Particle Size Analysis of three Holocene Soil Profiles in South-Central Ontario

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A chronosequence in the Rouge River Basin of south-central Ontario, were studied to investigate methods for describing the particle size distributions and to determine whether there are significant differences in the distributions for soil sola of different ages. These soils, forming in alluvium of mixed mineralogy, represent weathering and soil formation in the late Holocene (Site R13), mid-Holocene (Site R12) and early Holocene.

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Assessment of the time factor in soil formation is achieved using the chronosequence concept of Jenny (1941, 1980). This is defined as a sequence of soils developed in similar parent materials and topographic settings, under the influence of non raying climatic and biotic factors whose different states can be attributed to lapse in time since the initiation of soil formation (time zero). The soil morphogenesis process involves weathering and leaching, which induces gains, losses, transformations and translocations of organic and inorganic constituents. These variations are reflected in the morphological, physical, chemical and mineralogical properties of the soils.

Soil formation often involves increases in finer texture (Birkeland, 1984), changes in structure (Mahaney, 1974, 1978, 1984), solum thickness and horizon development (Mahaney and Fahey, 1976), changes in surface and subsurface color (Crocker and Major, 1955). Many chronosequence studies reveal that, over time, organic matter increases, and soluble salts, basic cations and pH decrease (Crocker and Major, 1955; Dickson and Crocker, 1954; Franzmeier et al., 1963). The development of Fe oxides in the soil provides an index of time (Alexander, 1974; Campbell, 1971) and increases in total clay content reflect the time factor (Ahmad et al., 1977). The present paper considers, in particular, the size distributions of samples from soil profiles of different ages. A method of characterizing the size distributions is proposed and tentative conclusions on the differences between size distributions are drawn.

FIELD AREA

The valleys of south-central Ontario are characterized by alluvial terraces and floodplain deposits formed by postglacial stream activity. Fluvial sediments in the Rouge River Valley (Figure 1a) are derived from a wide range of glacial and nonglacial deposits, which have shale, limestone, granitic, and gneissic clasts incorporated in them. Stream incision has given rise to three distinct age surfaces, shown in Figure 1b. Sample site locations representing these surfaces are shown in Figure 1a. The deposits are named from oldest to youngest: Rouge, Twyn Rivers, and Highland Formations. Soils formed in these deposits are given the prefix 'post', to avoid a terminologic proliferation. The two oldest soils, post-Rouge and post-Twyn

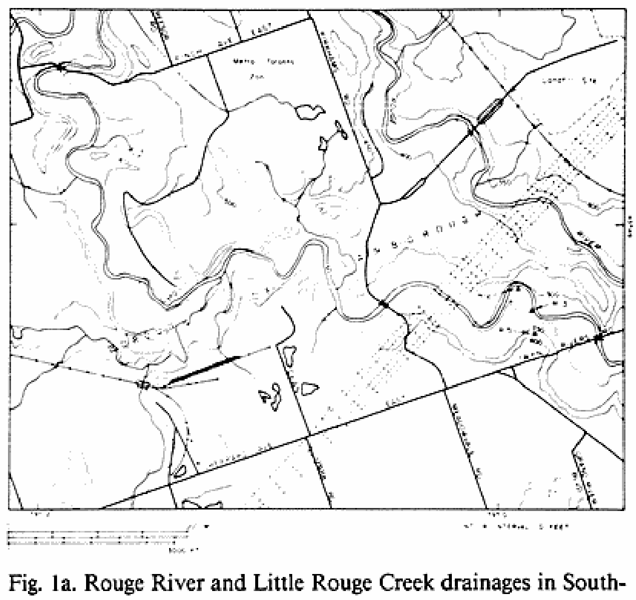

Fig. 1a. Rouge River and Little Rouge Creek drainages in South-Central, Ontario.

