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MINERALOGY OF SOME ORTHIC PODZOLS IN QUEBEC

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Abstract

Five horizons were sampled in profiles taken from four soil series of Orthic Podzols in the Province of Quebec. Rapid quantitative mineralogical analysis was performed on the primary minerals in these samples using x-ray diffraction methods. Statistical analysis of the results showed that seven minerals out of the twelve identified varied significantly between horizons. The minimum percentages for minerals found susceptible to weathering were usually found in the Ae horizon rather than the F, suggesting that some circulation of sand particles does occur.

New indices of severity of weathering and heterogeneity of parent material are suggested and compared with the literature. Use of these indices suggests that texture of the parent material significantly affects the rate of weathering of primary minerals in soils. Comparison of results obtained for different soil types is suggested.

MINERALOGY OF SOME ORTHIC PODZOLS IN QUEBEC

by

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INTRODUCTION

Although some information is available in the literature on the weathering of primary minerals in soils, this has largely described detailed work on one or two profiles. As a result, there has been little opportunity to derive and test a suitable index of weathering for a profile, or to draw general conclusions about the variations in mineral percentage with depth for specific soil types.

The aim of this study was to perform rapid mineralogical analysis on samples from several profiles of Orthic Podzols, performing density separation with heavy liquids and analysis of each sample by either petrographic microscope or x-ray diffraction methods. Five horizons were sampled in each profile: the F or humus layer, the elluviated Ae, the illuviated Bfh and Bf, and the C horizon composed of relatively unaltered parent material.

It was hoped that the relatively large number of profiles examined would provide sufficient information to make possible statistical conclusions regarding the typical variation of mineral percentages with depth due to weathering in Orthic Podzols., It was also hoped that suitable indices of weathering and heterogeneity of parent material could be derived and tested. From this it was intended that comparison would be made with work done on the same profiles by Valentine (1966) based on the physical properties of these profiles. He concluded that the lithology of the parent material profoundly affected the physical properties of the soils, and that such a criterion should be introduced at the family level of the Canadian system of soil classification. It was hoped that a similar conclusion could be arrived at with respect to the severity of weathering of primary minerals.

LITERATURE REVIEW

Primary Minerals in Soils

1. Primary Minerals Identified in Soils

The first stage in any quantitative analysis consists of the identification of the constituent minerals. Lamar and Grim (1937) identified hornblende, pyroxenes, garnet, magnetite, epidote, tourmaline and zircon in some Illinois sands and gravels of 'glacial and recent' age. They stated that the deposits were of fairly uniform composition. Tamura and Swanson (1954) reported chlorite, hematite, quartz and feldspars in amounts of 5 to 10 per cent in a brown, podzolic silt-loam derived from sandstone and shale. Dell (1959) identified hornblende, garnet, micas, magnetite and pyroxenes (in decreasing order of abundance) in the heavy fraction of a 'glacial sand' from southern Ontario. These authors' work was done using the petrographic microscope.

Brydon and Patry (1961) used x-ray diffraction methods to examine the silt fraction of a Rideau clay and some Champlain Sea sediments. The light fraction, comprising 90 per cent of the total, was composed of 50 per cent potassium feldspar and 25 per cent each of quartz and plagioclase feldspar. The heavy fraction contained hornblende, pyroxenes, garnet, tourmaline and zircon. Little variation was found between size fractions.

Millette and Langmaid (1964) and Pawluk (1961) used heavy liquids to separate a specific size fraction into three density fractions to obtain better mineral segregation. For a specific gravity of less than 2.70, both identified quartz, plagioclase and orthoclase. For the fraction 2.70 to 2.95, both found muscovite, biotite and chlorite, with Millette finding impure quartz and plagioclase in this fraction, and Pawluk finding weathered amphiboles and pyroxenes. In the heavy fraction both identified zircon, tourmaline and epidote. Millette mentions spinel, hornblende and 'opaques' while Pawluk identified magnetite, hematite, amphiboles, garnet, pyroxenes and apatite. A comparison of the results in these papers is also of interest since Millette, using optical methods, produced quantitative results, while Pawluk, using x-ray diffraction, produced only semi-quantitative results but was able to identify the opaque minerals. Millette and Langmaid's results were for various Podzols and Dark Grey Gleysolic soils developed on weathered shale and till, while Pawluk's were for a Grey Wooded soil developed on glacial till.

2. Relative Resistance of Minerals to Weathering

a. Evidence from Geology

Many factors affect the persistence of a mineral, those due to its surroundings and those inherent in its composition. Upon leaving the environment of its formation, a mineral is no longer in equilibrium with its new environment and is subject to decomposition. At or near the surface of the ground, weathering varies considerably in its rate for a given mineral depending on, among other things: climate, soil type and particle size.

In order to average these effects, Pettijohn (1941) examined the frequency of occurrence of several mineral species in sedimentary rocks of increasing age and proposed a sequence which is a measure of their relative persistence. Abbreviated to the minerals identified in this work, his list in order of decreasing stability would be:

Muscovite, rutile, zircon, tourmaline, garnet, biotite, ilmenite, magnetite, epidote, hornblende and augite.

This compares well with the sequence of Goldich (1938) based on the order of crystallization in a melt:

Quartz, muscovite	biotite, hornblende, augite, olivine.
	K-feldspar, alkali feldspar, Ca-plagioclase

Smithson (1941) stated that zircon, rutile, tourmaline and apatite were 'stable', garnet was 'unstable' and the ferromagnesians were 'very unstable'. Brewer (1964) compares the results of several workers and states that Pettijohn and Goldich summarize current information fairly well.

b. Evidence from Mineral Analysis of Soils

Soils in general have a relatively restricted range of chemical conditions compared with geologic processes as a whole. A specific soil type, in turn, has an even more restricted chemical environment so that general conclusions for average geological conditions need not apply. Considerable work has been done in examining the behavior of minerals in different soils. As Hendricks and Newlands (1927) stated: "A knowledge of the minerals present (in the soil) is...of importance...Such information should be utilized in soil study, and the mineralogical composition of the soil deserves attention in drawing up a scheme of soil classification." Graham (1950) examined several soil types and concluded that anorthite weathered about sixteen times as fast as albite in soils and suggested that the Ca:Na radio in the plagioclase feldspars be used as a weathering index. Harris and Adams (1966) examined five weathering profiles on granitic rocks and concluded that, regardless of climate or local physiochemical variations, the sequence of decreasing stability was:

quartz, K-feldspar, biotite and plagioclase feldspar.

He also concluded that the largest physical and chemical changes occurred in the transition from the C horizon to the B horizon.

Turning to Podzol soils in particular, Pawluk (1960) stated that feldspar weathered faster than quartz; hematite weathered faster than hornblende; and garnet weathered faster than magnetite, for two Podzol profiles in Alberta. Alias (1961), working on a Humic Podzol, stated that, in the 50 to 240 micron size range - from the A to C horizons - the stability of heavy minerals against chemical attack decrease in the order:

zircon, iron ores, tourmaline, garnet epidote = augite, hornblende.

For the light minerals the order of decreasing stability was:

quartz, microcline, orthoclase, albite, oligoclase, muscovite.

Hornblende was the most strongly affected mineral, especially in the very fine sand. In 1964 the same author produced results for an Iron-Humus Podzol and gave the following results for decreasing stability:

quartz = zircon, tourmaline = opaque minerals = microcline, orthoclase, epidote = plagioclase, hornblende = muscovite = biotite

Jackson (1953) took another approach by stating that "there is a minimum size at which a mineral of given stability can exist in a given intensity and time of weathering." For quartz he found this to be 0.1 microns in a temperate climate, and for feldspars, this would be about 2 microns. However, for young soils on glacial material two differences exist. Firstly, feldspars of less than 0.2 microns may be found in large percentages; and, secondly, calcium feldspars weather more rapidly than sodium or potassium feldspars. He concluded that feldspar content and species in the clay fractions were a sensitive measure of the degree of weathering of a parent material.

c. Evidence from Element Mobility

Several workers have attempted to examine the weatherability of primary minerals in a soil by comparing the mobility of various consitiuent elements. Loughnan (1962) stated that the weathering of silicates was a function of mineral structure and the mobility of the essential ions. Correns (1963), from laboratory work on chemical weathering and the effects on feldspars, brucite, amphiboles, and olivine, concluded that the more common minerals vary in vulnerability to weathering and that the stability of a mineral depends on external conditions such as pH.

Gradusov and Dzyadevich (1961) stated that, in a podzolic horizon, the order of decreasing mobility of elements is: K, Ca, Mg, Si, Al = Fe, with all elements mobile except the Si of quartz. Bloomfield (1964) said that "contrary to the premise that iron oxides are among the least readily mobilized minerals in soil forming processes, laboratory investigations and studies of gley soils and Podzols show Fe is very readily mobilized; but that reprecipitation of ferric oxide during supervening oxidising conditions frequently obscures evidence of translocation in the field."

3. Mineral Weathering in Soils

a. Variation with Horizon

Even if a mineral is shown to weather significantly in the surface environment, its susceptibility will vary considerably between the various horizons of a soil since each of these is a function of the chemical environment. Cady (1940) found that podzolization caused a reduction in hornblende but had little effect on epidote, garnet and magnetite. Matelski and Turk (1947), working in Podzols, found that the total amount of heavy minerals was greatest in the C horizon and lowest in the B. He identified hornblende, garnet, epidote, zircon, tourmaline, tremolite, muscovite and opaques. Cady (1960) concluded that "The formation of true

Podzols causes the destruction of weatherable minerals in the A_2 horizon and the movement of the products out of the solum or into the B horizon. In Podzols in glacial material containing an assortment of weatherable minerals, particularly hornblende, augite and hypersthene, from the C horizon upward to the top of the B horizon, these minerals are fresh-appearing, and their percentages are almost the same in both horizons. On the other hand, in the A horizon, the percentage of such minerals drops by sixty to seventy-five per cent, and the remaining grains show etching and pitting, some to such an extent that they appear skeletal." Pawluk (1961), working in Grey Wooded soils, developed on glacial till in Alberta, stated that pyroxenes and amphiboles showed weathered coatings towards the surface, feldspars showed dissolution, and iron oxides and apatite showed some significant trend with depth.

Three workers examined the effect of Podzols on feldspars. Van der Marel (1949), examining the greater than sixteen micron fraction, stated that podzolization is accompanied by a strong attack on the minerals by humic and organic acids. 'Resistant minerals' (opaques, staurolite, rutile, tourmaline and quartz) concentrated in the zone of strong weathering at the expense of amphiboles, muscovite, epidote and saussurite. The zircon concentration remained almost the same throughout, increasing only in the 16 to 60 micron separate. Feldspars showed a marked decrease only in the 'lead sand' horizon. He concluded that the K-feldspars are decomposed only by strong acid concentrations, and the plagioclases hardly at all. Of the primary minerals in the clay sizes, only quartz was left. Novorossova (1952) found that the Fe, Ca and Mg oxides from the breakdown of feldspars increase with depth. Cann and Whiteside (1955) used quartz as the standard in the resistant mineral method of Marshall and Haseman (1942) and concluded that, as a result of podzolization, there was a slight gain in orthoclase and a loss of plagioclase.

b. Physical Weathering and Choice of Stable Minerals

Many problems of soil formation are considerably simplified if one mineral in the soil can be considered 'stable' i.e. it does not decrease significantly in either size or absolute weight in the soil environment. If this is so, and the parent material may be considered homogeneous, a comparison of the proportions of minerals present before and after soil formation may be made. However, neither of these assumptions are universally valid. St. Arnaud and Whiteside (1963) suggest, as a result of their laboratory work, that physical breakdown of minerals does occur with freezing and expansion, in particular for quartz. If physical decrease in particle size occurs for the 'stable mineral' in the soil, the discovery of equal quartz percentages up the profile for a given size fraction is not necessarily due to homogeneous parent material. They therefore conclude that only total quartz, for all size fractions, could be considered a 'stable mineral'. Russell (1936, 1937) examined hundreds of samples from the length of the Mississippi River and concluded that there was no significant sorting or destruction of any minerals by the river, justifying the assumption that loss by abrasion is non-existent in soils.

Raeside (1959) said that, "Because of its susceptibility to physical breakdown and solution, quartz can only be accepted as a stable mineral with certain reservations. It may be admissible as an index mineral in young soils, or in semi-arid soils with pH values below 7.0." With respect to garnets, he stated that, "Some members of the group may be sufficiently stable to serve as index minerals, but there seems good reason to exclude garnets high in iron from the list." With respect to zircon he quotes Carroll (1953) who concluded that zircon grains do corrode, especially in lateritic soils subject to alkali leaching.

Cogen (1935) questions the use of a 'stable mineral' as a standard since this assumes that the material is resistant to abrasion and decomposition, and that it is uniformly distributed through the profile. Tedrow and Wilkerson (1953) point out that minerals weather from the surface inwards. This may well affect results based on size-fractionated samples.

4. The Effect of Parent Material on Variations in Mineral Proportions

The variations in mineral composition of a soil are a partial reflection of the mineralogy of the parent material. Hendricks and Newlands (1923) stated that local differences in silicates in the soil indicated local differences in the parent rock. Jeffries (1937) and Jeffries and White (1937, 1938) examined soils derived from various limestones, dolomites, and shales in the eastern United States and found their mineralogy qualitatively similar but quantitatively different for some minerals. They recommended examination of some of the heavy minerals for comparison of soils.

Rubey (1933) found that epidote, kyanite, andalusite, rutile and hypersthene percentages increased with increasing particle size. Jeffries and Yearick (1948) found that in the sand and silt sizes, variations in mineral percentages in the soil were mainly due to variations in the processes that deposited the parent material, and they concluded that the main differences between soil types were found in the clay fraction. Chernov (1965), however, said that "Accumulation of the clay fraction in the illuvial horizon depends less on the degree of podzolization than on the mechanical composition of the parent rock and is greater the lighter the parent rock." Haseman and Marshall (1945) stated that differences in the origin of parent material at different depths are readily shown by heavy mineral analysis. Bear (1964) and Brewer (1964) contain excellent discussions of the available methods for testing the homogeneity of the parent material.

