A. M. GRUBB and B. T. BUNTING*
Hamilton

MICROMORPHOLOGICAL STUDIES OF SOIL TONGUING PHENOMENA IN THE BURFORD LOAM, SOUTHERN ONTARIO, CANADA

Abstract

Pedological and lithostratigraphical studies of some soil tongue features developed in a geomorphological profile of superposed silt loams on calcareous gravelly loams, in southern Ontario, supplemented by micromorphological examination of the soil materials, permit a reconstruction of the sequence of development of such soil tongues.

The uppermost soil horizons are formed in a presumed niveoalluvial or loessic material deposited on the surface of a compacted gravelly loam material derived from an active layer. This material showed surface irregularities formed by shallow linear channels or round hollows. Later concentration of soil processes in these areas led to the deep tongue or channel phenomena through carbonate solution and emphasized by clay illuviation and by disruption of the linearity of the gravel bands at the junction of the deepended areas and the stable material to the sides. Marker bands of gravel ayers can be traced within the soil tongues, sagging more deeply in the upper parts, less deeply in their lower parts. This llustrates the continuity of development of these tongues throughout post-glacial time and refutes the origin of these eatures as fossil forms related to the former existence of ice wedges.

INTRODUCTION

The Burford loam is an Orthic Grey-brown Luvisol (Glosstc Hapludalf), widespread in the Hamilton area of Ontario, that consists of an irregular loamy A horizon overlying a well-defined, thick, B horizon that tongues wedge-like into the underlying calcareous gravels of the C horizon (pl. 1). Similar features have been referred to as soil tongues by YEHLE (1954) who regarded them as solution forms. However, other hypotheses advanced to explain similar features include differential weathering under periglacial conditions (MARUSZCZAK, 1960; KELLAWAY, HORTON and POOLE, 1971) and the infilling of fluvial channels (PRESANT and PROTZ, 1967). However, as will be shown, the stratigraphy of these features is complicated and some of the features have had a complex development, not attributable to any single cause, but to a sequence of events in early post-glacial times. That southern Ontario did experience a fairly severe periglacial climate and that soil surface patterns relatable to such an influence exist, has been demonstrated by MORGAN (1972) in the nearby Waterloo area. Therefore, the possibility exists that the soil tongues of the Burford loam may have originated as a result of some form or sequence of forms of periglacial influence rather than being simple solution forms, or else a combination of the two effects.

* Pedology Laboratory, McMaster University, Hamilton, Ontario, Canada.

METHODS OF STUDY

The sites studied are indicated in Figure 1. At each site, study of the soil tongues included precise measurement of their vertical section and analyses of the soil using standard techniques. At three sites the lateral variation of the surface morphology of the upper B horizon, underlying the surficial materials, was determined by augering on a grid pattern, or by excavation, to determine the form of the interface of the two materials.

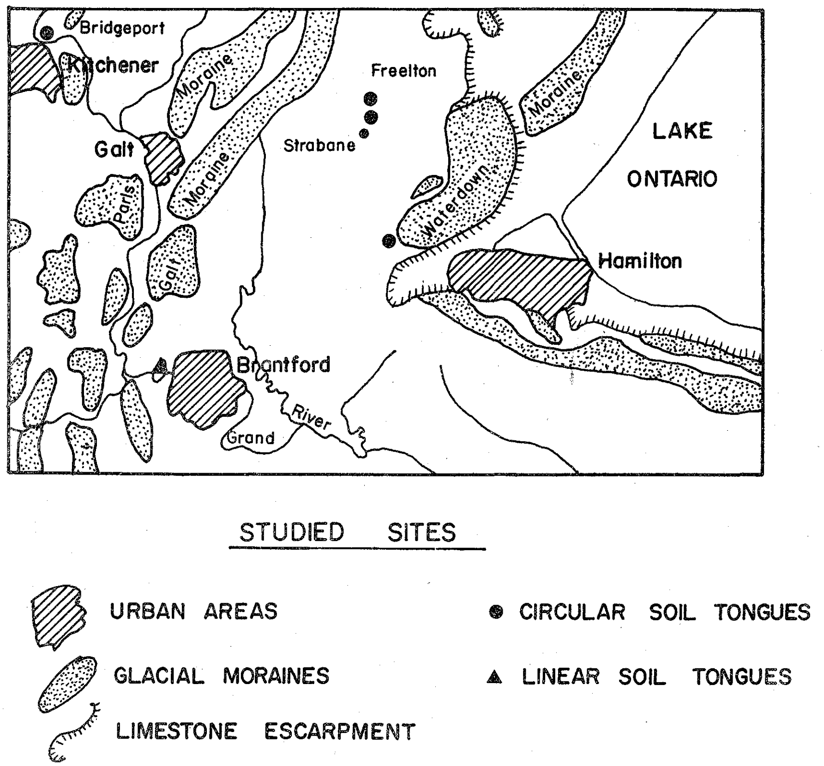


Fig. 1. Location of the studied soil tongue features; Bridgeport, Freelton, Strabane and Brantford. Map width is 60 km.

At the Freelton site undisturbed samples were taken so that large (10×5 cms) thin sections of the soil material could be prepared. These thin sections were used to make a detailed study of the microstructure of the horizons and deposits in one of these soil tongues. The methods used in the preparation of these thin sections, and the terminology used in their description, are those of FitzPatrick (1970, 1971).

GEOMORPHOLOGICAL OBSERVATIONS

VERTICAL PROFILES

At the Bridgeport, Freelton and Strabane sites soil tongues were commonly-encountered in sections in gravel pits, while at Brantford only two distinct features were found. Measurements at the first three sites indicate that there is considerable variation in the degree of development of soil tongues. At Freelton (pl. 1) the soil tongues were deeper and wider than at the other two sites, having maxi-