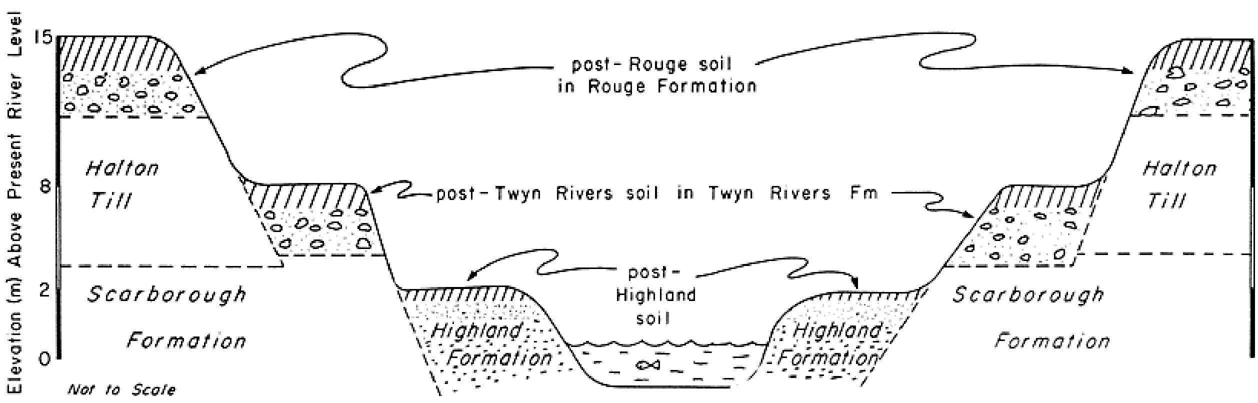

Fig. 1b. Cross-Section of Rouge River Valley showing positions of Holocene deposits and soils.

Rivers, developed in pebbly loamy alluvium. These soils are found in very late Pleistocene/Holocene to late Holocene surfaces and are classified as an Orthic Regosol (post-Highland soil, R13); and Orthic Sombric Brunisols (post-Twyn Rivers, R12; and post-Rouge soils, R15), Canada Soil Survey Comm., 1977. The post-Highland soil is estimated to be late Holocene in age (4000 radiocarbon years B.P.) and undergoing continual redeposition of sediments by river flooding. The post-Twyn Rivers soil is estimated to be mid-Holocene in age while the post-Rouge soil is likely early Holocene to very late Pleistocene in age.

Soils were sampled in terrace surfaces with less than 1-2° slope. The climate of the area is humid continental, cool summer, no dry season type described by Brown (1968) and Mahaney and Ermuth (1974). The average temperature ranges from 20° C in July to -7° C in January; extremes reach 40°C in July and -34° C in January. A frost-free period of 150 days lasts from mid-May to early-October. Wind in the area is dominantly westerly, and mean annual precipitation is 850 mm.Soils were sampled in areas covered with sugar maple and beech stands (two highest surfaces) and willow stands (low surface). Some clearing for cultivation had occurred at site R12; sites R15 and R13 were undisturbed (Figure la for location).

METHODS

Duplicate soil samples were collected from each soil profile described in detail. Soil descriptions follow Canada Soil Survey Comm. (1977) and Birkeland (1984), while soil color was determined from the Standard Soil Color Charts of Oyama and Takehara (1970). Soil samples were air dried and passed through a 2 mm sieve. For particle size analysis samples were treated with H_2O_2 to remove organic constitutents, and with sodium pyrophosphate to achieve deflocculation. All samples were agitated with a Branson 350 cell dismembrator to separate clay constituents. Sands were wet sieved using 63 mm sieves and coarse grade sizes were determined after dry sieving. Fine grade sizes of silt plus clay were determined by sedimentation following Bouyoucos (1962) and Day (1965). The statistical analysis was carried out using standard linear regression techniques, for example see Moore and Edwards (1965).

RESULTS AND DISCUSSION

The three soils were sampled to different depths. Because the soils in each terrace are similar, results from one of each soil stratigraphic unit were presented. Only the morphologic and particle size parameters of importance to soil genesis are discussed below.

Morphology

The morphology of the three soils is presented in Tables 1,2 and 3. The color in the upper solum is fairly uniform between the three soils, while subsoil (subsolum) color varies with a trend from lighter 10YR 5 and 6 hues to darker 10YR 4 hues over time. These colors grade into 2.5Y and light 10YR hues in the parent materials (Cu horizons). A parallel trend is observed with topsoil structure which ranges from weak granular in the youngest soil to a stronger grade of granular development in the older pedons. Structure below the Ah horizons in the lower solum and subsoil ranges from depositional stratification in the youngest profile (post-Highland soil) to weak blocky aggregates in the B horizons of the older soils (post-Twyn Rivers and post-Rouge soils). The consistence of the surface soil horizons does not differ appreciably, but some differences in the lower horizons are discernible, presumably the result of particle size variations. Coatings on ped faces occur only in the B horizon of the oldest profile (post-Rouge soil). Increasing age of each soil is reflected by deeper pedons, greater solum thickness, and horizon differentiation (especially the development of B horizons). Exact differences in profile depth as a function of age are complicated by the presence of buried soil horizons in the post-Highland soil.

Table 1.