Coninck and Larnelle (1960) consider the main Podzol-forming factors to be the mineral composition of the parent rock, the texture of the parent material and the drainage conditions and humidity of the soil. Sokolova (1964) stated that a soil on granite had a profile typical of podzolic soils, while on amphibolite there were no morphological signs of podzolization, although analysis showed them to be podzolized.

Jeffries and Jackson (1949) suggested that one should identify as many mineral species as possible, especially the accessory minerals, when wishing to make a comparison between soils. Rubey (1933) stated that it is not possible to compare different-size fractions of samples or even the same size fractions of different samples. Cogen (1935) agreed, adding that one cannot compare results from one size fraction with results from unfractionated samples.

Carroll (1952) stated that, in statistical analysis of particle size distribution, soils derived in situ from granitic rocks tend to exhibit a positive skewness, whereas soils from sedimentary rocks have a negative skewness. The same author in 1957 concluded that "Analysis of variance can be used for counts of heavy minerals, expressed as a number percent, because the population will have an approximately normal distribution." The use of statistical methods in the description of mineral variation was an important part of the work undertaken by the writer.

SOILS AND METHODS OF ANALYSIS

1. Field Sampling

The work undertaken by the author was a continuation of that of Valentine (1966) and, for this reason, the sample sites chosen were identical to his. A relatively homogeneous parent material was required in order to permit study of the effect of soil horizons on the physical and mineralogical changes within the soil profile. Consequently, four soil series, all developed on glacial till, were taken as representative of orthic Podzols. These four were the Ascot, Greensboro, Magog and Roxton series. Profiles were examined at five sites in each series for five horizons - the F, Ae, Bfh, Bf and C horizons - of the Canadian System of Soil Classification. A listing by co-ordinates of the locations of the sample sites will be found in Appendix 1. Profile descriptions may be found in the soil survey reports of Stanstead, Richmond, Sherbrooke and Compton Counties (Cann & Lajoie, 1942) and Shefford, Brome and Missisquoi Counties (Cann et al.,1947) in the Province of Quebec.

2. Preparation for Particle Size Analysis

Samples of approximately 500 gm were taken from each horizon, returned to the laboratory and air dried. A representative portion weighing approximately 20 gm was obtained from each sample by the method of quartering, except in the case of the F horizon where larger portions were taken due to the high content of organic matter. After removal of gravel and root fibres by passing through a 2.0 mm sieve, the samples were weighed and treated for the removal of organic matter by Kunze & Rich's method as quoted in Black (1965). Free iron oxides were then removed as suggested by Mehra and Jackson (1960) as quoted by Kunze in Black (1965).

3. Particle Size Analysis and Density Fractionation

Separation of the silt and clay from the sand fraction was performed by wet sieving through a 53 micron sieve. Both fractions were then oven dried at 80° C and weighed. The sand fraction was further split into five size fractions (2000 to 500, 500 to 250, 250 to 105, 105 to 53 and less than 53 microns) by sieving for 10 minutes on a reciprocal shaker. The three middle sand sizes for each sample were then separated into three specific gravity separates after the method of Cady in Black (1965). Mixtures of tetrabromethane and nitrobenzene were used, resulting in separates with densities greater than 2.95 gm/cc, 2.75 to 2.95 gm/cc and less than 2.75 gm/cc. The silts and clays were separated into three sizes; greater than 2.0, 2.0 to 1.0 microns and less than 1.0 micron equivalent diameter, using the sedimentation column method. Rates of fall were obtained from Tanner and Jackson Each fraction was then dried and weighed.

4. Quantitative Mineralogical Analysis

Quantitative analysis on the various sand fractions was first attempted using grain counting techniques with a petrographic microscope. The grains were gelatin-mounted (by the method of Marshall and Jeffires (1945), and the light fraction was stained for feldspar identification as suggested by Millette and Langmaid (1964). The petrographic methods used for grain identification were obtained from Fry (1933), Milner (1952), Cady in Black (1965), Wahlstrom (1962) and Berry and Mason (1959). This approach, however, was found to have various drawbacks, in particular the length of time required per analysis, inconsistent results from staining techniques and inability to identify heavily weathered minerals and many of the opaque minerals. Consequently, x-ray diffraction analysis as suggested by Erdosh (1965) was finally adopted.

5. X-Ray Diffraction Procedures

Erdosh (1965) worked on instrumental methods for the rapid modal analysis of rocks and devised the basic method used in this work. After density separation, samples were ground in a pestle and mortar and slides prepared by a paste method similar to that suggested by Theisen and Harward (1962). The middle density fraction was re-combined with the light fraction, due to its very low yields, mostly of impure quartz. Erdosh strongly recommended the calibration of results by the addition to the sample of a known proportion of an internal standard. Unfortunately, this was not possible in the current work due to the extremely small weight of some fractions after both size and density fractionation. It is recommended that in any similar work at least 50 gm of soil be treated for each horizon in order to avoid this problem.

Klug and Alexander (1954), p. 412, showed that the basic equation of quantitative analysis was:

$$I_i = \frac{K_i X_i}{\rho_i \left(X_i(\mu_i - \mu_m) + \mu_m\right)}$$

where I_i is the intensity of diffraction due to a particular d-spacing of component i; K_i is a constant for component i and the apparatus used; ρ, X and μ are the density, weight fraction and mass absorption coefficient of mineral i and matrix m.

From the above equation it can be seen that:

$$I_{100,\, i} = \frac{K_i}{\rho_i \mu_i}$$

where $I_{100,i}$ is the intensity of diffraction of a pure sample of component i. Since μ_m is the sum of $\mu_j X_j$ for the remaining components, it can be shown that:

$$X_i = \frac{I_i}{I_{100,i}} \cdot \frac{\sum_j (\mu_j X_j)}{\mu_i}$$

Thus, if it can be assumed that all components of the x-ray sample have been identified, measured and their mass absorption coefficients known, it is possible to perform quantitative analysis on the sample. Due to the number of sample fractions to be analyzed, as well as the small quantity of many of them, no more time-consuming method of standardization was considered feasible. Diagnostic peaks were chosen for each of the minerals identified, and the peak intensities were measured for standard mineral samples. Checks were taken at frequent intervals to see if any unidentified minerals were present in large quantities. Since the samples from any one soil series were of very similar origin, this was considered a sufficient check.

Although this method is doubtless less accurate than the internal standard method, and it must be stressed that quoted percentages are subject to considerable error, the approach was considered justified for the following reasons:

1. The absence of an internal standard peak for comparison purposes would produce random errors in percentage values. This would decrease the sensitivity of the statistical operations performed, rather than produce erroneous conclusions, particularly since the factorial design of the analysis of variance is based on means of at least 60 replicates in the three-factor design and 15 replicates in the two-factor design.

2. Random errors due to the presence of a non-systematically varying unidentified component could produce additional random error and a decrease in mean values obtained, but would have no effect on statistically identified trends.

3. Systematic errors due to the presence of a systematically varying unidentified component could influence identified trends if present in relatively large proportions in the analyzed fractions. Spot checks taken at random showed no evidence of persistent, systematic or large unidentified peaks in the range of 10° to 60° 2 Θ, CuKa radiation. Table 1 compares results obtained by the author using x-ray diffraction methods with results obtained by A. Schori using optical microscopy. It should be emphasized that the five profiles compared were sampled in the field on separate occasions for the two methods and will thus exhibit differences due to sampling as well as

TABLE 1: COMPARISON OF ANALYTIC METHODS

Profile	Horizon	Quartz % (X-ray)	Quartz % (Optical)	Plagioclase % (X-ray)	Plagioclase % (Optical)	Orthoclase % (X-ray)	Orthoclase % (Optical)
Ascot 1	Ae	67.4	100	25.9	Trace	2.7	0
	Bfh	77.2	82	15.8	18	1.9	0
	Bf	70.5	71	22.8	24	2.3	5
	C	67.8	66	20.6	30	6.5	4
Ascot 2	Ae	83.2	100	10.8	Trace	1.7	0
	Bfh	82.2	95	9.2	5	1.8	Trace
	Bfd	66.1	80	17.6	20	3.2	Trace
	C	67.0	72	16.4	23	2.7	5
Ascot 3	Ae	81.5	100	14.1	0	1.1	0
	Bfh	75.6	90	15.7	10	2.0	Trace
	Bf	64.6	77	25.1	23	3.0	Trace
	C	69.9	69	20.9	28	2.5	3
Ascot 4	Ae	87.1	100	8.0	0	2.0	0
	Bfh	86.3	88	8.6	12	0.8	0
	Bfd	81.1	76	12.2	20	2.4	4
	C	68.6	--	24.5	--	5.0	--
Ascot 5	Ae	83.8	100	10.5	0	1.2	0
	Bfh	78.4	89	13.9	11	1.8	0
	Bf	71.5	81	17.0	19	3.4	Trace
	C	83.5	70	2.6	25	4.4	5

laboratory technique.

Values obtained in this way were combined to give percentage of each mineral in each size fraction fraction using the weight of each density fraction. Fig. 1 shows a flow chart of laboratory techniques, and Fig. 2 a flow chart of statistical tests applied to these results.

FIGURE 1: FLOW CHART OF SAMPLE ANALYSIS

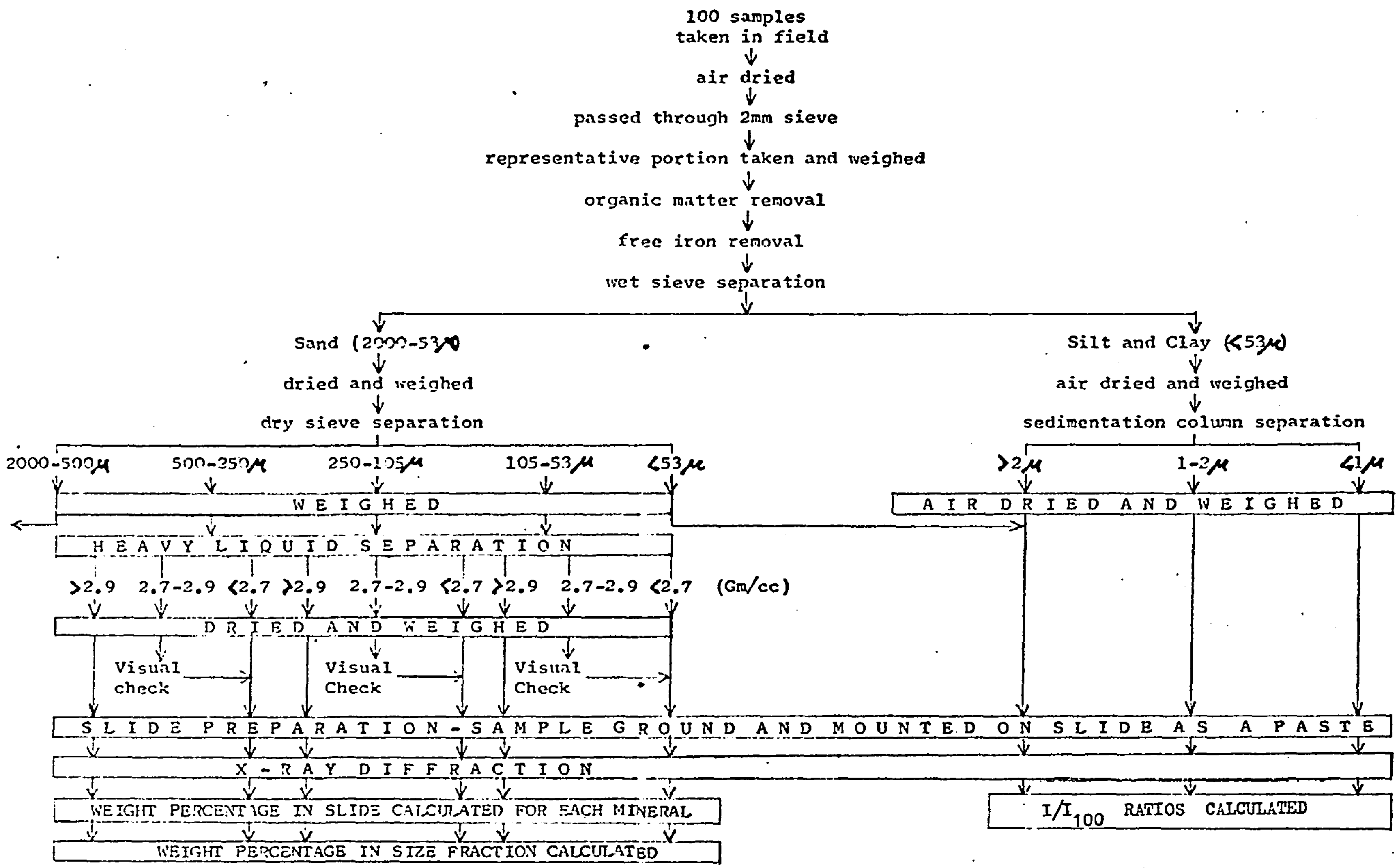
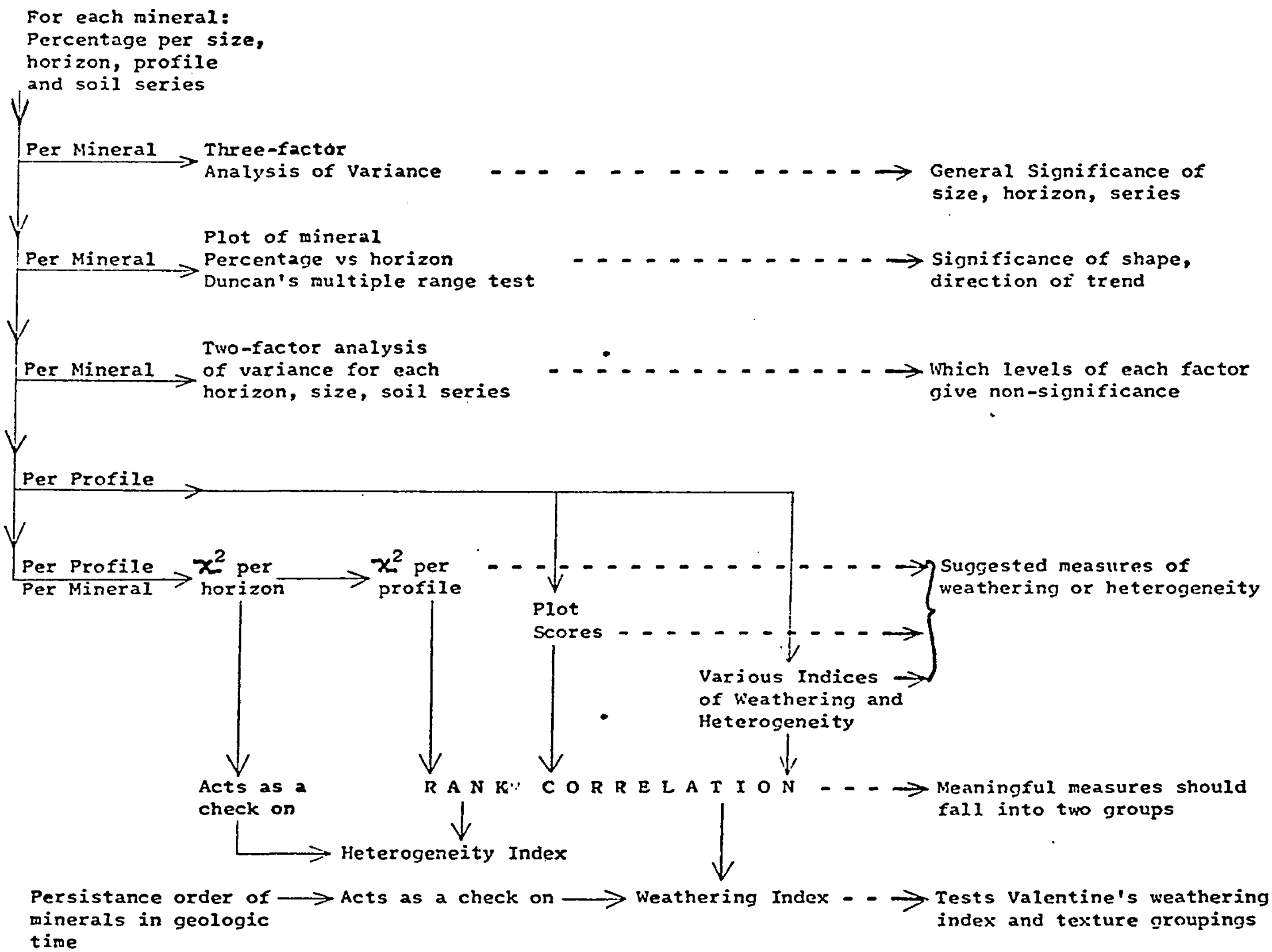