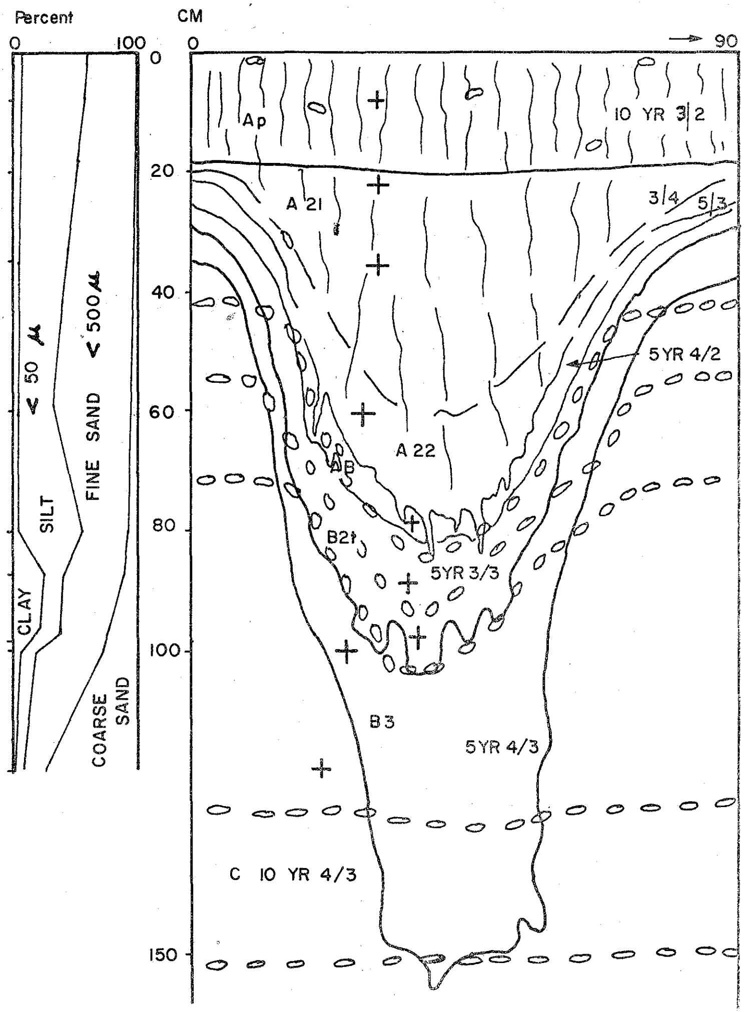


Fig. 2. Diagram of the soil tongues and horizontation with sagging marker bands

Particle size distribution shown to the left. Note that the C horizon sample is offset to the side of the feature. The original lithologic discontinuity would have been at 23 cm depth mum depths of about 2 m and being on average 1 m apart. At Strabane the deepest soil tongues were only about 1 m deep, their lateral spacing was approximately 50 cms apart.

The soil tongues at all four sites exhibit a downward-tapering wedge shape together with overlying pocket-like masses of loamy A2 horizon material as a component of the upper wedge infilling. The strata adjacent to the soil tongues were disturbed within 1 m of the surface, but were distincly and evenly-bedded below 1 m depth. In a number of cases bands of gravel were found to cross the soil tongues with no apparent break in continuity, although tending to "sag" within the soil tongue (see Fig. 2). Such continuous bands may be termed ***marker bands***, and are found crossing the very lowest portions of the soil tongues with little or no "sagging", whilst higher up such marker bands exhibit sag to a marked degree. However, these bands do not cross the included pockets of loamy A2 horizon material, although bedded gravels frequently occurred to either side of these features. In most cases the bedding of the gravel is disrupted where it approaches the upper portion of the soil tongues, having a collapsed appearance.

Although the upper gravels at each site show frost disturbance there is little evidence of frost sorting, since only a small proportion of the pebbles are vertically-oriented. The disturbed gravels are best seen at Bridgeport (Pl. 2) where they are compacted and many pebbles have silt coatings (Pls. 6, 7), which may indicate freeze—thaw activity (FITZPATRICK, 1956). The best development of this disturbed horizon which, it is suggested, represents a former active layer, is found west of the Galt moraine in the same area that MORGAN (1972) has described polygonal ground forms, while to the east and south of the Galt moraine the disturbed layer is less well-developed or absent.

Very little evidence of the former existence of ice wedges was found. Only at the Freelton site two minor frost cracks were found, the larger was traceable to a depth of 2 m being only 2 cms wide and rather sinuous in form. Being narrow there was only a small amount of fine pebbles infill, which was similar to the matrix, and difficult to trace. The gravel beds were turned down slightly as they approached the frost crack (Pl. 3).

HORIZONTAL SECTIONS

The soil tongues of the Burford Loam in Southwest Ontario apparently are of two types, one being roughly circular and the other linear in form.

Circular forms

Augering on a grid pattern at Bridgeport and Freelton to determine the characteristics of the B horizon surface produced rather complex patterns (Fig. 3, Freelton). The surface of the B horizon would in each case seem to be arranged in a series of enclosed depressions, up to 120 cms in depth. As only the upper surface of the B horizon was recorded by this method, it is not absolutely certain that all the depressions in it were underlain by soil tongues. In some areas the surface

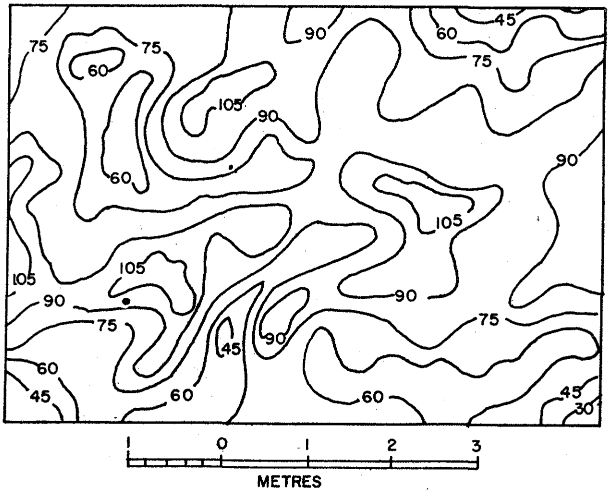


Fig. 3. Subsurface isopachs of the upper B horizon showing system of enclosed depıessions at Freelton, containing silt loam material

soil had been removed and it was possible to see the circular form of the soil tongue exposed in horizontal cross section. The soil tongue exposed at Freelton is oval, 2 by 1.3 m, and contains a pocket of loamy material of the A2 horizon that is 60 cms deep. The lateral removal of vertical slices from the soil tongue sections also indicated that the dominant soil tongue form at Bridgeport, Freelton and Strabane, was roughly circular. Thus the soil tongues at these three sites have the form of inverted cones.

Linear forms

At Brantford, auguring revealed a simple linear pattern branching and extending for at least 7 m behind the soil tongues exposed in the face of the gravel pit (Fig. 4). These channel forms are much larger than those described by Yehle (1954) and resemble those described by Presant and Protz (1967). The depth of each channel varies, but is on average 75 cms, increasing to 90 cms in places. The channels appear to be leading towarding the nearby Grand River valley. Such subsurface channel features are not revealed on aerial photographs.