Soil profile R13 in the low (2m) terrace, Rouge River Basin, Ontario

Horizon	Depth (cm)	Description[a]
Ahk	0-6	Yellowish brown (10YR 6/3m) and grayish yellow brown (10YR 5/2d) sandy loam, very weak granular structure, friable consistence, slightly plastic and nonsticky
Cuk	6-17	Dull yellow (2.5Y 6/3m) and grayish yellow (2.5Y 6/2d) loamy sand, massive, friable to very friable consistence, slightly plastic and nonsticky
Ahbk	17-23	Grayish yellow brown (10YR 4/2m) and brownish gray (10YR 5/1d) sandy loam, very weak granular structure, friable to firm consistence, plastic and slightly sticky.
Cubk	23-27	Dull yellow orange (10YR 6/3m) and grayish yellow brown (10YR 6/2d) sandy loam, massive, firm consistence, plastic and sticky.
Ahbk	27-46	Dull yellowish brown (10YR 4/3m) and grayish yellow brown (10YR 5/2d) sandy loam, weak granular structure, friable consistence, plastic and slightly sticky
Cbk	46-76	Dull yellowish brown (10YR 5/4m) and dull yellow orange (10YR 6/3d) sandy loam, massive, firm to friable consistence, slightly plastic and sticky
Cubk	76+	Yellowish brown (2.5Y 5/4m) and dull yellow orange (10YR 7/3d) sandy loam, massive, friable consistence, slightly plastic and slightly sticky

a. Soil descriptions follow Birkeland (1984), CSSC (1977), and Soil Survey Staff (1951, 1975). Colors were taken from Oyama and Takehara (1970) in the moist (m) and dry (d) states. Consistence is given in the moist state. Parent material (Cu) is based on criteria established by Hodson (1976).

Table 2.

Soil profile R12 in the intermediate (8 m) terrace, Rouge River Basin, Ontario

Horizon	Depth (cm)	Description[a]
Ah1	0-6	Brownish black (10YR 2/3m) and dull yellowish brown (10YR 5/3d) sandy loam, granular structure, friable consistence, plastic and slightly sticky
Ah2	6-11	Brownish black (10YR 3/2m) and dull yellowish brown (10YR 5/3d) sandy loam, granular structure, friable consistence, plastic and slightly sticky
Bm	11-28	Brown (10YR 4/4m) and dull yellow orange (10YR 6/4d) sandy loam, weak blocky structure, firm consistence, plastic and sticky
Ck1	28-42	Dull yellowish brown (10YR 5/4m) and dull yellow orange (10YR 6/3d) pebbly loamy sand, massive structure, very friable consistence, slightly plastic and nonsticky
Ck2	42-66	Olive brown (2.5Y 4/4m) and dull yellow orange (10YR 6/3d) pebbly loamy sand, massive, very friable to loose consistence, nonplastic and nonsticky
Cuk	66+	Dull yellow (2.5Y 6/3m) and dull yellow orange (10YR 6/3d) pebbly loamy sand, massive, very friable to loose consistence, nonplastic and nonsticky

a. Soil descriptions follow Birkeland (1984), CSSC (1977), and Soil Survey Staff (1951, 1975). Colors were taken from Oyama and Takehara (1970) in the moist (m) and dry (d) states. Consistence is given in the moist state. Parent material (Cu) is based on criteria established by Hodson (1976).

Particle Size

Data resulting from particle size analyses of the three soils are shown in Table 4. While the distributions of sand and silt varied somewhat, the values for clay increased slowly with depth in the post-Highland soil (R13). However, in the older post-Twyn Rivers soil (R12), silt and clay are higher in the solum than in the subsoil and parent material. A similar pattern occurs in the post-Rouge soil (R15) where clay in the upper solum increases to 10 per cent. The trend towards greater clay content in surface soil horizons with increasing age suggests increased production of clay over time as a function of weathering. It is also possible that these variations occur as a function of paleohydrological changes in stream regimen, or as a result of airfall influx of material. However, no minerals that might have an allochthonous origin were discovered in the clay-silt grade sizes in the soil sola.

Particle size distribution

A statistical analysis was carried out to investigate whether the size distributions of the samples could be correlated satisfactorily by the Rosin-Rammler equation. This equation is widely used to describe the size distributions of crushed materials such as coal (for example, Rose and Cooper, 1977), and has the following simple analytical form: $y=\exp(-ax^b)$ ') where y is the fraction of the sample with particle diameters greater than x microns, and a and b are constants.

It is usual to exclude measurements for which there is less than 2 per cent oversize, as the Rosin-Rammler distribution does not normally apply in such cases.

