SOIL TONGUES IN THE BURFORD LOAM

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A pedological investigation was made of the soil tongues in the Burford loam soils of S. W. Ontario. The purpose of the study was to determine the characteristic features of the soil tongues. The physical and chemical properties of a number of soil tongues were determined and one was used for a micromorphological investigation. Measurements of horizontal and vertical extent were also made. Discussion of the various hypotheses that might account for soil tongue development is included. Evidence for a periglacial climate is given and also for the existence of two distinct types of soil tongues.

ACKNOWLEDGEMENTS

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THE CHARACTER AND ORIGIN

OF THE

SOIL TONGUES IN THE BURFORD LOAM

By

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

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CHAPTER I

INTRODUCTION

I. Aims and Location of Study

The Burford loam, classed as a Typic Hapludalf (USDA 1967) or as an Orthic Gray Brown Luvisol (Nat. Soil Surv. Comm. of Can. 1968), consists of a loamy A horizon overlying coarse, calcareous outwash deposits. Separating the A horizon from the calcareous gravels is a well defined reddish-brown B horizon. A characteristic feature of the Burford loam in S.W. Ontario, is the extremely irregular nature of the A and B horizons. The A horizon material often has the appearance of irregular pockets, whilst the B horizon immediately below these pockets, is found extending down into the underlying gravels producing features known as soil tongues (Fig. I).

Fig.I Soil tongue in the Burford loam, Freelton, Ontario.

The origins of features similar to the soil tongues in the Burford loam have been discussed in only a relatively small number of studies (e.g., Yehle 1954, Maruszczak 1960, Presant and Protz 1967) and there is no general agreement on their formation. There is also a lack of quantitative data, particularly about particle size distribution characteristics of the material within soil tongues.

The aims of this thesis can therefore be summed up as being : (i) an attempt to provide detailed physical and chemical analyses of features previously little reported in the literature and (ii) to

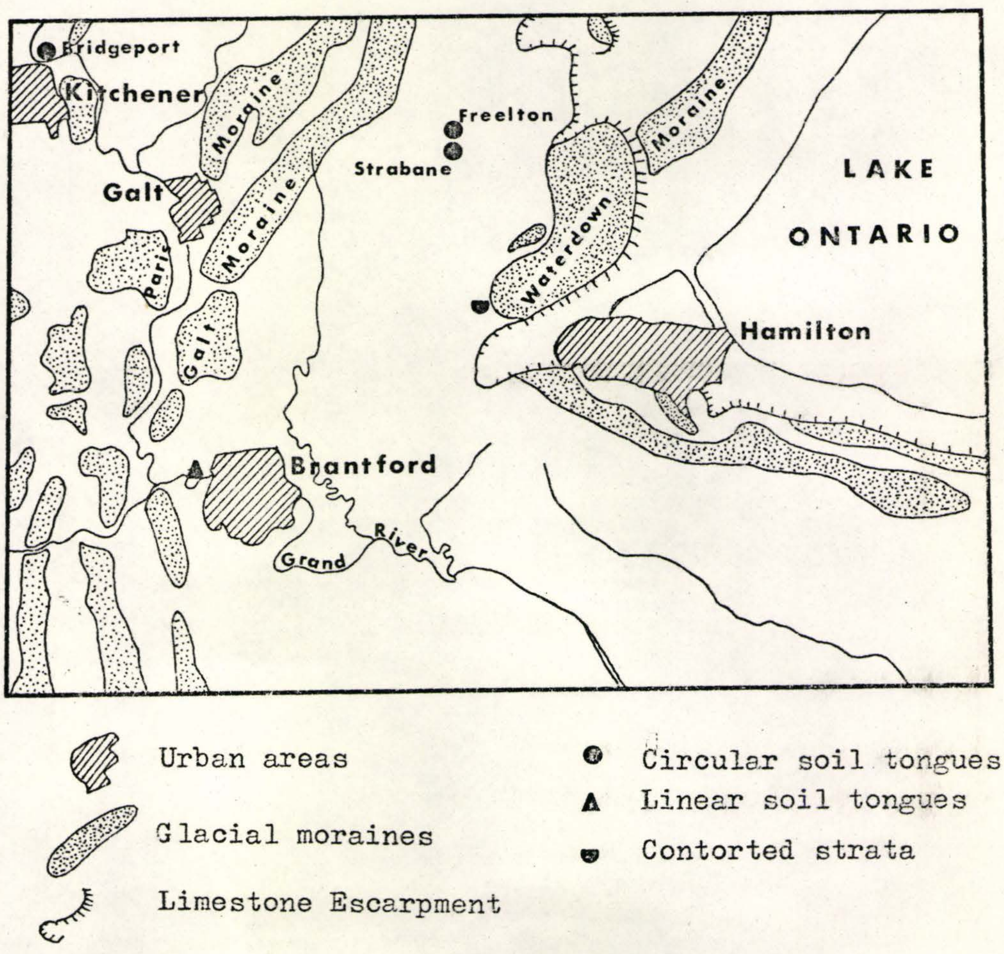


Fig. 2 Map showing sampling sites and glacial moraines.

examine the possible origins of such features.

The area of study is shown on the map (Fig. 2). The surface materials over most of the area consist of glacial or fluvioglacial deposits. The soil tongues in the Freelton area are developed in outwash deposits, whilst those at Bridgeport and Brantford are developed in terrace gravels of the Grand River. However, the material underlying the solum is in each case a coarse, calcareous gravel that differs very little from site to site. Although only four soil tongue locations are indicated, it should be noted that such features occur very frequently in the Burford loam and other similar gravelly soils.

2. Literature Review

Several alternate hypotheses can be suggested for the formation of soil tongues. These include :

I Development under a 'spotted tundra' as described by Maruszczak (1960).

2 Deposition of material in orientated, fluvial channels, as suggested by Presant and Protz (1967).

3 Differential soil formation due to concentration of ground water, as described by Brade-Birks and Furneaux (1928), Yehle (1954), Johnsson (1959) and Bartelli and Odell (1960).

4 Growth and decay of tree roots, as described by Lyell (1866), Shaler (1891) and Lyford and Goodlett (1963).

5 Windthrow of trees, a view put forward by Wretlind (1934) and Lutz and Griswold (1939).

6 Development of ice wedges, i.e., the soil tongues are really fossil ice wedges, similar to those described by Pierzchalko (1956).

Maruszczak (1960), describes features from outwash-gravel deposits on the Szeskie Hills, Poland, that are very similar to the soil tongues of S.W. Ontario. In horizontal section the features described appear as irregular nests of fine, sandy material surrounded by wide bands of a more compact ferruginous-stained horizon which penetrates the underlying gravels. Such features are thought by Maruszczak (1960), to have originated under unvegetated patches in the tundra, similar to those described by Grigoriev (1956) and Tyrtikov (1956). The pockets of fine, sandy material are thought to result from freeze-thaw activity, whilst the ferruginous-stained horizon marks an accumulation of eluviated material at the top of a former permafrost horizon. The irregularities in the upper surface of this permafrost horizon are attributed to a greater depth of summer thawing under unvegetated patches.

The fluvial channel-filling hypothesis put forward by Presant and Protz (1967), does not attempt to explain the origin of all soil tongues in the Burford loam and other similar soils of S.W. Ontario, but is concerned with one particular variety. Recognising that the soil tongues found in S. W. Ontario, have usually been attributed to either solution or periglacial processes, Presant and Protz (1967), show that certain soil tongues near Kitchener, Ontario, are linear features that have a fluvial origin.

Therefore, it would seem that in S. W. Ontario there are two kinds of soil tongue, those that are linear like those described by Presant and Protz (1967) and those that are irregular, circular forms similar to those reported by Maruszczak (1960), the cross sectional forms of which are very similar. Thus, as Presant (1970) emphasizes, many of the soil tongues in S. W. Ontario which have been assumed to be circular, discontinuous features, may actually be channel forms, indicating the need for a consideration of the horizontal extent, as well as the vertical section of the soil tongues.

The idea that soil tongues result from the growth and decay of tree roots was advanced as long ago as 1866, by Lyell who thought that certain alluvium filled tongues and hollows in unconsolidated sediments, "... may be spaces which the roots of large trees have once occupied, gravel and sand having been introduced after their decay". Shaler (1891) has put forward the view that root growth leads to compaction of the soil and the formation of channels when they decay, which are infilled with material from above. A more recent study by Denny, Lyford and Goodlett (1963), shows that the B horizon of the Howard Series of north east U.S.A. is extremely irregular, tonguing down into underlying calcareous gravels. These deeply penetrating tongues are thought to result from the downward penetration of large roots which have since completely disappeared.

The effect of tree throw on soil morphology is thought by Lutz and Griswold (1934) to lead to the development of soil tongues under certain circumstances. Although the features described are not well defined soil tongues, they do illustrate that tree throw can cause changes in soil morphology and they make the point that such disturbances may have been wrongly attributed to periglacial processes in the past.

The origin of pipes or tongues of material in the chalk of east Kent, England is attributed by Brade-Birks and Furneaux (1928) to the incipient piping of the rock, resulting from the concentration of ground water. A major study of soil tongues is that by Yehle (1954), who describes features very similar to those in the Burford loam, from South-central Wisconsin. The soil tongues described are either circular, or linear, branching, wedge shapes of limited extent, or irregular in form. These tongues of the B horizon are attributed to differential solution of the underlying calcareous gravels. Evidence for this view is found in the existence of marker beds that cross the soil tongues without loss of continuity and the almost complete loss of carbonate pebbles from the soil tongues. The initiation of this differential solution is thought by Yehle (1954) to be a result of the original irregular microrelief.

Features that consist of an irregular B horizon enclosing pockets of a lighter coloured A horizon, are referred to as 'Podsolschornsteine' by Johnsson (1959), who regards them as being produced by differential soil development initiated either by the slight sinking of material, or the initial disposition of the parent material.

Bartelli and Odell (1960) describe a Beta horizon with a tonguing lower boundary, which they suggest is due to the concentration of soil water drainage in a relatively small number of vertically orientated zones. Such preferred drainage lines are attributed by Day and Luthin (1953) to the tensional effects produced when a fine material overlies a coarser, so that soil water is channelled away at a small number of points. These channels are thought by Bartelli and Odell (1960) to develop into soil tongues.

The concentration of soil water at one point may also result from stem flow from trees, as Gersper and Holowaychuk (1970) suggest. However, they found no evidence of tongues in the B horizon, although slight thickening of the horizons is reported where the water is concentrated.

As most of the soil tongues described in the literature are found in areas of glaciofluvial outwash, which may have experienced a periglacial climate, the possibility cannot be overlooked that they are fossil ice wedges, or that they result from the concentration of ground water along the line of a former frost crack or ice wedge. Also it is apparent that the vertical wedge shape of soil tongues has in the past been misinterpreted as a fossil ice wedge, as noted by Yehle (1954).

It is hoped that by an examination of the horizontal and vertical sections of the soil tongues in the Burford loam, to provide evidence to support one or other of the above hypotheses.

3. Methods of Study

Four sites were selected for study (Fig.2) and at each soil profile descriptions were made using standard procedures. Classification is according to the revised 7th Approximation (USDA 1967).

Colours are reported for the moist state using a Munsell Color Chart. Samples were collected for chemical and mechanical analysis. Undisturbed samples were taken at the Freelton site, so that large (10 x 5 cms.) thin sections could be prepared. The thin sections were prepared using methods suggested by FitzPatrick (1970) and the terminology used in their description is that of FitzPatrick (1971). Vertical section measurements included the distance between soil tongues, the thickness of the B horizon and depth to the upper surface of the B horizon. The surface morphology of the B horizon was determined by auguring on a grid pattern (8 x $7m^2$) at 45 cm. intervals at three sites. Successive vertical slices were also removed from soil tongues to check lateral continuity.

Mechanical analyses consisted of determination of the particle size distribution by means of dry sieving for the sand fraction and pipetting for the silt and clay fractions. The liquid limit of the samples was determined.

A partial chemical analysis determined organic matter content by peroxide digestion, loss on ignition at 850°C, moisture content pH in water, and determination of exchangeable bases and free iron in a flame photometer.

CHAPTER II

PROFILE DESCRIPTION OF A SOIL TONGUE IN THE BURFORD LOAM

I. Soil Macromorphology

The soils at all four sites are very similar and therefore, only one profile description is given for the Burford loam (page 10).

Cultivation has produced a sharply defined Ap horizon at each site. The A2 horizon has been partially removed in places by ploughing, so that it often occurs as discontinuous pockets. The textures of the A horizons vary only slightly between the five profiles, being mostly loamy sand except at Brantford where the profiles are siltier.

The most characteristic feature of the Burford loam is the existence of large tongues of the B horizon extending into the C horizon. In these soil tongues, the B horizon is frequently at least I metre thick, but between them it may only be about 10 cms. thick. Consequently the subdivisions of the B horizon tend to be rather discontinuous being best developed in the thicker sections. Where the B horizon is fairly thick, it has at least three subdivisions: (i) a zone of maximum clay accumulation, the B2t, (ii) underlying this a B3 horizon and (iii) an AB horizon consisting of structural units resembling those of the B2t horizon, but the coatings of bleached grains, similar to the material found in the A22 horizon. These coatings resemble the silans described by McKeague et al (1967), rather than albic tongues (USDA 1967) as they are discontinuous and are best described as interfingering. This horizon is best developed at the Bridgeport site.

Profile Description of the Burford loam

Location Freelton Grid Reference 40 P/8 East Half Edn.4,786047

Parent Material Calcareous kame gravel Height 875 feet

Classification Typic Hapludalf (U.S.), Orthic Gray Brown Luvisol (Can.)

Horizon

Ap 0 to 20 cms., very dark greyish brown (10YR3/2m) loam, medium granular or platy; friable; common very fine to fine roots; pebbles rare; sharp even boundary; no HCl reaction.

A2I 20 to 60 cms., or destroyed by ploughing; dark yellowish brown (10YR3/4m) loamy fine sand; weak fine to medium platy; very friable; common very fine and fine roots; few pebbles; clear, slightly wavy, discontinuous lower boundary; no HCl reaction.

A22 60 to 75 cms., or destroyed by ploughing; brown (10YR5/3m) fine sandy loam; weak, fine to medium platy or granular; friable; common very fine roots; clear, wavy, discontinuous lower boundary with some shallow tongues into the underlying horizon; no HCl reaction.

AB 20 to 26 cms., or 75 to 80 cms., brown to dark brown(7.5YR4/2m) loam, with streaks of bleached (10YR7/Im) quartz grains along the surfaces of structural units; fine to medium platy; firm; few, very fine roots; clear, slightly wavy lower boundary no HCl reaction.

B2t 26 to 30 cms., or 80 to 95 cms.; dark reddish brown (5YR3/3m) gravelly, coarse sandy loam; fine sub-angular blocky; friable; few, very fine roots; lower boundary clear to diffuse and very irregular with shallow to deep tongues extending into the underlying horizon; numerous pebbles, mainly weathered and very friable; weak HCl reaction.

B3 30 to 35 cms., or 95 to 150 cms., or more; reddish brown (5YR4/3m) gravelly, loamy coarse sand; granular; very friable; very few, very fine roots; lower boundary clear to diffuse and very irregular, with shallow to fairly deep tongues penetrating into the underlying horizon; abundant pebbles, occasionally weathered; moderate HCl reaction.

C 35+ or 150+ cms.; brown to dark brown (10YR4/3m) gravelly, loamy coarse sand; single grain; loose; no roots; abundant pebbles and a few cobbles; strong HCl reaction.

That the B horizon is a textural B and not solely a Bfe is indicated by the thin clay coatings readily distinguishable in the field samples. At Freelton and Strabane, the B2t horizon is a sandy loam, whilst at Brantford and Bridgeport it is a sandy clay loam. This horizon contains numerous, highly decomposed pebbles at each site that have weathered in situ and have been a major source of the clay present in this horizon.

The C horizon at each site is a coarse, calcareous deposit composed predominantly of pebbles of dolomite and limestone, together with minor amounts of shale, sandstone, igneous and metamorphic pebbles. These gravels are fairly well bedded except for the top I metre or so, which appears to have been frost churned.

2. Soil Micromorphology

Thin sections were made for one profile only. The profile chosen is the same as that for which a macromorphological description has been given. The undisturbed samples were taken from a soil tongue feature and their location within this soil tongue is indicated in Fig. 3.

Micromorphological studies of soils using thin sections pioneered by Kubiena (1938), have now become a major part of all pedological investigations(e.g., Brewer 1964, FitzPatrick 1971). The need for large thin sections in studying the thin section morphology of soils has been demonstrated by Jongerius and Heintzberger (1964). The thin sections used in this study are 10 x 5 cm., except the one from the B2t horizon, which due to the friability of the horizon is only 6 x 5 cm., in size. Analysis was carried out with a petrological microscope and photomicrographs were made for each thin section. In addition, contact prints were made at a slightly enlarged scale.

Detailed descriptions of each thin section are included in an appendix, whilst a generalized account is given below. The terminology used throughout is that suggested by FitzPatrick (1971).

Structure

The macro-structural characteristics of each horizon sampled are illustrated by Figs. 4 - 8. The Ap horizon has a mainly granular

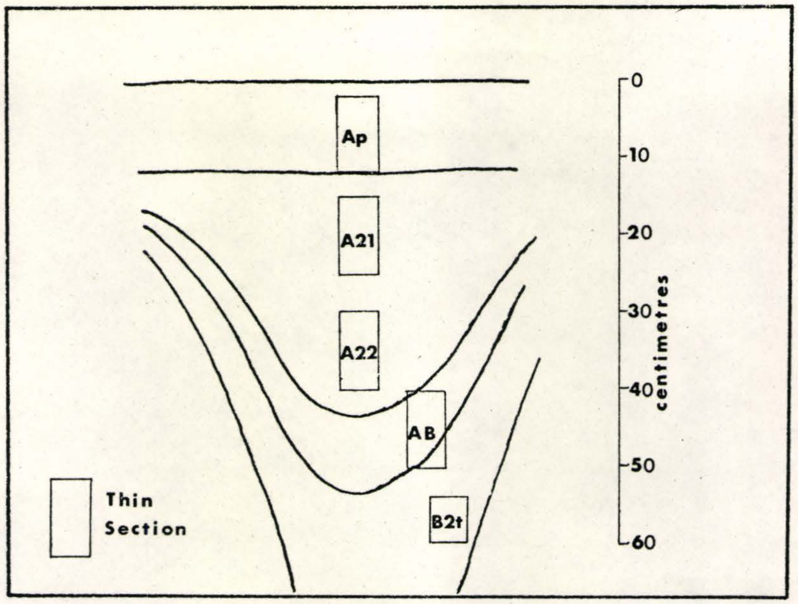
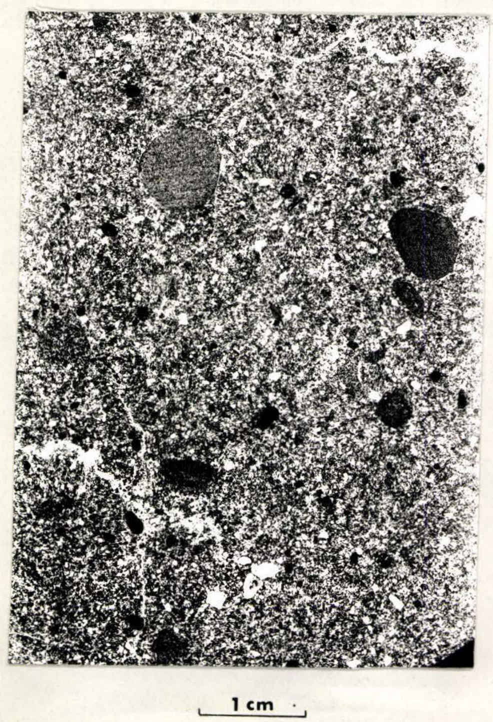


Fig. 3. Location of thin sections in soil tongue at Freelton.

