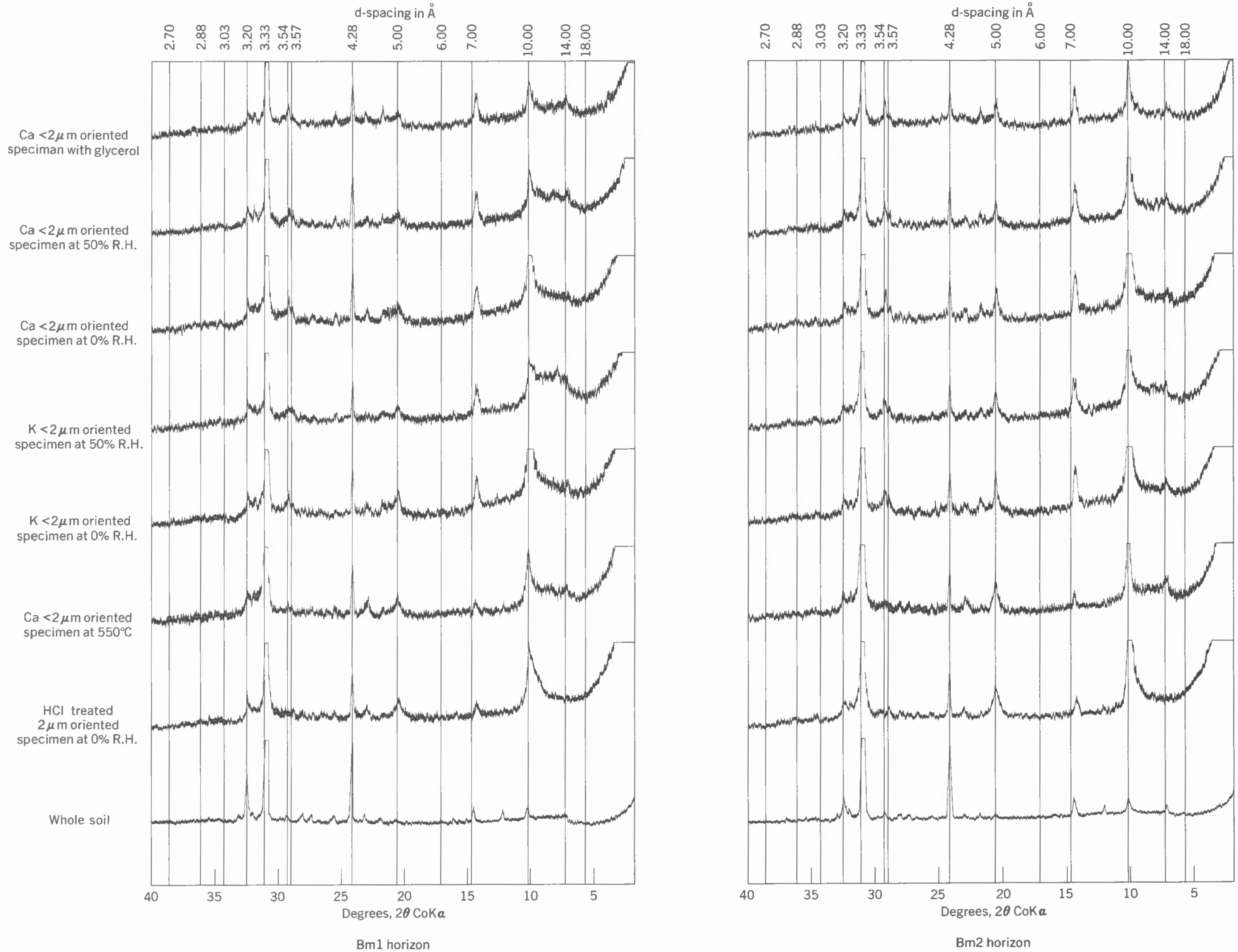

Figure 11. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid outwash gravel surface, Bm1 and Bm2 horizons, site 3.