FIGURE 2: FLOW CHART OF STATISTICAL ANALYSIS



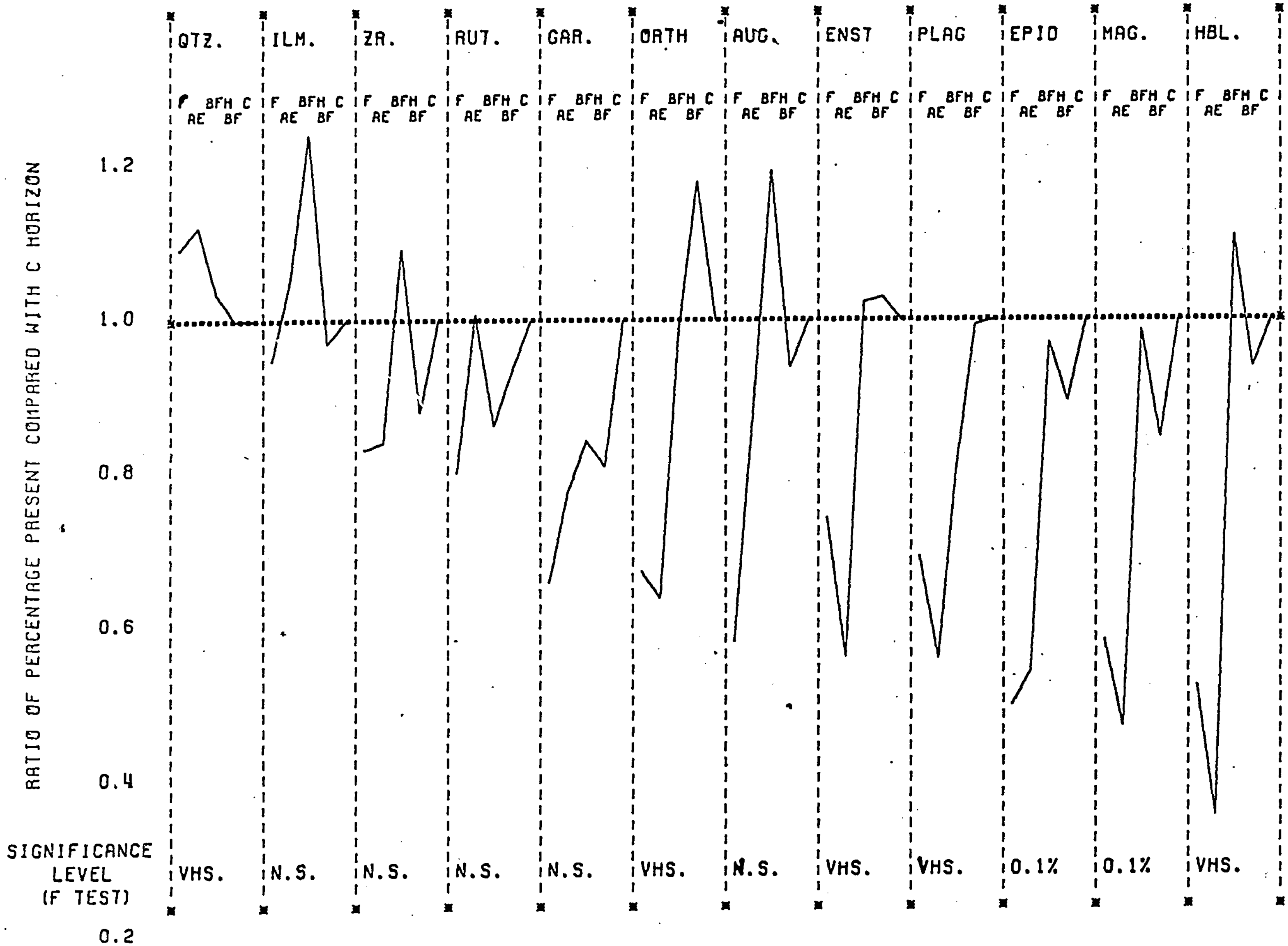
RESULTS & DISCUSSION

1. Existence of Trends - Analysis of Variance

a. Overall Analysis of Sand Size Fractions

Analysis of variance was performed on the results for each soil series, profile, horizon and size fraction using a three-factor split-plot design for each mineral. Hornblende, magnetite, epidote, plagioclase, enstatite and orthoclase were seen to decrease significantly in the F and Ae horizons as compared with the percentages present in the C horizon. The Bf horizon was grouped with the C, while the Bfh was usually intermediate between the two. The percentage of quartz present increased significantly in the F and Ae horizons as compared with the Bfh, Bf and C. Ilmenite, zircon, rutile, garnet and augite were not found to vary significantly with depth. Of those minerals that did vary significantly with depth, the most susceptible to weathering was hornblende, the mean value in the Ae horizon being 35% of the mean value in the C, followed by magnetite with 47%, epidote with 50%, plagioclase and enstatite with 56% and orthoclase with 64%. Of those minerals whose variation with depth was not shown to be significant, possible due to analytic techniques in some cases, augite decreased to 60% in the F horizon, garnet decreased to 66%, zircon and rutile to 83% and ilmenite to 94%, all in the F horizon, with an unexplained maximum of 124% in the Bfh horizon for ilmenite. These results are shown in Fig. 3,

FIG. 3 CHANGE IN MINERAL COMPOSITION OF THE SAND FRACTION OF ORTHIC PODZOLS WITH HORIZON



Quartz also increased significantly to 112% in the Ae horizon due to loss of other minerals, primarily the feldspars.

Variation in mineral percentage due to particle size was also tested for in the analysis of variance design. This was highly significant, in almost all cases, at a considerably higher level than variation with horizon: Over the range 53 to 500 microns all the minerals increased in percentage significantly with decreasing particle size, with the exceptions of orthoclase, which had a maximum in the 105 to 250 micron range; garnet, which tended to decrease in percentage above 250 microns, and quartz, which increased significantly in percentage with increasing particle size up to at least 500 microns. These are probably reflections of the composition of the parent material but do not seem to vary much between soil series. Mean particle sizes for sand between 53 and 500 microns are given in Table 2. Since only three class intervals are used, these are necessarily approximate.

TABLE 2: MEAN PARTICLE SIZE IN MICRONS

Mineral:	Quartz	Plagioclase	Orthoclase	Hornblende	Zircon	Rutile
Mean Size:	224	195	210	175	170	189

Mineral:	Enstatite	Augite	Magnetite	Ilmenite	Garnet	Epidote
Mean Size:	181	203	177	156	191	174

b. Analysis for each Soil Series

For the seven minerals found to have significant variation with depth, analyses of variance were performed for each soil series separately in order to see whether significant trends existed in each soil series, and whether these trends conformed with the overall trend.

Significant variation with particle size and horizon were found for most mineral and soil series, in most cases at the less than 0.1% level. Those analyses that were found not to vary significantly with horizon at the 5% level were: orthoclase, enstatite, magnetite and epidote in the Roxton soil series; magnetite and enstatite in the Ascot series and epidote in the Magog. With the exceptions of the above four minerals in the Roxton series, all the means followed the established trends even when not shown significant.

c. Analysis for each Size Fraction

When analysis of variance was performed for each size fraction separately, several things were found. As expected, zircon, rutile, augite, ilmenite and garnet did not vary significantly with horizons for any size fraction. Hornblende was found to be non-significant in the 500 to 250 micron fraction as was enstatite. Examination of the relevant plot in Appendix suggests that this is due to the relatively low percentage present in that size fraction - a reflection of the parent material. A similar situation was found for both the 500 to 250 and 250 to 105 micron fractions for magnetite, and for epidote, only the 500 to 250 micron fraction showed significant variation with horizon.

Analysis of variance performed on the weights of each size fraction of sand, silt and clay, after sieving and before density separation, showed that the effect of horizons on percentage of each size was significant at better than 5% for all sizes from very coarse sand to clay, with the exception of the 105 to 53 micron very fine sand and the less than one micron clay.

d. Plots of Trends

An analysis of variance table for each of the twelve minerals, together with a plot of mineral percentage (average value over five profiles) against size fraction and horizon is contained in Appendix 2 due to space considerations. Curves are included for each soil series separately as well as the overall average. The relevant significance levels from analysis of variance are also shown.

It will be noted that, if the curve for any soil series deviates strongly from a trend found significant in the remaining series, the significance level is consistently lower. This suggests that, although a variation in percentage found significant with either particle size or horizon may be destroyed by various local factors, no opposing trend is produced. An example of this in the particle size curves is the Greensboro series for quartz, plagioclase, hornblende, rutile, enstatite, augite and garnet. As discussed later, this is probably due to lack of homogeneity in some of the sample profiles in that series.

e. Silt and Clay Size Fractions

Appendix 2 also contains analysis of variance tables and plots for the silt, coarse clay (1 to 2 microns) and medium and fine clay (less than 1 micron). Due to difficulties in heavy liquid separation of fine material, no attempt was made to separate and identify the heavy minerals. Quantitative analysis of layer silicates was considered to be beyond the scope of this work. Consequently, the values quoted for quartz, plagioclase and orthoclase may not be considered as absolute percentages but only as uncorrected I/I_{100} values. It is interesting to note, however, that these three minerals showed significant variation with particle size, quartz and plagioclase showing an increase, and orthoclase a decrease, with increasing particle size. Quartz showed a significant increase in the Ae horizon only, plagioclase showed a highly significant decrease towards the surface of the soil and orthoclase showed no significant trend, probably due to the low percentages present within the fraction analyzed on the x-ray diffractometer.

2. Form of Trends

Duncan's multiple range test applied to the mean values in Fig. 3 grouped the F and Ae horizons as significantly different from the Bfh, Bf and C for quartz, orthoclase, enstatite, epidote, magnetite and hornblende, but showed the Bfh horizon falling between the two groups in the case of plagioclase. An examination of each profile separately, however, gave a less clear picture. Only in the cases of enstatite and hornblende were the Bfh horizons frequently grouped with the Bf and C. In all other cases no consistent pattern for the Bfh horizon occurred.

Of the seven significantly varying minerals, the maximum values could be found in any of the Bfh, Bf or C horizons, except in the case of plagioclase, for which it rarely fell in the Bfh, and quartz, for which the minimum values were frequently found in the Bf. The Ae horizon usually contained the maximum percentage of quartz and the minimum percentages of plagioclase, hornblende, enstatite and, less frequently, orthoclase. Magnetite and epidote would have minimum values in either the F or Ae horizons. This is summarized in Table 3 and illustrated in Appendix 2.