Fig. 4.

Thin section of Ap horizon of soil tongue at Freelton, showing mainly granular texture. Dark areas are stones.



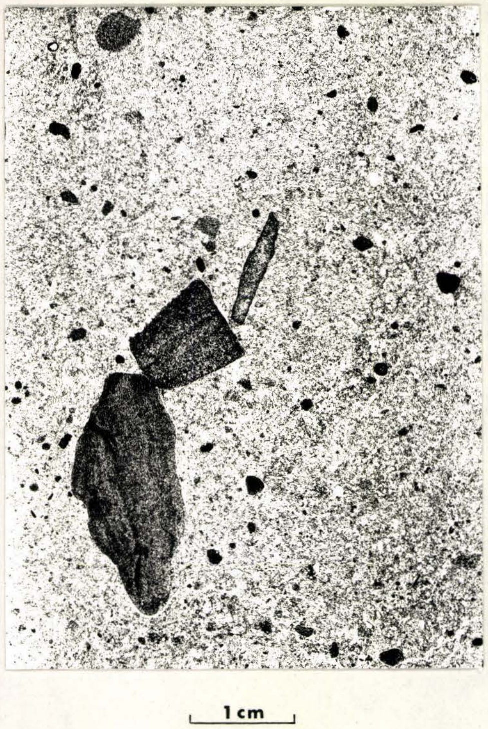
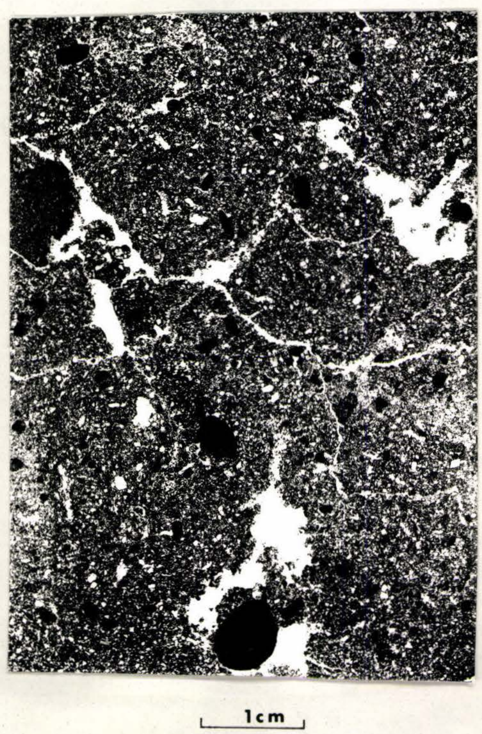


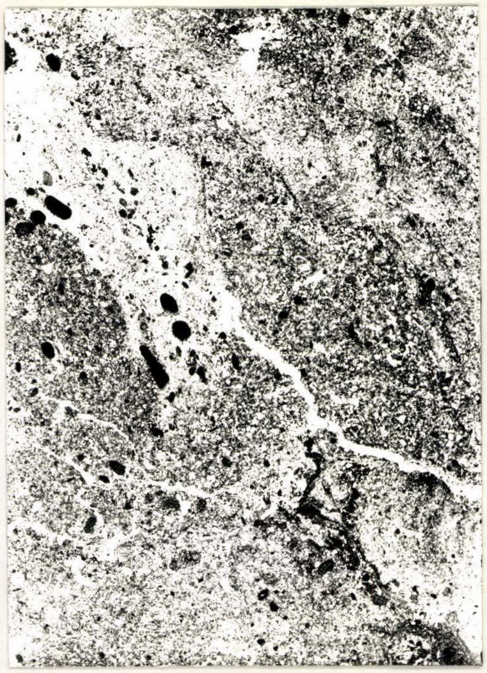
Fig. 5

Thin section of A21 horizon of soil tongue at Freelton showing alveolar structure. Larger stones show vertical orientation. Some of the dark areas are concretions. Note lack of continuous pore space.

Fig. 6

Thin section of A22 horizon of soil tongue at Freelton showing Alveolar and weekly developed, incomplete, angular blocky structure. Continuous pore space and very large irregular pore spaces.





1cm

Fig. 7

Thin section of AB horizon of soil tongue at Freelton showing Banded structure which contains alveolar, single grain and weakly developed platy structures. Zones of silt separation and zones of bleached sand grains are prominant. Oblique orientation of sand and small pebbles can be seen.

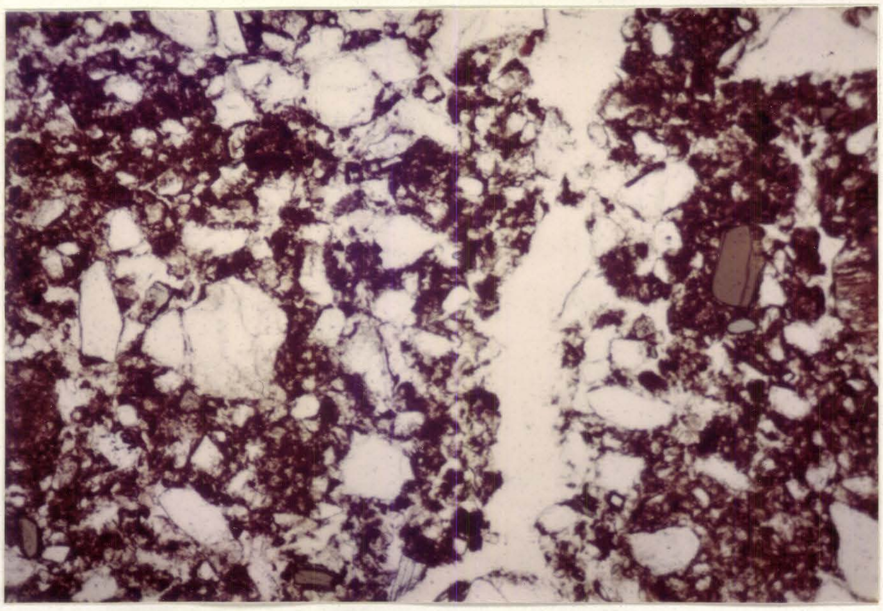
Fig. 8

Thin section of B2t horizon of soil tongue at Freelton showing alveolar and sub-angular blocky structure. Many pebbles present and extensive continuous pore space.

1cm

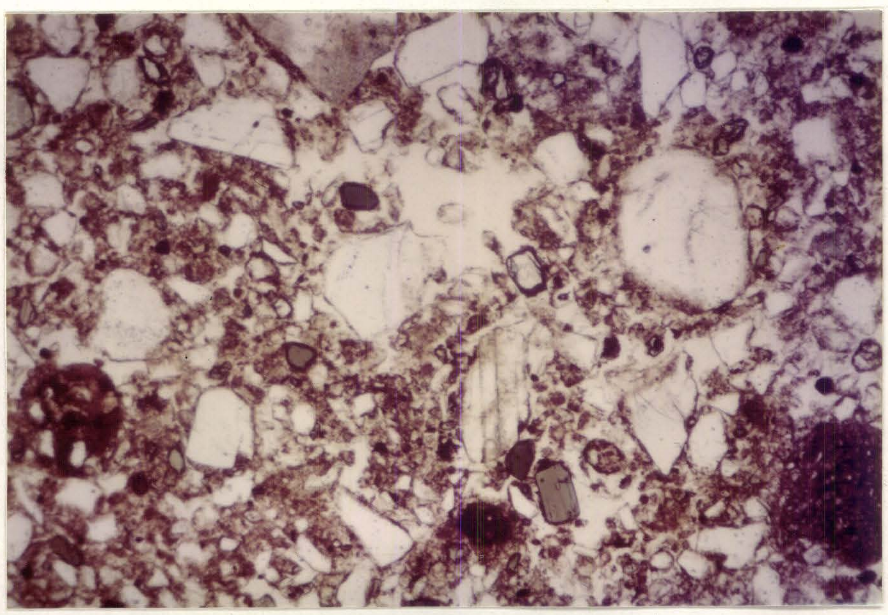
structure (Figs. 4 & 9), whilst the A2 horizon has a predominantly alveolar structure due to the close packing of the grains, giving a honeycomb pattern of pore space (Figs. 5,10 & 11). In the lower A22 horizon this alveolar structure is accompanied by a weakly - developed, angular blocky structure (Fig. 6). The AB horizon shows a marked change of structure (Fig. 7) with the development of bands with single grain structure (Figs. 13 & 14) giving a weakly developed, platy structure. The occurrence of banded structure is typical of the AB horizons of many Udalfs (Grey Brown Podzolics) as noted by Stobbe (1952) and of Boralfs (McKeague and St. Arnaud 1969). The latter have noted that concentrations of soil matrix at the top of lenticular plates and coarser grains near the base, are typical of strongly leached Boralfs. Similar size separations into bands of coarse and finer material are seen in the AB horizon of the Burford loam. (Figs. 15 & 16). Within the coarse bands a high degree of parallel orientation of the sand grains can be seen (Fig.15). The structure of the B2t horizon indicates a greater degree of development of sub-angular blocky structure (Fig.8). However, there is no evidence of a platy or banded structure.

Only a slight variation in pore space is apparent in the A horizons and consists of a change from poorly developed continuous pores in the Ap horizon, to a dominance of small, irregular, oval or short branching pores in the A2 horizon. The lower A22 horizon is marked by an increase in continuous pore space, which is not continued into the AB horizon, where there is an increase in packing voids due to the single grain structure. Continuous pore space is



500μ

Fig.9 Photomicrograph of Ap horizon in plain light showing typical fabric of isotropic matrix enclosing sand grains. Continuous and short branching pore space.



500μ

Fig. 10 Photomicrograph of A21 horizon showing alveolar structure and three undifferentiated sesquioxidic concretions.

is best developed in the B2t horizon.

Matrix

The most obvious changes of matrix between horizons are in colour and dominant grain size. The colour varies from dark brown in the Ap horizon to light olive-brown in the lower A2 hroizon and to yellowish red in the B2t horizon. This colour change is a reflection of the process of eluviation, which causes bleaching of the A2 horizon material and a reddening of the illuvial B horizon.

The dominant constituent of the matrix in the A horizons is silt, the size of which seems to vary very little down the profile although its prominance and distribution vary considerably. In the upper A horizon, the matrix is found as a continuous soil phase, enclosing mineral grains (Fig. 10) whilst in the lower A2 horizon it is less continuous and occurs as coatings around larger mineral grains. (Fig. 11). In the AB horizon in the bands containing coarse sand, it occurs only as very discontinuous coatings (Fig.13). On the other hand, bands of finer material show a concentration of matrix which encloses the smaller grains and exhibits a flow pattern (Fig. 16).

In the B horizon, the soil matrix is dominated by the presence of clay-sized material, which has a very uneven distribution, in some places enclosing small grains, in others occurring as coatings upon and as bridges between grains (Figs. 19 & 20). Clay cutans are indicative of the trans-location of material into this horizon. However, much of the matrix is largely unorientated and has a flecked appearance.

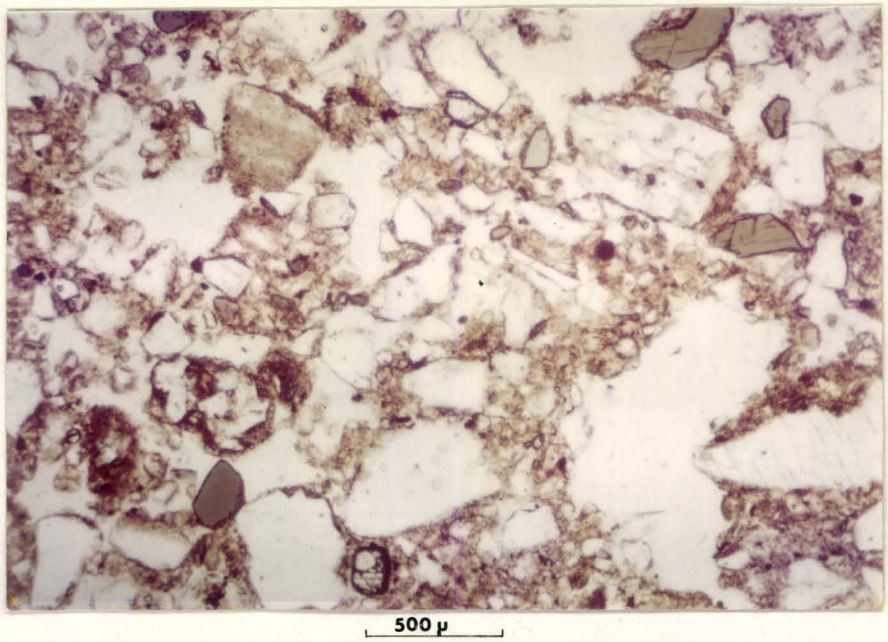


Fig. II Photomicrograph of A22 horizon showing well developed alveolar structure and less silt sized material than in the A2I horizon.

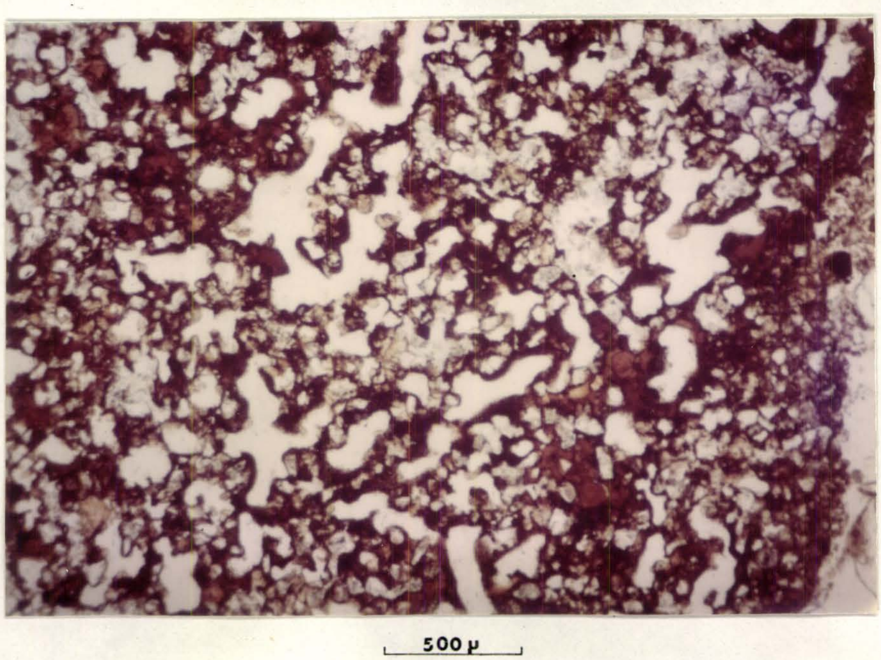


Fig. 12. Photomicrograph of weathered stone fragment in the A22 horizon showing abundant pore space and thin clay cutans.

Stones

An advantage of large thin sections, is that it is possible to study the distribution of the coarser fragments in the soil. As Figs. 4 - 8 indicate, stones are present in all horizons of the soil tongue sampled. A summary of the number and type of stones present is given in Table I below.

Table I Number and type of stones present in soil thin sections

Horizon	Fine Sandstone or Shale	Quartzite	Metamorphic or Igneous
Ap	9	3	-
A21	8	-	I
A22	II	-	-
AB	13	2	I
B2t	28	4	I

B2t thin section 6cm. x 5 cm., the rest 10cm. x 5 cm.

Although one should not attribute too much importance to a single sample, it is certain that there is a reduction in the number of stones upwards in the profile. It is also evident from the thin sections that the stones in the A horizon are highly weathered and it contains many lithorelicts (Fig.12). Within the A2 horizon, the vertical orientation of the stones (Fig.5) indicates the past action of frost in the soil.

The majority of the weathered stones in the A and B horizons appear to be shales. However, in the B2t horizon there are a large number of stones that have been totally weathered and that remain as lattice frameworks of weathering products, together with some quartz grains that were impurities in the original stone; such features are all that remain of dissolved dolomite or limestone pebbles,(Fig.20).

Sand Fraction

The thin section evidence indicates little difference in the distribution and orientation of sand grains in the Ap, A2I and A22 horizons. Small concentrations of quartz grains occur, that probably represent the remnants of weathered stones. Otherwise the sand grains seem to be randomly distributed. However, in the AB horizon there is a definite pattern of distribution. The banded nature of this horizon has already been mentioned. The sand grains in these bands show an oblique orientation towards the centre and base of the soil tongue, (Fig. 15). The numerous bands of sand grains present, differentiated either by size or degree of leaching (Figs. 14 & 15) are mostly very wide (Fig. 7).

The sand fraction of the B2t horizon shows no evidence of a banded structure, although there is a certain amount of size separation. Areas occur in which are found concentrations of medium-sized sand grains (Fig.19) and others that contain mainly fine to very fine grains (Fig.18). These clusters of grains may be the result of the in situ weathering of pebbles, or they may be an inherited lithological characteristic.

Silt Fraction

In the Ap and A2 horizons, silt forms coatings on large grains and encloses smaller grains. In the lower part of the A horizon there is evidence of leaching in the bleaching of silt sized grains as well as of the sand fraction. In the AB horizon, the very uneven

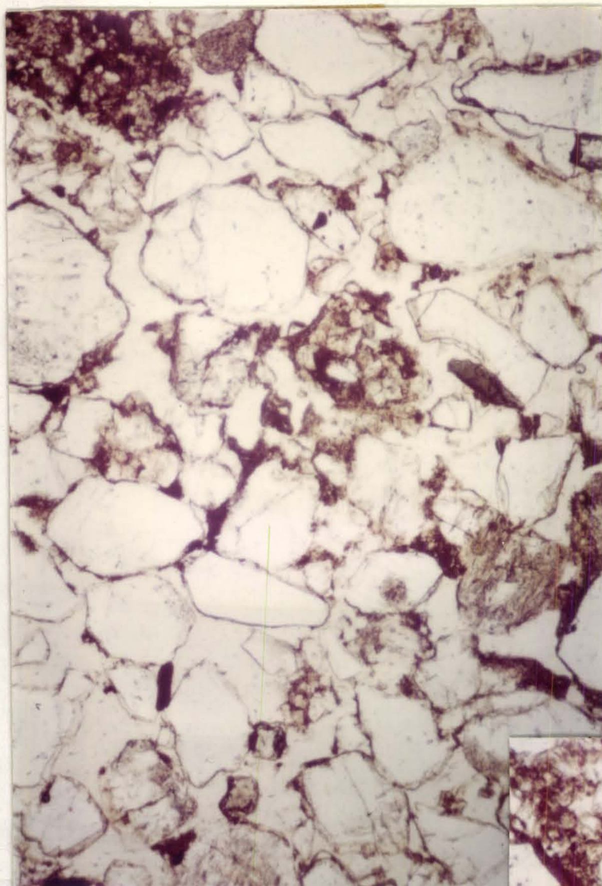


Fig. 13

Photomicrograph of Ab horizon showing leached zone of fine of fine to medium sand grains and oblique orientation of the grains.