PEDOLOGICAL CHARACTERISTICS

SOIL MACROMORPHOLOGY

The most characteristic feature of the Burford loam is the existence of large tongues of the B horizon extending down into the C horizon. Within the soil tongues the B horizon is often 1 m thick, whilst between the tongues it may only be

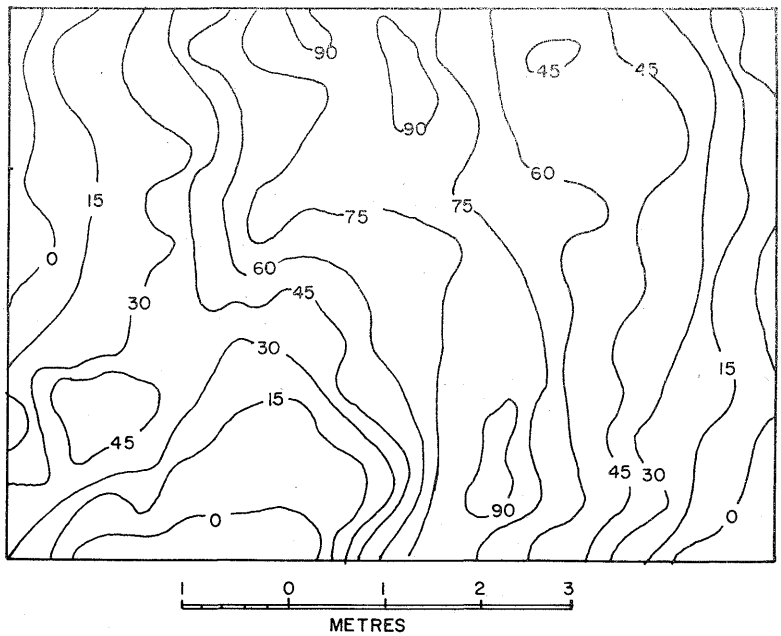


Fig. 4. Subsurface isopachs of the upper B horizon at Brantford, showing linear depression pattern of the silt loam infilling

10 cms in thickness. Consequently the subdivisions of the B horizon tend to be discontinuous. Where the B horizon is fairly thick it has at least three sub-divisions: (1) a central horizon of maximum clay accumulation, the B2t horizon (Tab. I, col. 7), (2) underlying this is a transitional B3 horizon and (3) an overlying AB horizon consisting of structural units resembling those of the underlying B2t horizon, but with coatings of bleached grains similar to the material found in the A22 horizon. The AB horizon is best developed at the Bridgeport site.

Profile Description of the Burford loam in a soil tongue (*pl. 1*) *Location* Freelton, *Grid. Ref.* 40 P/8 East Half 786047; 43°20'N, 80°10'W.

Parent material Calcareous kame-gravel, *Height* 270 metres
Classification Orthic Grey-Brown Luvisol.
Horizon:

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

A21 — 20 to 60 cms, dark yellowish brown (10YR3/4 m) 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, brown (10YR5/3 m) 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 75 to 80 cms, brown to dark brown (7.5YR4/2m) loam, with streaks of bleached (10YR7/1m) 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 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 95 to 150 cms, 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 C horizon; abundant pebbles, occasionally-weathered; moderate HCl reaction.

C 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.

The soil profile away from such tongues is shallower, the B2t horizon occurring between 26 to 30 cm depth, the C horizon at 35 cm depth. It will be noted that the A2 horizons are platy-structured, the B2t markedly gravelly and friable, the structural units stabilized by clay coatings. The depth of root penetration is generally to 75 cm depth.

SOIL MICROMORPHOLOGY

Micromorphological studies of soils using thin sections, pioneered by KUBIENA (1938), have now become a major part of all pedological investigations. The need for large thin sections in studying the genesis of soils of complex morphology has been demonstrated by JONGERIUS and HEINTZBERGER (1964). Consequently, five large thin sections were prepared from one of the soil tongues at Freelton with the aim of discovering differences in micro-structure diagnostic of the major processes responsible for the genesis and development of each layer in the profile.

STRUCTURE

Contact prints made from these thin sections are illustrated in Pl. 4 and show very clearly the variations in microstructure that occur within the profile. The Ap horizon has a predominantly granular structure and is underlain by an A2 horizon having an alveolar structure (Pl. 4: a), but accompanied in the lower A22 horizon by weakly-developed, angular blocky structure (Pl. 4: b). A marked change of structure is contained in the AB horizon, where there is a banded structure indicating grain size separation and preferred orientation of grains (Pl. 4: c). The occurrence of such a banded structure is typical of the AB horizons of many Grey Brown Podzolics (Udalfs) as noted by STOBBE (1952) and also of Boralfs (MCKEAGUE and ST. ARNAUD, 1969). The latter authors have recorded concentrations of soil matrix material at the top of lenticular platy structures and of coarser grains near the base, and regard them as typical of strongly-leached Boralfs. Similar size separations are found within the AB horizon of the Burford loam (Pl. 5) and a high degree of parallel orientation of sand grains is also evident (Pl. 4: d) but has little indication of a platy or banded structure.

Pore space varies from poorly-developed continuous pores in the Ap horizon, to mainly small, irregular, oval or short, branching pores in the A2 horizon. However, the AB horizon is characterized by an increase in packing voids due to the fine single grain structure (Pl. 6) and the B2t horizon shows the greatest development of continuous pore space (Pl. 4: d).

THE CHARACTER AND COMPONENTS OF THE MATRIX

The colour of the matrix varies from dark brown in the Ap horizon to light olive-brown in the lower A2 horizon and to yellowish-red in the B2t horizon. Such a colour contrast is a reflection of the process of eluviation and illuviation, both of iron and of clay and silt particles. Silt is the dominant matrix material in the A horizons. In the Ap horizon it occurs as a continuous soil phase enclosing mineral grains (Pl. 7) whilst in the A2 horizon it varies from a continuous phase in the A21 horizon to a less than continuous phase in the A22 horizon, where it mainly occurs as silt coatings around the larger mineral grains. Within the AB horizon size separation means that layers consisting mainly of sand grains possess only very discontinuous silt coatings (Pl. 4: c), whilst those containing much finer sand material show a concentration of matrix enclosing the grains, the whole exhibiting a complex flow pattern (Pl. 5).

The matrix of the B2t horizon is mainly clay-sized material, which has a very uneven distribution, in some places enclosing grains, and in others forming coatings or acting as bridges between grains (Pl. 8).