One point that will be noticed is that, as a general rule, the maximum and minimum values are not found in the top or bottom horizons as might be expected. Although it is not possible to distinguish between them by Duncan's multiple range test, the Ae horizon usually contains a more extreme value than the F. No explanation is offered for this since it would be assumed that primary minerals now in the F horizon had, at some previous time, been in the Ae horizon and

TABLE 3: VARIATION IN MINERAL PERCENTAGE WITH HORIZON

	F	Ae	Bfh	Bf	C	Bfh Grouped With: (by profiles)	Bfh Grouped With: (by means)
Quartz		Maximum		Minimum		?	Minimum
Plagioclase		Minimum		Maximum		?	?
Orthoclase		Minimum		Maximum		?	Maximum
Hornblende		Minimum		Maximum		Maximum	Maximum
Enstatite		Minimum		Maximum		Maximum	Maximum
Magnetite		Minimum		Maximum		?	Maximum
Epidote		Minimum		Maximum		?	Maximum

would therefore have been as heavily weathered. It is suggested that either the soils examined were so young that minerals in the F horizon could not be assumed to have once been in the Ae or else this is diagnostic of an Orthic Podzol. A similar, but less pronounced, problem exists with respect to the relationship between the Bfh, Bf and C horizons. It is suggested that the overall curve shapes shown in Fig. 3, as well as the relative extents of weathering of each mineral, might be diagnostic of a particular soil type.

3. Comparisons of Soil Profiles

a. Plot Scores

Although significant trends were found for seven of the twelve minerals identified, and no opposing significant trends were noted, non-significance was found in some soil series for a trend found significant in another. In order to try and attribute some of the variation causing non-significance to a lack of homogeneity of the parent material in specific profiles, plots were drawn of mineral percentage against horizon for each of the seven significant minerals in each profile. These plots were compared with the significant trend of the means for each horizon (Fig. 3) which, in all cases except quartz (for which the trend was reversed), was defined as possessing a minimum in the F, Ae or Bfh horizons and a maximum in the C, Bf or Bfh horizons.

Each plot was then assigned a score from zero to four, depending how closely it followed the trend, so that a good fit for all seven minerals would give a profile a maximum score of 28. The results are shown for each profile in Table 4 together with a score, out of a possible 80, for each mineral.

TABLE 4: PROFILE SCORES

Profile No: Soil Series	1	2	3	4	5	Total Series
Greensboro	27	25	22	18	9	101/140
Roxton	16	9	22	21	18	86/140
Ascot	25	27	24	14	25	115/140
Magog	22	25	25	22	25	124/140

Mineral:	Quartz	Plagioclase	Hornblende	Magnetite
Score:	77	75	65	58

Mineral:	Epidote	Orthoclase	Enstatite
Score:	52	49	44

On this basis it was decided that profiles Greensboro No. 5 and Roxton No. 2 should be rejected as conforming less than 33% with established trends, and Greensboro No. 4, Roxton Nos. 1 and 5 and Ascot No. 4 should be considered to be of poor homogeneity as scoring less than 75%. The Roxton soil series in general was concluded to be formed on parent material of poor mineralogical homogeneity. It may also be distinguished from the other three series on the basis of showing significant and consistent trends for only three minerals out of seven, and having a mean quartz percentage considerably lower than the other series.

b. Indices of Weathering

Unfortunately, too little information was available from other sources to check the validity of these conclusions. Valentine (1966) eliminates Ascot 4 and Magog 1, 2 and 3 on the basis of clay distribution in the profile, etc. Since this does not agree well with the profile scores of Table 4, some other parameter was looked for to clarify the picture. Two sources of variation were considered: that due to lack of homogeneity of the parent material prior to weathering taking place, and that dependant on the severity of the weathering processes.

As quoted previously, Jackson (1953) concluded that feldspar species and content, in the clay fractions, were a sensitive measure of the weathering of a soil profile. On this premise, a weathering index W was designed for each silt and clay size fraction of each profile such that:

$$W = \left(\frac{Q_{Bf}}{P_{Bf} + O_{Bf}} + \frac{Q_C}{P_C + O_C} \right) \div \left(\frac{Q_F}{P_F + O_F} + \frac{Q_{Ae}}{P_{Ae} + O_{Ae}} \right)$$

where Q, P and O are the quartz, plagioclase and orthoclase percentages of the respective F, Ae, Bf and C horizons. Thus, W = 1.0 for a homogeneous parent material with no weathering and tends towards zero with increased loss of feldspars in the F and Ae horizons by weathering. W was calculated for the less than one micron clay, the 1 to 2 micron clay and the silt fractions, hereafter referred to as W(0), W(1) and W(2).

Brewer (1964) quotes two weathering ratios proposed by Ruhe (1956) for very fine sand; the first being for the light fraction, the second for the heavy fraction:

$$Wrl = \text{quartz} \div \text{feldspars}$$

$$Wrh = (\text{zircon} + \text{tourmaline}) \div (\text{amphiboles} + \text{pyroxenes})$$

where each mineral species is expressed as a percentage of the size fraction. Since these values apply only to a single horizon, an estimate of the difference in weathering severity between the top and the bottom of the profile may be obtained by:

$$Wl = \frac{Wrl\ (Bf) + Wrl\ (C)}{Wrl\ (F) + Wrl\ (Ae)}$$

$$Wh = \frac{Wrh\ (Bf) + Wrh\ (C)}{Wrh\ (F) + Wrh\ (Ae)}$$

which have the same form as the weathering index previously derived for the clays. This was done for both the very fine sand and the total sand to give Wl (F), Wl (T), Wh (F) and Wh (T) respectively.

c. Chi - Square

Barshad, writing in Bear (1964), describes the use of the particle size distribution of resistant minerals to examine changes in composition of the parent material with depth. If a parent material is homogeneous, he argues that the proportions of the total amount of the resistant mineral found in a horizon that fall into a given size class will not vary between horizons. If a break in homogeneity occurs, it will be easily identifiable. Table 5 illustrates this.

TABLE 5: PARTICLE SIZE DISTRIBUTION OF ZIRCON IN A TILSIT SILT LOAM PROFILE (From Barshad (1964))

	Zircon Fractions (%)			
Depth	0.1-0.05 mm	0.05-0.02 mm	0.02-0.01 mm	Total
0 - 8 in.	5	83	12	100
8 - 17 in.	3	81	16	100
17 - 28-1/2 in.	5	85	10	100
- - - - - -	- - - -	- - - -	- - - -	- - - -
28-1/2 - 35 in.	17	76	7	100
Weathered Sandstone	25	74	1	100
Fresh Sandstone	31	67	2	100

(The dashed line denotes the depth at which stratification occurs)

He adds, "In fact, the change in particle size distribution of a mineral in soils with an increasing degree of weathering can be used as a criterion for establishing its degree of resistance." Thus, the deviation of the size distribution in any horizon from the expected size distribution would be due to lack of homogeneity of the parent material, sampling and analytic error or differential weathering of certain size fractions. This last would be expected to occur frequently with those minerals susceptible to a particular chemical environment whereas the other sources of deviation would be expected to affect the results for all mineral species. The expected size distribution would be defined as consisting of the averages, over all horizons, of the proportion found for each size fraction. This deviation from the mean may conveniently be expressed by a form of the statistical function χ^2 (chi square) sometimes used as a test of heterogeneity between experiments.

This test was applied as follows:

1. For any given mineral, the proportions in each size class were summed for all horizons within a given profile and then scaled to sum to unity. This gave an average particle size distribution for any given mineral and profile. These values were designated m_1 to m_j where j = the number of size fractions tested.

2. For each horizon, the raw values, consisting of the percentages of the mineral found in each size fraction tested, were summed. For a given horizon this was designated n.

3. χ^2 was calculated for each horizon, using the equation $\chi^2 = \sum_{i=1}^{j}\left(\frac{a_i^2}{m_i n}\right) - n$ where a_i is the value obtained for that mineral in the i-th size fraction.

4. Sum the χ^2 values obtained for each horizon of the profile. This total may be tested for significance with one degree of freedom less than the number of horizons since one degree of freedom was lost by calculating the expected distribution. The null hypothesis is that no values differ significantly from the expected mean values. Thus, whether shown significant or not, the value of χ^2 for a particular mineral in a particular profile is a measure of the departure of the profile from homogeneity.

Heterogeneity χ^2 was calculated for each mineral in each profile (Table 6). Only in the feldspars were significant values reached (the 10% level = 7.78, 5% = 9.49, 1% = 13.3). Totals for each mineral and each profile, as well as for the light and heavy mineral assemblages, are included. With reference to the comment of Barshad quoted earlier, the total for each mineral should provide a measure of the susceptibility of that mineral to weathering in the specific soil type examined. By this criterion, the sequence in order of decreasing susceptibility is: plagioclase, orthoclase, enstatite, quartz, epidote, hornblende, magnetite, garnet, zircon, augite, ilmenite and rutile. The position of quartz in the list is anomalous since its deviation consists of an increase up the profile due to the loss of other minerals. Comparison of the heavy minerals with Pettijohn's (1941) persistence sequence in geologic time, produces reasonable agreement with the exception of augite whose low value is probably due to the low percentages identified and hence loss of accuracy of measurement. Alias (1961) found that plagioclase weathered more easily than orthoclase in a Humic Podzol. Thus, with the exceptions noted above, the function χ^2 produces a weathering sequence in general agreement with those authors quoted in the review of literature.

d. Correlation of Parameters

Since the weathering sequence of minerals is derived by summing over all profiles, its validity depends on the

TABLE 6: VALUES OF X^2 FOR EACH MINERAL AND PROFILE

Soil Series:		Quartz	Plag.	Orth.	Hbl.	Zircon	Rutile	Enst.	Augite	Mag.	Ilmenite	Garnet	Epid.	Total	Light Total	Heavy Total
Greensboro	1	0.577	6.805	4.528	0.143	0.362	0.073	0.436	0.258	0.153	0.087	1.395	0.985	15.801	11.910	3.892
	2	1.633	10.316	4.385	1.155	1.412	0.151	1.160	0.101	1.761	0.422	0.803	1.288	24.587	16.334	8.253
	3	0.964	2.184	3.620	3.760	1.669	0.193	5.486	1.107	1.078	1.236	1.045	3.636	25.979	6.767	19.212
	4	1.182	5.828	4.773	1.654	0.442	0.247	3.512	0.439	0.925	0.557	2.132	0.864	22.556	11.783	10.773
	5	2.137	12.799	7.460	0.341	0.608	0.153	1.747	0.183	0.907	0.317	0.660	0.659	27.971	22.396	5.575
Roxton	1	1.248	12.547	13.178	1.205	0.878	0.267	1.586	0.845	1.283	1.798	1.147	1.712	37.694	26.972	10.721
	2	1.911	9.971	9.700	2.852	0.347	0.556	2.678	0.689	1.364	0.690	1.048	1.550	33.356	21.582	11.774
	3	6.402	17.253	14.323	1.817	0.749	1.251	1.596	0.776	0.537	0.713	1.553	1.117	48.085	37.977	10.108
	4	4.832	31.170	9.465	2.367	0.362	0.494	3.638	0.254	0.695	0.950	0.710	1.251	56.186	45.467	10.719
	5	4.255	17.438	6.843	5.187	1.792	0.588	4.575	2.584	4.283	0.962	0.927	5.404	54.837	28.536	26.301
Ascot	1	2.234	9.707	8.287	0.819	0.969	0.340	1.398	0.468	0.370	0.569	0.250	0.675	26.086	20.227	5.859
	2	1.673	6.609	1.223	0.802	1.586	0.531	2.513	1.114	2.038	1.324	0.828	0.306	20.545	9.505	11.041
	3	0.907	3.394	1.523	0.968	0.200	0.293	3.283	0.723	0.502	0.063	1.039	0.262	13.157	5.824	7.333
	4	1.823	12.137	5.422	0.291	0.558	0.041	1.944	0.463	0.317	0.234	0.331	0.226	23.786	19.382	4.404
	5	2.580	21.989	1.714	0.715	0.396	0.134	1.848	0.774	0.716	0.584	0.729	1.522	33.699	26.283	7.417
Magog	1	0.877	9.479	5.348	1.031	0.600	0.175	2.588	0.829	1.749	0.162	1.244	2.375	26.459	15.705	10.754
	2	0.946	5.504	3.836	0.442	0.464	0.120	2.249	0.501	1.609	0.257	1.019	3.666	20.613	10.285	10.328
	3	1.484	9.522	3.802	0.884	0.235	0.139	2.097	0.452	0.504	0.232	1.004	0.575	20.929	14.808	6.121
	4	1.232	3.369	5.197	0.895	0.461	0.348	1.472	1.004	0.526	0.641	1.022	1.930	18.094	9.797	8.297
	5	1.289	10.891	5.901	0.780	0.511	0.168	0.623	0.179	0.530	0.394	0.379	1.362	23.008	18.082	4.926
TOTAL		40.185	218.911	120.527	28.107	14.599	6.260	46.428	13.744	21.846	12.191	19.264	31.366			

assumption that variation in values due to error and heterogeneity are averaged out. This appears to be justified by comparison with the results of previous workers. However, for comparison between individual profiles, this would not be the case, and therefore both a measure of heterogeneity and a measure of weathering intensity would be useful. It might be suspected, for example, that χ^2 for the resistant minerals (those at the low end of the susceptibility scale) would predominantly be due to profile heterogeneity, whereas those minerals that weather easily would give a value of χ^2 that would give a better measure of the severity of weathering.

In order to test this hypothesis, correlation was performed between all the values obtained for each profile by several methods. Spearman's rank correlation was used since it made no assumptions about the population distribution. The correlation consists of a comparison of how well the sequence of the profiles arrived at by ranking them according to the values obtained by one method compares with the sequence obtained for another method. The various methods used to rank the profiles were:

1. The weathering indices for the silt and clay fractions previously described as W(0), W(1) and W(2).

2. A score applied to each profile depending on whether Valentine classified it as heterogeneous due to clay distribution, etc. or not. This is called 'Val.' in Tables 7 and 8.

3. The depth of the C horizon below the surface.

4. The plot score described earlier.

5. The weathering indices of the sand fractions described earlier as Wl (F), Wl (T), Wh (F) and Wh (T).

6. χ^2 for each of the twelve minerals.