500μ

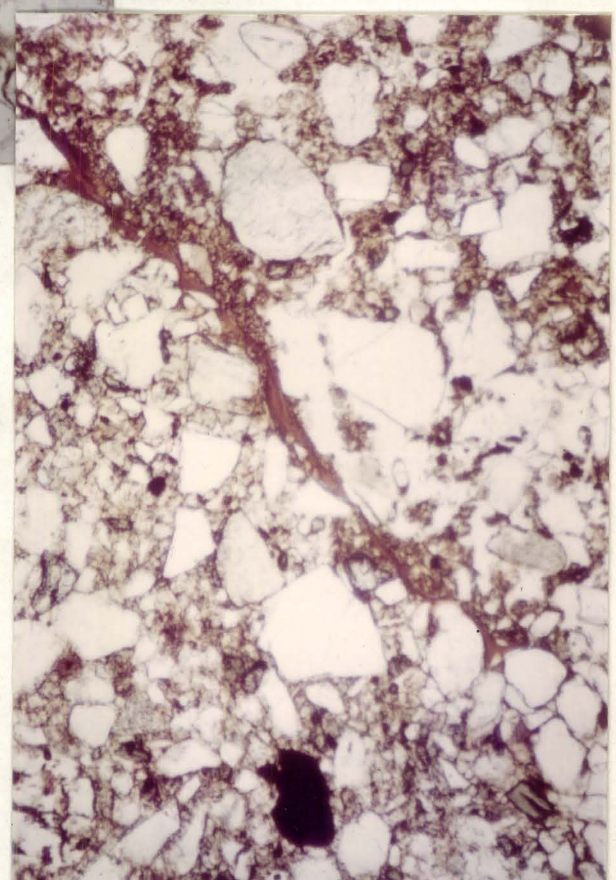


Fig. 14

Photomicrograph of AB horizon showing a bleached and unbleached band of fine to medium sand, the junction of which is marked by a clay cutan that appears to be disintegrating.

500μ

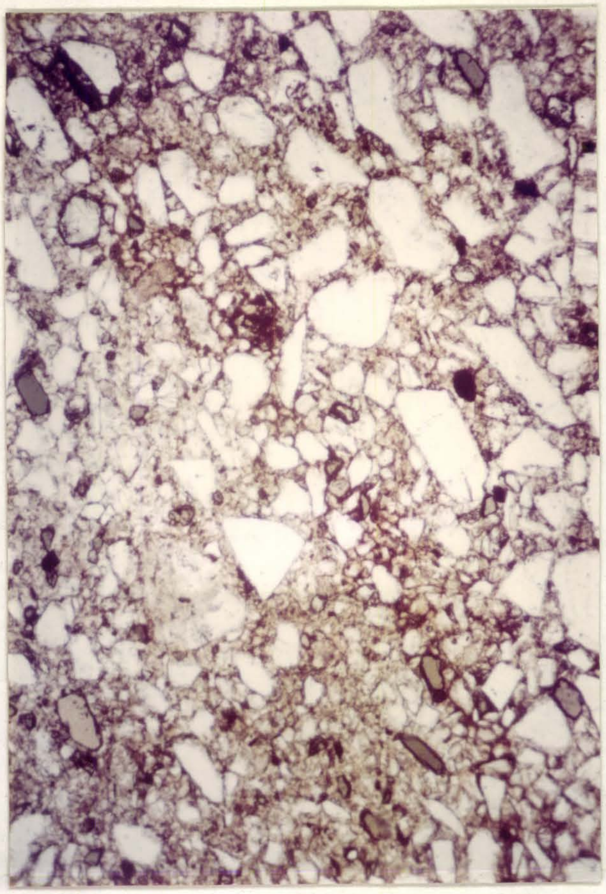
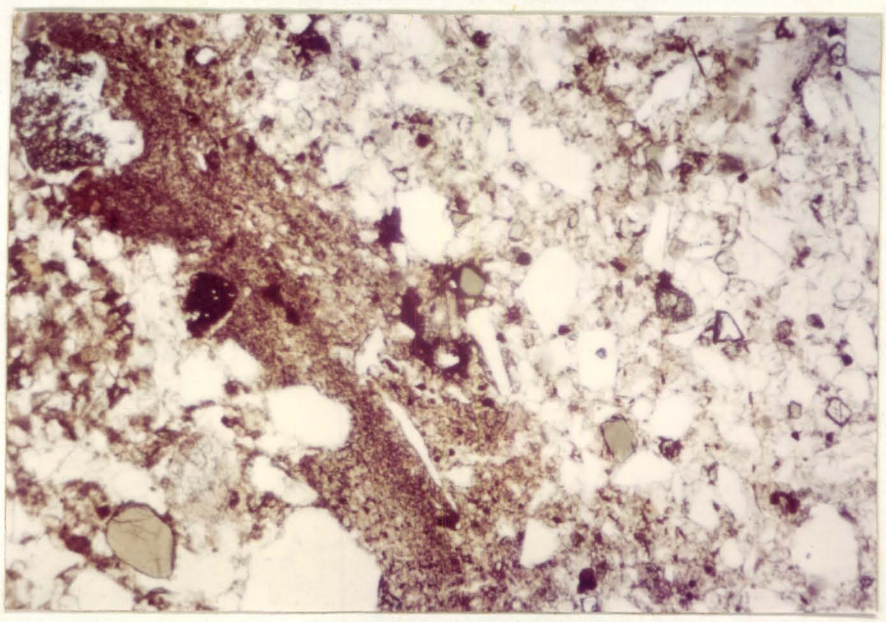


Fig. 15

Photomicrograph of AB horizon showing size separation of sand grains that also exhibit oblique orientation.

500µ



500µ

Fig. 16 Photomicrograph of AB horizon showing separation of silt.

distribution of the silt is readily seen (Fig.16). In the bands of bleached sand grains silt is almost totally absent (Fig.13), whereas in other areas banded concentrations of silt occur (Fig.16) with a gradation from coarse silt to the base of the band to finer material at the top. The relative lack of silt in the upper part of the section and its greater abundance, together with the flow patterns in the lower section, would seem to indicate a movement of silt down the profile (Fig. 7).

Several authors (e.g., Thorp, Cady and Gamble 1959, Cady 1960, McKeague, Bourbeau and Cann 1967) have described silt coatings on ped faces and in pores of the AB and upper B horizons, and regard them as indicating the translocation of silt down the profile. The experimental work by Wright and Foss (1968) also provides evidence for the movement of silt from the lower A2 and AB horizons into the upper B horizon of Alfisols. Thus it is possible to explain the uneven distribution of silt and the flow patterns by a process of translocation. The weathering of carbonate pebbles in the B horizon will create pore space into which material can be washed. Also, as Taylor (1957) points out, where a fine material (B horizon) overlies a coarse then the passage of water down the profile is impeded, a situation made more probable as the clay content of the B horizon increases, with the result that the soil water is forced to move along the interface until it can drain away along selected channels. The redistribution of the silt would occur during this lateral movement and also as a result of the collapse of material into the soil tongues, due to the reduction in volume caused by solution of carbonate material. Such collapse of material, evidenced by the sagging of marker beds (Chapter IV), also explains the oblique orientation of the sand grains.

Concretions

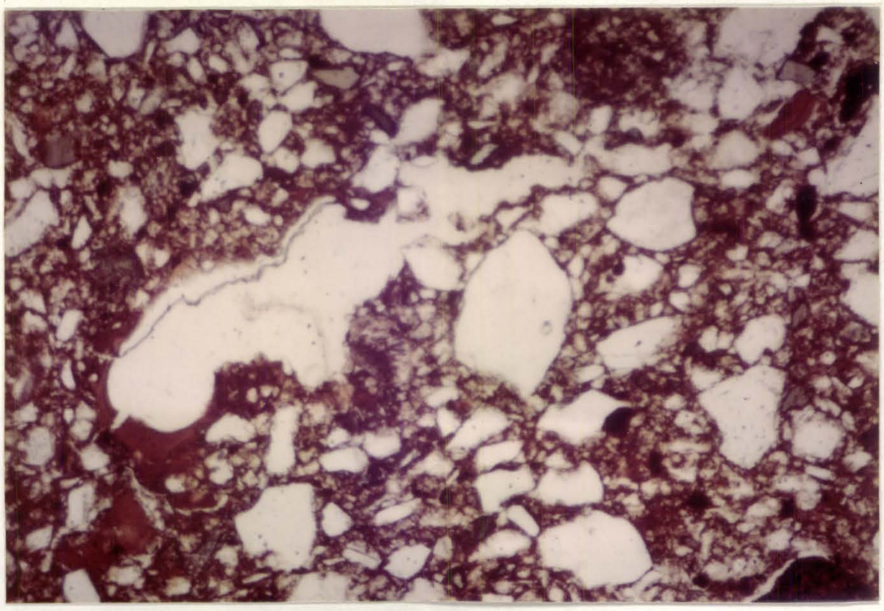
Within the Ap horizon iron and manganese concretions, tend to be round, concentrically banded, with sharp boundaries and up to I mm. in width. In the lower A2 and AB horizons, concretions tend to have diffuse boundaries, which Brewer (1964) suggests indicate in situ formation. The B2t horizon, contains both concentric and undifferentiated concretions, as well as features that have a lattice-like framework (Fig. 20). The evidence indicates that concretions are in the process of forming in the AB and B horizons and this implies that water is held in these horizons longer than in the overlying horizons.

Papules

These are small areas of clay-sized material that represent weathered mineral grains or are fragments of cutans. Papules, that are fragments of clay cutans, are frequent in the Ap horizon due to the incorporation of material by ploughing and in the AB horizon, where they indicate the extension of the lower A2 into the B horizon (Fig. 17).

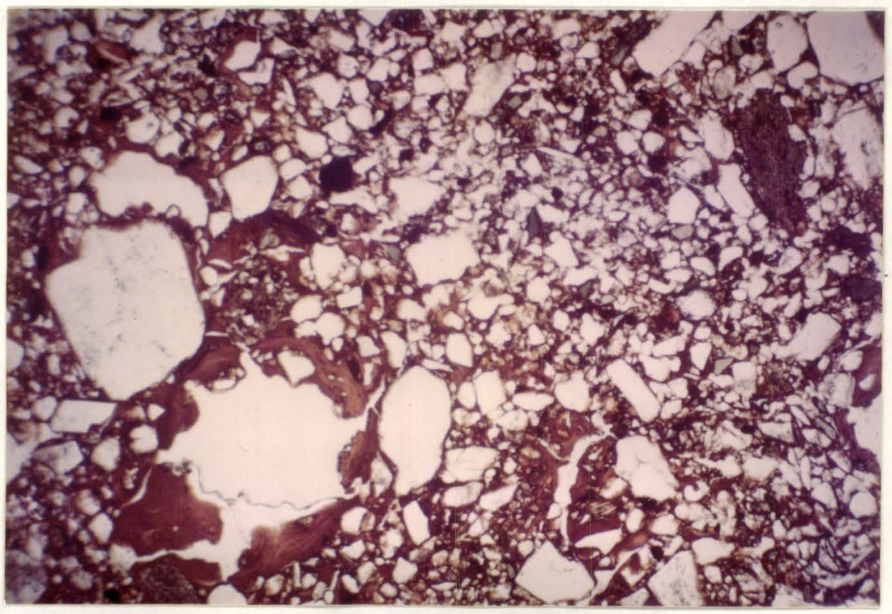
Cutans

These are concentrations of clay or silt sized material on the surfaces of peds, pores, sand grains or stones (FitzPatrick 1971).



500 μ

Fig. 17 Photomicrograph of AB horizon showing a pore with a disintegrating clay cutan and two clay papules (x).



500 μ

Fig. 18 Photomicrograph of upper B2t horizon showing concentration of very fine to fine sand and clay cutans that appear to be disintegrating.

Such concentrations of material to form films are regarded as being due to the translocation of material through the soil in the form of a colloidal suspension (McCaleb 1954).

Clay cutans, occurring in the B horizon, are often taken to imply a process of translocation from a higher horizon. However, such clay illuviation as a factor in the production of textural B horizons has at times been overestimated and not enough consideration has been given to differential in situ weathering of the A and B horizons, or to inherited sedimentary characteristics (Brewer 1956).

In the Burford loam, clay cutans are present in significant proportions only in the B2t horizon. Within the A horizon clay cutans are found in pore spaces in weathered stones, (Fig.12) where their characteristics agree with the definitions of depositional clay cutans given by both Brewer (1964) and FitzPatrick (1971). However, these cutans are clearly the product of in situ weathering and not the result of clay illuviation from a higher horizon. They indicate that clay minerals do not have to be transported very far before they become optically orientated and exhibit all the characteristics of depositional clay cutans. Such findings must bring into question the use of the ratio of orientated to non-orientated clay in determining the relative importance of clay illuviation and in situ weathering, within B horizons.

However, the occurrence of clay cutans only within weathered stones, in the A horizon, indicates that conditions are not conducive to their formation outside these stones. In some cases well developed cutans show no continuation outside the stones, which indicates the rapid removal of clay from this horizon.

Clay cutans are best developed in the B2t horizon where they are multilayered and fairly continuous (Fig. 19). However, the upper part of the section shows slight evidence of degradation of the cutans (Fig. 18). A similar, although more pronounced process of clay cutan degradation is apparent in the AB horizon, where cutans in the lower part of the section are discontinuous, with fractures rather than smooth surfaces (Fig. 17). The upper part of the AB section contains fewer cutans, but has a number of papules and shows a greater degree of bleaching of the sand and silt fraction.

The evidence indicates that the B2t horizon is an unstable one, which is undergoing continual change. The existence of discontinuous clay cutans in the A22 and AB horizons and the more continuous clay cutans of the B2t horizon, point to the gradual replacement of the B2t horizon by the AB horizon and the replacement of the AB horizon by the A22 horizon. A similar development has been noted by Pettapiece and Zwarich (1970) in a Grey Wooded soil. Lebedeva (1969) in a study of a Grey Brown Podzolic suggests that the study of the B horizons of such soils on the basis of average samples, has often mistakenly led to the conclusion that the process of illuviation is the only process operating there. Evidence is provided by Lebedeva (1969) that in the B horizons of such soils there are two processes operating simultaneously. Illuviation leads to the formation of depositional clay cutans in the lower Bt horizon, whilst a process of

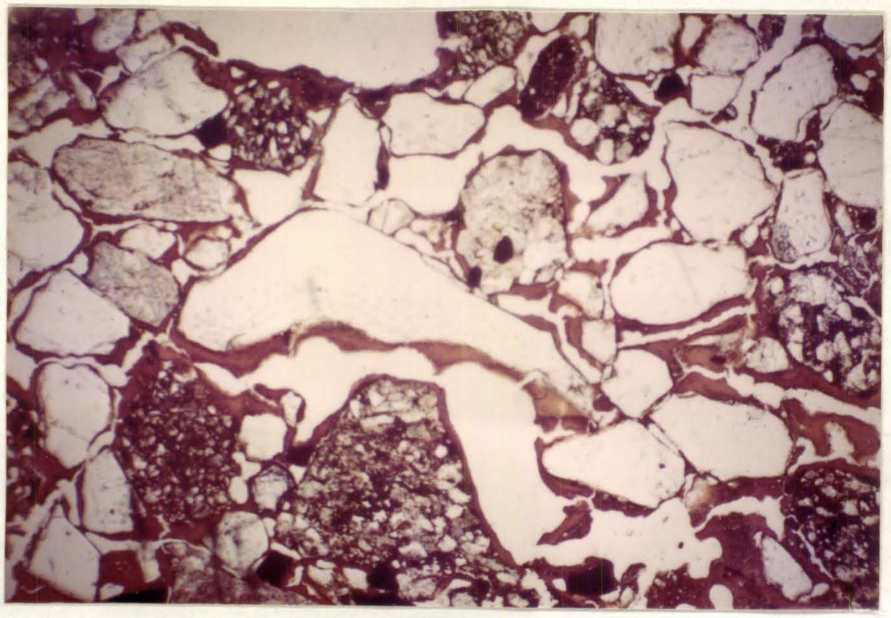


Fig. 19 Photomicrograph of the B2t horizon showing concentration of medium sized sand with well developed pore and grain cutans.

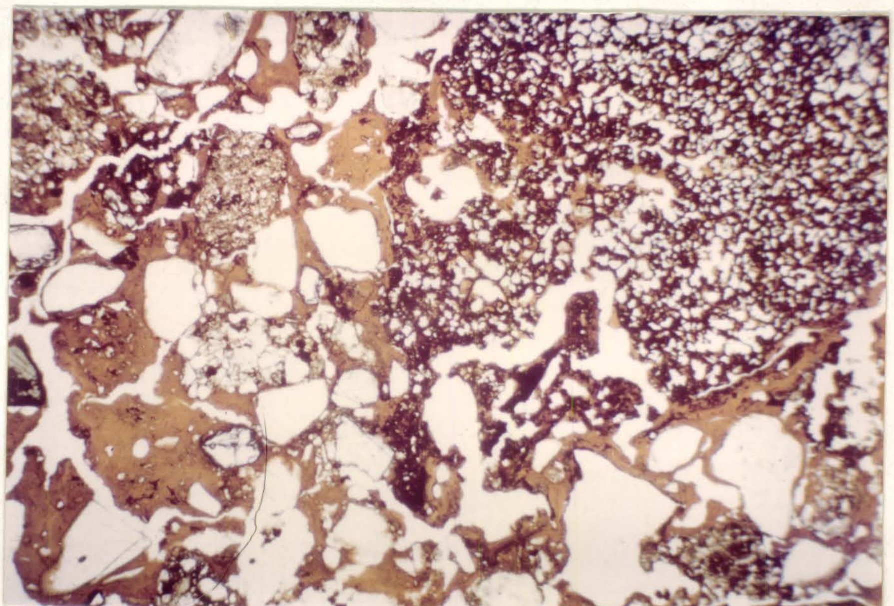


Fig. 20 Photomicrograph of the B2t horizon showing highly weathered dolomite pebble. Most of the clay visible is unorientated but clay cutans are present along pore and grain boundaries.

degredation operates in the upper part of the horizon. The existence of discontinuous cutans in the AB horizon indicates that the illuvial process which was once active there has now been replaced by a process of eluviation. In the Burford loam, the main reason for the displacement of the various horizons ever deeper, would seem to be the gradual leaching out of carbonates, which act as flocculants in the clay and the weathering of pebbles in the B horizon, so that the textural junction of coarse and fine material is progressively deeper.

The thin sections indicate that the A horizon of the Burford loam is characterised by a process of eluviation, that is gradually producing a carbonate free, silica rich horizon, which may be expected to increase in acidity as leaching continues. The B2t horizon is characterised by the illuviation of clay from the overlying horizons and by the in situ production of clay due to the weathering of carbonate and shale pebbles.

Thus the evidence would seem to indicate that the soil tongues in the Burford loam are zones in which there is a localization of the pedogenic processes causing the solution of the underlying calcareous gravels, collapse of material within the soil tongue and the continuing extension of the soil tongues.

CHAPTER III

PHYSICAL AND CHEMICAL ANALYSES OF SOIL TONGUE SAMPLES.