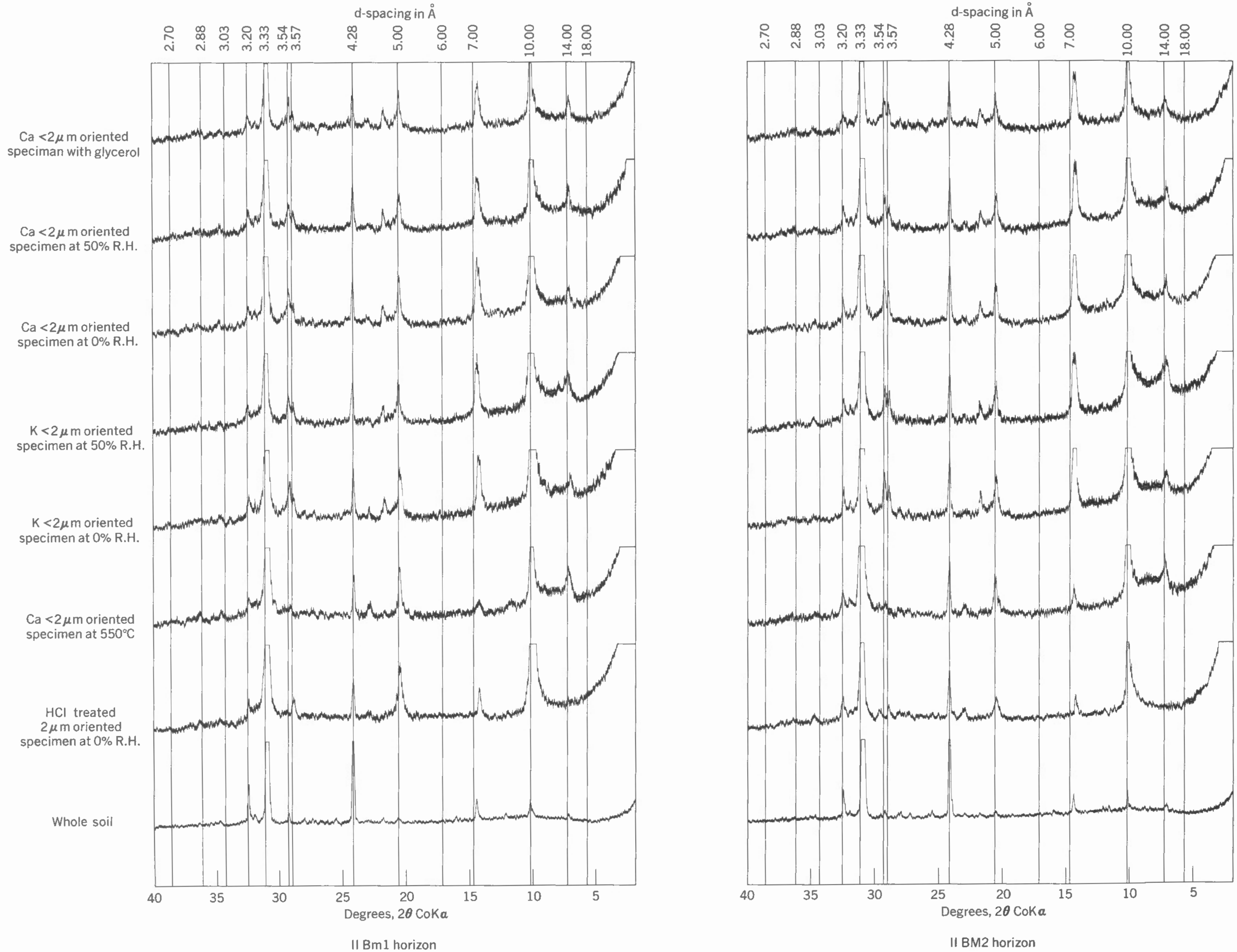

Figure 12. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid outwash gravel surface, II Bm1 and II Bm2 horizons, site 3.

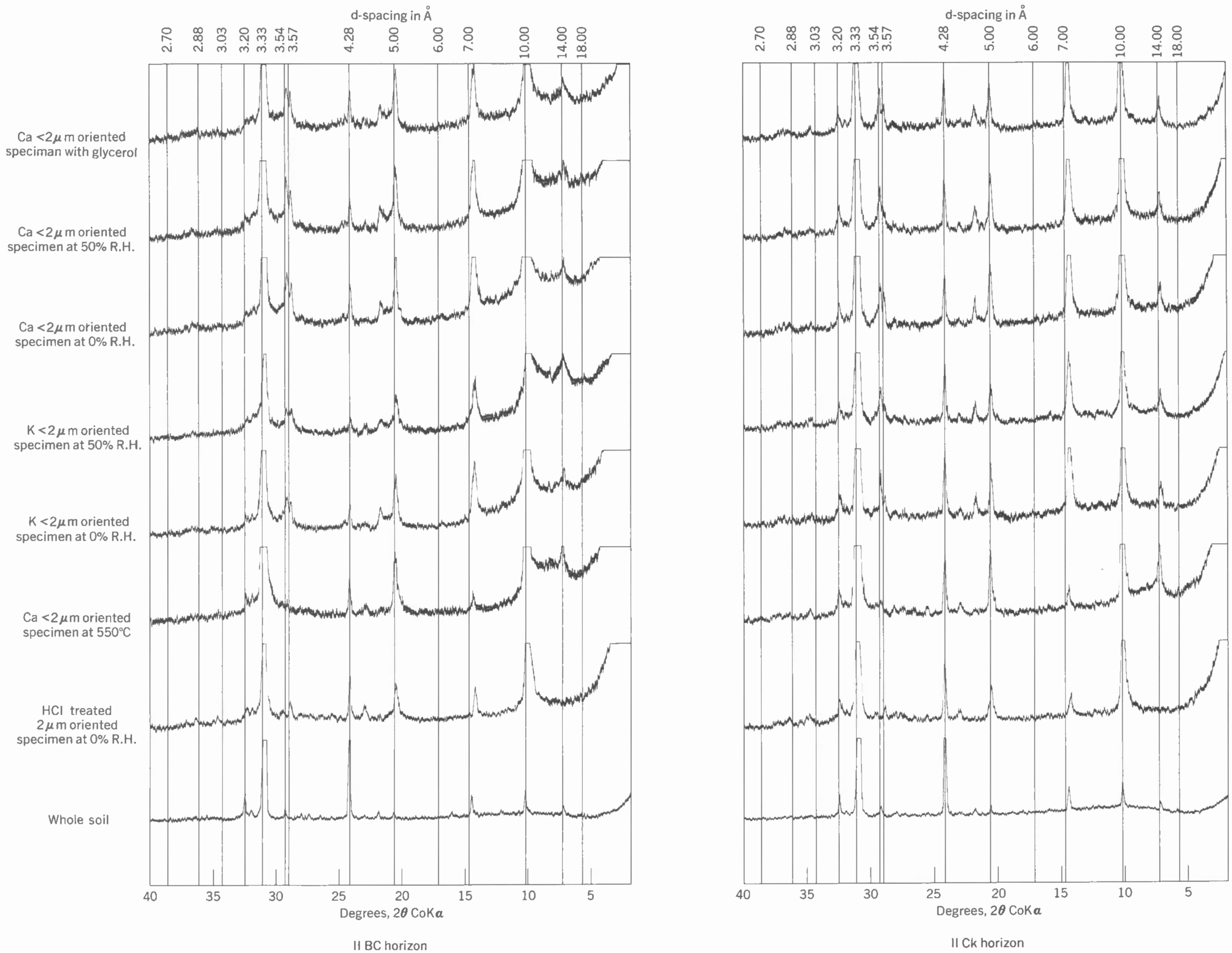

Figure 13. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid outwash gravel surface, II BC and II Ck horizons, site 3.