STONES

An advantage of large thin sections is the ease of study of the distribution of the coarser fragments. Stones are present in all the horizons and an analysis of their number and lithology in each thin section indicates a reduction in the frequency of stones in the upper horizons. Many of the stones present in the B3 show evidence of severe weathering and in the B2t horizon there are almost completely-weathered pebbles of limestone or dolomite still in place (Pls. 2 and 4 d).

SAND FRACTION

Within the Ap, A21 and A22 horizons the sand grains appear to be randomly--oriented, unlike these in the AB horizon which are most often aligned obliquely towards the centre and base of the soil tongues (Pl. 6). The sand fraction of the B2t horizon shows no such preferred orientation, although there are clusters of similarly-sized grains, which may represent lithomorphs from weathered pebbles.

SILT FRACTION

The most striking thing about the silt fraction is the concentration into bands in the AB horizon. The upper part of the thin section of this horizon indicates that silt has been leached out and this, together with the flow patterns in the lower part of the thin section (Pl. 5), would seem to indicate that silt is being moved down the profile. Several authors (e.g. THORP, CADY and GAMBLE, 1959) have described silt coatings on ped faces and in pores of the AB and upper B horizons and regard them as indications of the translocation of silt down the profile. Such would be brought about by solution of carbonate pebbles causing a volume reduction in the soil tongue and consequently collapse of overlying material. Such a collapse of material into the soil tongue would also explain the orientation of the sand grains.

CONCRETIONS

The presence of diffuse iron concretions, especially within the AB and B2t horizons, would seem to indicate that these horizons hold water longer than the overlying horizons and thus led to some deposition as nodules under oxidative conditions.

PAPULES

These features are common 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 horizon into the B horizon.

CUTANS

Clay cutans or coatings occuring in the B2t horizon are often taken to be an indication of translocation from a higher horizon. However, as BREWER (1956) has pointed out, the importance of clay illuviation in forming a textural B horizon has at times been overestimated with insufficient consideration being given to differential *in situ* weathering of the A and B horizons, or to inherited sedimentary characteristics. The only clay cutans to occur in the thin sections of the A horizon are those found within weathering stones. The existence of such cutans indicates that clay minerals do not have to be transported very far before they become optically-oriented and exhibit all the characteristic of depositional cutans. Such a finding must bring into question the use of the ratio of oriented to non-oriented clay in determining the relative importance of clay illuviation and *in situ* weathering in any horizon.

Clay cutans are best developed in the B2t horizon where they are fairly continuous (Pl. 8). However, the upper part of the section shows some evidence of progressive degradation of the cutans (Pl. 9). 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 fractured surfaces. The upper part of the AB section contains fewer cutans, but has many papules and shows a greater degree of bleaching.

The evidence suggests that the B2t horizon in the soil tongue is an unstable one, which is undergoing continual change, with the B2t horizon being replaced by the AB horizon and the AB horizon being gradually replaced by the A22 horizon by progressive alteration of the clay coating. LEBEDEVA (1969) in a study of a Grey Brown Podzolic soil in Soviet Union suggests that the study of the B horizons of such soils, on the basis of average samples, has often led mistakenly to the conclusion that the process of illuviation is the only process acting there, and proposes that the clay is moved to depth in various stages. This is supported by the present study, indicating that there are two processes operating simultaneously, with the lower Bt horizon experiencing illuviation whilst the upper part of the Bt horizon is undergoing progressive clay degradation.

Thus the thin sections indicate that the A horizon of the Burford loam is characterized by a process of eluviation, gradually producing a quartz-rich horizon, whilst the B2t horizon is characterized by the illuviation of clay from the overlying horizons and also by the *in situ* production of clay. The soil tongues of the Burford loam are, therefore, zones in which there is solution of the calcareous gravels creating a volume reduction and leading to the collapse of overlying material and the continuing extension of the soil tongues, and into which the clay is being illuviated much more strongly than in the soils to the side.

PARTICLE SIZE ANALYSES

The micromorphological study has shown that the AB horizon and probably most of the A22 horizon have formed as a result of the gradual replacement of the underlying horizon. However, it is less certain that the A21 horizon has originated in the same way. Therefore, it is essential to determine the degree of similarity between the particle size distribution curves for the upper A21 horizon and the lower A and upper B horizons (Tab. I, cols. 9—12). If all of the A horizon material has developed *in situ* then relatively parallel distribution curves will be expected. However, if the upper and lower A horizons have developed in materials which mutually differ as well as being different from that composing the C horizon, then the textural curves, and their dependent properties, would be different (Fig. 5.).

Table I

Mechanical and chemical properties of the major profiles

1. Brantford. The linear depression forms

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Ap	10	8.8	15.6	61.4	4.5	9.8	17.4	2.64ϕ	0.00	0.73	5.01	1.2	2.4	6.2	7.3	1.0	1.8	0.21
A21	25	2.3	7.1	76.1	4.3	10.6	18.0	1.93ϕ	+0.76	0.64	5.86	0.9	2.2	5.8	5.4	0.7	2.3	0.24
A22	54	1.4	12.7	65.7	7.1	13.1	19.7	2.27ϕ	+0.58	0.66	6.03	0.5	2.4	5.7	6.2	1.0	n.d.	0.30
B21t	62	30.1	19.7	19.0	4.1	27.1	20.5	4.63ϕ	+0.23	0.38	5.16	1.4	3.6	5.9	9.8	2.2	6.5	0.41
B22t	120	27.2	27.2	20.1	9.1	16.0	22.0	4.57ϕ	+0.31	0.42	5.01	1.0	12.2	7.3	7.5	3.2	3.8	0.16
B3	130	41.7	20.1	26.9	5.8	5.5	17.9	2.12ϕ	+0.50	0.45	2.78	0.3	18.0	7.5	10.0	1.4	2.2	0.13
C*	105	58.0	36.5	4.0	1.1	22.4	14.8	1.37ϕ	+0.36	0.70	0.90	0.2	25.6	7.9	11.7	0.5	1.4	0.10