I. Particle Size Distribution

If there are differences in the modes of origin of the A2 horizon material between the various sites, then the particle size distribution figures will be expected to show this. If the A horizon has developed from material similar to the C horizon then relatively parallel particle size distribution curves would be expected. However, if the A horizon has been developed in material deposited over the gravels of the C horizon then the curves would not be expected to be parallel.

Clay Fraction

The particle size analyses (Tables 2 - 6) support the identification of an argillic horizon that meets all the requirements for such an horizon (USDA 1967). The clay content of the B2t horizon varies from site to site, being greatest at Brantford and least at Freelton. However, despite the fact that the clay content of the B2t horizon at Freelton is only 13.4% it is still within the limits set for such horizons by the USDA (1967), in that it contains almost twice as much clay as any overlying horizon and possesses orientated clay totalling more than 1% of the horizon in thin section (Chpt.II).

Although the two profiles at Brantford are only 10 metres apart, the results indicate significant differences between them.

TABLE 2

MECHANICAL AND CHEMICAL ANALYSES OF PROFILE I AT FREELTON

Horizon and sample depth (cms)		Very coarse sand (micron) 2000-I000	Coarse sand I000-500	Medium sand 500-250	Fine sand 250-I00	Very fine sand I00-50	Coarse silt 50-20	Medium silt 20-5	Fine silt 5-2	Total silt 50-2	Clay <2μ
Ap	I0	I.0	2.7	9.5	I8.7	I7.I	27.4	II.I	4.7	43.2	7.8
A2I	23	0.4	I.8	II.3	29.3	20.4	23.I	5.8	2.2	3I.0	5.7
A2I	45	0.3	I.6	I0.9	3I.8	23.8	I6.9	7.8	2.0	26.7	4.9
A22	90	0.7	2.I	I2.6	36.6	25.9	I7.5	3.5	I.9	I7.5	4.6
A22	I05	I.2	4.3	I3.5	29.7	20.7	I6.8	7.3	3.I	27.2	3.4
AB	I20	4.0	9.I	II.I	I0.9	9.I	I9.2	2I.5	7.5	48.3	7.6
B2t	I30	7.4	26.5	I6.0	6.4	6.5	I3.2	6.4	4.2	23.8	I3.4
B3	I50	II.3	I8.0	I7.7	9.0	8.6	I4.3	9.0	I.3	24.6	I0.8
*C	I50	I2.8	36.4	I8.8	3.5	3.9	7.9	I0.0	I.5	I9.4	5.2

		Organic matter Pct.	Loss on ignition Pct.	Moisture content Pct.	pH	Liquid limit	Exchangeable bases (meq/I00 gm soil) Ca	Mg	Na	K	Fe Pct.
Ap	I0	3.I	3.6	3.3	6.I	I8.I	I4.4	I.6	I.I	2.4	0.23
A2I	23	0.9	I.4	2.I	6.5	I5.5	6.6	0.5	0.8	3.2	0.I5
A2I	45	0.6	I.8	3.3	6.5	I4.6	5.4	0.3	0.7	5.0	0.2I
A22	90	0.5	I.4	2.I	6.7	I6.7	3.7	0.2	0.8	3.I	0.I9
A22	I05	0.6	I.6	2.6	6.7	I2.5	4.3	0.2	I.0	2.6	0.I9
AB	I20	I.0	2.4	7.4	6.5	I9.0	6.6	0.2	I.0	2.5	0.26
B2t	I30	I.0	3.8	II.0	7.I	22.9	I4.2	I.3	I.4	5.9	0.32
B3	I50	0.6	II.8	0.9	7.9	I8.2	I4.0	nd	nd	nd	nd
*C	I50	0.6	I3.8	0.6	8.2	I8.2	I6.I	0.5	I.8	2.9	0.2I

*C horizon sample taken to one side of soil tongue. nd not determined

TABLE 3

MECHANICAL AND CHEMICAL ANALYSES OF PROFILE 2 AT BRIDGEPORT

(micron)

Horizon and sample depth	cms	Very coarse sand 2000-I000	Coarse sand I000-500	Medium sand 500-250	Fine sand 250-I00	Very fine sand I00-50	Coarse silt 50-20	Medium silt 20-5	Fine silt 5-2	Total silt 50-2	Clay <2μ
Ap	8	0.4	I.2	8.2	I8.4	I5.I	29.6	9.4	9.0	48.0	8.7
A2I	20	0.2	0.8	9.I	2I.7	I6.2	27.7	I2.8	4.0	44.6	7.5
A2I	35	0.2	0.7	I0.I	27.5	I7.3	26.0	9.4	3.6	39.0	5.2
A22	60	0.6	I.3	II.0	24.4	30.7	I3.4	9.8	4.8	28.0	4.0
AB	80	I.3	4.3	2I.9	7.8	7.7	36.5	5.5	9.0	5I.0	6.0
B2t	87	I.8	6.I	I8.7	26.9	5.5	8.8	5.4	3.3	I7.5	23.5
B3	I00	I6.8	I0.5	20.3	29.5	8.2	5.5	3.8	0.3	9.6	5.I
*C	I20	25.8	47.2	I0.6	4.0	2.4	3.0	4.2	0.8	8.0	2.0

		Organic matter Pct.	Loss on ignition Pct.	Moisture content Pct.	pH	Liquid limit	Exchangeable bases (meq/I00 gm soil) Ca	Mg	Na	K	Fe Pct.
Ap	8	3.0	4.8	I4.7	6.2	I6.8	I5.7	2.8	I.2	2.7	0.22
A2I	20	I.6	2.6	I2.5	6.4	I5.4	9.0	I.4	I.I	3.I	0.2I
A2I	35	I.5	2.4	I0.6	6.7	I3.7	6.7	0.9	I.2	I.6	0.2I
A22	60	2.3	2.8	II.7	6.5	I3.9	9.0	I.I	I.I	2.6	0.2I
AB	80	I.0	2,0	8.5	6.8	I2.3	5.3	0.5	I.6	3.2	0.24
B2t	87	0.7	4.2	I2.5	6.8	I8.8	I8.4	3.2	2.3	nd	0.29
B3	I00	I.I	23.0	3.3	7.7	I3.4	20.2	I.I	I.4	2.4	0.07
*C	I20	0.5	29.0	2.3	8.I	I5.4	I6.2	0.6	0.6	I.2	0.I0

*C horizon sample taken to one side of soil tongue **nd not determined**

TABLE 4

MECHANICAL AND CHEMICAL ANALYSES OF PROFILE 3 AT STRABANE

(micron)

Horizon and sample depth	cms	Very coarse sand 2000–I000	Coarse sand I000–500	Medium sand 500–250	Fine sand 250–I00	Very fine sand I00–50	Coarse silt 50–20	Medium silt 20–5	Fine silt 5–2	Total silt 50–2	Clay $<2\mu$
Ap	I0	2.5	8.2	I5.4	I0.I	8.7	20.8	I2.6	5.5	38.9	I6.2
A2	25	2.8	9.9	I4.3	I3.2	II.0	2I.9	I2.9	4.5	39.3	9.5
B2t	45	7.4	I7.8	I6.0	6.2	9.3	I3.0	8.4	2.8	24.2	I9.I
B2t	60	3.6	I3.2	3I.0	5.9	4.9	II.2	7.8	2.6	2I.6	I9.8
B3	80	I0.5	2I.I	37.3	7.I	3.3	7.2	6.3	2.4	I5.7	4.8
*C	90	I5.7	25.2	29.6	6.6	3.4	5.6	5.7	6.2	I7.5	2.0

	cms	Organic matter Pct.	Loss on ignition Pct.	Moisture content Pct.	pH	Liquid limit	Exchangeable bases (meq/I00 gm soil) Ca	Mg	Na	K	Fe Pct.
Ap	I0	3.0	5.6	I3.0	6.5	20.9	nd	nd	nd	nd	nd
A2	25	0.9	2,6	I2.5	6.7	I6.3	nd	nd	nd	nd	nd
B2t	45	I.3	5.2	I2,2	7.I	23.5	nd	nd	nd	nd	nd
B2t	60	I.5	7.2	I3.4	7.2	24.2	nd	nd	nd	nd	nd
B3	80	0.2	I5.0	4.0	7.6	I2.0	nd	nd	nd	nd	nd
*C	90	0.4	I8.8	3.9	7.7	I2.5	nd	nd	nd	nd	nd

*C horizon sample taken to one side of soil tongue
nd not determined

TABLE 5

MECHANICAL AND CHEMICAL ANALYSES OF PROFILE 4 AT BRANTFORD

(micron)

Horizon and sample depth	cms	Very coarse sand 2000-I000	Coarse sand I000-500	Medium sand 500-250	Fine sand 250-I00	Very fine sand I00-50	Coarse silt 50-20	Medium silt 20-5	Fine silt 5-2	Total silt 50-2	Clay <2μ
Ap	I0	2.9	5.9	5.2	3.6	6.8	44.0	I7.4	4.5	65.6	9.8
A2I	25	0.4	I.9	I.3	I.0	4.8	52.7	23.4	4.3	80.3	I0.6
A22	54	0.2	I.2	I.3	I.5	9.9	48.3	I7.4	7.I	72.8	I3.I
B2It	62	I0.9	I9.2	I0.6	6.4	2,7	8.8	I0.2	4.I	23.I	27.I
B22t	I20	5.8	2I.4	II.I	5.4	II.I	I5.4	4.7	9.I	29.2	I6.0
B3	I30	I4.3	27.4	I0.2	3.I	6.8	I6.6	I0.3	5.8	32.7	5.5
*C	I05	8.5	49.5	27.3	5.I	2.I	2.0	2.0	I.I	5.I	2.4

	cms	Organic matter Pct.	Loss on ignition Pct.	Moisture content Pct.	pH	Liquid limit	Exchangeable bases (meq/I00 gm soil) Ca	Mg	Na	K	Fe Pct.
Ap	I0	I.2	2,4	I6.3	6.2	I7.4	7.3	I.0	I.8	I.I	0.2I
A2I	25	0.9	2.2	I4.0	5.8	I8.0	5.4	0.7	2.3	I.3	0.24
A22	54	0.5	2.4	I6.7	5.7	I9.7	6.2	I.0	nd	nd	0.30
B2It	62	I.4	3.6	I5.6	5.9	20.5	9.8	2.2	6.5	I.5	0.4I
B22t	I20	I.0	I2.2	I0.9	7.3	22.0	7.5	3.2	3.8	I.3	0.I6
B3	I30	0.3	I8.0	6.7	7.5	I7.9	I0.0	I.4	2.2	I.4	0.I3
*C	I05	0.2	25.6	4.6	7.9	I4.8	II.7	0.5	I.4	I.0	0.I0

*C horizon sample taken to one side of soil tongue   nd not determined

TABLE 6

MECHANICAL ANALYSES OF PROFILE 5 AT BRANTFORD

(micron)

Horizon and sample depth	cms	Very coarse sand 2000-I000	Coarse sand I000-500	Medium sand 500-250	Fine sand 250-I00	Very fine sand I00-50	Coarse silt 50-20	Medium silt 20-5	Fine silt 5-2	Total silt 50-2	Clay <2μ
A2	20	0.3	2.I	46.I	37.0	3.9	2.8	I.3	5.0	9.0	I.5
B2t	25	I.3	9.4	29.I	30.0	8.8	6.3	2.5	I.8	I0.6	I0.8
A'2	35	0.I	3.0	II.I	58.0	I3.9	5.9	I.3	I.2	8.4	5.5
B'I	43	0.3	I.2	2.4	6.8	35.6	2I.8	I3.4	4.2	39.2	I4.3
B'2t	60	3.6	I3.0	7.6	9.5	8.4	8.I	I2.9	II.5	32.4	25.4
B'2t	86	3.2	I3.8	I3.5	7.4	5.I	6.5	6.6	7.I	20.2	36.8

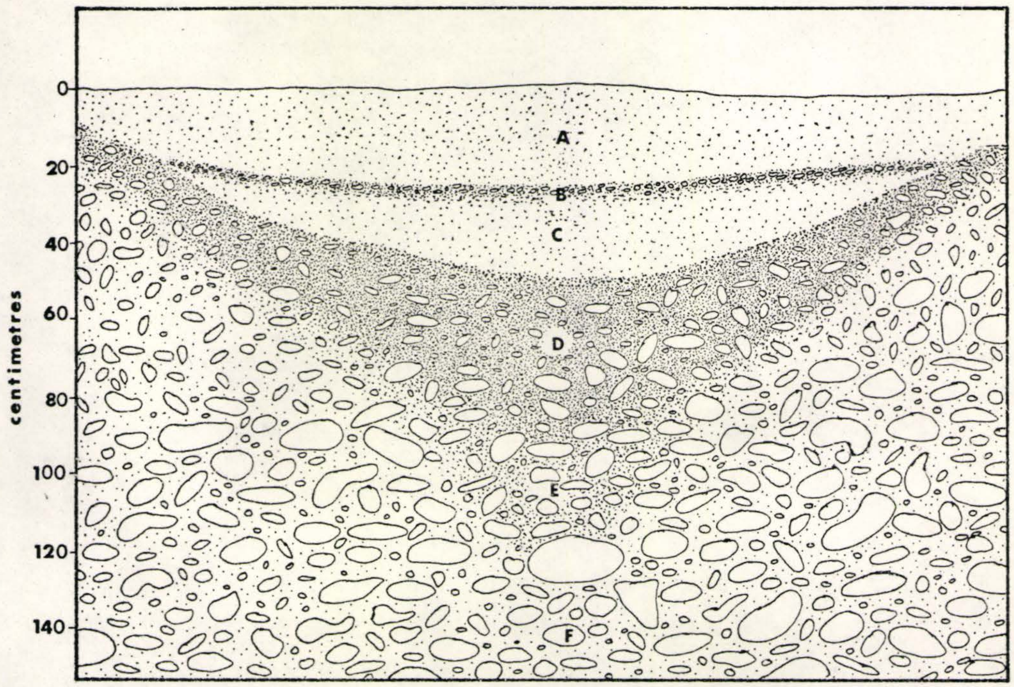
Profile 5 is unusual in that it possesses two horizons of clay maximum whilst 4 has only one. The highest, the B2t horizon, occurs at a depth of 25 cms., below the stripped surface and contains 10.8% clay. The horizons above and below this B2t horizon contain significantly less clay. The second horizon of clay accumulation is the B'2t which contains 36.8% clay and occurs at depths of up to 60 cms. These two horizons are separated by one which contains only 5.5% clay and which appears similar to the A22 horizon of profile 4.

The development of this bisequal profile would seem to be due to the presence of a bed of partly weathered, calcareous pebbles that is 3-5 cms., thick and which seems to be causing an accumulation of clay (Fig.21).

The Ap horizons at all sites possess relatively high clay contents ranging from 7.8% at Freelton to 16.2% at Strabane, whereas the A2 horizons, particularly at Freelton and Bridgeport have fairly low clay contents indicating that there is loss of clay from this horizon. The high clay content of the B2t horizons suggests that this translocated clay is accumulating there to form an argillic horizon. The figures for the B3 horizon indicate that either clay is being translocated below the level of maximum accumulation, or that there is in situ formation of clay.

Thus the profiles all show evidence of eluvial and illuvial horizons typical of Udalfic soils. However, although the results indicate a process of clay eluviation, it is obvious that there is also in situ clay formation in the B2t horizon due to the weathering

Fig. 2I Soil tongue at Brantford (profile 5) showing development of a bisequal profile



(gravels not drawn to scale)

A A2 horizon containing mainly medium to fine sand

B B2t horizon consisting of a thin band of gravel with an accumulation of clay

C A'2 horizon containing mainly fine and medium sand

D B'I horizon and B'2t horizon consisting of gravels with an accumulation of clay

E Tongue-like extension of stained gravels

F Calcareous outwash gravels

of calcareous gravel.

Sand and Silt Fraction

The particle size analyses (Tables 2 - 6) indicate a deficiency of coarse material in the A horizons and it is obvious from field observations that in comparison to the B and C horizons there is a marked absence of gravel sized material.

As the two Brantford profiles are underlain by similar material, the A horizons of each profile should be almost identical if they have formed as a result of the weathering of the calcarious gravels. However, the particle size distribution figures (Tables 5 & 6) and curves (Figs. 25 & 26) indicate significant differences. Profile 4 has an A horizon which is dominated by silt, 72.8% in the A22 horizon, whilst profile 5 has A horizons dominated by fine medium sand. Such contrast between two profiles only 10 metres apart can only be explained by their being a depositional feature.

The sand and silt contents of the Freelton and Bridgeport profiles are similar, both have Ap horizons characterized by coarse silt and fine sand and both show decreasing silt contents down to the C horizon, except for the AB horizon which in each case has an increase in silt. The sand fraction increases from the Ap to the C horizon and becomes progressively coarser. Similar trends are apparent in the Strabane profile, except that it lacks a well defined AB horizon.