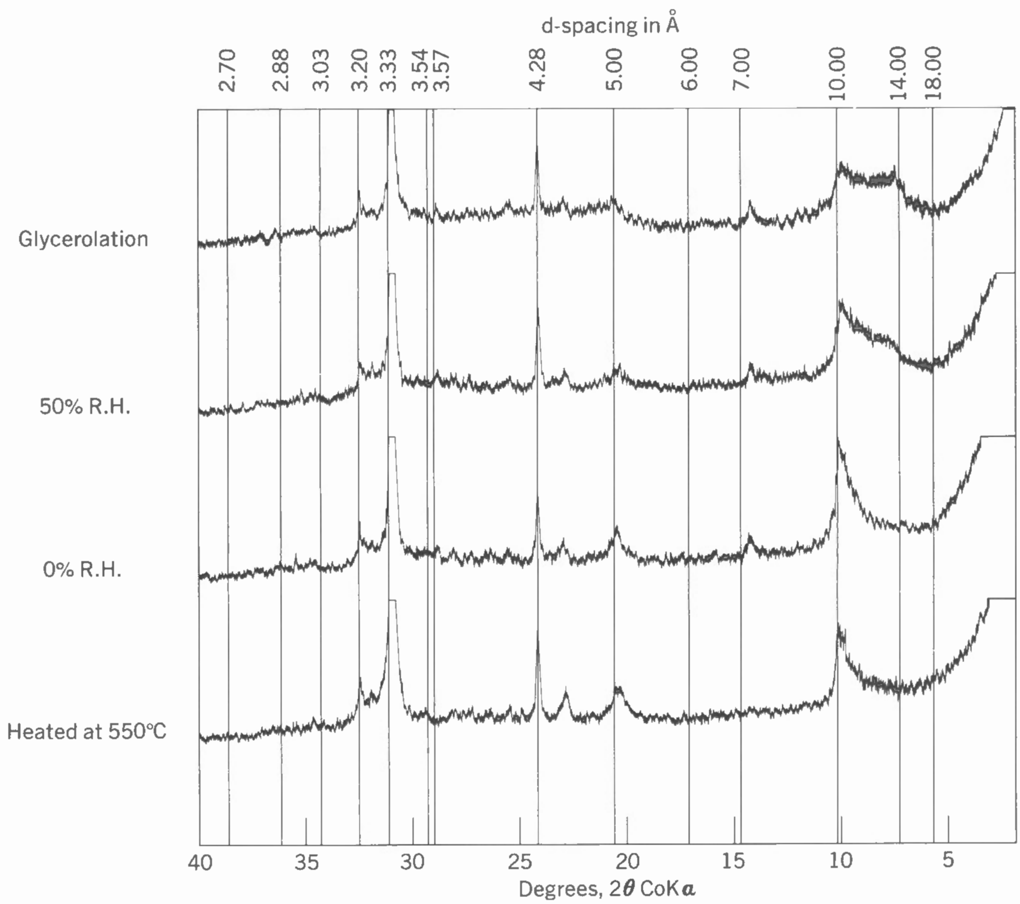

FIGURE 14. X-ray diffractograms of <2μm oriented fraction from the Bm1 horizon after the removal of chlorite by HCl treatment. X-ray patterns of the same specimen under different conditions (a) glycerolation, (b) 50 per cent R.H., (c) 0 per cent R.H., and (d) heat treatment at 550°C for two and one-half hours