7. Totals of χ^2 for all twelve minerals, the light fraction and the heavy fraction.

The correlation matrix is found in Table 7, and the corresponding values of t in Table 8. For the required 18 degrees of freedom, the values of t for significance levels of 10% = 1.734, 5% = 2.101, 2% = 2.552, 1% = 2.878 and 0.1% = 3.922. For the purposes of discussion, the tables have been divided into three parts:

1. Correlation of χ^2 for individual minerals against other minerals.

2. Correlation of various weathering indices, etc. against each other.

3. Correlation of members of group 1 against members of group 2.

Dashed lines separating minerals of the heavy fraction from those of the light fraction and from the totals are also included. Correlations found significant at 10% or better are underlined.

Although significant correlations are found in all sections, certain generalizations may be made:

1. The various indices of weathering and heterogeneity correlate positively but very poorly with each other.

TABLE 7: RANK CORRELATION COEFFICIENTS BETWEEN VARIOUS INDICES OF WEATHERING AND HETEROGENEITY

W (1)	W (2)	'Val.'	Depth of 'C'	Plot Score	Wl(F)	Wl(T)	Wh(F)	Wh(T)	χ^2 Qtz.	χ^2 Plag.	χ^2 Orth.	χ^2 Hbl.	χ^2 Zr.	χ^2 Rut.	χ^2 Enst.	χ^2 Aug.	χ^2 Mag.	χ^2 Ilm.	χ^2 Gar.	χ^2 Epid.	χ^2 Total	Total χ^2 (Light)	Total χ^2 (Heavy)	
0.17	-0.04	0.22	0.22	0.06	-0.04	-0.33	0.22	-0.03	-0.01	-0.07	0.04	-0.05	-0.16	-0.20	0.06	0.15	-0.13	-0.16	0.05	$\underline{0.42}$	0.01	0.01	-0.03	W (0)
	$\underline{0.48}$	0.30	0.01	$\underline{0.46}$	0.05	0.15	0.22	0.08	-0.23	-$\underline{0.55}$	-$\underline{0.52}$	-0.12	-0.10	-0.03	0.11	0.21	-0.10	-0.12	-0.04	-0.07	-$\underline{0.41}$	-$\underline{0.56}$	-0.00	W (1)
		$\underline{0.44}$	0.16	0.32	0.12	$\underline{0.44}$	0.14	0.32	-0.19	-0.17	-$\underline{0.48}$	-0.06	-0.36	-0.09	0.34	0.16	0.11	-0.19	0.11	-0.05	-0.21	-0.29	0.16	W (2)
			0.36	-0.03	0.33	0.14	0.34	-0.07	-$\underline{0.50}$	-$\underline{0.53}$	-0.31	-0.08	-0.14	-$\underline{0.38}$	0.27	0.12	-0.00	-0.33	0.24	0.18	-0.34	-$\underline{0.47}$	0.11	'Val.'
				-0.01	0.05	-0.08	0.01	-0.05	0.06	0.02	-0.06	0.07	-0.17	-0.06	0.13	-0.04	0.20	-0.27	0.12	0.24	0.04	0.04	0.07	Depth of 'C'
					0.35	$\underline{0.38}$	0.25	0.32	-0.34	-0.31	-$\underline{0.61}$	-$\underline{0.42}$	-0.04	-0.27	-$\underline{0.39}$	-0.08	-0.15	-0.23	-0.10	-0.12	-$\underline{0.53}$	-$\underline{0.43}$	-0.30	Plot Score
						0.35	$\underline{0.74}$	0.11	-$\underline{0.69}$	-$\underline{0.46}$	-0.26	-0.17	-0.02	-0.34	-0.37	-0.05	-0.13	-$\underline{0.44}$	0.29	-0.03	-$\underline{0.52}$	-$\underline{0.48}$	-0.26	Wl (F)
							-0.05	$\underline{0.76}$	-0.30	-0.11	-0.37	-0.34	-0.11	-0.36	-0.20	-0.25	0.05	-0.13	-0.25	-0.09	-0.36	-0.27	-0.20	Wl (T)
								-0.17	-$\underline{0.51}$	-$\underline{0.41}$	0.04	-0.06	-0.24	-0.10	-0.35	0.14	-$\underline{0.40}$	-0.32	$\underline{0.47}$	0.05	-0.33	-0.28	-0.22	Wh (F)
									-0.07	-0.10	-0.29	-0.17	-0.28	-0.14	-0.12	-0.18	0.20	0.01	-0.22	0.13	-0.31	-0.21	0.01	Wh (T)
										$\underline{0.74}$	$\underline{0.52}$	0.28	0.15	$\underline{0.47}$	0.07	-0.02	0.11	$\underline{0.50}$	-$\underline{0.42}$	-0.09	$\underline{0.70}$	$\underline{0.75}$	0.14	χ^2 Qtz.
											$\underline{0.57}$	0.07	0.11	0.11	-0.12	-0.22	0.05	0.25	-$\underline{0.39}$	-0.02	$\underline{0.80}$	$\underline{0.95}$	-0.11	χ^2 Plag.
												0.31	0.14	$\underline{0.41}$	-0.17	-0.12	-0.05	0.29	-0.01	0.16	$\underline{0.67}$	$\underline{0.77}$	0.03	χ^2 Orth.
													0.22	$\underline{0.72}$	$\underline{0.58}$	$\underline{0.39}$	$\underline{0.47}$	$\underline{0.59}$	$\underline{0.39}$	$\underline{0.44}$	$\underline{0.51}$	0.22	$\underline{0.79}$	χ^2 Hbl.
														0.24	-0.03	$\underline{0.38}$	$\underline{0.50}$	$\underline{0.53}$	-0.16	0.27	0.32	0.13	0.33	χ^2 Zr.
															0.34	$\underline{0.49}$	0.31	$\underline{0.65}$	0.20	0.16	0.38	0.24	$\underline{0.61}$	χ^2 Rut.
																$\underline{0.40}$	$\underline{0.41}$	0.24	0.22	0.17	0.21	-0.11	$\underline{0.72}$	χ^2 Enst.
																	0.37	$\underline{0.52}$	0.33	$\underline{0.42}$	0.12	-0.14	$\underline{0.63}$	χ^2 Aug.
																		$\underline{0.47}$	0.18	$\underline{0.55}$	0.33	0.05	$\underline{0.79}$	χ^2 Mag.
																			0.03	0.36	$\underline{0.54}$	0.34	$\underline{0.66}$	χ^2 Ilm.
																				0.28	-0.11	-0.24	$\underline{0.42}$	χ^2 Gar.
																					0.35	0.12	$\underline{0.55}$	χ^2 Epid.
																						$\underline{0.89}$	0.36	TOTAL χ^2
																							-0.00	TOTAL χ^2 (Light)

TABLE 8: 't' VALUES FOR RANK CORRELATION BETWEEN VARIOUS INDICES OF WEATHERING AND HETEROGENEITY

	W (1)	W (2)	'Val.'	Depth of 'C'	Plot Score	Wl(F)	Wl(T)	Wh(F)	Wh(T)	$\bar{\chi}^2$ Qtz.	$\bar{\chi}^2$ Plag.	$\bar{\chi}^2$ Orth.	$\bar{\chi}^2$ Hbl.	$\bar{\chi}^2$ Zr.	$\bar{\chi}^2$ Rut.	$\bar{\chi}^2$ Enst.	$\bar{\chi}^2$ Aug.	$\bar{\chi}^2$ Mag.	$\bar{\chi}^2$ Ilm.	$\bar{\chi}^2$ Gar.	$\bar{\chi}^2$ Epid.	Total $\bar{\chi}^2$	Total $\bar{\chi}^2$ (Light)	Total $\bar{\chi}^2$ (Heavy)
W (0)	0.75	-0.18	0.97	0.97	0.26	-0.18	-1.48	0.95	-0.12	-0.02	-0.31	0.16	-0.20	-0.59	-0.84	0.24	0.65	-0.56	-0.69	0.19	1.98	0.05	0.05	-0.11
W (1)		2.30	1.35	0.05	2.20	0.23	0.64	0.96	0.34	-0.99	-2.77	-2.59	-0.50	-0.41	-0.14	0.48	0.89	-0.43	-0.53	-0.19	-0.30	-1.89	-2.87	-0.02
W (2)			2.09	0.68	1.45	0.52	2.11	0.62	1.43	-0.81	-0.72	-2.31	-0.26	-1.66	-0.38	1.53	0.70	0.46	-0.83	0.45	-0.22	-0.93	-1.27	0.67
'Val.'				1.64	-0.12	1.47	0.62	1.56	-0.31	-2.43	-2.62	-1.38	-0.33	-0.60	-1.77	1.18	0.53	-0.00	-1.49	1.05	0.78	-1.54	-2.29	0.46
Depth of 'C'					-0.05	0.19	-0.35	0.06	-0.23	0.24	0.10	-0.26	0.31	-0.71	-0.24	0.54	-0.15	0.84	-1.18	0.50	1.07	0.19	0.18	0.29
Plot Score						1.59	1.76	1.08	1.42	-1.52	-1.38	-3.24	-1.95	-0.17	-1.17	-1.80	-0.34	-0.65	-1.00	-0.42	-0.52	-2.62	-2.01	-1.33
Wl (F)							1.58	4.61	0.49	-4.09	-2.21	-1.12	-0.73	-0.09	-1.53	-1.71	-0.21	-0.57	-2.09	1.29	-0.15	-2.61	-2.33	-1.14
Wl (T)								-0.20	5.00	-1.34	-0.47	-1.68	-1.52	-0.47	-1.65	-0.88	-1.11	0.23	-0.56	-1.10	-0.38	-1.65	-1.20	-0.85
Wh (F)									-0.74	-2.52	-1.89	0.17	-0.25	-1.06	-0.41	-1.57	0.61	-1.84	-1.43	2.28	0.22	-1.46	-1.23	-0.97
Wh (T)										-0.30	-0.43	-1.28	-0.75	-1.22	-0.58	-0.53	-0.81	0.80	0.04	-0.98	0.55	-1.38	-0.91	0.03
$\bar{\chi}^2$ Qtz.											4.67	2.57	1.23	0.63	2.23	0.31	-0.08	0.45	2.43	-1.97	-0.38	4.13	4.88	0.59
$\bar{\chi}^2$ Plag.												2.98	0.31	0.47	0.45	-0.52	-0.95	0.20	1.11	-1.80	-0.07	5.66	12.55	-0.49
$\bar{\chi}^2$ Orth.													1.37	0.60	1.89	-0.74	-0.50	-0.20	1.31	-0.04	0.67	3.87	5.12	0.13
$\bar{\chi}^2$ Hbl.														0.97	4.41	3.04	1.79	2.24	3.08	1.80	2.06	2.52	0.95	5.45
$\bar{\chi}^2$ Zr.															1.06	-0.13	1.73	2.46	2.64	-0.68	1.21	1.43	0.55	1.49
$\bar{\chi}^2$ Rut.																1.53	2.37	1.40	3.64	0.85	0.67	1.72	1.06	3.31
$\bar{\chi}^2$ Enst.																	1.87	1.93	1.06	0.93	0.74	0.92	-0.46	4.41
$\bar{\chi}^2$ Aug.																		1.70	2.57	1.50	1.96	0.49	-0.60	3.41
$\bar{\chi}^2$ Mag.																			2.29	0.78	2.79	1.40	0.23	5.38
$\bar{\chi}^2$ Ilm.																				0.12	1.66	2.72	1.54	3.73
$\bar{\chi}^2$ Gar.																					1.23	-0.47	-1.07	1.99
$\bar{\chi}^2$ Epid.																						1.58	0.52	2.83
TOTAL $\bar{\chi}^2$																							8.09	1.62
TOTAL $\bar{\chi}^2$ (Light)																								-0.02

The only exceptions to this are Wl (F): Wl (T) and Wh (L): Wh (T) since they are very similar functions to each other.

2. The various indices of weathering and heterogeneity correlate negatively with the mineral χ^2 values. There are very few significant correlations between these indices and χ^2 for minerals of the heavy fraction, and those few are of a poor level of significance. Significant correlation exists between several of these indices and χ^2 values for the minerals of the light fraction, the light total and the overall total.

3. Those indices that tend to show significance with the minerals of the light fraction and the totals are W(l), Valentine's heterogeneity rating, the Plot Score and Wl (F).

4. The χ^2 values for each mineral usually correlate positively with each other. The minerals of the light fraction correlate well with each other and with the overall and light totals, but not at all well with minerals of the heavy fraction or the heavy total. The heavy minerals correlate well with each other and the heavy total but not with the overall and light totals.

5. Quartz, plagioclase and orthoclase all correlate well with each other but quartz shows some tendency to correlate significantly with the minerals of the heavy fraction also. Hornblende, augite, magnetite and ilmenite correlate well with most minerals of the heavy fraction but garnet only correlates significantly with hornblende.

6. The overall total correlates very significantly with the total for the light fraction.

e. Choice of Weathering & Heterogeneity Indices

Thus, although the various weathering indices obtained from the literature appear rather inconclusive when used with the data obtained in this study, the values of χ^2 obtained for each mineral appear to correlate well with each other to form two separate groups. Since significant correlation implies that both variables are measuring the same property or related properties, it is reasonable to conclude that two independent properties are being measured by the variables used.

One of these is measured by the χ^2 values of the heavy minerals and is best approximated by the sum of the χ^2 for all the heavy minerals. This approximation may tentatively be considered as an index of heterogeneity of the parent material since it includes the 'resistant' minerals. Various minerals that have been shown to weather significantly by analysis of variance fall into this category. Since these correlate well with the 'resistant' minerals, it is suggested that this is due to any lack of homogeneity of the parent material. This would tend to affect the heavy minerals more severely than minerals of the light fraction, due to their relatively low percentages in the soil.