Table 3. Soil profile R15 in the high (15 m) terrace, Rouge River Basin, Ontario

Horizon	Depth (cm)	Description[a]
Ah	0-13	Brownish black (10YR 2/2m, 3/2d) sandy loam, granular structure, friable consistence, plastic and slightly sticky
Bm1	13-46	Brown (10YR 4/4m) and dull yellow orange (10YR 7/4d) sandy loam, sub-angular blocky structure, firm consistence, plastic and slightly sticky
Bm2	46-69	Brown (10YR 4/6m) and bright yellowish brown (10YR 7/6d) sandy loam, blocky structure, firm to friable consistence, plastic and slightly sticky
Ck1	69-99	Yellowish brown (10YR 5/6m) and dull yellow orange (10YR 7/3d) pebbly sandy loam, massive, very friable, nonplastic and nonsticky
Ck2	99-147	Bright yellowish brown (10YR 6/6m), olive brown (2.5Y 4/4m) and dull yellow orange (10YR 6/3d, 6/4d) pebbly sandy clay loam, massive, very friable to loose consistence, nonplastic and nonsticky
Cuk	147+	Dull yellow (2.5Y 6/3m) and pale yellow (2.5Y 8/4d) pebbly loamy sand,massive, firm consistence, plastic and sticky

a. Soil descriptions follow Birkeland (1984), CSSC 1977), and Soil Survey Staff (1951, 1975). Colors were taken from Oyama and Takehara (1970) in the moist (m) and dry (d) states. Consistence is given in the moist state. Parent material (Cu) is based on criteria established by Hodson (1976).

The Rosin-Rammler equation can be transformed into a linear equation in the parameters log(a) and b, as follows: $b \log x + \log a = \log \log (1/y)^2)$.

An ideal Rosin-Rammler particle size distribution therefore gives a straight line if the log-log-reciprocal oversize is plotted against the log particle size.

The parameters a and b were obtained for each of the samples described in Table 4 by carrying out a linear regression analysis (least – squares fit) on the transformed equation (2). The data used in the analysis were given in the table, except that the measurements for 7.8 microns and below were excluded.

For many of the samples, however, it would have been sufficiently accurate to plot the data on log-log-reciprocal v log graph paper (for example, Chart Well 5596) and fit a straight line 'by eye'. The parameters a and b can then be calculated by choosing two points on the line, substituting the values into equation 2, and solving the resulting simultaneous equations.

Table 4. Detailed size distributions of selected samples

Particle size (microns)	Percentage oversize R13 Ahk	R12 Ah1	R12 Ah2	R12 Bm	R15 Ah	R15 Bm1	R15 Bm2
500	0.8	5.7	3.4	5.0	2.2	1.8	1.4
250	5.3	21.1	14.0	16.3	13.0	8.9	8.6
125	28.0	43.4	33.9	37.2	39.0	34.3	32.7
63	61.3	65.4	60.0	64.1	62.0	60.3	60.2
31.2	76.0	77.5	74.0	76.0	70.0	76.0	76.0
15.6	94.5	86.5	82.5	86.0	81.0	85.0	85.5
7.8	97.0	92.0	90.5	92.0	88.5	88.0	89.0
3.9	97.5	94.5	93.0	94.0	90.0	90.0	90.5
1.95	97.8	96.2	94.8	95.5	92.6	91.0	91.0
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The experimental data are shown in Figures 3 to 9, together with the line corressponding to the 'best-fit', obtained by the statistical analysis descriped above. As illustrated in the figures, the Rosin-Rammler equation generally provides a reasonable describtion of the size distribution for particles greater than about 10 microns, the distribution below this size being significantly finer than would be expected by extrapolation from the coarser sizes.

The results are summarized in Table 5, together with the standard error of predicting the percentage oversize for the data points used in the analysis. As shown in the table, the standard error lies in the range 1.1 to 3.1 percentage points for particle sizes greater than (or equal to)

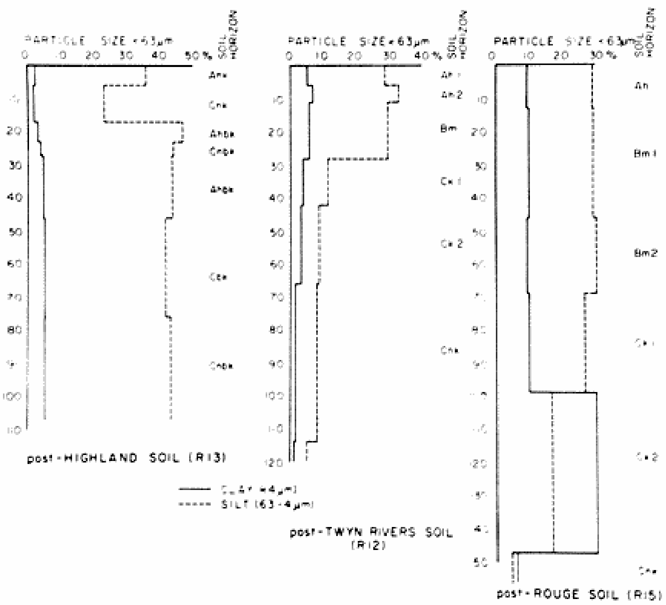

Fig. 2. Distributions of silt and clay with depth in the three Holocene soil profiles.