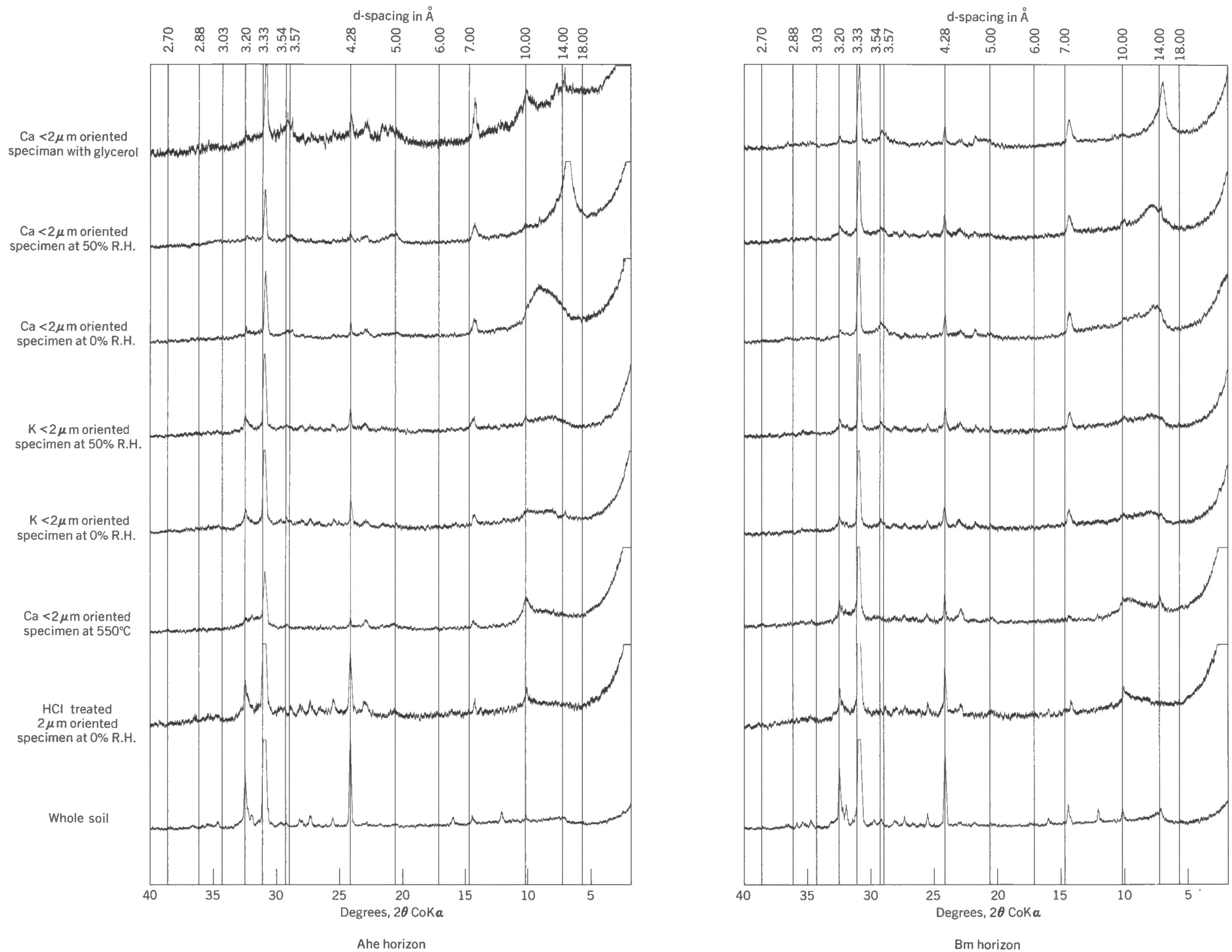

Figure 15. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid till, Ahe and Bm horizons, site 5.

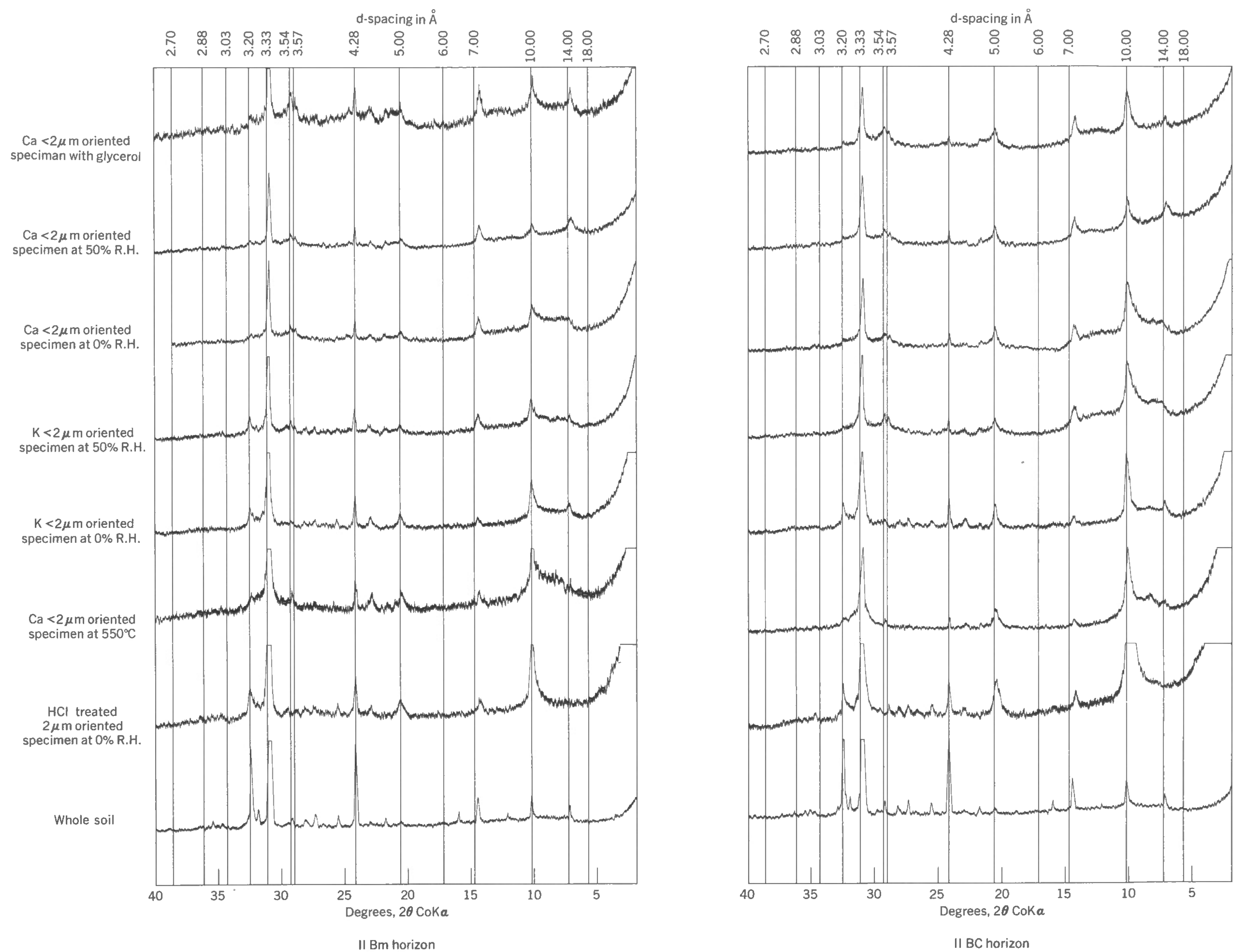

Figure 16. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid till, II Bm and II BC horizons, site 5.