The second property is measured by the χ^2 values for the light minerals and, to a lesser extent, by a few of the other weathering indices. It is approximated by the sum of the χ^2 values for the light minerals and may tentatively be considered as an index of weathering.

f. Comparison of Weathering Indices and Texture Grouping

Valentine (1960), working on the same profiles, grouped them according to texture of rock type and parent material (Table 9) in an attempt to show the influence of these textures on the severity of weathering. It was therefore of interest to see if χ^2, used as a measure of the severity of weathering in the profile, produced a sequence of profiles that compared well with his groupings. Table 10 shows the sequence of profiles obtained using the sum of the χ^2 for the light minerals and for the heavy minerals, together with the sequence obtained by ranking Valentine's weathering index, based on particle size analysis. Beneath each profile name is stated the texture grouping to which the profile was assigned. This is only available for 15 of the 20 profiles since he rejected 5 profiles due to suspected lack of homogeneity of parent material.

As can be seen, Valentine's weathering index separates the three texture groupings very well, the f/f grouping showing the least weathering, the c/c intermediate and the f/c grouping strong weathering. Using the χ^2 total for light minerals, a fairly good separation is achieved, with only Magog 4 and

TABLE 9: SOIL GROUPINGS ACCORDING TO THE TEXTURE OF THE ROCK TYPES IN THE GRAVEL AND THE TEXTURE OF THE PARENT MATERIAL (From Valentine (1966))

	Soil Groupings 1	Soil Groupings 2	Soil Groupings 3
Texture of rock types	Fine shale, slate and schist	Fine shale and slate	Coarse sandstone, quartz and quartzite
Texture of parent material	Fine L-Sil	Coarse S-Sl	Coarse Sl-Ls
Soil Series and Sites	Ascot 1 Ascot 5 Greensboro 5 Magog 4 Magog 5	Roxton 1 Roxton 2 Roxton 3 Roxton 4 Roxton 5	Ascot 2 Ascot 3 Greensboro 1 Greensboro 2 Greensboro 4
Connotative nomenclature used in text	"f/f grouping"	"f/c grouping"	"c/c grouping"

TABLE 10: PROFILE SEQUENCES FROM RANKED WEATHERING AND HETEROGENEITY INDICES

Valentine's Weathering Index

Index	7.3	9.0	9.6	9.7	12.4	13.2	16.3	21.1	21.8	25.2	29.8	32.0	36.3	40.4	53.8
Profile	M4	M5	A5	G5	A1	G2	A2	G1	A3	R2	G4	R1	R4	R5	R3
Grouping	f/f	f/f	f/f	f/f	f/f	c/c	c/c	c/c	c/c	f/c	c/c	f/c	f/c	f/c	f/c

Total X^2 for Light Minerals

Index	5.82	6.77	9.51	9.80	10.29	11.78	11.91	14.81	15.71	16.33	18.08	19.38	20.23	21.58	22.40	26.28	26.97	28.54	37.98	45.47
Profile	A3	G3	A2	M4	M2	G4	G1	M3	M1	G2	M5	A4	A1	R2	G5	A5	R1	R5	R3	R4
Grouping	c/c		c/c	f/f		c/c	c/c			c/c	f/f		f/f	f/c	f/c	f/f	f/c	f/c	f/c	f/c

Total X^2 for Heavy Minerals

Index	3.89	4.40	4.93	5.58	5.86	6.12	7.33	7.42	8.25	8.30	10.11	10.33	10.72	10.72	10.75	10.77	11.04	11.77	19.21	26.30
Profile	G1	A4	M5	G5	A1	M3	A3	A5	G2	M4	R3	M2	R1	R4	M1	G4	A2	R2	G3	R5

Soil Series: G = Greensboro R = Roxton A = Ascot M = Magog

Roxton 2 out of position. This time, however, the c/c grouping exhibits the least, the f/f grouping intermediate and the f/c grouping the most weathering. This discrepancy is reflected in some other parts of Valentine's work where the f/f and c/c groupings are not easily distinguished from each other but are distinct from the f/c grouping.

g. Heterogeneity Index

Examination of the χ^2 values for total heavy minerals in Table 10 will show that the last two profiles, Greensboro 3 and Roxton 5, possess values considerably larger than the rest. This would suggest the elimination of these two profiles from any subsequent analysis due to poor homogeneity. This is supported by further evidence since the χ^2 values are calculated for each horizon before being added to produce one figure for each profile. These intermediate values may be examined and any horizon noted whose χ^2 value differs very strongly from the others. Table 11 contains a list for each mineral in each profile of those horizons that seem to be aberrant. If the discrepancy is very strong, the horizon is underlined. It will be seen that, for a given profile, most discrepancies fall in the same or adjacent horizons for different minerals. The profiles that show the most consistent deviations are: Greensboro 3 in the Bfh horizon, Greensboro 4 in the C, Roxton 5 and Magog 1 in the Ae and Bfh. The table in general supports the heterogeneity sequence in Table 10.

TABLE 11: HORIZONS EXHIBITING HIGH X^2 VALUES

	Greensboro					Roxton					Ascot					Magog				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Quartz		Ae	Bfh Ae	C	Bf			Bf		Ae Bfh	F			C		Ae	Ae C			
Plagioclase	Ae Bf	F Ae	Ae C	C	Bf			Bfh Bf		Ae Bfh				C	C	Ae	Bf	Ae C	C	
Orthoclase	Bf			Bf	Bf	C		Bf F		Bfh	Bf		C	C	C	Ae C	Bfh	Bf	Bfh	
Hornblende			Bfh	C		Bfh						Ae C	Ae							Ae
Zircon			Bfh	C						Bfh						Bfh		C		
Rutile								C												
Enstatite			Bf Bfh	F			Ae			C			Bfh				Bfh	C	Bf	
Augite			Bfh			Ae		C		Ae		Bf				Bfh		C		
Magnetite		Bfh	Bfh	C						C										
Ilmenite			Bfh	C							Bfh	C				Bfh				Ae
Garnet			Bfh	C								C								
Epidote			Bfh	C		Bf	Ae	Bf		F					Bfh Bf	Bf C	Bfh C			

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h. Comparison between Soil Series and Texture Groupings

Fig. 4 contains 72 plots of mineral percentage against horizon for the three sand size fractions. These plots consist of the 'average profile' (obtained by averaging the results of five replicates) for each soil series and texture grouping. This was done for each of the 12 minerals, and the relevant χ^2 value is included. These plots have been drawn to illustrate how the deviations of the size fractions from their mean values influence the value of χ^2 obtained and also to show the effect of grouping profiles according to texture or soil series. The f/c grouping and the Roxton series are identical (Table 9).

No particularly noticeable effect is produced by taking the average profile for groupings instead of soil series. Examination shows that some soil series have patterns distinctly different from the others and that this pattern is repeated for several minerals. The Greensboro series exhibits relatively little difference between particle sizes both in mineral percentage and severity, especially for the light minerals. A peak in the Bfh for many heavy minerals in that soil series is due to heterogeneity in the profile Greensboro 3, as previously described. The Roxton series shows the widest difference between particle sizes for the light minerals plus several heavy minerals. It tends to exhibit a steeper slope than the Greensboro series for the weatherable