The particle size distribution curves for the Freelton, Bridgeport and Strabane profiles (Figs. 22 - 26) indicate a relatively

Fig. 22 Particle size distribution (semilog) of soil tongue samples from Freelton

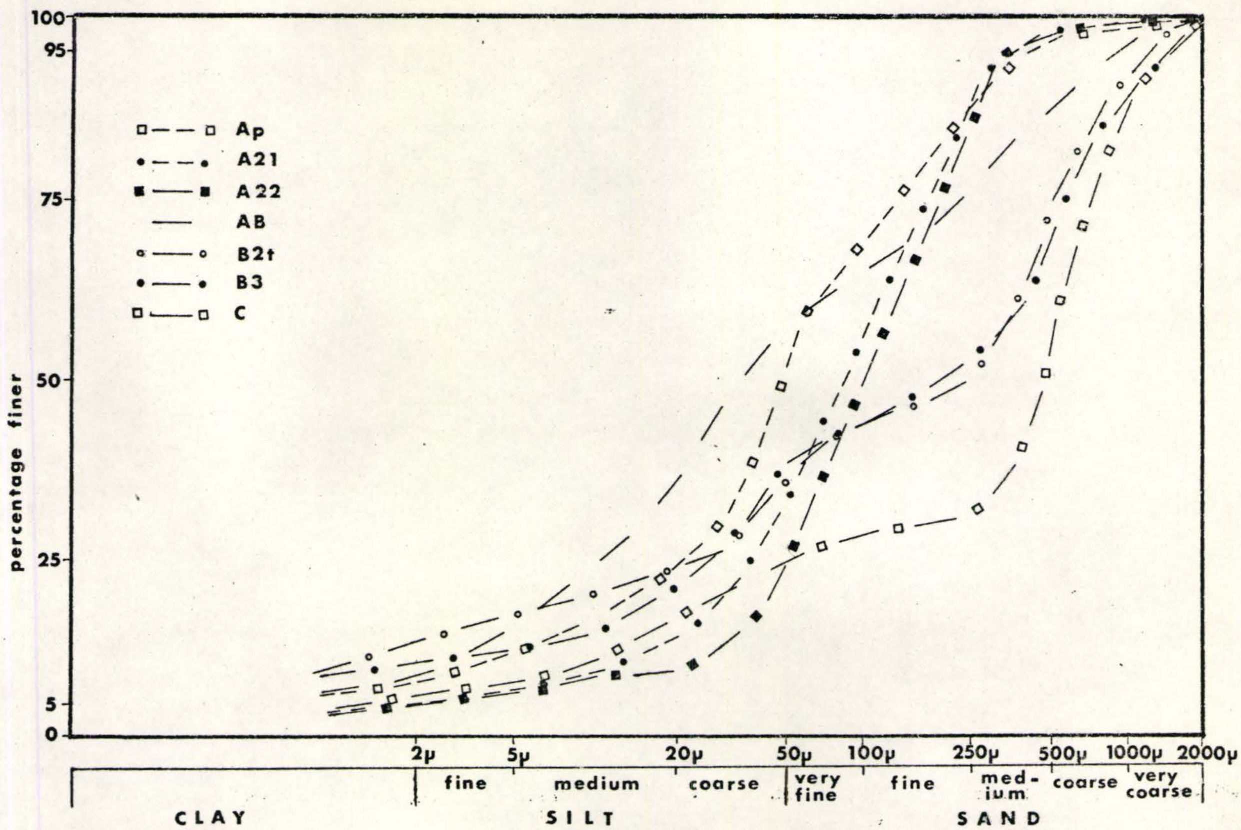


Table 7 Statistical parameters of particle size

Horizon	Inclusive graphic standard deviation σ_I	Inclusive graphic skewness Sk_I	Kurtosis K_G	K'_G	Graphic mean Mz
Ap	2.57 ∅	+0.I8	I.33	0.5I	4.46 ∅
A2I	2.04 ∅	+0.29	I.40	0.58	3.72 ∅
A2I	I.03 ∅	+0.40	I.30	0.57	3.76 ∅
A22	I.82 ∅	+0.38	I.69	0.63	3.30 ∅
AB	I.02 ∅	+0.30	I.32	0.57	3.46 ∅
B2t	3.54 ∅	+0.0I	0.95	0.49	4.I6 ∅
B3	4.23 ∅	+0.48	I.02	0.50	3.52 ∅
C	3.23 ∅	+0.68	I.0I	0.50	2.33 ∅

Fig. 23 Particle size distribution (semilog) of soil tongue samples from Bridgeport

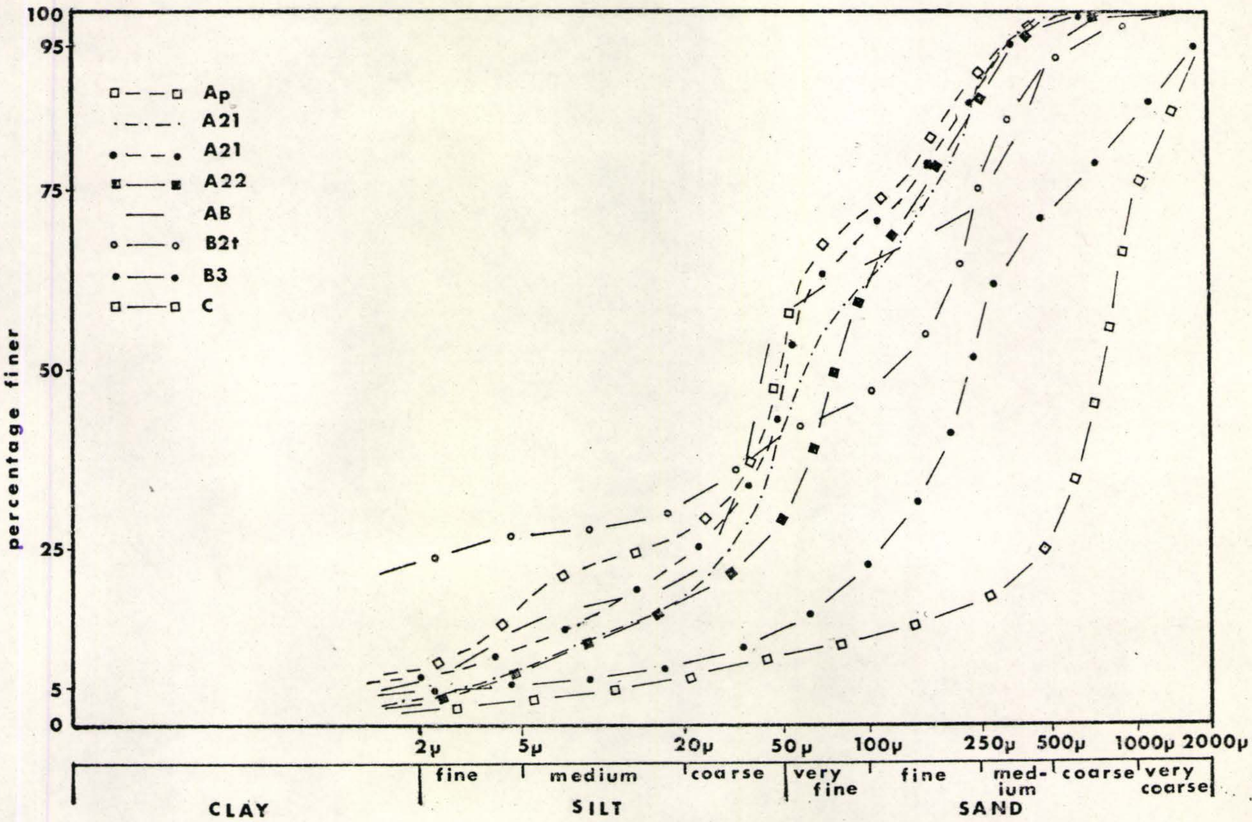


Table 8 Statistical parameters of particle size

Horizon	Inclusive graphic standard deviation σ_I	Inclusive graphic skewness Sk_I	Kurtosis K_G	K_G'	Graphic mean Mz
Ap	2.79 ∅	+0.28	I.37	0.58	5.02 ∅
A2I	2.49 ∅	+0.22	I.37	0.58	4.46 ∅
A2I	2.06 ∅	+0.2I	I.I8	0.54	4.04 ∅
A22	2.04 ∅	+0.30	I.32	0.57	3.98 ∅
AB	2.63 ∅	-0.05	I.03	0.5I	4.40 ∅
B2t	4.I0 ∅	+0.65	0.77	0.43	5.04 ∅
B3	2.48 ∅	+0.I9	I.66	0.62	2.0I ∅
C	I.64 ∅	+0.64	2.30	0.70	0.70 ∅

Fig. 24 Particle size distribution (semilog) of soil tongue samples from Strabane

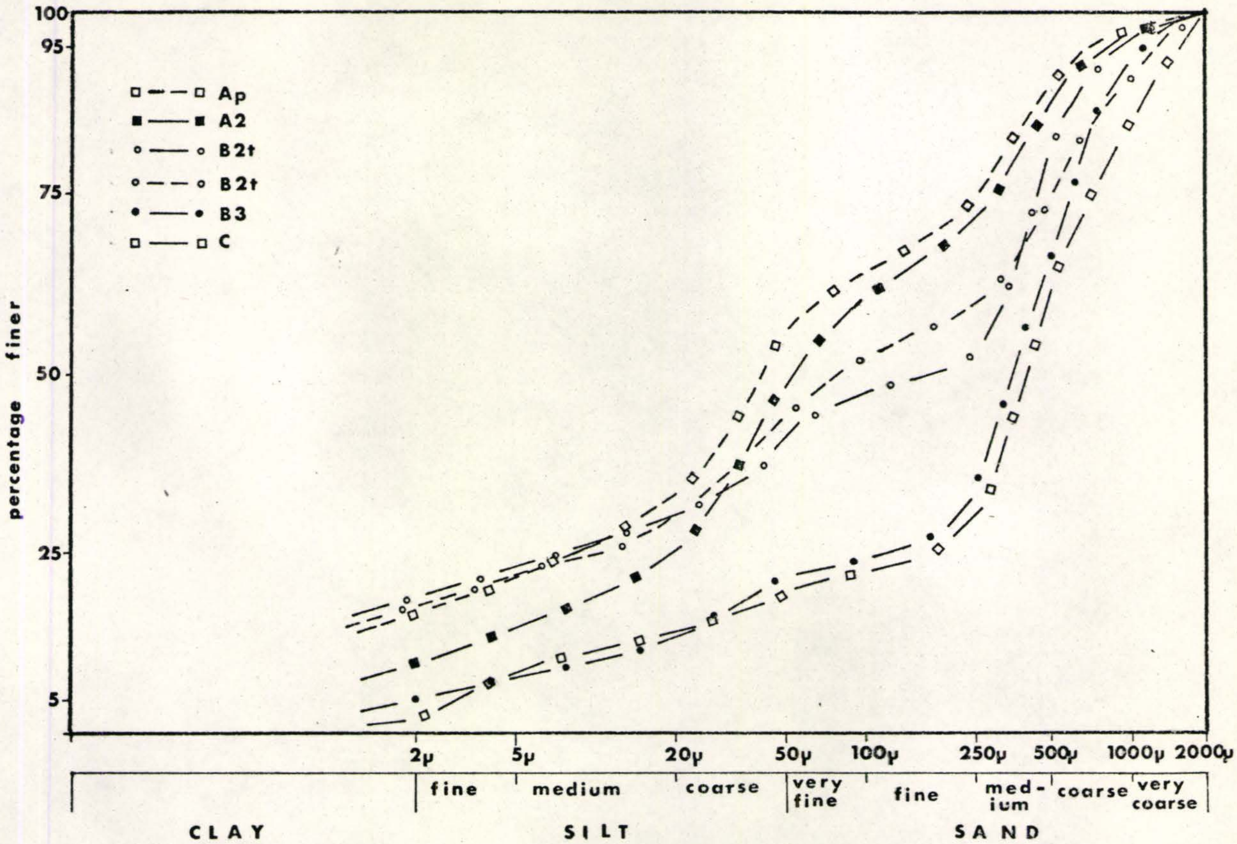


Table 9 Statistical parameters of particle size

Horizon	Inclusive graphic standard deviation σ_I	Inclusive graphic skewness Sk_I	Kurtosis K_G	K'_G	Graphic mean Mz
Ap	3.75 ∅	+0.19	1.01	0.50	5.05 ∅
A2	2.97 ∅	+0.09	1.12	0.52	4.18 ∅
B2t	4.35 ∅	+0.36	0.98	0.49	4.73 ∅
B2t	4.20 ∅	+0.69	0.97	0.49	4.45 ∅
B3	2.88 ∅	+0.53	1.59	0.61	2.30 ∅
C	2.88 ∅	+0.54	1.63	0.62	2.10 ∅

Fig. 25 Particle size distribution (semilog) of soil tongue samples from profile 4 at Brantford

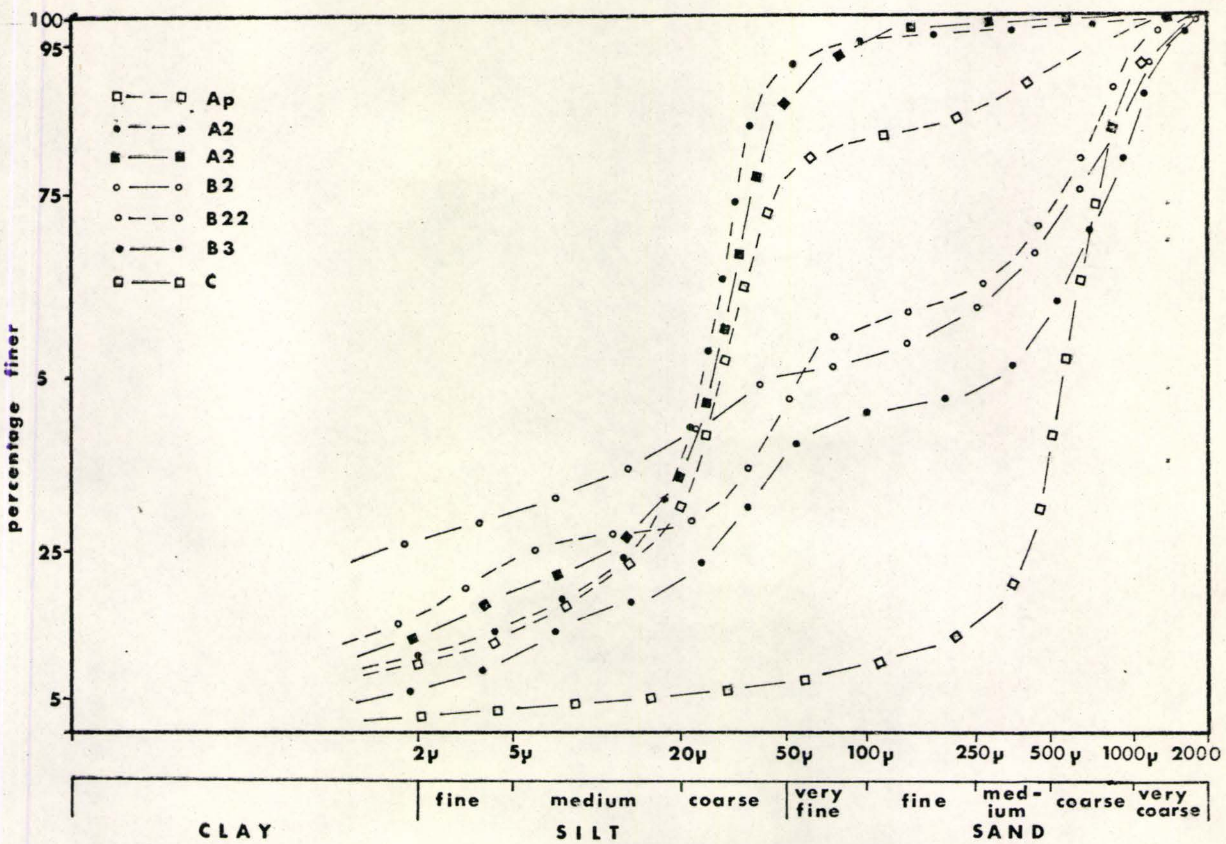


Table IO Statistical parameters of particle size

Horizon	Inclusive graphic standard deviation σ_I	Inclusive graphic skewness Sk_I	Kurtosis K_G	K_G'	Graphic mean Mz
Ap	2.64 ∅	0.00	2.67	0.73	5.00 ∅
A2I	I.93 ∅	+0.76	I.75	0.64	5.86 ∅
A22	2.27 ∅	+0.58	I.96	0.66	6.03 ∅
B2It	4.63 ∅	+0.23	0.65	0.38	5.I6 ∅
B22t	4.57 ∅	+0.3I	0.74	0.42	5.0I ∅
B3	2.I2 ∅	+0.50	0.82	0.45	2.78 ∅
C	I.37 ∅	+0.36	2.33	0.70	0.90 ∅

Fig. 26 Particle size distribution (semilog) of soil tongue samples from profile 5 at Brantford

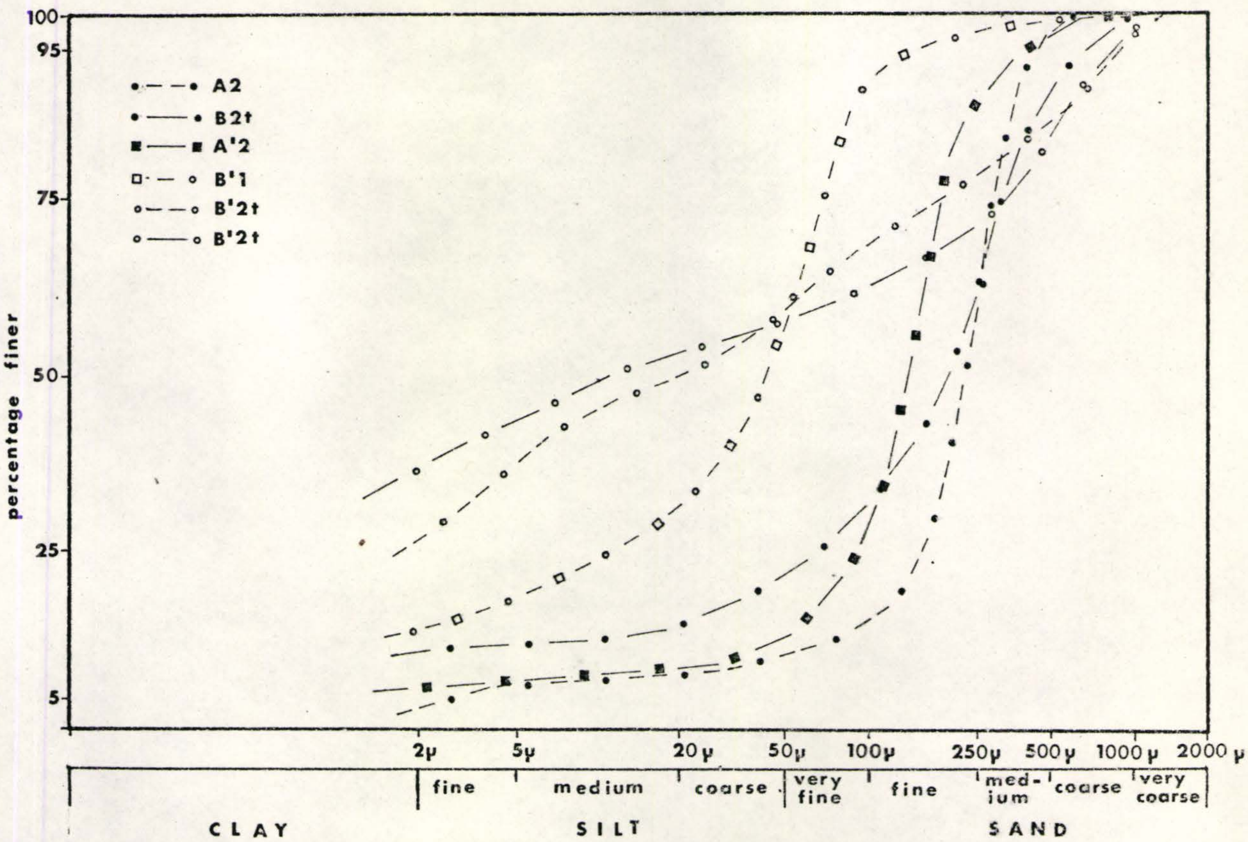


Table II Statistical parameters of particle size

Horizon	Inclusive graphic standard deviation σ_I	Inclusive graphic skewness Sk_I	Kurtosis K_G	K'_G	Graphic mean Mz
A2	I.42 ∅	+0.58	2.83	0.74	2.25 ∅
B2t	2.9I ∅	+0.64	2.02	0.67	3.26 ∅
A'2	I.76 ∅	+0.45	3.24	0.76	2.97 ∅
B'I	2.77 ∅	+0.55	I.35	0.57	5.27 ∅
B'2t	4.32 ∅	+0.I3	0.77	0.44	5.57 ∅
B'2t	4.77 ∅	+0.I2	0.60	0.38	6.I0 ∅

low degree of parallelism, but the differences between the curves for the A horizons and the C horizons are not marked enough to suggest either a genetic or a depositional origin.