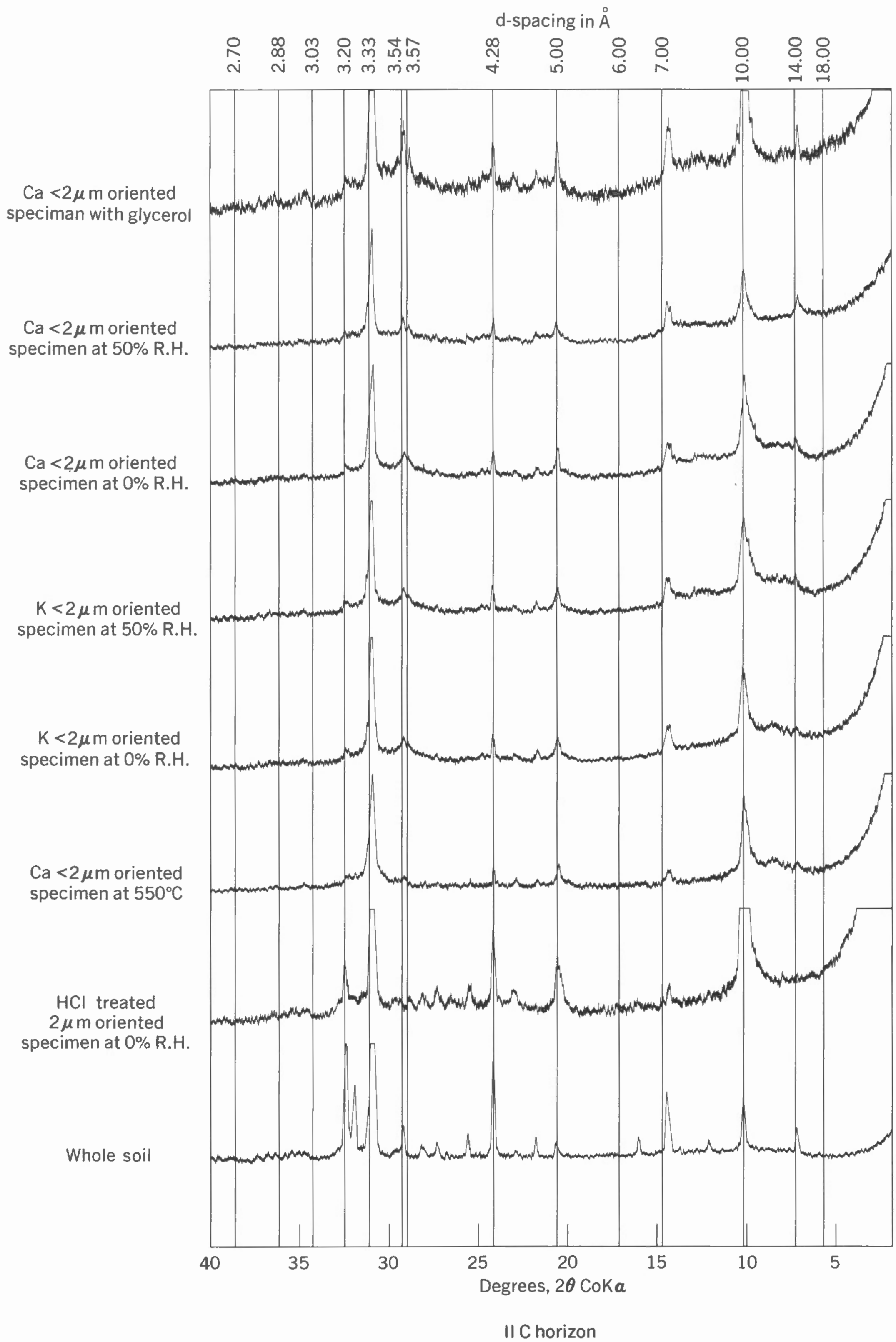

Figure 17. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on Reid till, II C horizon, site 5.