2. Freelton. The inverted-cone or "tongue" depression forms

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Ap	10	3.7	45.3	38.5	4.7	7.8	18.1	2.57	0.18	0.51	4.46	3.1	3.6	6.1	14.4	1.6	1.1	0.23
A21	23	2.2	51.0	28.9	2.2	5.7	15.5	2.04	0.29	0.58	3.72	0.9	1.4	6.5	6.6	0.5	0.8	0.15
A21	45	1.9	66.5	24.7	2.0	2.9	14.5	1.03	0.40	0.57	3.76	0.6	1.8	6.5	5.4	0.3	0.7	0.21
A22	90	2.8	75.1	21.0	1.9	4.6	16.7	1.82	0.38	0.62	3.30	0.5	1.4	6.7	3.7	0.2	0.8	0.19
A22	105	5.5	63.9	24.1	3.4	3.1	12.5	n.d.	n.d.	—	—	0.6	1.6	6.7	4.3	0.2	1.0	0.19
AB	120	13.1	31.1	40.7	7.5	7.6	19.0	1.02	0.30	0.57	3.46	1.0	2.4	6.5	6.6	0.2	1.0	0.26
B2t	130	33.9	28.9	19.6	4.2	13.4	22.9	3.54	0.01	0.49	4.16	1.0	3.8	7.1	14.2	1.3	1.4	0.32
B3	150	35.7	34.3	23.3	1.3	10.8	18.2	4.23	0.48	0.50	3.52	0.6	11.9	7.9	14.0	n.d.	n.d.	n.d.
C*	150	55.2	26.4	17.9	1.5	5.2	18.2	3.23	0.68	0.50	2.33	0.6	13.8	8.2	116.1	0.5	1.8	0.21

1 Horizon
2 Sample depth, cm
3 Coarse sand, 2–0.5 mm
4 Sand, 500–50 μ
5 Silt, 50–5 μ
6 Fine silt, 5–2μ
7 Clay, <2 μ
8 Liquid limit, Pct. H_2O
9 Inclusive graphic standard deviation, δ_I
10 Incl. graphic skewness, SK_I
11 Kurtosis, K_G'
12 Graphic mean ϕ, M_Z
13 Organic matter, pct.
14 Loss on ignition, 850°C
15 pH, 5:1 H_2O
16 Exchangeable bases
17 meq/100 gm
18 Ca Mg Na
19 Fe_2O_3, Pct.

* The sample points are marked in Fig. 2. Note that the C horizon sample is taken to the side of the tongue.

CLAY FRACTION

The clay content of the B2t horizon varies from site to site being greatest at Brantford and least at Freelton (Tab. I). Because the C horizon material is in every case outwash gravel such variation between the four sites can be attributed to the inhomogeneity of the underlying materials, or to variations in degree of leaching. However, the two profiles examined at Brantford show significant differences, although only 10 m apart. The most striking difference is that one of the soil tongues at Brantford exhibits a bisequal profile, having two clay maxima, whilst the other has a normal profile. The highest of the two clay horizons contains 10.8% clay and the lower 36.8% clay, whereas the intervening horizon contains only 5.5% clay. The development of this bisequal profile would seem to be due to the presence of a thin band of carbonate pebbles, which are weathering and causing clay accumulation.

SAND AND SILT FRACTIONS

Because the two profiles at Brantford are developed over similar materials and are so close together, identical profiles would be expected, if they have been formed solely through the weathering and solution of the underlying gravels. However, the particle size distributions curves (Fig. 5) indicate significant differences, with one profile having an A horizon dominated by silt, 72.8% in the A22 horizon (illustrated), and the other an A horizon dominated by fine to medium sand. Such a con-

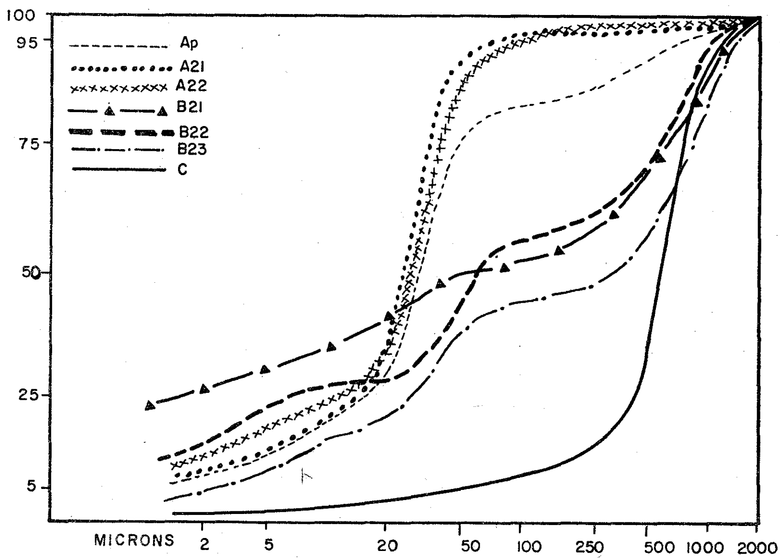
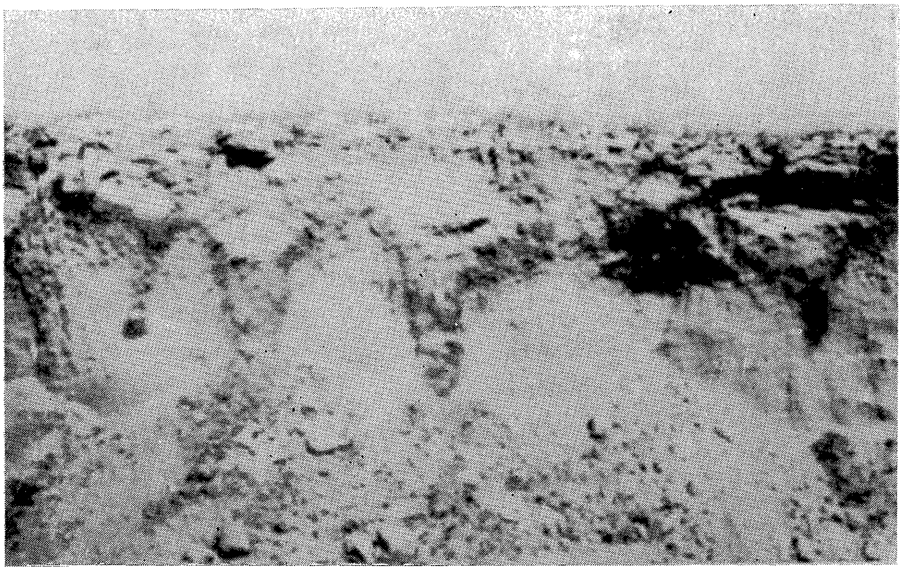
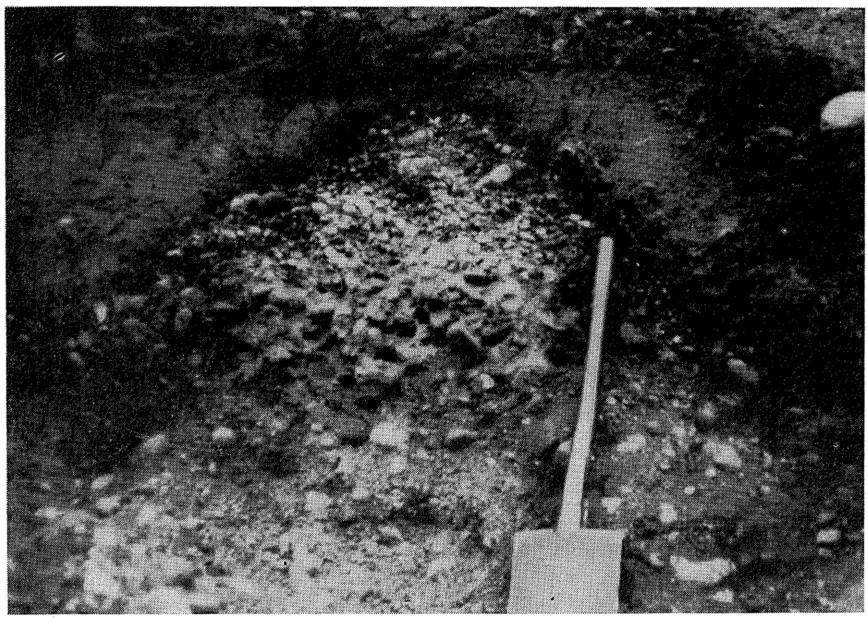