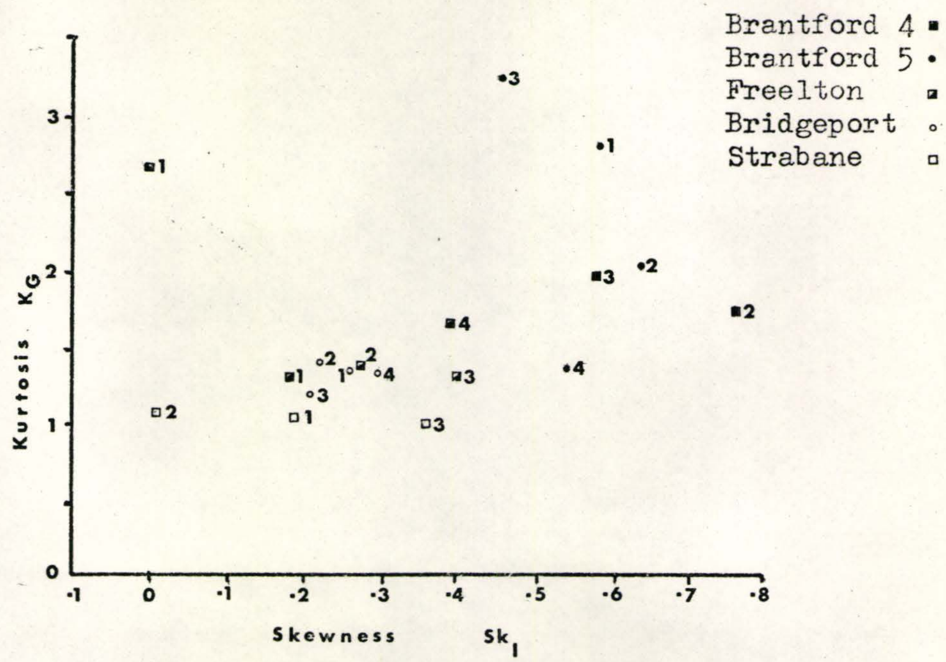
Statistical Particle Size Parameters

The particle size parameters of the B horizons (Tables 7-11) are those expected for an argillic horizon overlying a coarse gravel deposit. The σ_I values (Folk 1968) for this horizon at all of the sites indicate extremely poor sorting due to the admixture of clay and gravel. The high clay content is also responsible for the strongly fine-skewed nature of the particle size distribution and for the tendency to a bimodal distribution.

It appears that the five profiles differ very little in degree of sorting, or in skewness and kurtosis. Poor sorting characterises each of the profiles, even those at Brantford which have higher contents of silt and fine sand. The Freelton, Bridgeport and Strabane sites have profiles that are finely skewed in the Ap horizon, fine to strongly fine skewed in the A2 horizon, except at Strabane where it is near symmetrical. All three are strongly fine-skewed in the C horizon, reflecting the coarse nature of the gravels and the lack of sorting. In contrast the Brantford profiles are more strongly fine skewed. The kurtosis values show rather more variation, but in most cases the most peaked distribution curves are also the most strongly fine skewed.

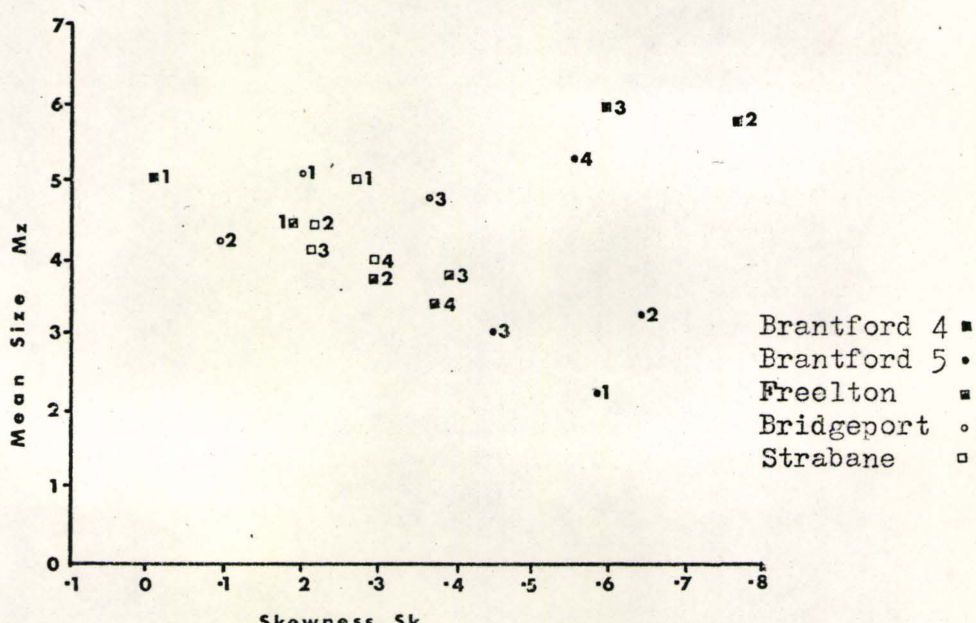
The greatest contrast between the Brantford profiles and the others is found in the mean particle size (Mz). Whereas the Mz

Fig. 27 Skewness and kurtosis of A horizon samples from all five profiles



(samples are numbered from the surface downwards)

Fig. 28 Skewness and mean particle size of A horizon samples from all five profiles
(samples are numbered from the surface downwards)



values tend to increase from the Ap horizon to the A2 horizon at Freelton, Bridgeport and Strabane, in profile 4 at Brantford it decreases from 5.00 ϕ to 6.03 ϕ in the A22 horizon. The Mz values for profile 5 at Brantford differ from those of profile 4, with the upper horizons being coarser and the B'2t being finer with an Mz value of 6.1 ϕ. These differences are readily seen in the particle size distribution curves (Figs. 22 - 26). However, all profiles show an increase of particle size in the B and C horizons.

Mason and Folk (1958) have suggested that the best parameters to use in differentiating sediments are the values of skewness and kurtosis. Therefore, kurtosis has been plotted against skewness for the A horizons of all five profiles to check the apparent similarity of those at Freelton, Bridgeport and Strabane and their contrasts with those at Brantford, (Fig 27). The resulting scatter shows a clustering of the A horizon samples from Freelton, Bridgeport and Strabane, whilst those from Brantford although not clustered are clearly separated from the others. A plot of particle ~~grain~~ size against skewness also shows a clustering of the samples from the Freelton, Bridgeport and Strabane sites, whilst those from Brantford are more widely scattered (Fig. 28).

2. Chemical Analyses

If the A2 horizon material at Freelton, Bridgeport and Strabane has originated through pedogenic processes, whilst the A2 horizon material at Brantford has a depositional origin, then differences in their chemical characteristics may be expected. However, as a comparison of the chemical analyses indicates there is very little difference in the results for the three profiles analysed (Tables 2 - 6).

The organic matter content figures indicate little difference between the profiles studied. The variations in loss on ignition would appear to have little significance and all the profiles show similar trends.

The pH values are fairly high, indicating that leaching has not progressed very far in the Burford loam at any of the sites. The A2 horizons at Freelton, Bridgeport and Strabane have pH values of 6.5 - 6.7, increasing to pH 8 in the C horizon. However, the Brantford profile has pH values of 5.7 in the A22 horizon rising to pH 7.9 in the C horizon and would therefore appear to have suffered a slightly greater degree of leaching than the other profiles.

The figures obtained for exchangeable bases are very high, even in the A2 horizons. Although variations occur between sites, they are very slight and even though the pH values for the Brantford profile are lower, this does not seem to be reflected in a significant decrease in exchangeable bases in this profile.

The data for free Fe indicate little difference between the A horizons of the three profiles analysed, except that the Brantford profile contains a slightly higher percentage in the A22 horizon. All three profiles show an increase in the B2t horizon, which is greatest at Brantford where it is 0.41%. Burgess and Drover (1953) have suggested that the leaching of Fe does not occur above pH 6 and the figures from the Freelton and Bridgeport sites would seem to bear this out, whilst the higher percentage in the B2t horizon at Brantford may be explained by the lower pH of the A2 horizon. However, the increases of Fe would seem to be mainly a result of a passive movement, with the eluviation of the clay being the dominant process.

3. Discussion of Results

The theories advanced to explain soil tongues all seem to regard the extension of the lower B horizon as a result of soil forming processes (Yehle 1954, Denny, Lyford and Goodlett 1963, Presant and Protz 1967). However, there is less agreement as to the mechanism whereby such localization occurs and also as regards the origin of the pocket-like masses of A2 horizon material. Chapman and Putnam(1966) suggest that they result from a blanket of fine material deposited over outwash gravels and incline to this view not because of any physical distinction between the fine covering (loess) and weathered silt but because "... the variable depth of the silt can hardly be attributed to weathering " (p.118 Chapman and Putnam 1966). Although not stated, it is implicit in the above that the surface so covered was a hummocky one.

If the pockets of A2 horizon material are the product of in situ weathering either by mechanical processes, as suggested by Maruszczak (1960), or by chemical processes then similarities between the particle size distribution within the A,B and C horizons might be expected. As shown the Brantford profiles provide evidence of a lithological discontinuity between the A and C horizons, indicating that the A horizon material has originated in a non-pedogenic manner.

Whereas the Freelton, Bridgeport and Strabane profiles neither exhibit a distinct similarity nor a distinct contrast between the A and C horizon material.

The particle size distribution curves of the Brantford profiles (Figs. 6 & 7) are not typical of established loess deposits as they are not well enough sorted. However, the A2 horizon material in profile 4 at Brantford has such a high silt content that a loessic origin is implied. Russell (1944) describes loess deposits as having over 50% of particles in the 10-50u fraction. However, the absence of such a high silt content in profile 5 indicates a fluvial origin.

The A2 horizon material at Freelton, Bridgeport and Strabane is much less typical of established loess deposits. However, Pitcher, Shearman and Pugh (1954) describe basal loess deposits as having only 45% of particles in the 10-50u fraction and as being poorly sorted. Thus, even though the A2 horizon material at these three sites differs from that at Brantford, a loessic, or more likely, a fluvial origin is still conveivable.

There is no evidence to either support or disprove the mechanical weathering hypothesis of Maruszczak (1960) in the data obtained from mechanical and chemical analyses.

The existence of a thin bed of gravel near the top of the soil tongue in profile 5 at Brantford implies that either the rate of weathering is slow, or that deposition of this material occurred relatively recently. However, as it is likely that deposition of the A2 horizon material at Brantford occurred during the retreat of the ice from the Galt moraine, then it is of roughly the same age as the material at Freelton and Strabane and younger than that at Bridgeport, which lies to the west of the Breslau moraine. If this is so, then it is difficult to see how pedogenic weathering can have produced pockets of A2 horizon material at Freelton, Bridgeport and Strabane often up to I metre deep and yet have failed to remove a thin bed of gravel at Brantford. The chemical analysis data also indicates a relatively slight degree of pedogenic development.

CHAPTER IV

SOIL TONGUE MORPHOLOGY

I. Vertical Section Form

In addition to the between site variations in the particle size distribution characteristics of the soil tongues, variations in their depth and in their horizontal form were also found. Thus the numerous deep, well-developed soil tongues at Freelton (Fig. 29) contrast with the smaller, less numerous soil tongues at Strabane (Fig. 30). Arnold (1966) has suggested a method whereby such cyclic variations may be quantified by the measurement of average cross sectional parameters and the production of an index of variability. The parameters used are : (i) average depth to lower boundary of soil tongue, (ii) vertical range of this boundary and (iii) horizontal frequency of soil tongues. Measurements were made at Freelton, Bridgeport and Strabane but not at Brantford, since there were only two soil tongues present there. The parameters allow the classification of base period, disturbance and variability into one of four categories, with class I/A representing minimum values and class 4/D maximum values (Table 12). The figures indicate that the deepest soil tongues occur

Table 12 Average soil tongue parameters and Variability index.

Location	Base cms.	Base class	Period cms.	Period class	Disturbance Pct.	Disturbance class	Variability Index	Variability class
Freelton	122	4	109	2	44	2	16	D
Bridgeport	60	2	90	3	38	2	12	C
Strabane	53	I	56	3	44	2	6	B

Fig. 29 Soil tongues at Freelton.

Fig. 30 Soil tongues at Strabane.

at Freelton, whilst their frequency is greatest at Strabane, and that disturbance at the three sites is similar. However, the variability of the B horizon is greatest at Freelton and least at Strabane. The soil tongues at Brantford are wider and deeper than those at the other sites (Fig. 33).

The wedge shape of the soil tongues in vertical section is the result of the downward tapering, extensions of the B horizon and above these tongues occur pocket-shaped extensions of the A2 horizon (Fig. 29). In some cases the soil tongues consist of very narrow extensions of A2 material into the C horizon, rather than broad pockets (Fig.31). The soil tongues at first sight resemble fossil ice wedges and similar features have many times been mistakenly interpreted as such (e.g., Yehle 1954, p.532). However, there are a number of features that can be used to distinguish soil tongues from fossil ice wedges. Both Yehle (1954) and Maruszczak (1960) describe bands of gravel traversing the tonguing B horizon more or less intact, that show none of the disturbance expected in fossil ice wedges. Such marker bands, consisting of distinctive layers of gravel cross a number of soil tongues at Freelton, Bridgeport and Strabane, with no break in their continuity, although they tend to be depressed in the soil tongue (Fig.32). At the base of many soil tongues, such marker bands are found to continue through the soil tongue with little or no sagging, whilst higher up such marker bands show an increasing degree of sagging. Where the pockets of fine sandy A2 horizon material occur, no marker bands are to be found crossing the soil tongues,

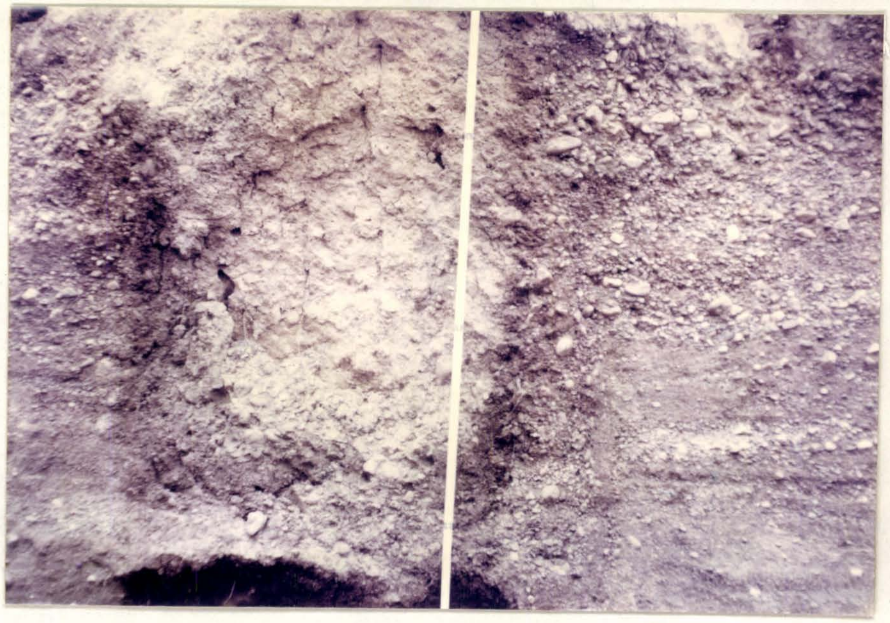


Fig. 31 Soil tongue at Freelton showing a narrow tongue of A2 horizon material, bordered by disturbed and slumped gravel (Tape marked in feet).

Fig. 32
Soil tongue at Freelton showing a sagging marker band.

although bedded gravels occur either side. In most cases the bedding of the gravels is disrupted where it approaches the upper portion of the soil tongues, and has a collapsed appearance, as the original bedding can frequently be traced downwards by the occurrence of a line of pebbles (Fig.31). This disruption does not, however, resemble the distortion which might suggest the growth of ice wedges. The down-sagging of the marker beds does not resemble the downturning of strata associated with fossil ice wedges as there is no break in their continuity. Also the fact that the degree of sagging increases from the base upwards would seem to indicate that it has not been the result of ice wedge growth. The down-sagging of these marker beds has been attributed by Yehle (1954) to the solution of calcareous material within the soil tongue causing a decrease in volume and consequently, downslumping of the beds. The fact that the degree of sagging increases upwards in the soil tongues supports such a view.

An investigation of the vertical sections of a number of soil tongues at each of the sites also shows that there is no evidence to support a theory of frost sorting for the origin of the pockets of A2 horizon material, as there is little indication of vertically orientated pebbles, either within the A2 pockets, or in the surrounding gravels. However, there is some evidence to support the view that the upper gravel layers have been disturbed by frost action. In this zone, many of the pebbles are frost split and the bedding appears to have been totally disrupted (Fig. 46). Such a disturbed layer is found at all four sites occurring within I metre of the surface and varying between 30 - 60 cms., in thickness. The lower boundary of this layer is fairly even, whilst the upper surface is marked by the occurrence of the B horizon, which in places, penetrates through it in the form of a soil tongue (Fig.46).

The disturbed layer is best developed at Bridgeport, where there is evidence to suggest that it is also much more compact than the underlying gravels, and that it contains a concentration of silt or fine sand forming coatings on the pebbles (Fig.46).

Although disturbed soil horizons may be explained by the action of tree roots (Shaler 1891), it is difficult to see how such action could have led to a concentration of fine material to form coatings on the pebbles. Such coatings resemble the silt cappings described by FitzPatrick (1956) from soils in N.E. Scotland, which he attributes to former frozen ground conditions, the silt coatings having been formed by the movement of silt into voids left by the melting of small ice lenses. Thus it is here suggested that this disturbed layer with its coatings of fine material might represent the former active layer of a fairly deeply frozen soil. Evidence to support the view that the soils, at least in the Bridgeport area, were deeply frozen, has been given by Morgan (1972), who describes the existence of fossil tundra polygons near Kitchener, Ont..

2. Horizontal Section Form

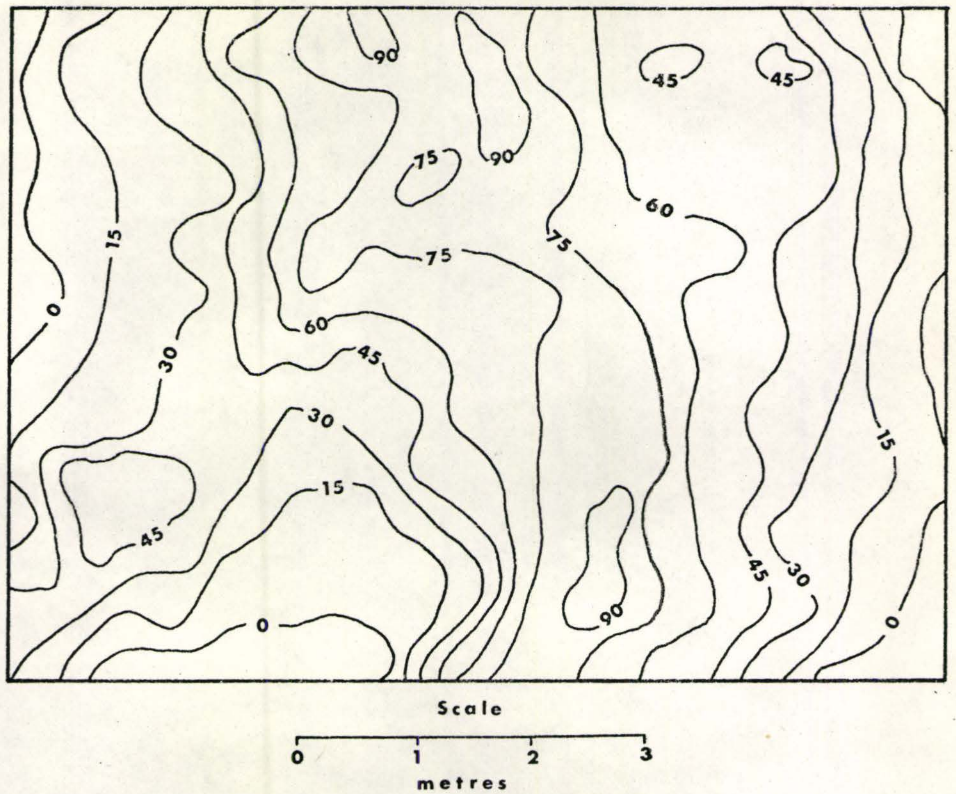
The soil tongues described by Yehle (1954), Maruszczak (1960) and Denny, Lyford and Goodlett (1963) are all roughly circular in plan. The soil tongues described by Presant and Protz(1967) however, are continuous channel features. In order to decide to which of these two categories the soil tongues investigated belong, a series of augurings on a grid pattern were made behind soil tongues at three sites. Although all the sites studied were located in gravel quarries, it was only at Freelton that the stripping off of the top soil had left a surface in which it was possible to trace the outline of the soil tongues without auguring.