Table 5. Results of the linear regression analysis

Parameter	R13 Ahk	R12 Ahl	R12 Ah2	R12 Bm	R15 Ah	R15 Bm1	R15 Bm2
a	0.0018	0.0129	0.0169	0.0130	0.0173	0.0101	0.0093
b	1.360	0.866	0.853	0.883	0.852	0.975	0.995
Standard error (%)	3.1	1.1	2.0	2.0	1.8	2.2	2.0
Median size (microns)	81	100	78	90	76	77	76
Upper quartile (microns)	133	222	175	198	172	156	153
Lower quartile (microns)	42	36	28	33	27	31	31
Interquartile range (microns)	91	186	147	165	145	125	122
Excess less than 2 microns (%)	1.8	1.5	2.3	2.2	4.4	7.2	7.2

15.6 microns. Also shown in the table is the difference between the observed percentage of the material less than 1.95 microns and that predicted by extrapolation of the best-fit Rosin-Rammler equation. With the exception of R15-Bm1 and Bm2, the differences are less than 3 percentage points.

The best-fit equation was used to estimate the median size of the distributions, and the upper and lower quartiles; these values are also given in Table 5.

DISCUSSION

The particle size distributions were compared in order to investigate the differences between the samples. A formal 'analysis of variance' approach was not employed because of the limited number of data points available. Three parameters were chosen to characterize the size distributions:

1) The median particle size (this gives a general indication of whether the size distribution is 'coarse' or 'fine').
2) The parameter b of the Rosin-Rammler equation (a high value corresponds to a smaller spread of particle sizes, or equivalently a more 'peaky' size distribution, than a low value).
3) The excess material finer than 2 microns.

For the A horizons, these parameters are compared in Figure 10. Although there is no clear overall trend, it appears that the R13 size distribution is more 'peaky' than those for R12 and R15. The data also suggest that R15 has a lower median size than R13 and R12, and also contains more excess fine material less than 2 microns. For the B horizons, the trends are shown in Figure 11. The indications are that R15 has a somewhat more 'peaky' size distribution, a lower median particle size, and more excess fine material below 2 microns than R12.

In the present study, the limited amount of data makes it difficult to establish the statistical significance of these trends, although the standard test could be applied in situations where more data (including replicate samples) are available. Even so, the use of the Rosin-Rammler equation as described makes it easier to identify trends than when working directly from the 'raw' data in Table 4.

CONCLUSIONS

On the basis of the above, limited analysis, two conclusions are tentatively proposed:

1) The Rosin-Rammler equation can provide a satisfactory description of the size distribution of soil samples taken from the Rouge River Basin for particles larger than about 10 microns. This therefore includes, in one continuous distribution, the sand and much of the silt.
2) The particle size distributions can be characterized by the three parameters median size, the parameter b of the Rosin-Rammler equation, and the difference between the measured and predicted amounts of fine particles (the 'excess material' below 2 microns). Comparison of these parameters for the present samples indicates that, for the A horizons, R13 has a smaller range of particle sizes than R12 and R15. For the B horizons, R15 has a somewhat smaller range of particle sizes, a lower median size and more excess fine material below 2 microns than R12.

ACKNOWLEDGEMENTS

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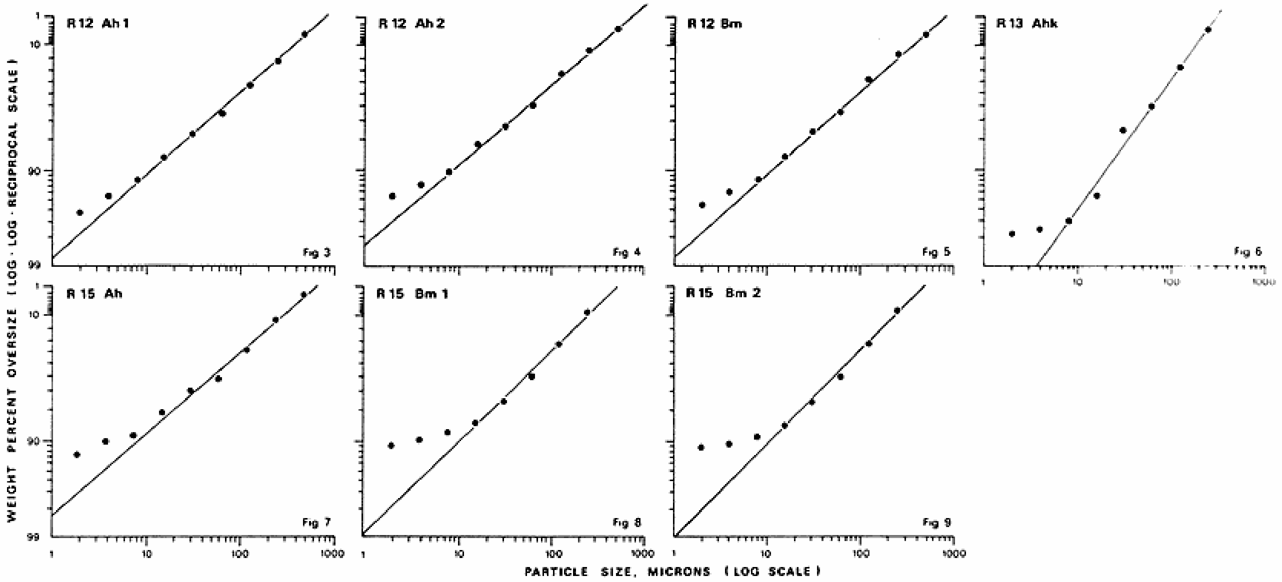
Summary