Fig. 5. Particle-size accumulation curves of the finer-textured Brantford profile



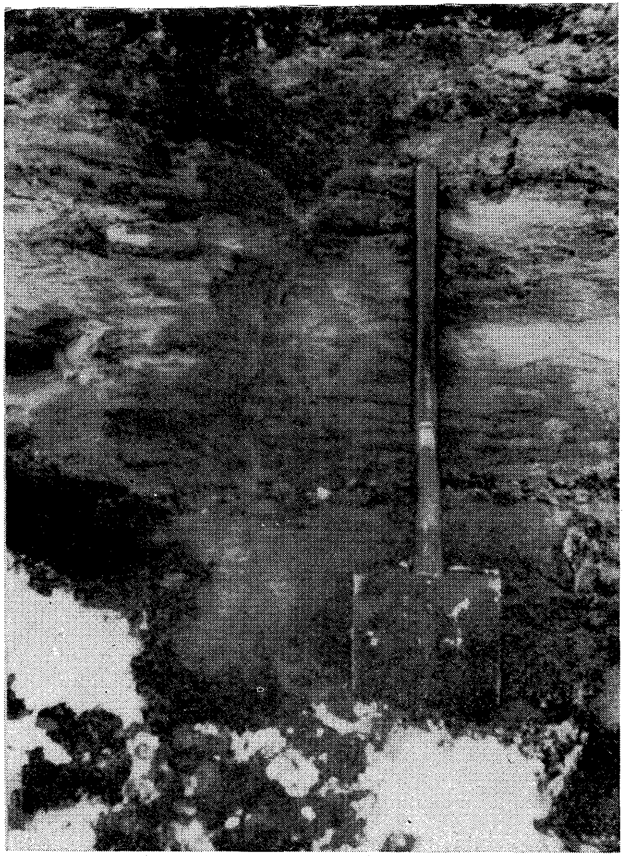
Pl. 1. Soil tongues in the Burford loam, Freelton, Ontario, showing the soil profile horizontation

Width of picture equal to 10.5 metres

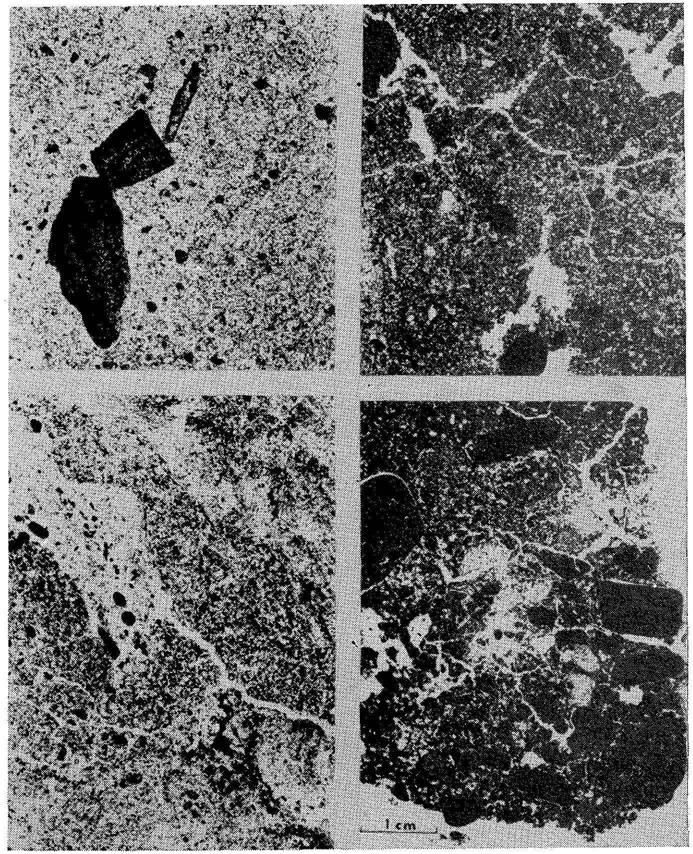


Pl. 2. Compacted gravels in the inter-tongue pedon, Bridgeport

Lateral width is 75 cm



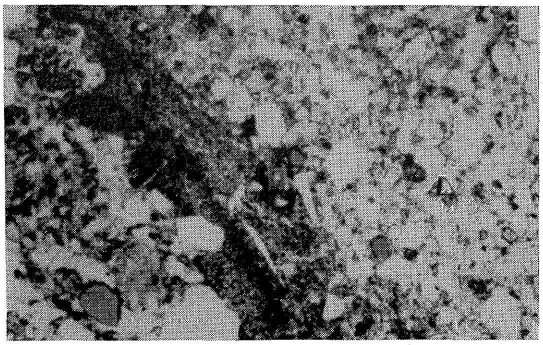
Pl. 3. Minor frost crack feature at Freelton showing surface silt loam over bedded gravels