At Brantford the augurings were carried out at 45 cm., intervals on a grid 8 metres long and some 7 metres back from the exposed face. Thus the size of the grid employed is considerably larger than that used by Presant and Protz (1967), which was just over three metres square. The depth to the top of the B horizon was recorded at each auguring point on the grid. The results obtained were used to plot surface contours at 15 cm., intervals for the B horizon of the two soil tongues seen in Fig. 34. The resulting contour map indicates that the soil tongues are cross sections of two connected, continuous channel forms. The larger soil tongue (profile 4) continues as a channel feature for over 7 metres, whilst the smaller (profile 5) continues as a channel to a junction with the larger form some 4 - 5 metres back. These channel forms are much larger than the branching soil tongues described by Yehle (1954) and seem to be identical to the channel forms described by Presant and Protz (1967). The depth of each channel varies, being on average 75 cms., but increasing to 90 cms., in places. The trend of the channels is towards the nearby Grand River and it is suggested that they form

Fig. 33 Soil tongues at Brantford (profile 4 on the right) that have the appearance of fluvial channels in plan.

Fig. 37 Stripped surface exposing nest of fine sandy A2 horizon material surrounded by reddish-brown B horizon.

Fig. 34 Surface of B horizon behind soil tongues at Brantford



(Contours at 15 cm. intervals)

part of an integrated drainage system linked to the dry valleys indicated on the 1:50,000 topographic map of the area (Brantford 40 P/I West half Edn. 3, Grid Ref. 5578). Although aerial photographs of this site were studied, the scale was too small to identify such small features. However, it should be possible using large scale aerial photographs to trace a more complete drainage pattern connecting these channels to others nearby, as Svensson (1967) has done.

Similar grid augurings were carried out at Freelton and Bridgeport using a 5 X 7 m. grid and the resulting contour maps of the surface of the B horizon (Figs. 35 & 36) show patterns that are rather more complex than at Brantford. The surface of the B horizon would

Fig. 35 Surface of B horizon behind soil tongues at Bridgeport (cms.)

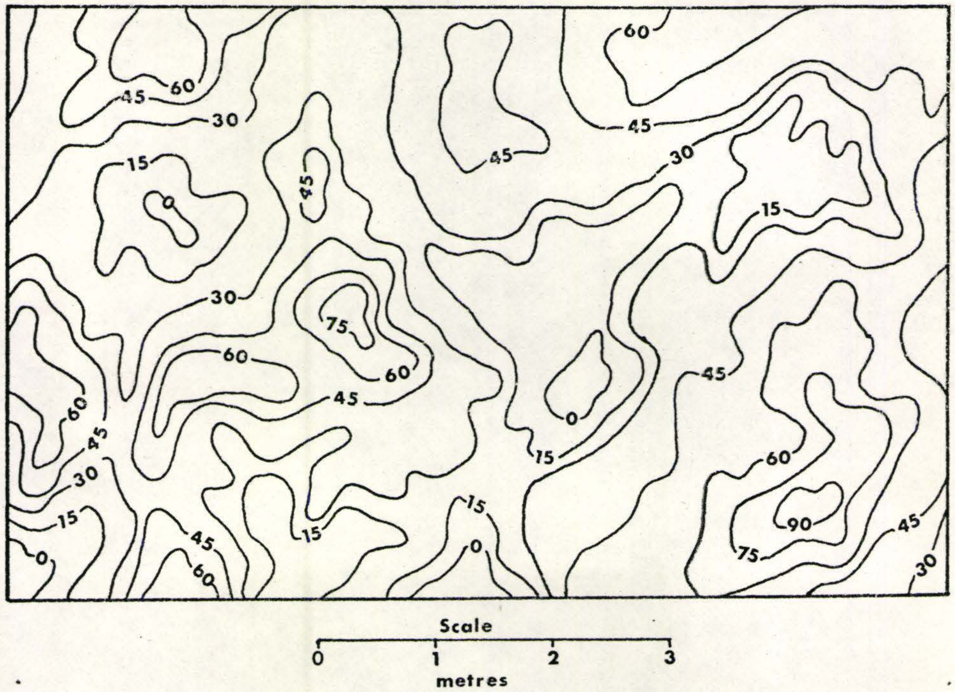


Fig. 36 Surface of B horizon behind soil tongues at Freelton (cms.)

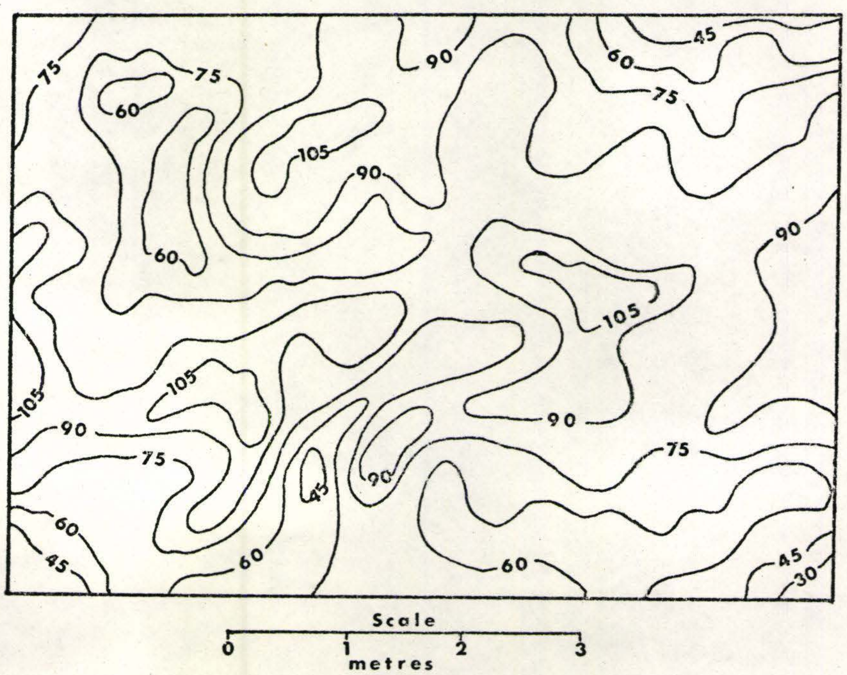


Fig. 38 Soil tongue at Bridgeport showing deep narrow pocket of A2 horizon.

Fig. 39 The removal of a I metre slice shows that the tongue of A2 horizon material seen in Fig 38 has a limited horizontal extent.

in each case seem to be arranged in a series of irregular depressions anything up to 120 cms., in depth. The most striking thing about the patterns at Freelton and Bridgeport is the absence of any regular arrangement as found at Brantford.

As only the upper surface of the B horizon was recorded, it is not certain that depressions recorded in it were underlain by soil tongues. However, since depressions of the upper B horizon seen in exposed faces are almost always underlain by soil tongues, it would seem reasonable to assume that the depressions recorded are underlain by such tongues.

In certain areas the surface soil has been removed and it is possible to see the form of the soil tongues exposed in horizontal section (Fig. 37). The soil tongue exposed is oval, being 2 metres by 1.3 metres and the pocket of fine material extends to a maximum depth of 60 cms. The characteristics displayed by this stripped surface are identical to Maruszczak's (1960) description of irregular 'nests' of fine material surrounded by a more compact reddish-brown, iron-stained horizon.

In addition to auguring, a number of soil tongues at Freelton, Bridgeport and Strabane were examined, by removing successive vertical slices, and recording the changing pattern of the horizons revealed. The change in vertical form over very short lateral distances is often very great, as can be seen from a comparison of Figs 38 and 39, which illustrate the fading out of a soil tongue at Bridgeport. Thus it would seem that the soil tongues at Freelton, Bridgeport and Strabane consist of irregular pockets of fine material, surrounded by a gravelly B horizon, which descends pipe-like beneath them, giving rise to funnel-shaped features, that appear as soil tongues in cross section.

The above findings confirm the report by Presant and Protz (1967) of two types of soil tongues in S.W. Ontario, and illustrate the necessity of examining both the vertical and horizontal form of the soil tongues.

CHAPTER V

EVIDENCE FOR THE FORMER EXISTENCE OF PERMAFROST

The linear soil tongues at Brantford lack the characteristics of fossil ice wedges and as the particle size distribution data show it is unlikely that they owe their origin to the concentration of pedogenic processes along a former frost crack. Therefore, a periglacial origin for these features has no support. However, the possibility that the circular soil tongues have originated in the manner suggested by Maruszczak (1960) has to be fully investigated. If the circular soil tongues are due to mechanical weathering of material overlying an irregular permafrost horizon then the existence of other features indicative of the former presence of permafrost will be expected. Therefore, evidence of any feature that would indicate permafrost or even a milder periglacial regime was sought.

If permafrost has existed within the area of study then fossil ice wedges may be found, or if the climate were milder evidence of contorted strata, fossil frost cracks, patterned ground, frost shattering and dusturbance may be present.

I. Contorted Strata

The term involution, although regarded by Embleton and King (1966) as having no genetic implication, has by its frequent use in connection with frost-induced contortions been given such an implication, as McArthur and Onesti (1970) point out. Thus, in discussing features whose origins are in doubt, it is better to use a term that has no genetic connotation, such as contortion or contorted strata.

It would seem from the literature, that it has been the existence of contorted strata in Pleistocene unconsolidated sediments, rather than any objective criterion, that has led many authors to regard such features as being formed by some periglacial process. Thus descriptions of contortions as the products of a periglacial environment have often been made despite a general lack of agreement as to their exact mode of origin (e.g., Denny 1936, Sharp 1942, Schafer 1949, Jahn 1956). However, recent studies show that similar features may be produced by non-periglacial processes, such as loading (Hills 1966), which have cast doubt upon the use of contortions as indicators of periglacial activity.

Within the area of study, contorted strata are present in outwash sands overlying the Niagara Escarpment, near Dundas. Approximately 4 - 6 metres of material overlay the limestone, which show little sign of being frost shattered and consist of clay overlain by sand and silt (Fig.40).

The section described contains two distinct zones of contorted strata, the lower of which occurs 2 metres below the surface and the other within 0.5 metres of the surface. The lower zone consists of fine sand and silt showing current bedding, which is almost undisturbed at the base but which shows an increasing degree of contortion as the top of this zone is approached (Fig.41). The top of the lower zone of contortions is in places marked by interpenetrations

Fig. 40 Contorted Strata in outwash deposits at Dundas.

of the overlying silt into the finely bedded contorted layer. In some cases, the contortions in this zone resemble sand volcanoes (Fig. 41) and in others, ball and pillow structures (Fig. 42) similar to those described by Potter and Pettijohn (1963). There are also features similar to the brodel phenomena described by Johnsson (1962) as frost pits, that he attributes to frost action causing an horizontal layer to crack and curl up to form, at first shell-like features

Fig. 41 Contorted strata in outwash sands near Dundas

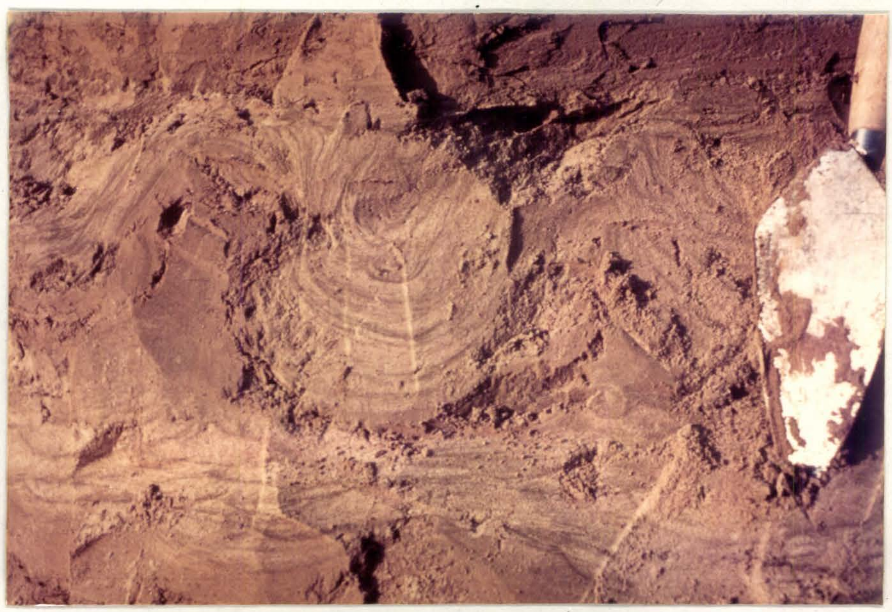


Fig. 42 Contorted strata in outwash sands near Dundas, showing features similar to frost pits.

similar to those seen in Figs. 41 and 42, and finally completely closed frost pits showing concentric banding.

Immediately overlying the lower zone of contortions is a fairly thick band of silt, the lower surface of which is marked by irregular lobes penetrating downwards. However, despite this contorted lower surface and the lack of any distinct bedding, it would seem that this silt layer is largely undeformed. The occurrence of two thin bands of whitish sand near the top of the silt, showing boudinage structure, confirms the absence of large scale contortions. Above the silty band occurs the second zone of contortions, in which it is difficult to trace the outlines of the structures. The upper limit of this zone is only 0.5 metres below the surface and is characterised by a distinctly platy structure.

Periglacial processes that have been advanced to explain the origin of such features are, (i) the squeezing of a moist plastic layer between two freezing fronts, and (ii) the differential growth of ice masses in frost susceptible materials. Many authors have tended to favour a combination of such processes. For instance Sharp (1942), states "... involutions are the product of vigorous and repeated differential freezing and thawing and the development and melting of masses of ground ice... Freezing probably occurred both from above and from below owing to the underlying frozen ground..".

However, contorted strata in water-laid sediments may also be produced by loading (Butrym et al., 1964). Such loading may result from the weight of overlying strata, with or without the additional weight of water or ice. Where there exists a sequence of beds of varying texture which are saturated, pressure will gradually expel the water contained in the sediments and will cause the moist plastic layer to deform. It would be expected that such deformations would increase upwards, producing features similar to those seen in Fig. 41. That the thickness of the overburden need not be very great has been indicated by Hills (1966).

Thus, despite the similarity of the contortions at Dundas to those attributed to the action of freeze-thaw processes and the presence of permafrost (Johnsson 1962, Theakstone 1965), it is not possible to suggest a similar origin for them without supporting evidence. In the absence of other features contortions should not be used, as they have been, as evidence of the former existence of permafrost, or intense frost action (Frye and Willman 1958, Wayne 1967). As Dylik (1965) states, the periglacial origin of structures described as involutions or cryoturbations, raises more doubts than ice fissure structures.

2. Frost Cracks

Frost cracks were found only at Freelton, where they were developed in coarse sands and gravels. The two frost cracks described were located on the wall of the gravel pit opposite to that with the most marked development of soil tongues. The larger of the two features is seen in Fig. 43 and is a distinct feature consisting of a well defined crack, first discernable some 50 cms below the stripped surface and traceable to a depth of at least two metres.

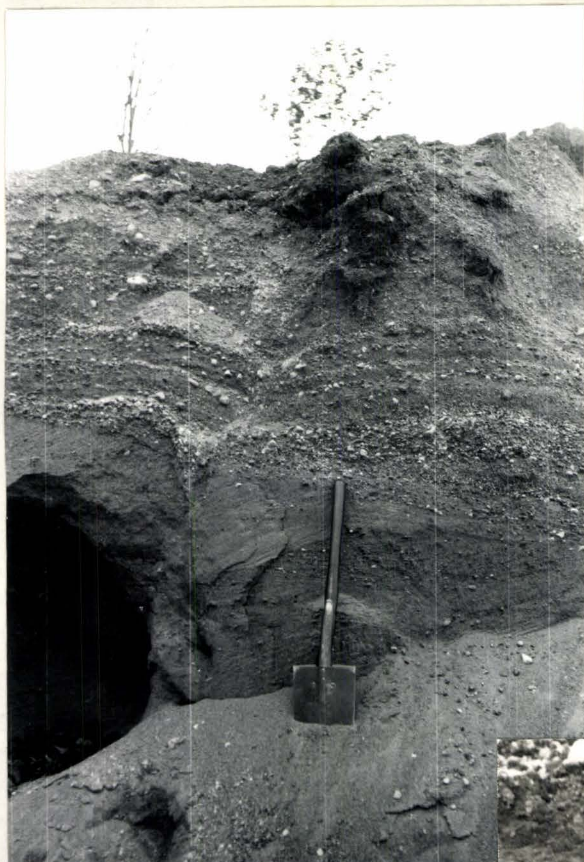


Fig. 43

Frost crack in kame gravel

at Freelton.

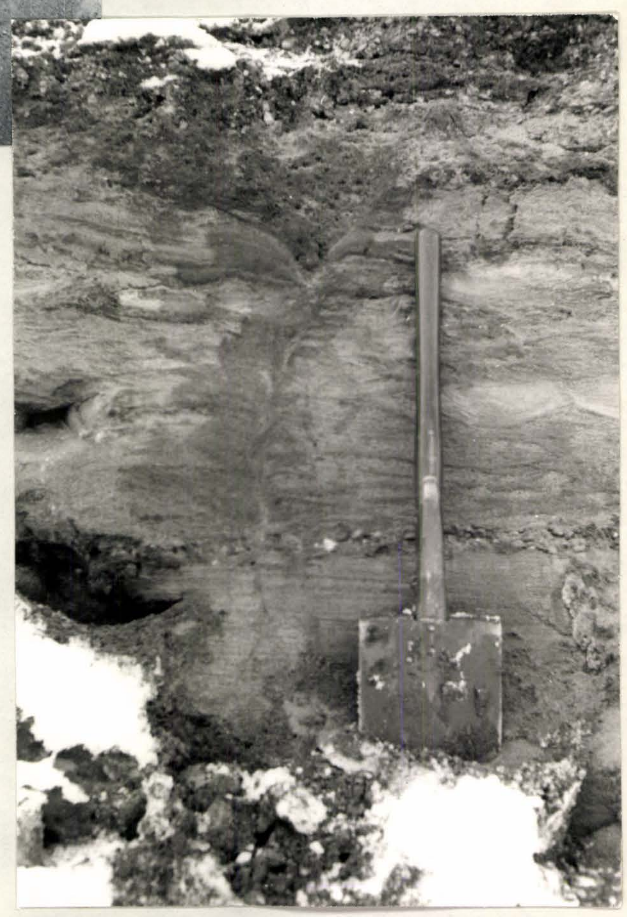


Fig. 44

Frost crack in kame gravel

at Freelton.