Three soils of postglacial age, representing a chronosequence in the Rouge River Basin of south-central Ontario, were studied to investigate methods for describing the particle size distributions and to determine whether there are significant differences in the distributions for soil sola of different ages. These soils, forming in alluvium of mixed mineralogy, represent weathering and soil formation in the late Holocene (Site R13), mid-Holocene (Site R12) and early Holocene/late Pleistocene (R15) surfaces. With increasing age, horizon differentiation and soil thickness increases, along with percent clay in the sola (A+B horizons) of the three soils show that the Rosin-Rammler equation provides a reasonable description of the size distribution for particles greater than 10 microns. The distribution below this size (fine silt and clay) is finer



(as determined by experimental results) than would be expected by extrapolation from the coarser sizes. An analysis of parameters derived from the Rosin-Rammler equation permits two conclusions to be drawn on the differences in the size distributions:[1]) The Rosin-Rammler equation provides a satisfactory description of the size distribution of soil samples for particles larger than about 10 microns, and [2]) particle size distributions can be characterized by the three parameters – median size, parameter b of the Rosin-Rammler equation, and the difference between the measured and predicted amounts of fine particles.

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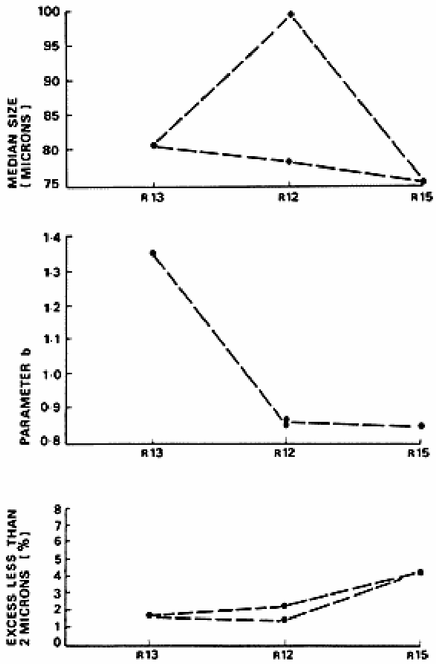


FIG. 10 COMPARISON OF THE A HORIZONS

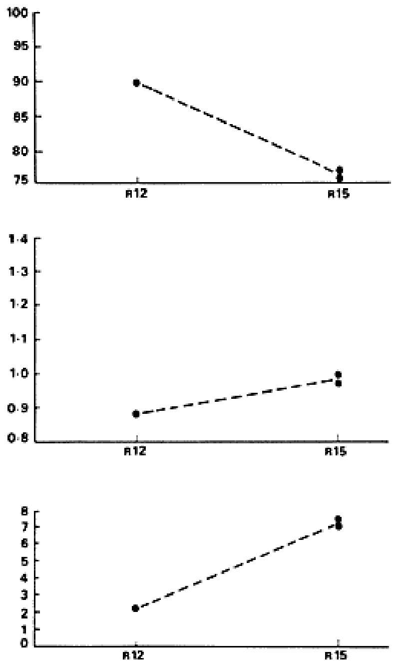
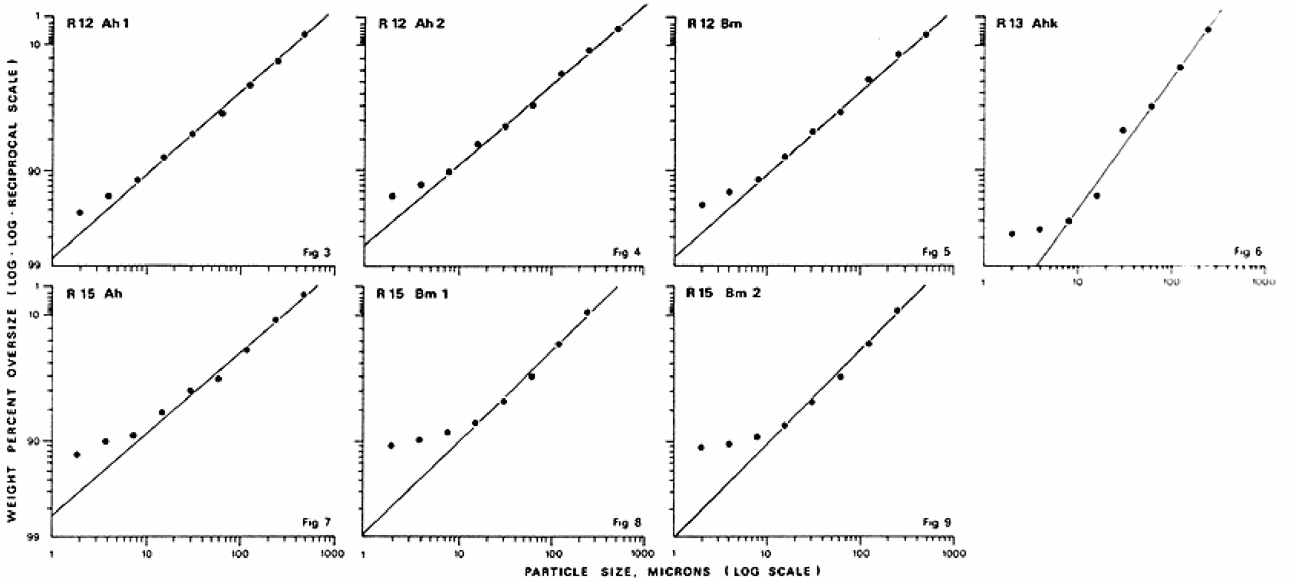