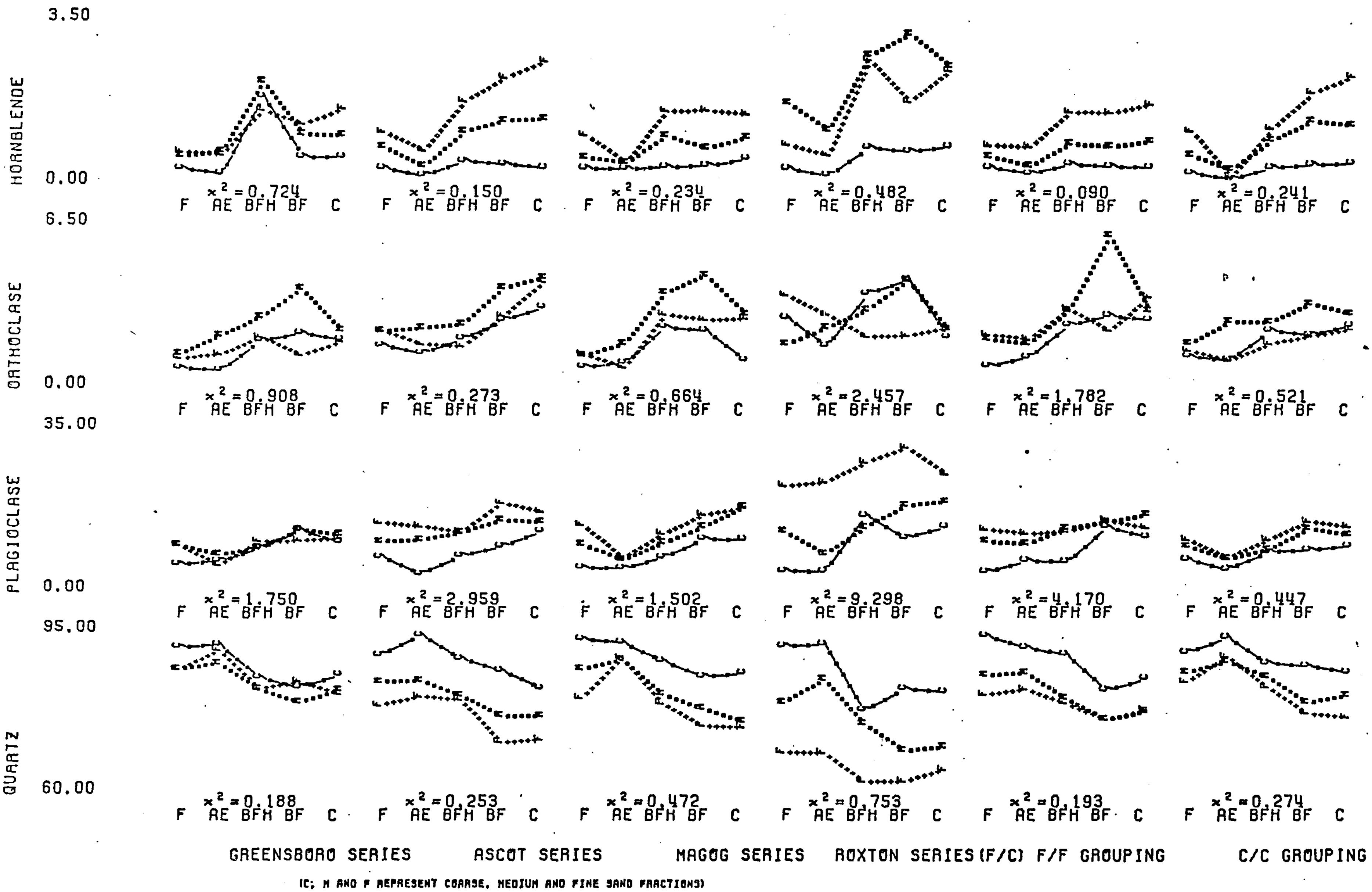

FIG. 4 pt. 1 VARIATION OF SIZE DISTRIBUTION OF MINERALS WITH HORIZON FOR SEVERAL AVERAGE PROFILES

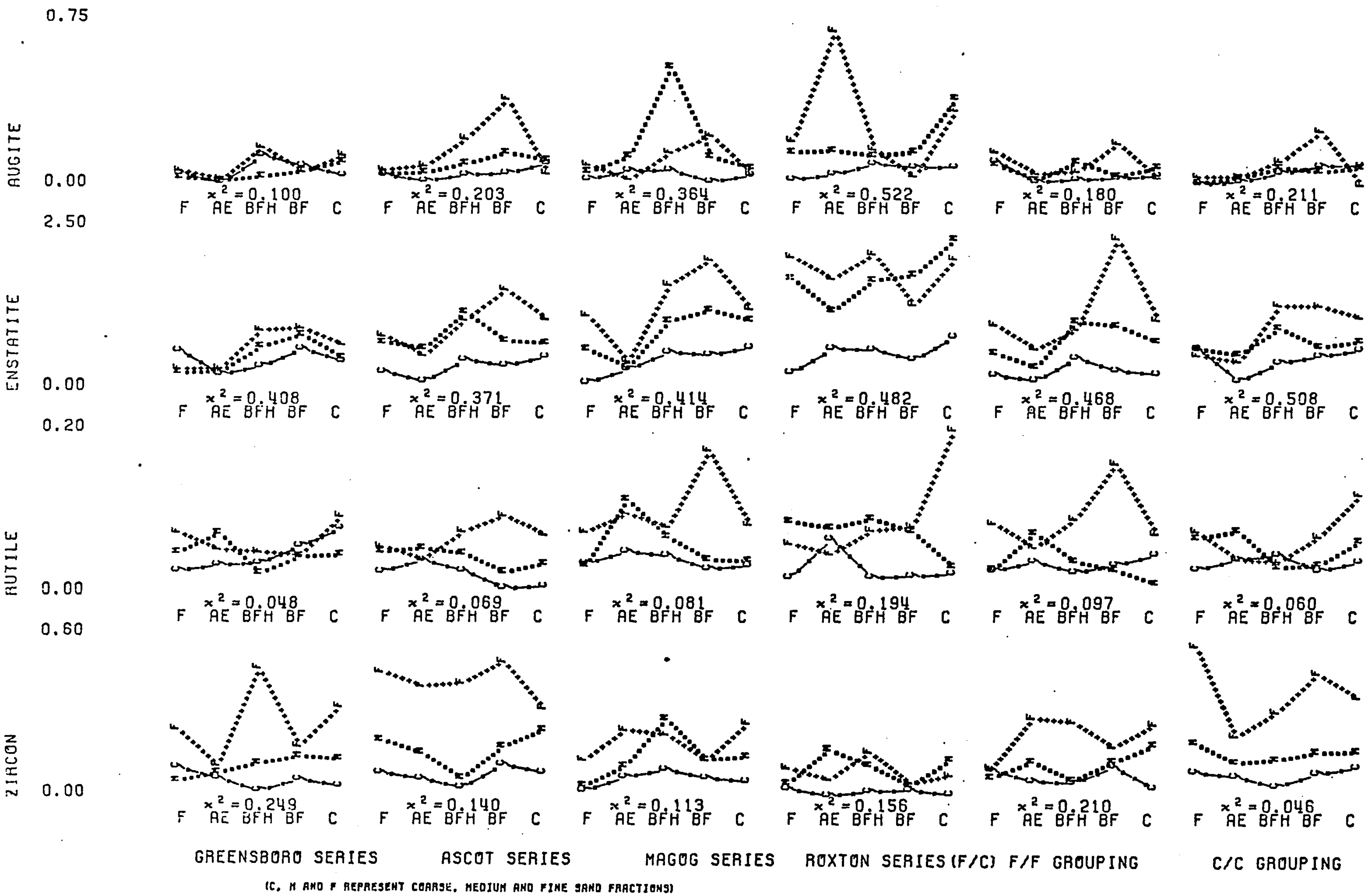

FIG. 4 pt. 2 VARIATION OF SIZE DISTRIBUTION OF MINERALS WITH HORIZON FOR SEVERAL AVERAGE PROFILES

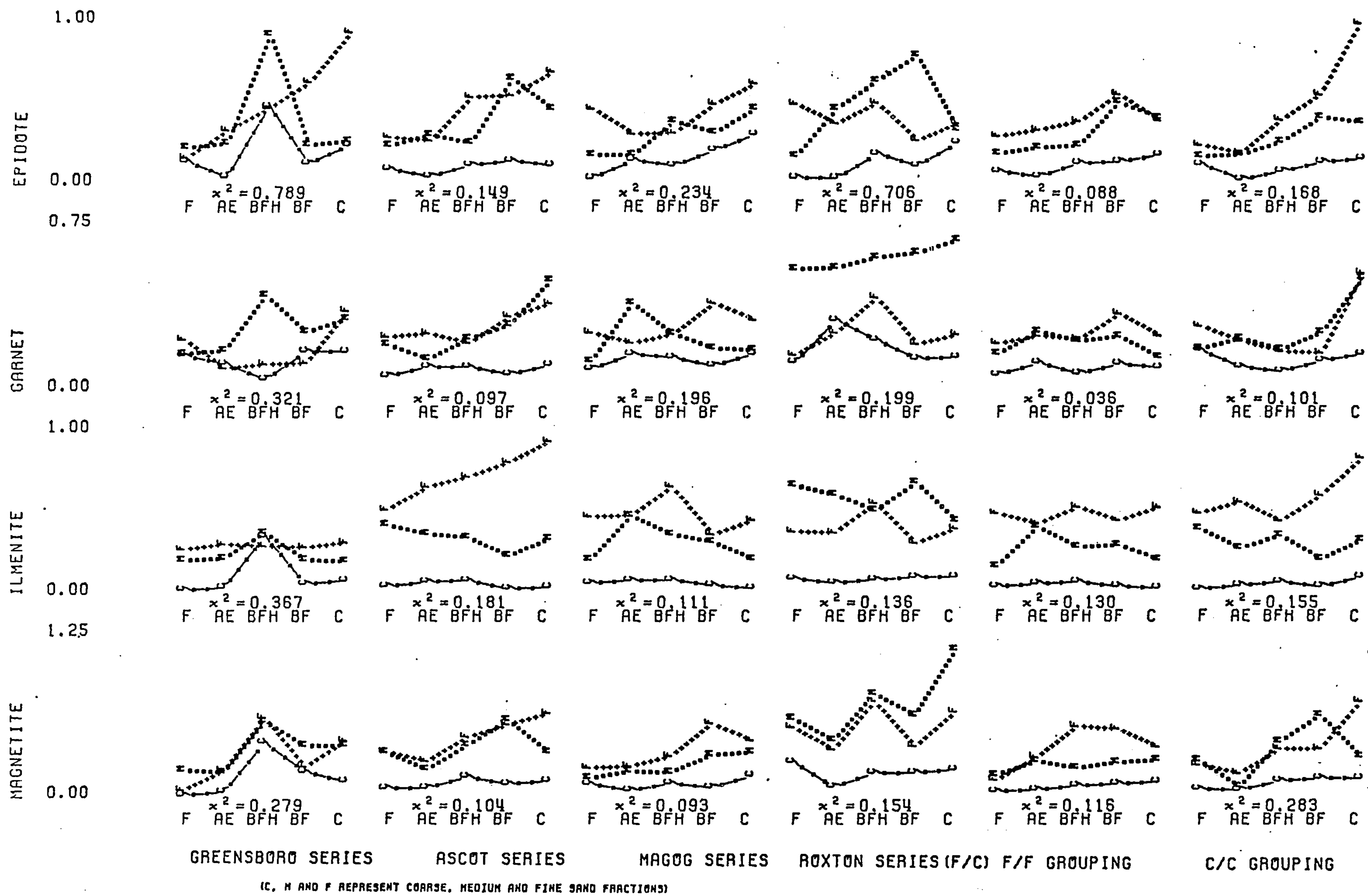

FIG. 4 pt. 3 VARIATION OF SIZE DISTRIBUTION OF MINERALS WITH HORIZON FOR SEVERAL AVERAGE PROFILES

minerals suggesting more severe weathering. The Ascot and Magog series are difficult to tell apart, as are the f/f and c/c texture groupings. The Roxton series usually exhibits a larger value for χ^2 than the other series.

A comparison between minerals also shows several distinctive patterns. Quartz increases towards the surface and is most abundant in the coarse fraction. Orthoclase shows a maximum in the 250-105 micron fraction, fluctuates considerably, but shows an overall decrease in percentage towards the surface. Plagioclase exhibits consistent decrease towards the surface and also has the largest values for χ^2. Hornblende usually exhibits typical weathering curves as does enstatite and, to lesser extents, magnetite and epidote. The 'resistant' minerals - zircon, rutile, ilmenite and garnet - exhibit no trend except the particle size distribution of the parent material. The curves for augite suggest that it was identified in too low percentages, or too infrequently, to exhibit any statistical trend.

SUMMARY & CONCLUSIONS

Analysis of experimental results showed several interesting features in the soils sampled. Plagioclase, orthoclase, hornblende, enstatite, epidote and magnetite were shown to decrease significantly towards the surface of Orthic Podzols, with a consequent significant increase in quartz percentages. Garnet, zircon, rutile, ilmenite and augite were not shown to vary significantly in percentage with depth, possibly due to the low percentages discovered and the limitations of analytic accuracy.

For those minerals found to decrease significantly up the profile, the general trend showed a maximum in the Bf or C and a minimum in the F or Ae horizons, with the Bfh usually intermediate. Local variations could have destroyed this trend but showed no evidence of producing any other trend. Although it could not be shown to be statistically significant by Duncan's Multiple Range Test, the minimum was usually found in the Ae rather than the F horizon.

Since it was not likely than many of the profiles examined were very young, some mechanism may be suggested capable of moving less weathered material from lower in the profile to mix with the organic matter above the heavily leached Ae horizon. Since the Ae horizon was found intact, earthworm activity appeared to have been minimal suggesting other mechanisms such as deposition of wind-blown material from erosion surfaces (minimal in the forest environment) or mixing of the soil by the action of uprooted trees. Stephens (1956) showed that, over several hundred years, the effect of the uprooting of trees was a significant factor in the circulation of soil in the forest environment. Since Orthic Podzols are considered to be of forest origin, the criterion of a minimum below the surface could be considered in the classification of a soil. For this, further work should be done on different soil types.

New indices of weathering and heterogeneity are proposed. Other weathering indices suggested in the literature did not correlate very well with these or with each other. It would seem that χ^2 used as a measure of the variation in particle size distribution of a mineral through a profile posesses certain advantages. When values obtained for each mineral in each profile are correlated, the minerals fall into two groups, each approximating one of the two expected natural sources of variation.

In this study the minerals of the light fraction were most heavily affected by weathering severity and hence provided a measure of this, while the minerals of the heavy fraction, because of their relatively small concentration, provided a measure of the lack of homogeneity of the parent material of the profile. The profile ranking obtained from the first group could not be checked directly but, since the totals over all profiles rank the minerals in approximately the same persistance sequence as found in the literature, it was considered that severity of weathering was being measured. The profile ranking obtained by the second group of minerals could be checked in part by examination of χ^2 obtained for each horizon and was thus considered to be a measure of heterogeneity.

Profiles arranged in texture groupings by Valentine (1966) were separated into these groupings fairly well by the weathering index proposed, although the sequence was not the same as that found by Valentine. This suggests that the texture of the parent material and soil does affect the rate of weathering of primary minerals but not necessarily in the same way as particle size distribution is affected.

Although this project was concerned only with Orthic Podzols, the criteria used here should be equally applicable elsewhere. Comparative work between Orthic Podzols and other soil types could provide invaluable information on the relation between parent material, soil type and severity of weathering.

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APPENDIX 1

THE LATITUDE AND LONGITUDE OF THE TWENTY SITES SAMPLED

Ascot	1	Lat. 45° 31' 30" N	Long. 71° 53' 45" W
	2	45° 37' 00" N	71° 56' 00" W
	3	45° 24' 00" N	71° 57' 20" W
	4	45° 25' 50" N	71° 57' 20" W
	5	45° 29' 40" N	71° 55' 30" W
Greensboro	1	45° 27' 20" N	71° 28' 10" W
	2	45° 27' 50" N	71° 25' 15" W
	3	45° 31' 55" N	71° 13' 10" W
	4	45° 10' 20" N	71° 53' 55" W
	5	45° 07' 20" N	71° 57' 30" W
Roxton	1	45° 21' 20" N	72° 46' 40" W
	2	45° 21' 25" N	72° 48' 00" W
	3	45° 22' 10" N	72° 47' 15" W
	4	45° 28' 20" N	72° 45' 55" W
	5	45° 33' 45" N	72° 41' 20" W
Magog	1	45° 17' 20" N	72° 06' 25" W
	2	45° 19' 45" N	71° 59' 00" W
	3	45° 24' 40" N	71° 58' 55" W
	4	45° 35' 20" N	71° 15' 20" W
	5	45° 40' 35" N	71° 50' 05" W

APPENDIX 2

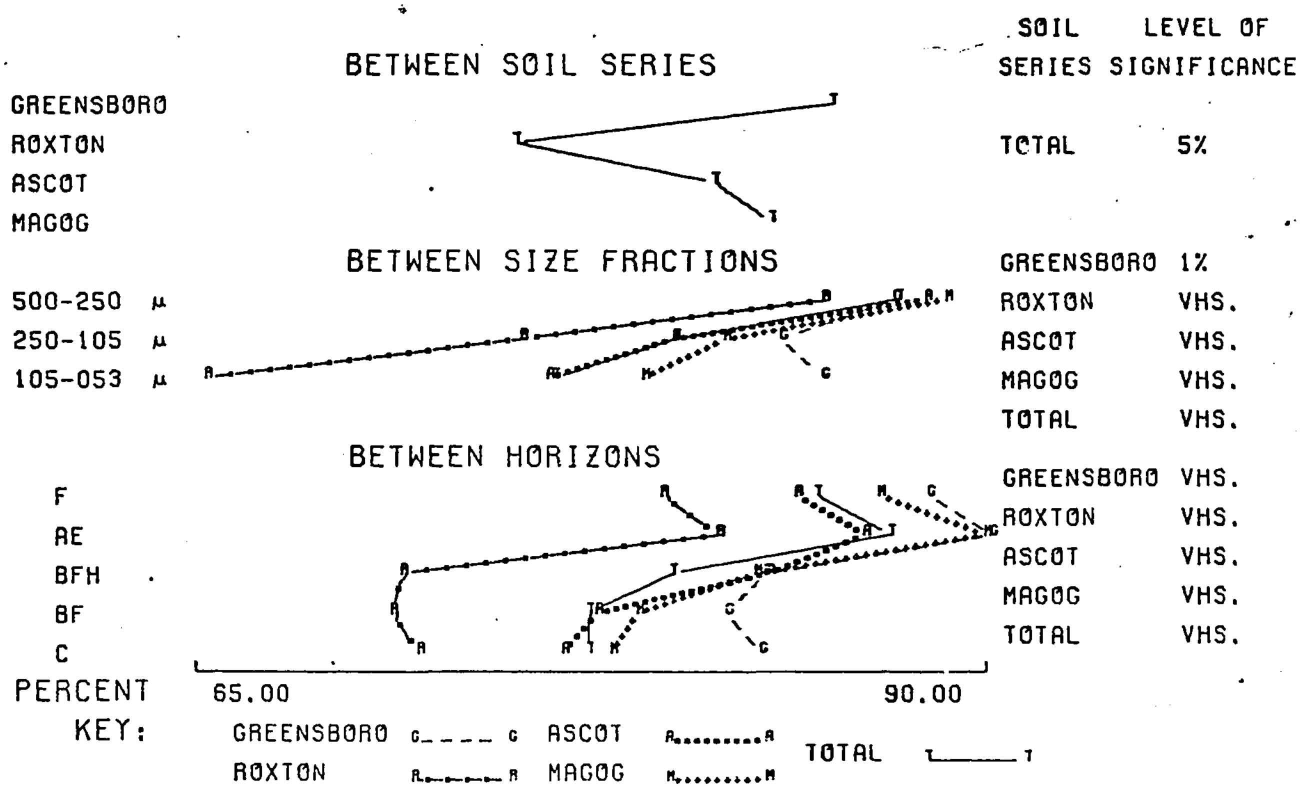
ANALYSIS OF VARIANCE TABLES

& MINERAL DISTRIBUTIONS

ANALYSIS OF VARIANCE TABLE FOR QUARTZ

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	4217.39844	1405.79932	4.65	5.0%
PROFILES (REPLICATES)	4	1425.86792	356.46680	1.18	N.S.
ERROR	12	3626.49854	302.20801		
SIZE FRACTIONS	2	6040.21094	3020.10547	157.85	VHS.
HORIZONS	4	4465.14062	1116.28516	58.34	VHS.
SIZE X HORIZON	8	130.42363	16.30295	0.85	N.S.
SIZE X PROFILE	38	3150.52197	82.90846	4.33	VHS.
HORIZON X PROFILE	76	2376.26318	31.26662	1.63	1.0%
ERROR	152	2908.25586	19.13326		