The frost crack is narrow, being only a few centimetres wide near the base, but widening out near the top and has a rather sinuous form. However, there is no evidence to suggest that the feature described is merely the lower section of a larger fossil ice wedge like those described by Watson (1965).

Being narrow, there is only a small amount of infill. The infill material consists of small pebbles which have obviously fallen in from the overlying gravels. Where the infilling material is similar to the layer the crack is passing through, it is difficult to pick out the line of the frost crack. The most prominent feature of this frost crack is the marked down-turning of the beds of gravel and sand as they approach the line of the crack. The horizontal continuation of the feature was confirmed by removing about I metre of the pit face.

An interesting feature of this frost crack is the absence of any evidence that it has formed a line along which there has been preferential movement of soil water, although the base of a small soil tongue was found near the top of the frost crack. The reason for this might be that surface morphology is more important in concentrating soil water drainage than are sub-surface features.

The second frost crack occurs some 60 metres from the first and is much smaller, being less than I metre deep, although its lower parts were obscured by a large debris accumulation, (Fig 44). The frost crack has a curved section and is only I cm., wide, which makes it quite difficult to trace through the coarse sand in which it occurs.

The material infilling the crack is mainly coarse sand and a few small pebbles. The bedding either side is downturned, although not to such an extent as in the first example.

That both the features described are frost cracks can be shown by a comparison with those described by Johnsson (1959, 1962), Czerwinski (1964), Watson (1965) and Tak-Schneider (1968) and with the list of features characteristic of frost cracks, given by Dylik and Maarleveld (1966) :

Characteristics of fossil frost cracks - Dylik and Maarleveld (1966).	Characteristics of the frost cracks at Freelton
1. Maximum width not exceeding 10cms.	Maximum width 4 - 5 cms.
2. Uniform width.	Slight increase upwards.
3. Contrasting infill.	Some slight contrast between infill and bordering material
4. Downturning of adjoining layers.	Downturning apparent.
5. Absence of swellings bordering the crack.	Swellings absent.
6. Polygonal plan pattern.	Not determined.
7. Short distance between cracks in section.	Only two recorded in a 60m. section.

The outwash gravels also contain a number of small faults that have become indurated by the deposition of carbonate material along them. Such faults sometimes show features that may lead to their being mistaken for frost cracks. However, whereas frost cracks show downturned strata on both sides, differential movement along a small fault causes the strata on one side to be downturned, whilst that on the other side is upturned (Fig.45).

The main question raised by the occurrence of frost cracks at Freelton is whether or not they are the product of periglacial environment and if so of what severity ? It has been demonstrated that frost cracking is not confined to polar or even sub-polar environments (Dylik and Maarleveld 1966) and may be found occurring in mid latitude climates (Washburn, Smith and Goddard 1963). The latter authors have shown that a dry winter with minimum January temperatures of - 13.6°C is sufficient to produce thin frost cracks. Such cracks were proven to descend to at least 40-50 cms., and to have a polygonal plan. The fact that similar frost cracking is also presently occurring in such periglacial areas as Alaska (Hopkins, Karlstrom et al 1955) offers obvious possibilities for confusion and misidentification of fossil features. Washburn, Smith and Goddard (1963) think it unlikely that such thin cracks could become infilled with material to the extent that they might be mistaken for fossil ice wedges, but consider it a distinct possibility that such features might be mistaken for a form of narrow and shallow ice wedge cast.

Most authors who describe frost cracks similar to those found at Freelton (E.g., Poser, 1948, Gallwitz 1949, Pierzchalko 1956, and Johnsson 1962) regard them as having formed in the space of one season. Poser (1948) describes frost cracks (frostspalten) as developing without the formation of a sheet of ice within them. The possibility that ice may have filled the frost cracks is also discounted by Katasonov (1962). However, the frost cracks described by Washburn, Smith and Goddard (1963) all had thin ice sheets infilling them. The downturning of adjacent strata has been attributed to the melting of ice causing the collapse of material (Gallwitz 1949, Kaplina and Romanovski 1960).

Therefore, whereas ice wedge casts are regarded as being indicative of permafrost and of a certain range of temperatures (Cailleux and Taylor 1954, Schumskii, Shvetsov and Dostovalov,1955, Vtyurin and Vtyurina 1960, Black 1965, 1969 and Pewe 1965), frost cracks are taken to indicate either an initial or short lived stage of periglaciation (Pierzchalko 1956) or simply severe conditions in a non-periglacial zone.

If we exclude the soil tongues, then no features resembling fossil ice wedges were noticed in the area of study that would definitely indicate the former existence of permafrost. However, the existence of such features within this area has been suggested by Straw (1970) and proven in the Kitchener area by Morgan (1972). Until the work of Morgan (1972), it had been generally assumed that the climate experienced in S.W. Ontario, was after the ice retreat a rapidly ameliorating one, in which permafrost would be unlikely to develop. However, the existence of fossil ice wedge polygons in the Kitchener-London area indicates that this area at least experienced a severe periglacial climate (Morgan 1972). All of the areas of patterned ground mapped are to the west of the Galt moraine and

Fig. 45
Fault in unconsolidated gravels showing both up and down turned strata, which distinguish it from a frost crack.

Fig. 46 Compacted and disturbed layer of gravel at Bridgeport.

no evidence of similar features was found to the east of this moraine. Thus Morgan (1972) suggests that it was only in the Ontario Island area, that conditions severe enough to produce permafrost existed. The absence of such features from the area east and south of the Galt moraine is taken to indicate that the periglacial regime had ended before the retreat of the lake from the Whittlesey shoreline.

Although the Bridgeport soil tongue site is located west of the Galt moraine and is close to the areas described by Morgan (1972) as having fossil ice wedges, no evidence of such features was found in the exposures visited.

3. Disturbed and Compacted Gravels

However, the Bridgeport site must have experienced similar severe conditions and would also have possessed a permafrost horizon. Evidence of such a former permafrost horizon is found in the existence of a zone of compacted and disturbed gravels at Bridgeport, that represents the former active layer (Fig. 46).

This zone of compacted gravels contains silt coatings on the pebbles which according to FitzPatrick (1956) indicates intense freeze-thaw activity. Although the other sites, which are all either east or south of the Galt moraine, possess disturbed and compacted horizons they are much less well-developed than that at Bridgeport.

Apart from a paper by Straw (1966) and the recent work by Morgan (1972) very little has been published on periglacial features in S.W. Ontario. However, taking into account these two papers, particularly the one by Morgan (1972) and the present study, it would seem that the absence of periglacial features may be a reflection of the lack of detailed studies, especially in the area known as the Ontario Island.

CHAPTER VI

CONCLUSIONS

It has been shown that there are two distinct types of soil tongue present in the Burford loam of S. W. Ontario, one with a Channel-like plan and the other with a circular plan. The former is similar to the features described by Presant and Protz (1967) and has the form of an infilled fluvial channel. The circular type of soil tongue has a more debateable origin.

The analyses of the characteristics of the circular type of soil tongue indicate that they are not infilled ice wedges and are unlikely to be the product of tree throw or root development and decay. Also it is unlikely that they have developed due to the concentration of ground water along a frost crack.

One difficulty in trying to determine the origin of these soil tongues, is that they consist of two elements which may not have originated in the same way. These are ; (i) pockets of A2 horizon material and (ii) tongues of the B horizon.

The tongues of the B horizon including those at Brantford, are obviously of pedogenic origin, as indicated by the active weathering of carbonate pebbles and the deposition of clay within them. Together with the presence of marker bands, such evidence supports the hypothesis put forward by Yehle (1954) that tonguing B horizons result from the localization of soil forming processes.

The pockets of A2 horizon material have three possible modes of origin : (i) they are due to the deposition of a loess or fluvial silt over an irregular surface, views implicit in statements by Yehle (1954) and Chapman and Putnam (1966), (ii) they result from mechanical weathering under freeze thaw conditions as suggested by Maruszczak (1960) or (iii) they are the product of in situ chemical weathering, which has led to a continual extension of the A2 horizon as the tongues of the B horizon are extended.

The particle size analyses neither prove nor disprove a loessic or fluvial origin for the A2 horizon material at Freelton, Bridgeport and Strabane. However, there would seem to be evidence for the presence of a loess or a fluvial silt in the upper A horizon at least.

However, if the pockets of A2 horizon material are the product of in situ weathering then such soil-forming processes must be capable of fairly rapid weathering, as the A2 horizon is often I metre or more thick. The retreat of the ice from the Galt moraine has been given as about II,300 years B.P. (Terrasmae, in Karrow 1963, Bell 1967), which would imply a fairly rapid rate of weathering.

There are a number of conflicting views as to whether or not such a rate of weathering is feasible. The rate of soil development by the Burford loam agrees with ideas on soil development on fresh parent materials expressed by Thorp and Smith (1949). However, Gaikawad and Hole (1965) report a minimal soil development upon dolomitic kame and esker gravels that have been exposed to pedogenic processes for about 14,000 years. The reason suggested for such a slow rate of development is the high infiltration capacity of the coarse parent material. However, the existence of a blanket of fine material overlying a coarse gravel deposit would tend to hold water at the interface and initiate a weathering front.

The chemical analyses, especially the evidence of a fairly even distribution of free Fe and the high proportion of exchangeable bases indicate a relatively slight degree of pedological development in the Burford loam. Such a degree of development cannot be reconciled with the existence of pockets of A2 horizon material that are often I metre thick. However, if the upper part of the A2 horizons is regarded as a fluvial or aeolian silt and only the lower A2 horizon as the result of pedogenesis then a more satisfactory solution is found. The minimal weathering that has occurred in profile 5 at Brantford also indicates a slow rate of pedogenic development, that implies a non-pedogenic origin for most of the A2 horizon material at Freelton, Bridgeport and Strabane.

Although Maruszczak (1960) quotes examples of soil tongues underlying unvegetated patches in tundra zones (e.g., Tyrtikov 1956), there seem to be no descriptions of similar features from sub-arctic areas in north America. If the hypothesis put forward by Maruszczak (1960) is correct, then evidence of the irregular surface of the permafrost might be expected. However, the evidence indicates that the former active layer possessed a fairly even base and that the soil tongues penetrate through this horizon with little suggestion that they occupy zones where the active zones was increased in thickness.

Thus, the circular soil tongues of S. W. Ontario are regarded as having developed through the deposition of a layer of silt over calcareous gravels that possessed an irregular surface, possibly the result of periglacial activity, which has led to subsequent localization of pedogenic processes, producing soil tongues beneath the infilled depressions.

Therefore, there would seem to be no difference in the mode of origin of the B horizon tongues at the four sites, despite the contrast between linear and circular forms. It is only in the method whereby localization of the pedogenic processes occurs that contrasts exist, with localization at Brantford resulting from the infilling of a fluvial channel and being due to the deposition of a more poorly sorted fluvial silt over an irregular surface at Freelton, Bridgeport and Strabane.

APPENDIX

Micromorphological Description of Burford Loam

Horizon	Description
Ap	2 - 12 cms., is very compact, few discrete peds. A more or less continuous soil phase shows weak, incomplete wedge structure, and a dominant granular structure. Granular peds are medium (1 - 2mm.), micropeds, sub-rounded, 200µ or larger. Ped surfaces are rough with accordant surfaces. Occasional continuous, irregular, interpedal pores, 100-I, 200µ wide, intersecting at 45^{o} with rough walls. Numerous small (< I00 µ), intrapedal, ovoid and short branching, unconnected pores. Root passages frequent, 200-800µ wide. Occasional faecal material - irregular ovoids, 40-60µ, much decomposed. Soil matrix dark brown to brown (7.5YR4/4), very frequent as coatings on larger grains and encompassing smaller grains; mainly isotropic, unorientated, flecked appearance. Domains rare. Organic matter abundant, mainly decomposed but occasionally fresh. Occasional stones, sub-angular to round, large (2-7.5mm.), rough to smooth surfaces, no preferred orientation, mainly fine sandstone or shale fragments. Sand very abundant to dominant, sub-angular to sub-rounded, rough to mammilated surfaces, uniformly distributed, occasionally clustered. Mainly quartz,

with hornblende, garnet, magnetite, microcline and plagioclase. Feldspars appear weathered and garnets are solution pitted. Silt fraction mineralogy similar, no preferred distribution, concentrations of silt in lithorelicts, together with banded clay cutans or ferri-argillans with continuous orientation. Papules rare - fragments of cutans, 20-30μ, with continuous orientation. Occasional sesquioxidic, undifferentiated and concentrically banded, subrounded nodules, 50-I,000μ, which have inclusions of small quartz grains.

A2I 15-25 cm. Poorly aggregated, granular to alveolar structure, with occasional incomplete peds, 300-500μ. Continuous soil phase with limited ped development. Occasional, narrow (50-200μ) irregular, continuous pores, with rough accordant walls. Frequent unconnected ovoid, and irregular, short branching pores I00-500μ. Frequent faunal passages, 400-500μ wide, irregular borders and loose faecal infillings. Occasional root passages, 200-500μ wide. Soil matrix, yellowish brown (IOYR5/6) to strong brown(7,5YR5/6), frequent, enclosing and forming bridges between mineral grains, anisotropic, unorientated and flecked, consisting mainly of silt sized particles and domains, which are more abundant than in the Ap. A number of para-cutans are present due to orientation of domains around skeleton grains. Occasional organic matter, both fresh and decomposed. Frequent stones

2-4mm., with three over IO mm., which are vertically orientated. Mainly shale fragments showing considerable weathering. Sand grains abundant, sub-angular, rough or mammilated surfaces and showing no preferred orientation. Mineralogy similar to Ap; Silt fraction more clearly seen because of lower content of isotropic organic matter, mineralogy similar to sand. Silt coatings, up to 200µ thick, around large sand grains; Though there are no silt coatings around the stones, within the weathered stones are silt separations showing flow structures. Clay cutans found in pores in weathered rock fragments, 50µ thick, showing continuous orientation, and occasionally just outside the stones. Occasional papules - fragments of clay cutans, smaller than 300µ, continuous orientation, sharp boundaries and sub-rounded. Occasional lithorelicts, flecked under crossed polarizers due to the presence of domains. Occasional sesquioxidic nodules, amorphous, with fine quartz inclusions, sub-rounded and 500µ in size or, concentrically banded, with inclusions in outer zone only. A few concretions have lattice frameworks and are possible pseudomorphs of completely weathered pebbles.

A22 30-40 cm. Alveolar structure in upper 5 cm., similar to A2I, whilst lower 5 cm., shows weakly developed angular blocky structure, combined with alveolar. The incomplete angular blocky peds are of large size, up to 10,000µ, weakly accordant with rough surfaces. Pore space in upper part consists of discrete oval and irregular pores,50-200μ, with some irregular branching pores, 400 μ wide and up to I,000μ long. In the lower part there are similar discrete pores and abundant continuous pore spaces, up to 5,000μ wide with an irregular, branching pattern and rough, weakly accordant sides. Also some very large pores, over 10,000μ which may be faunal passages, with rough and irregular walls. Infrequent root channels occur, up to I,000μ wide. Soil matrix, light olive brown (2.5YR5/6), birefringent, very frequent and occurs as coatings around grains, enclosing smaller sand grains and is composed mainly of silt-sized particles. Matrix is unorientated, flecked, with rare domains which often give rise to para-cutans around mineral grains and around ovoid pore spaces. Organic matter is rare, mainly decomposed roots and faecal material, 50-70μ. Occasional stones, some up to I0,000μ, and are mainly rounded shales and dine-grained sandstones, many appear highly weathered. Abundant sand, shows a random distribution, sub-angular to rounded with mammilated to smooth surfaces. The mineralogy is similar to overlying horizons. Abundant silt forms most of soil matrix and coatings on larger sand grains, but there is no evidence of silt separations either within weathered stones or soil matrix. Clay cutans, well developed within weathered stones, showing multiple banding and continuous orientation and are about 20μ wide, with sharp boundaries. Few papules. Occasional sesquioxidic concretions, largely undifferentiated with quartz inclusions, rounded and up to I,000μ, some with diffuse haloes.

AB 40-50cms. Complex structure, predominantly alveolar with single grain structure developed in well-defined bands and weak, incomplete, platy structure in the lower parts. The platy units range to I0,000μ, the banded fabric is 1,500-10,000μ wide, occasional continuous irregular oblique pores from I00-I,000μ wide, with rough accordant surfaces. Also abundant ovoid and irregular, short branching,50-300μ, discontinuous pores. No evidence of faunal passages and root passages are very rare. Soil matrix birefringent and light olive brown (2.5YR5/6) mainly silt-sized material occurring as coatings around mineral grains and as infillings between them, unorientated domains are very frequent in the fine matrix giving it a flecked appearance. In some bands the matrix is virtually absent and there is a single grain structure. Organic matter is very rare. Stones are frequent, randomly orientated and are mainly shales, rounded and very weathered. The sand fraction is dominant, sub-angular to sub-rounded 50-500μ. In some bands sand grains are bleached and show parallel orientation. Some of the bands, most apparent in the upper part of the section, also show a size separation, some having a concentration of grains I00-500μ, others mainly 50-I00μ in size. In the lower part of the section there is little preferred orientation of sand grains. Mineralogy is similar to overlying horizons. Silt is the dominant constituent of the soil matrix, resembles the sand fraction in mineralogy and occurs as unorientated material around larger grains. It is absent from certain bands and concentrated in others, mainly in the lower part of the section. The silt bands are I00-2,000μ wide. Discontinuous pore and grain surface clay cutans occur in the upper part of the section. In the lower part of the section more continuous clay cutans occasionally occur in the continuous pore spaces. All clay cutans show strong continuous orientation, sharp boundaries and banding. Occasional papules in the lower part of the section are clay cutan fragments, 50-200μ. Occasional sesquioxidic concretions,undifferentiated, with inclusions of small quartz grains, rounded and up to 600μ wide. A few lithorelicts also present.

B2t 54-60 cms. Irregular blocky structure, with large peds, I,000-I0,000μ and alveolar with micropeds < 500μ. Continuous pore space is very frequent, 50-I,000μ wide producing a rough trellis pattern, also discontinuous, ovoid and irregular pores, 20-200μ wide. Soil matrix is predominantly clay and fine silt, very frequent, birefringent and yellowish red (5YR5/8). It occurs as coatings and bridges on sand grains and encloses smaller grains, has uneven distribution. Domains are present, unorientated giving continuous extinction. Roots are rare and up to 500μ. Abundant stones, with horizontal orientation, mainly shale, sandstones and igneous or metamorphic pebbles. Abundant sand, sub-angular to angular, with rough to mammilated surfaces and shows no preferred orientation, but does show some size separation, with areas of coarse grains, up to I,000μ and others with finer grains IOO-500μ. Mineralogy is similar to that of the other horizons. Silt occurs as part of the soil matrix and not as separations. Clay cutans are frequent, both in pore spaces and around grains, and show strong continuous orientation, sharp boundaries and banding. Papules are present in the form of lithorelicts and there are occasional rounded and undifferentiated sesquioxidic concretions up to 400μ in size, with some showing a lattice structure.

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