FIG. 11 COMPARISON OF THE B HORIZONS



(as determined by experimental results) than would be expected by extrapolation from the coarser sizes. An analysis of parameters derived from the Rosin-Rammler equation permits two conclusions to be drawn on the differences in the size distributions:[1]) The Rosin-Rammler equation provides a satisfactory description of the size distribution of soil samples for particles larger than about 10 microns, and [2]) particle size distributions can be characterized by the three parameters – median size, parameter b of the Rosin-Rammler equation, and the difference between the measured and predicted amounts of fine particles.

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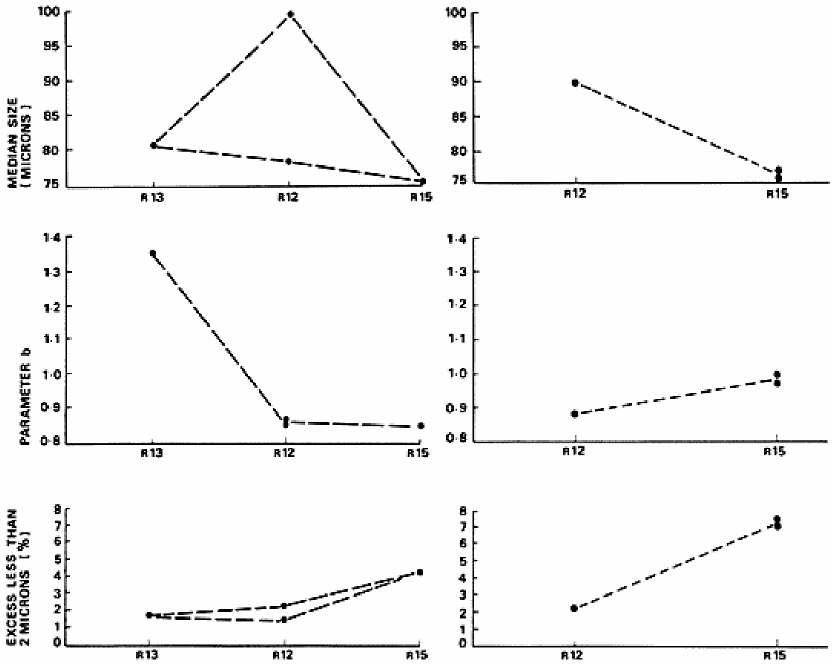

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FIG. 11 COMPARISON OF THE B HORIZONS

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Marginale landbrugsarealer

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Formerly, the farmers conceived the 'marginal arable land' as those areas which lay in their natural state, but offered a potential for cultivation. In contrast, marginal soils are today widely conceived as those it cannot pay to cultivate any longer and therefore should be abandoned.

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Keywords: *Marginaljorde, tilplantning, hedeopdyrkning, engvanding.*

De marginale landbrugsarealer er kommet i fokus gennem det sidste par år på grund af en tiltagende overskudsproduktion af fødevarer i Vesteuropa. En første indskrænkning af den hjemlige landbrugsproduktion, blev iværksat med kvotaordningen for mælk i 1984, og flere begrænsninger må imødeses.