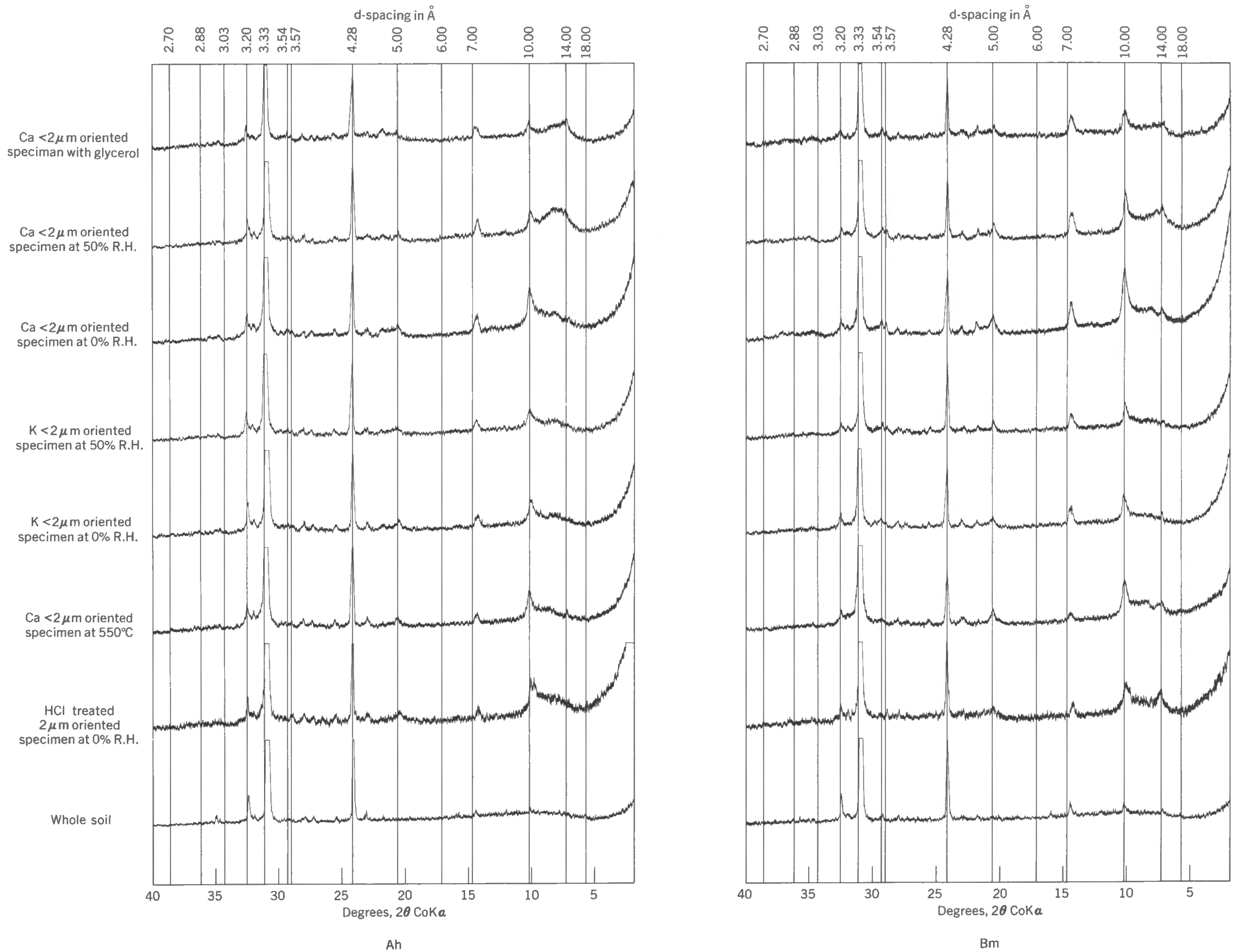

Figure 18. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on McConnell till, Ah and Bm horizons, site 4.

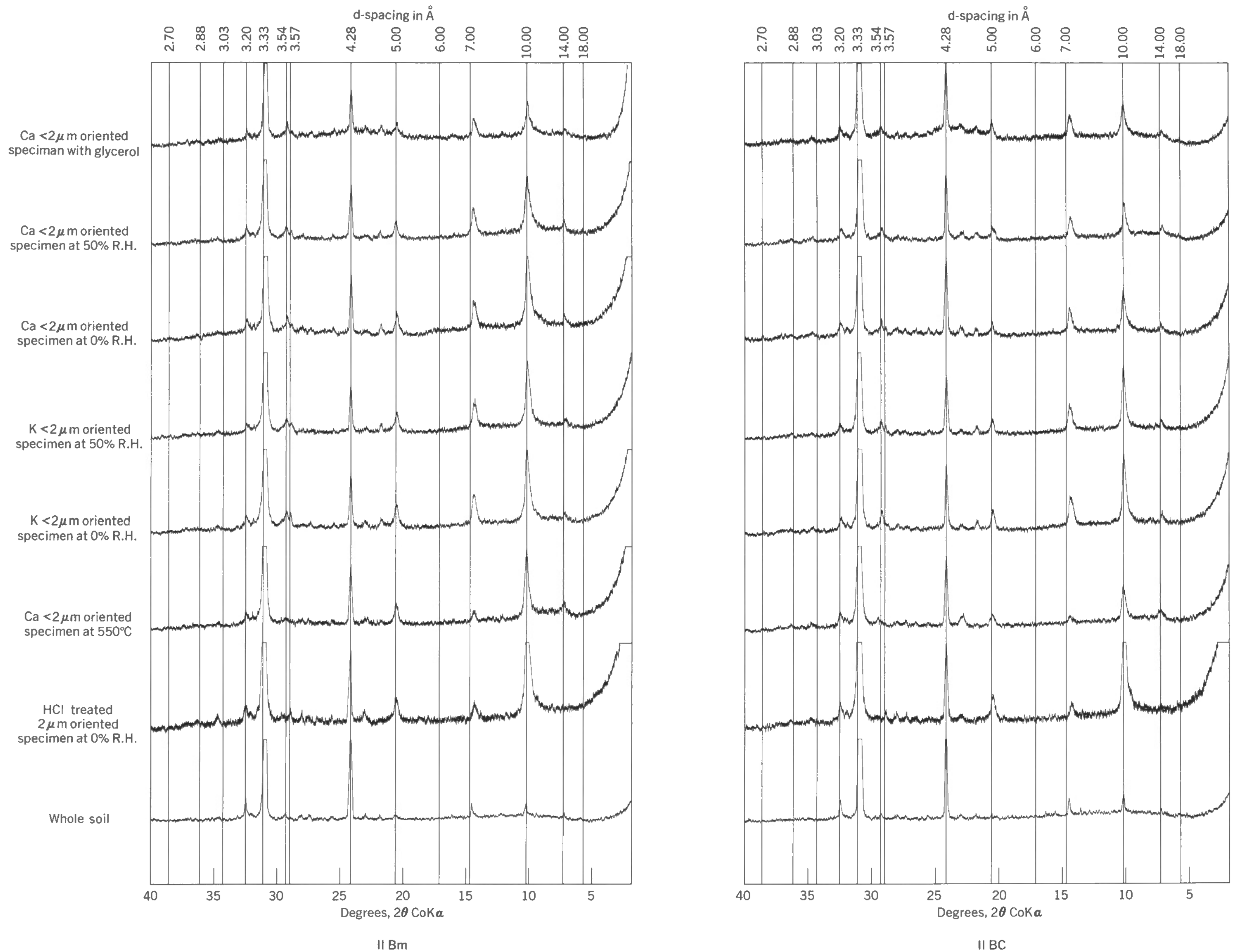

Figure 19. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on McConnell till, II Bm and II BC horizons, site 4.