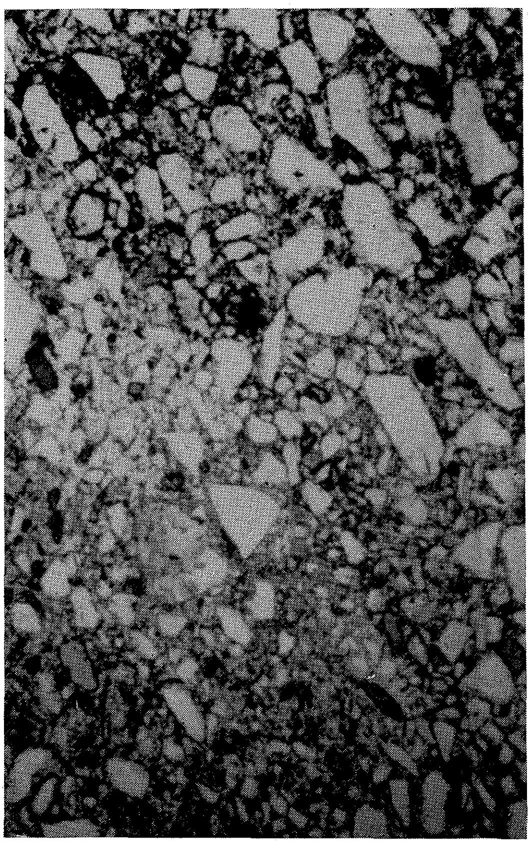


Pl. 4. Microstructure of the solum at Freelton

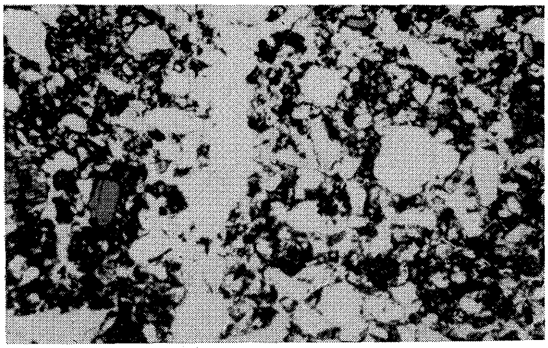
Alveolar structure of the Ap horizon; upper left (a). Weak angular blocky structure of the fine loam A22 material (upper right, (b). Lower left (c) – banded and oriented slumped material of the AB horizon (see sample site Fig. 2). Lower right (d) – oriented sand grains in the coarser material of the B2t horizon

Pl. 5. Concentration of fine material within the compact matrix of the AB horizon



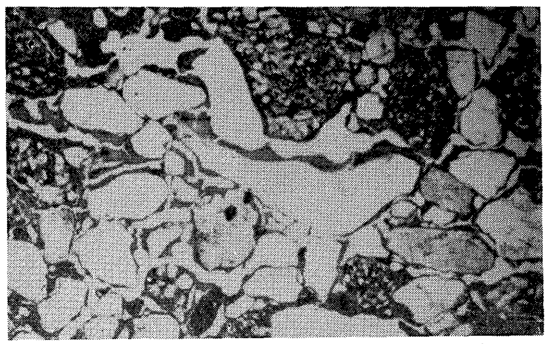


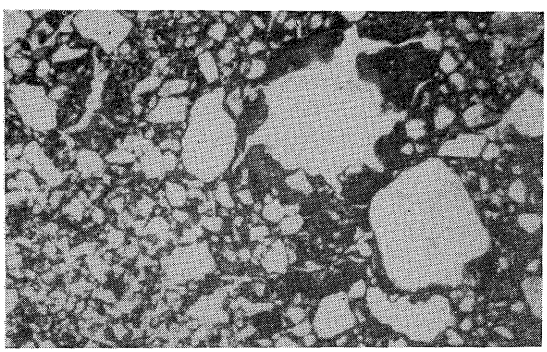
Pl. 6. Single-grain structure of the compact AB horizon with oblique alignment of grains and discontinuous dark matrix



Pl. 7. Continuous silt phase enclosing mineral grains in the upper A horizon, interrupted by vertical biogenic tubule

Pl. 8. Coarse grains enclosed by clay cutans, B2t horizon





Pl. 9. Partial degradation of clay cutans in voids in the uppermost B2t horizon

trast between two profiles only 10 m apart can only be due to the A horizon material being of largely non-pedogenic origin, and one or the other material being derived from different sources, or from very different sedimentological environments.

The sand and silt contents of the profiles at Bridgeport, Freelton and Strabane are all broadly similar and contrast with the much better-sorted A horizons at Brantford (Tab. I, cols. 9—12). However, the grain size distribution curves for the A, B and C horizons at Freelton, Bridgeport and Strabane are not sufficiently parallel to provide conclusive evidence for the derivation of the A horizon material from the underlying gravels.

CHEMICAL ANALYSES

Some analyses were made to determine the degree of carbonate leaching in the Brantford, Bridgeport and Freelton profiles, but, as the results (Tab. I, col. 13) indicate, there is very little difference to be noted. At all the sites the pH values (col. 15) are fairly high, indicating that acidification has not progressed very deeply in the Burford loam. This finding is supported by the rather high content of exchangeable cations including sodium (col. 18), even in the eluvial horizons.

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 to the origin of the pocket-like masses of loamy A2 horizon material in the upper horizons of such features.

Several alternate hypotheses have been suggested for the formation of soil tongues. These include:

(1) Development under a "spotted" tundra as described by MARUSZCZAK (1960).

(2) Deposition of material in oriented fluvial channels, as suggested by PRESANT and PROTZ (1967).

(3) Differential soil formation due to concentration of soil water, as described by BRADE-BIRKS and FURNEAUX (1928), YEHLE (1954), JOHNSSON (1959) and BARTELLI and ODELL (1960).

(4) The growth and decay of tree roots, as described by LYELL (1866), SHALER (1891) and DENNY *et al.* (1963).

(5) Windthrow of trees.

(6) The view that soil tongues may be fossil ice wedges.

One difficulty in determining the origin of the soil tongues is that they consist of at least two elements, the pockets of A2 horizon material and the tongues of the B horizon, which may not have originated in the same way. That the tongues of the B horizon have formed *in situ* and are of pedogenic origin is indicated by the active weathering of carbonate pebbles and the deposition of clay. Together with the evidence of marker bands these features support the hypotheses put forward by YEHLE (1954) that tonguing B horizons result from the localization of soil forming processes. Alternative hypotheses, such as, tree root growth and decay, or tree throw may be discounted in this case. The presence of the continuous marker bands and the rarity of ice wedges or micro slip planes indicate that physical disruption cannot be the cause of the tonguing B horizons.