Nedsættelsen af kornpriserne fra 1986-87 kan ikke undgå at få konsekvenser for planteproduktionens sammensætning i de kommende år og dermed for hele landbrugets arealanvendelse. Det aktualiserer samtidig vurderingen af økonomien på de lavt boniterede jorde, hvor produktionen mange steder er lidet rentabel, og her kan en direkte opgivelse af landbrugsarealer blive konsekvensen. Den store interesse for eventuelle nedlagte dyrkningsområder er dog især opstået i fredningsorganisationer og -styrelser og senest kommet til udtryk i et oplæg til debat om »miljøinteresser og marginaljorder« fra Miljøministeriet.

Det er imidlertid langtfra noget nyt fænomen, men tidligere har ændringerne i arealanvendelsen overvejende givet sig udslag i en tilplantning af opgivne dyrkningsområder, mens en udnyttelse til rekreative formål og til etablering af nye »naturarealer« ikke var så stærkt fremme – men dog inde i billedet i form af planer for naturparker m.v.

Table 5. Results of the linear regression analysis

Parameter	R13 Ahk	R12 Ah1	R12 Ah2	R12 Bm	R15 Ah	R15 Bm1	R15 Bm2
a	0.0018	0.0129	0.0169	0.0130	0.0173	0.0101	0.0093
b	1.360	0.866	0.853	0.883	0.852	0.975	0.995
Standard error (%)	3.1	1.1	2.0	2.0	1.8	2.2	2.0
Median size (microns)	81	100	78	90	76	77	76
Upper quartile (microns)	133	222	175	198	172	156	153
Lower quartile (microns)	42	36	28	33	27	31	31
Interquartile range (microns)	91	186	147	165	145	125	122
Excess less than 2 microns (%)	1.8	1.5	2.3	2.2	4.4	7.2	7.2

15.6 microns. Also shown in the table is the difference between the observed percentage of the material less than 1.95 microns and that predicted by extrapolation of the best-fit Rosin-Rammler equation. With the exception of R15-Bm1 and Bm2, the differences are less than 3 percentage points.

The best-fit equation was used to estimate the median size of the distributions, and the upper and lower quartiles; these values are also given in Table 5.

DISCUSSION

The particle size distributions were compared in order to investigate the differences between the samples. A formal 'analysis of variance' approach was not employed because of the limited number of data points available. Three parameters were chosen to characterize the size distributions:

1) The median particle size (this gives a general indication of whether the size distribution is 'coarse' or 'fine').
2) The parameter b of the Rosin-Rammler equation (a high value corresponds to a smaller spread of particle sizes, or equivalently a more 'peaky' size distribution, than a low value).
3) The excess material finer than 2 microns.

For the A horizons, these parameters are compared in Figure 10. Although there is no clear overall trend, it appears that the R13 size distribution is more 'peaky' than those for R12 and R15. The data also suggest that R15 has a lower median size than R13 and R12, and also contains more excess fine material less than 2 microns. For the B horizons, the trends are shown in Figure 11. The indications are that R15 has a somewhat more 'peaky' size distribution, a lower median particle size, and more excess fine material below 2 microns than R12.

In the present study, the limited amount of data makes it difficult to establish the statistical significance of these trends, although the standard test could be applied in situations where more data (including replicate samples) are available. Even so, the use of the Rosin-Rammler equation as described makes it easier to identify trends than when working directly from the 'raw' data in Table 4.

CONCLUSIONS

On the basis of the above, limited analysis, two conclusions are tentatively proposed:

1) The Rosin-Rammler equation can provide a satisfactory description of the size distribution of soil samples taken from the Rouge River Basin for particles larger than about 10 microns. This therefore includes, in one continuous distribution, the sand and much of the silt.
2) The particle size distributions can be characterized by the three parameters median size, the parameter b of the Rosin-Rammler equation, and the difference between the measured and predicted amounts of fine particles (the 'excess material' below 2 microns). Comparison of these parameters for the present samples indicates that, for the A horizons, R13 has a smaller range of particle sizes than R12 and R15. For the B horizons, R15 has a somewhat smaller range of particle sizes, a lower median size and more excess fine material below 2 microns than R12.

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Summary

Three soils of postglacial age, representing a chronosequence in the Rouge River Basin of south-central Ontario, were studied to investigate methods for describing the particle size distributions and to determine whether there are significant differences in the distributions for soil sola of different ages. These soils, forming in alluvium of mixed mineralogy, represent weathering and soil formation in the late Holocene (Site R13), mid-Holocene (Site R12) and early Holocene/late Pleistocene (R15) surfaces. With increasing age, horizon differentiation and soil thickness increases, along with percent clay in the sola (A+B horizons) of the three soils show that the Rosin-Rammler equation provides a reasonable description of the size distribution for particles greater than 10 microns. The distribution below this size (fine silt and clay) is finer