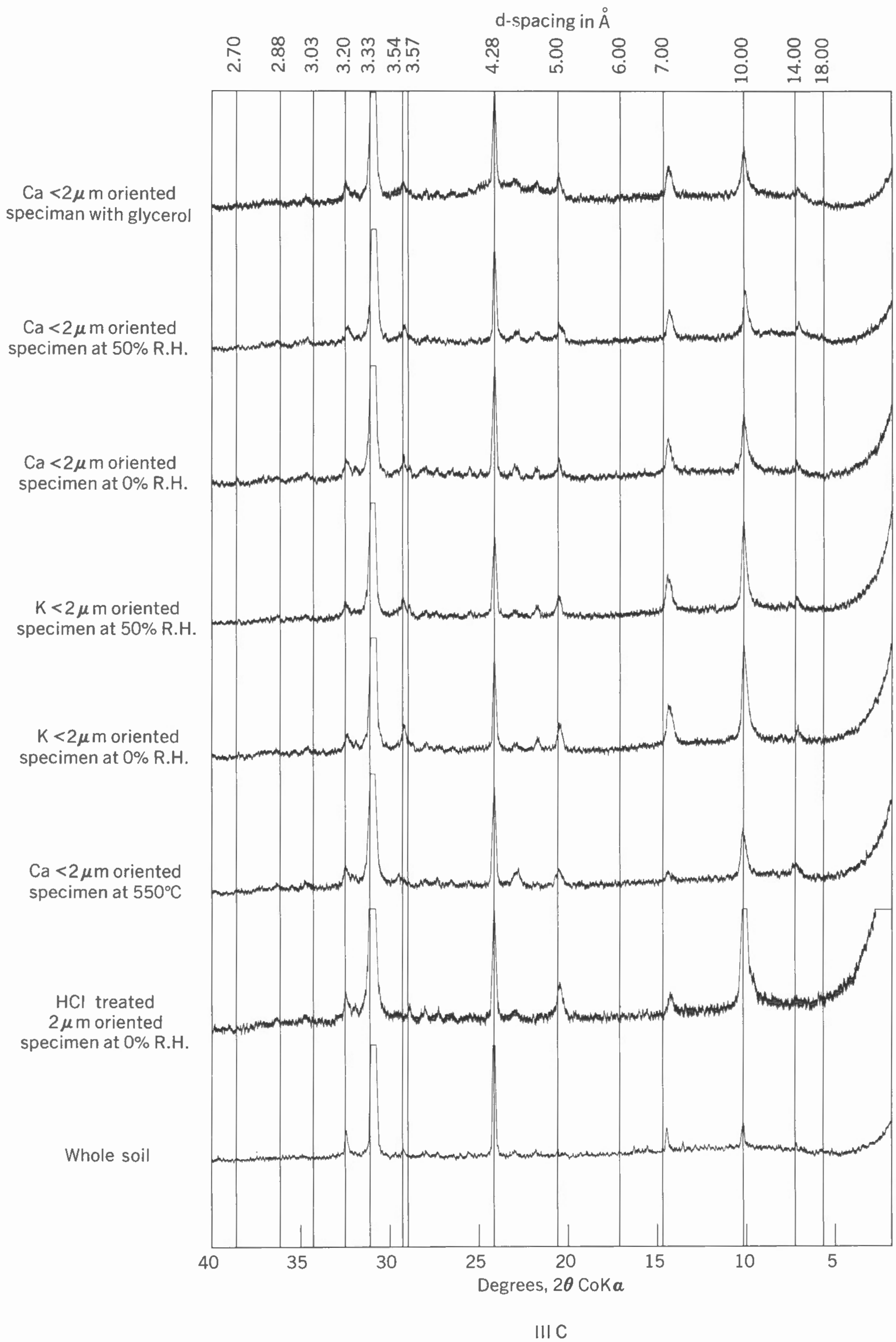

Figure 20. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on McConnell till, III C horizon, site 4.