However, this still leaves the problem of the origin of the pockets of A2 horizon material, and the reasons for the concentration of soil-forming processes to produce a tonguing B horizon. The pockets of A2 horizon material would seem to have three possible modes of origin: (1) they are due to the deposition of a loess or fluvial silt over an irregular surface, views implicit in statements by YEHLE (1954). Also CHAPMAN and PUTMAN (1966) suggest that they result from a blanket of fine material deposited over outwash gravels since "...the variable depth of the silt can hardly be attributed to weathering"; (2) they result from mechanical weathering under freeze—thaw conditions as suggested by MARUSZCZAK (1960), who described features very similar to the soil tongues of South-west Ontario from the Szeskie Hills of Poland. The irregular nests of fine, sandy material are surrounded by a more compact iron-stained horizon that penetrates the underlying gravels. Such features are regarded by MARUSZCZAK (1960) as having originated by freeze—thaw activity under unvegetated patches in the tundra, whilst the iron-stained horizons mark the top of a former irregular permafrost horizon; irregular because of the greater depth of summer-thawing under the unvegetated patches; (3) the pockets of loamy material are the product of chemical weathering, which has led to a continual extension of the A2 horizon material as the tongues of the B horizon are extended.

The A21 horizon material at all four sites is poorly-sorted and is not typical of established loessic deposits. However, the A21 horizon of one of the Brantford profiles has such a high silt content that it could be a loess deposit. The absence of such a high silt content from the other, nearby, profile indicates a fluvial rather than a loessic origin. Such a finding is in accordance with the channel-like form of the Brantford soil tongues in horizontal section and it is evident that these features are identical to those described by PRESANT and PROTZ (1967), having originated as infilled fluvial channels. The existence of an infill of fine material overlying a coarse gravel deposit would inevitably lead to a concentration of the soil-forming processes at the bottom of the channel feature.

The A2 horizon material at the Freelton, Bridgeport and Strabane sites is less typical of established loess deposits, although PITCHER, SHEARMAN and PUGH (1954) describe basal loess deposits as having only 45% of particles in the 10—50 μ fraction and poorly-sorted. Thus, a fluvial origin for the A2 material is conceivable, which may, as CHAPMAN and PUTNAM (1966) indicate, have covered an irregular surface, the irregular nature of which may have resulted from mild freeze—thaw activity causing hummocky ground.

CONCLUSION

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 had a slightly uneven surface, possibly the result of periglacial activity. The irregular nature of the interface has led to a localization of relatively weak pedogenic processes of carbonate solution and differential clay movement, deposition and degradation, which produced soil tongues beneath the infilled depressions. In the case of the linear soil tongues silt has been deposited within a fluvial channel. Therefore, there would seem to be little difference either in the mode of origin or in the effect of the Bt horizon which dominate the tongues at the four studied sites despite the contrast between both linear and circular forms in the original irregular surface.

References

Bartelli, L. J. and R. T. Odell, 1960 — Field studies of a clay-enriched horizon in the lowest part of the solum of some Brunizem and Gray-Brown Podzolic soils in Illinois. *Soil Sci. Soc. Am. Proc.*, 24; p. 388—390.

Brade-Birks, S. G. and B. S. Furneaux, 1928 — Soil profiles in Kent. *Jour. South East Agric. Coll., Wye, Kent*, 25.

Brewer, R., 1956 — A petrographic study of two soils in relation to their origin and classification. *J. Soil. Sci.*, 7; p. 268—279.

Chapman, L. J. and D. F. Putnam, 1973 — The Physiography of Southern Ontario. Univ. of Toronto Press, 386 pp.

Denny, C. S., W. H. Lyford, and J. C. Goodlett, 1963 — Surficial Geology and Soils of the Elmira-Williamsport region, New York and Pennsylvania. *U. S. Geol. Surv. Prof. Paper*; 379 p.

FitzPatrick, E. A., 1956 — An indurated soil horizon formed by permafrost. *J. Soil Sci.*, 7; p. 248—254.

FitzPatrick, E. A., 1970 — A technique for the preparation of large thin sections of soil and unconsolidated materials. *Tech. Monogr. Soil Surv. Eng. and Wales*, 2; p. 3—13.

FitzPatrick, E. A., 1971 — Pedology: A Systematic Approach to Soil Science. *Oliver and Boyd*, Edinburgh, 306 p.

Johnsson, G., 1959 — True and false ice-wedges in southern Sweden. *Geografiska Ann.*, 41; p. 15—33.

Jongerius, A. and G. Heintzberger, 1964 — The preparation of mammoth sized thin sections. *Soil Survey Papers I*, Soil Survey Inst., Wageningen.

Kubiena, W. L., 1938 — Micropedology. Collegiate Press Inc., Ames, Iowa.

Lebedeva, I. I., 1969 — Nature of the illuvial horizon of light-gray forest soils on moraine loams. *Soviet Soil Sci.*, 2; p. 3—11.

Lyell, C., 1866 — Elements of geology; or the ancient changes of the earth and its inhabitants as illustrated by geological monuments. Appleton and Co., New York.

Maruszczak, H., 1960 — Peryglacjalne utwory pokrywowe na obszarze Wzgórz Szeskich (résumé: Formations périglaciaires de couverture sur le territoire des collines Szeskie) *Biul. Peryglacjalny*, 7; p. 137—149.

McKeague, J. A. and R. J. St. Arnaud, 1969 — Pedotranslocation: eluviation — illuviation in soils during the Quaternary. *Soil. Sci.*, 107, 6; p. 428—434.

Morgan, A. V., 1972 — Late Wisconsin ice-wedge polygons near Kitchener, Ontario, Canada. *Can. Jour. Earth Sci.*, 9; p. 607—617.

Pitcher, W. S., D. J. Shearman, and D. C. Pugh, 1954 — The loess of Pegwell Bay, Kent and its associated frost soils. *Geol. Mag.*, 4; p. 308—315.

Presant, E. W. and R. Protz, 1967 — The origin of soil tongues in some Ontario soils. *Geol. Min. Assoc., Can.* and *Int. Joint Meetings, Kingston, Ontario.* Note in *Can. Mineralogist*, 9, pt. 2.

Shaler, N. S., 1891 — The origin and nature of soils. *12th Ann. Rept. U. S. Geol. Surv.*, 1890—91, Pt. I, Geology; p. 213—345.

Stobbe, P. C., 1952 — The morphology and genesis of the Gray-Brown Podzolic and related soils of E. Canada. *Soil Sci. Soc. Am. Proc.*, 16; p. 81—84.

Thorp, J., J. G. Cady, and E. E. Gamble, 1959 — Genesis of Miami silt loam. *Soil Sci. Soc. Am. Proc.*, 23; p. 65—70.

Yehle, L. A., 1954 — Soil tongues and their confusion with certain indicators of periglacial climate. *Amer. J. Sci.*, 252; p. 532—546.