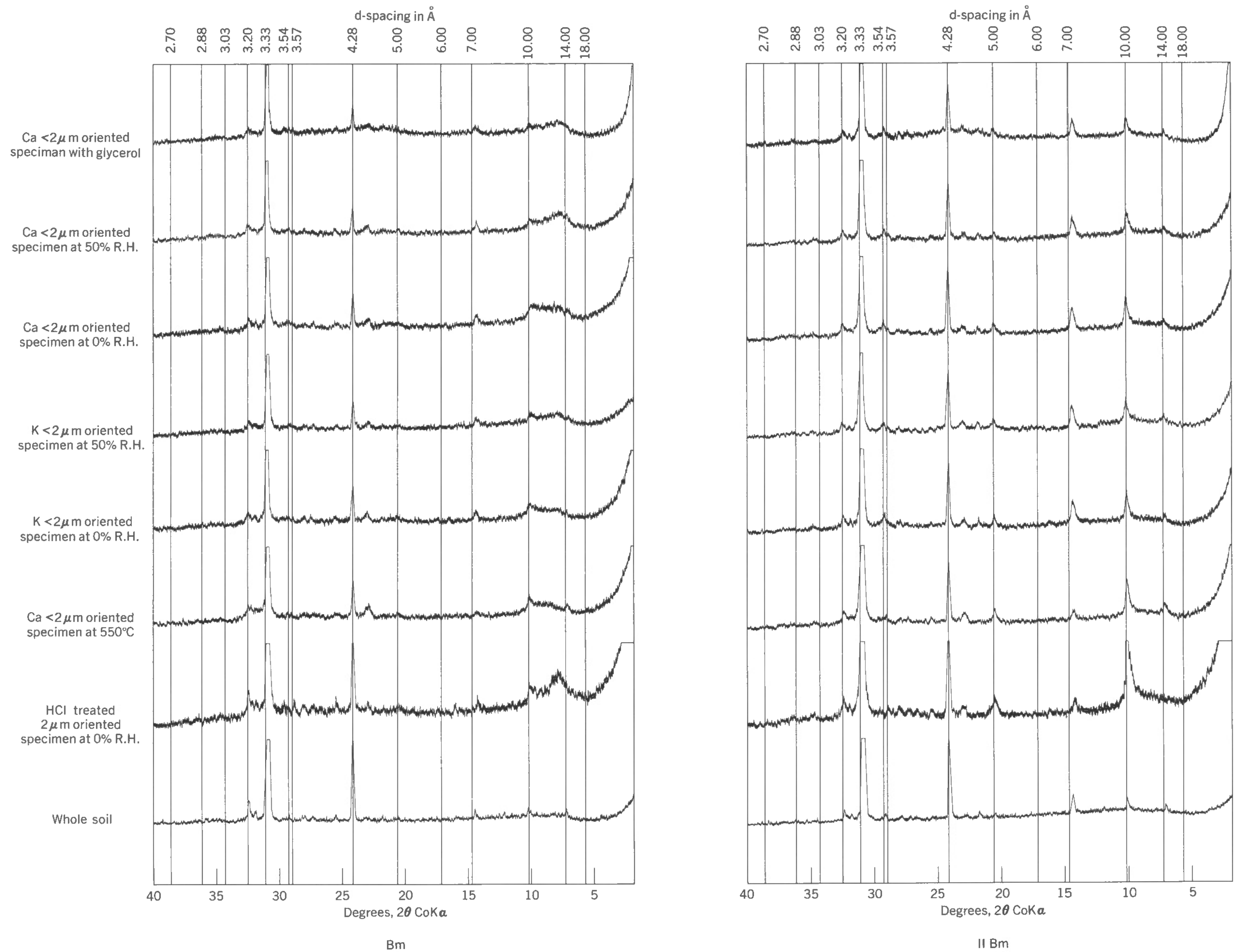

Figure 21. X-ray diffraction patterns of unoriented soils and <2μm oriented fraction under different treatments from a soil developed on McConnell outwash gravel, Bm and II Bm horizons, site 6.

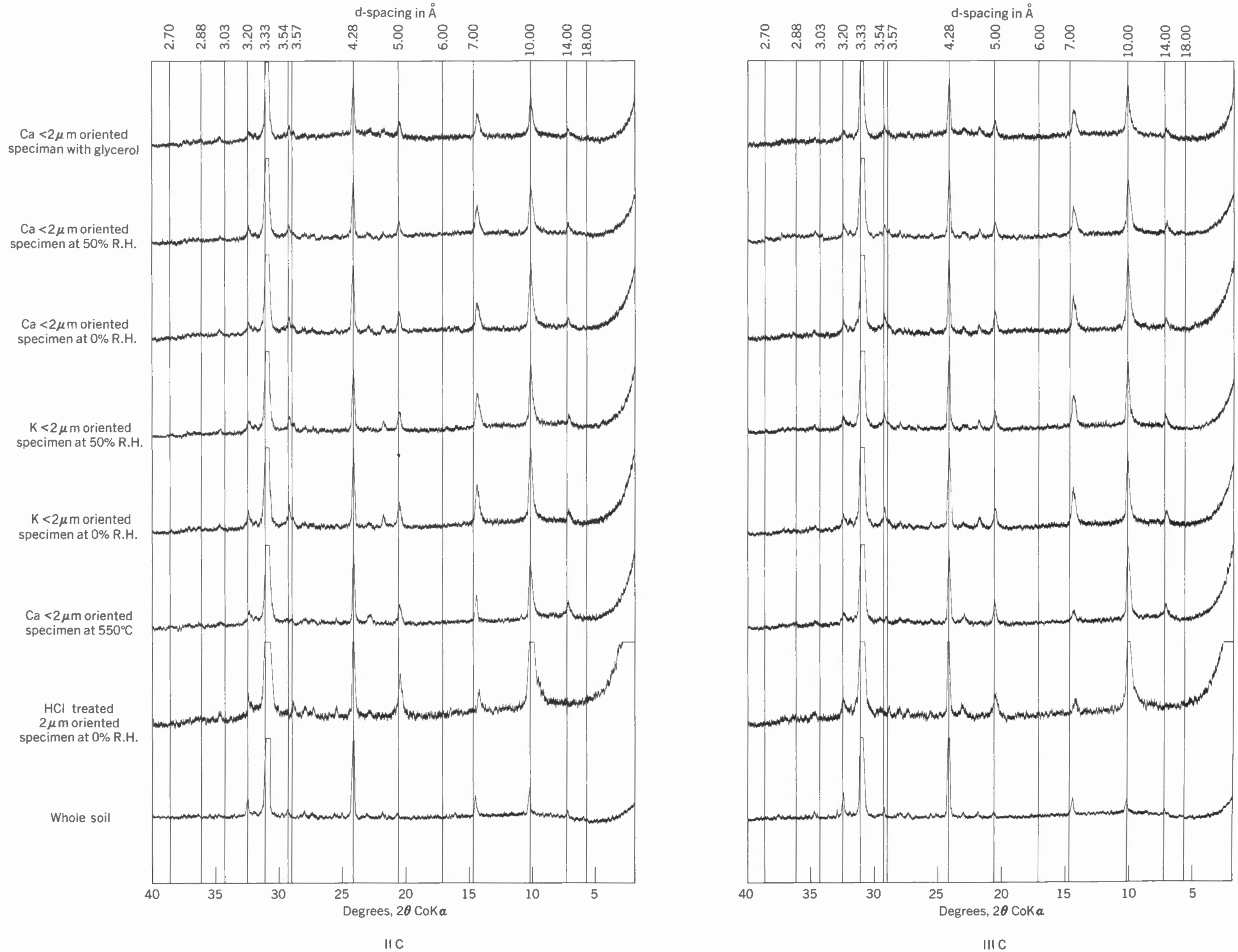

Figure 22. X-ray diffraction patterns of unoriented soils and <2µm oriented fraction under different treatments from a soil developed on McConnell outwash gravel, IIC and III C horizons, site 6.