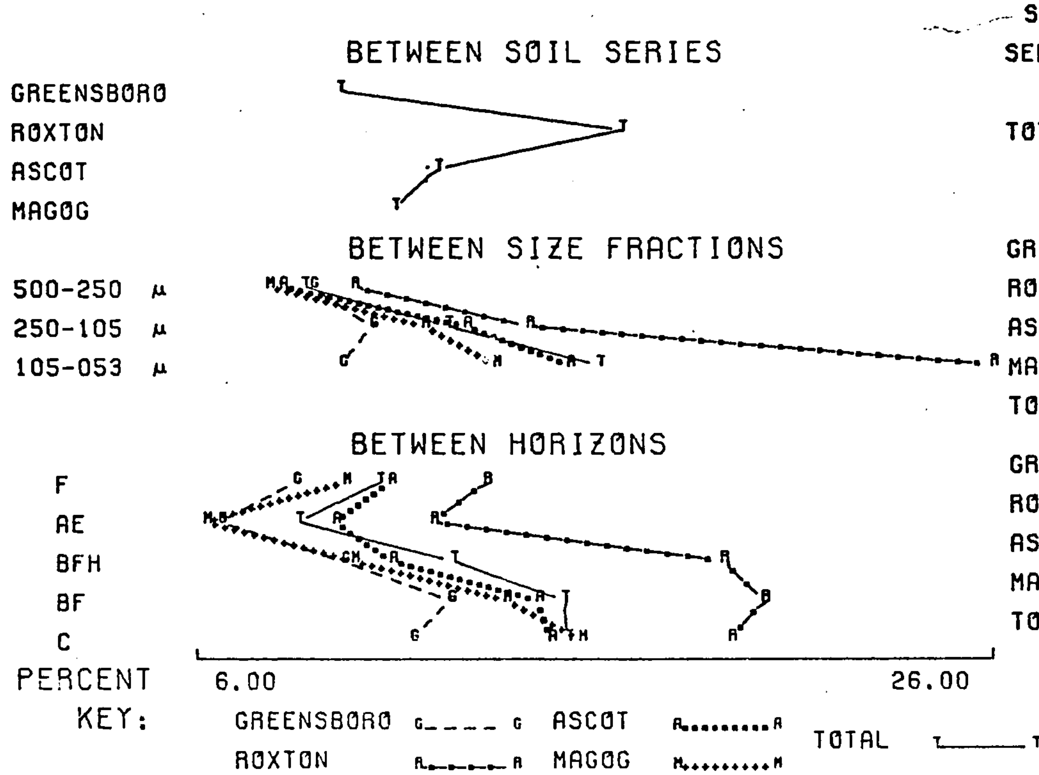
PLOT OF THE VARIATION OF THE QUARTZ CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR PLAGIOCLASE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	2139.07812	713.02588	6.07	1.0%
PROFILES (REPLICATES)	4	669.21533	167.30383	1.42	N.S.
ERROR	12	1410.07324	117.50610		
SIZE FRACTIONS	2	2742.06323	1371.03149	87.68	VHS.
HORIZONS	4	2069.68726	517.42163	33.09	VHS.
SIZE X HORIZON	8	158.36211	19.79526	1.27	N.S.
SIZE X PROFILE	38	2913.17773	76.66257	4.90	VHS.
HORIZON X PROFILE	76	1242.94043	16.35448	1.05	N.S.
ERROR	152	2376.68799	15.63610		

PLOT OF THE VARIATION OF THE PLAGIOCLASE CONTENT OF THE SAND

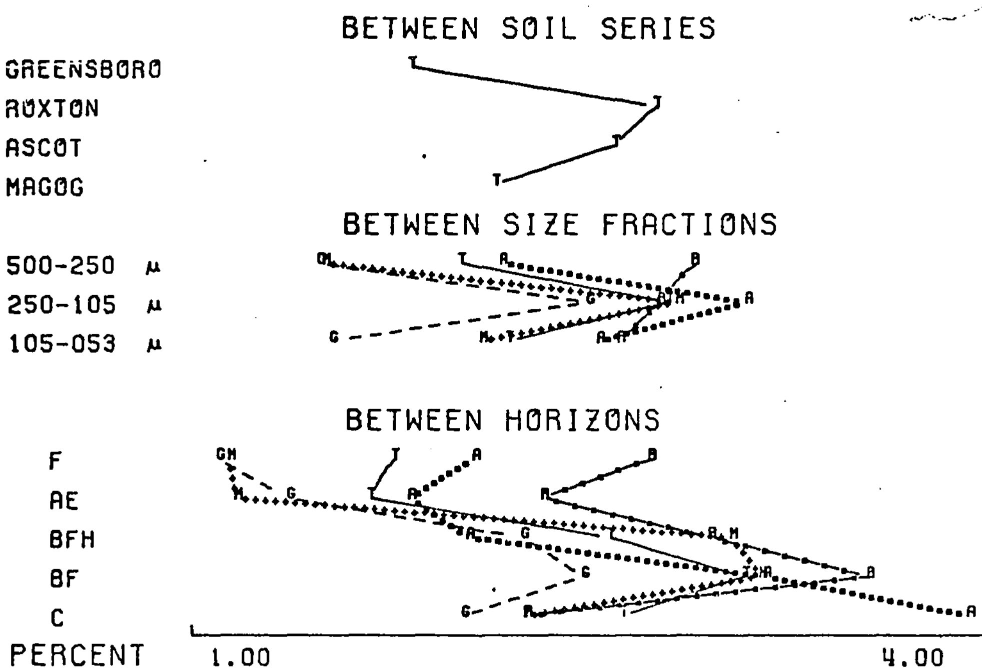


SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	1%
GREENSBORO	N.S.
ROXTON	VHS.
ASCOT	VHS.
MAGOG	VHS.
TOTAL	VHS.
GREENSBORO	0.1%
ROXTON	0.1%
ASCOT	0.5%
MAGOG	VHS.
TOTAL	VHS.

ANALYSIS OF VARIANCE TABLE FOR ORTHOCLASE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	35.65442	11.88481	1.68	N.S.
PROFILES (REPLICATES)	4	54.67424	13.66856	1.93	N.S.
ERROR	12	84.94855	7.07905		
SIZE FRACTIONS	2	25.99452	12.99726	7.10	0.5%
HORIZONS	4	76.58112	19.14528	10.45	VHS.
SIZE X HORIZON	8	36.48412	4.56051	2.49	5.0%
SIZE X PROFILE	38	84.07890	2.21260	1.21	N.S.
HORIZON X PROFILE	76	210.31192	2.76726	1.51	5.0%
ERROR	152	278.36475	1.83135		

PLOT OF THE VARIATION OF THE ORTHOCLASE CONTENT OF THE SAND



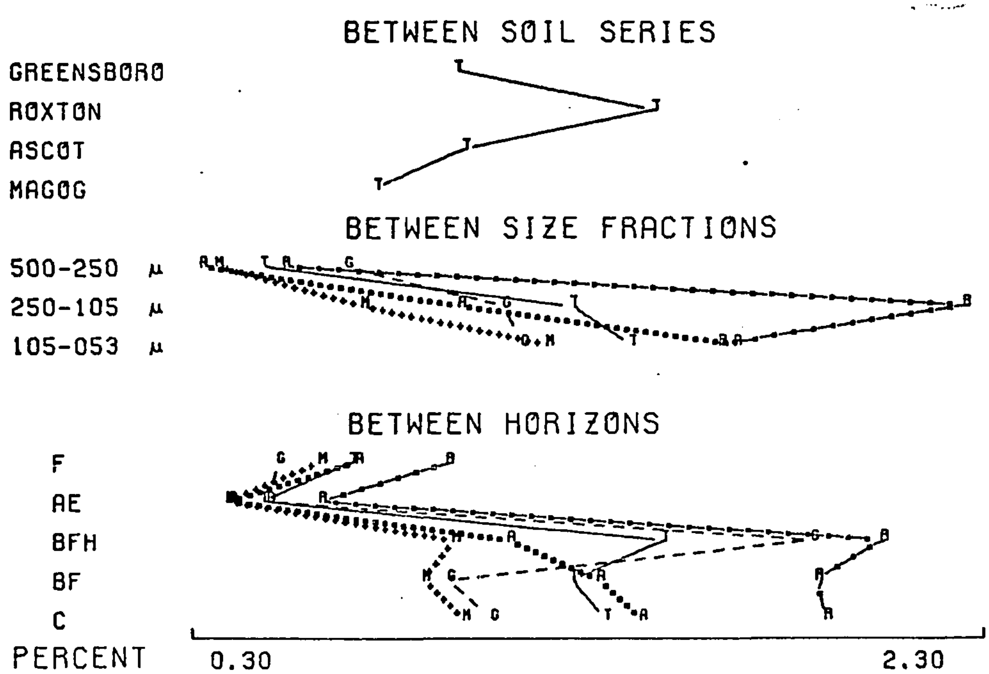
SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	N.S.
GREENSBORO	1.0%
ROXTON	N.S.
ASCOT	10%
MAGOG	0.5%
TOTAL	0.1%
GREENSBORO	5%
ROXTON	N.S.
ASCOT	0.1%
MAGOG	0.1%
TOTAL	VHS.

KEY: GREENSBORO G-----G ASCOT A.........A TOTAL T——T
ROXTON A-.-.-A MAGOG M+++++++M

ANALYSIS OF VARIANCE TABLE FOR HORNBLENDE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	20.13754	6.71251	1.35	N.S.
PROFILES (REPLICATES)	4	19.95720	4.98930	1.00	N.S.
ERROR	12	59.81207	4.98434		
SIZE FRACTIONS	2	50.40326	25.20163	71.86	VHS.
HORIZONS	4	46.27728	11.56932	32.99	VHS.
SIZE X HORIZON	8	8.92230	1.11529	3.18	0.5%
SIZE X PROFILE	38	42.40202	1.11584	3.18	VHS.
HORIZON X PROFILE	76	104.65274	1.37701	3.93	VHS.
ERROR	152	53.30865	0.35071		

PLOT OF THE VARIATION OF THE HORNBLENDE CONTENT OF THE SAND



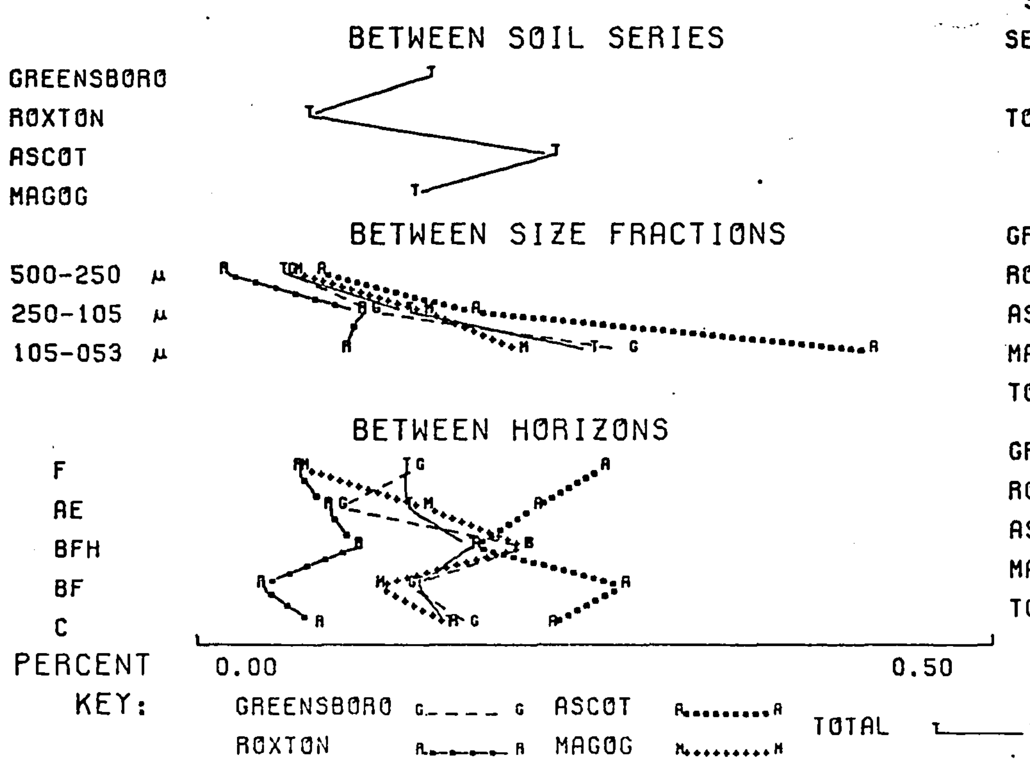
SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	N.S.
GREENSBORO	5%
ROXTON	VHS.
ASCOT	VHS.
MAGOG	VHS.
TOTAL	VHS.
GREENSBORO	VHS.
ROXTON	VHS.
ASCOT	VHS.
MAGOG	VHS.
TOTAL	VHS.

KEY: GREENSBORO G- - - -G ASCOT A........A ROXTON R-•-•-R MAGOG M........M TOTAL T———T

ANALYSIS OF VARIANCE TABLE FOR ZIRCON

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	0.95169	0.31723	4.31	5.0%
PROFILES (REPLICATES)	4	0.39960	0.09990	1.36	N.S.
ERROR	12	0.88360	0.07363		
SIZE FRACTIONS	2	1.64332	0.82166	27.91	VHS.
HORIZONS	4	0.09622	0.02405	0.82	N.S.
SIZE X HORIZON	8	0.13884	0.01736	0.59	N.S.
SIZE X PROFILE	38	1.47167	0.03873	1.32	N.S.
HORIZON X PROFILE	76	2.80148	0.03686	1.25	N.S.
ERROR	152	4.47480	0.02944		

PLOT OF THE VARIATION OF THE ZIRCON CONTENT OF THE SAND

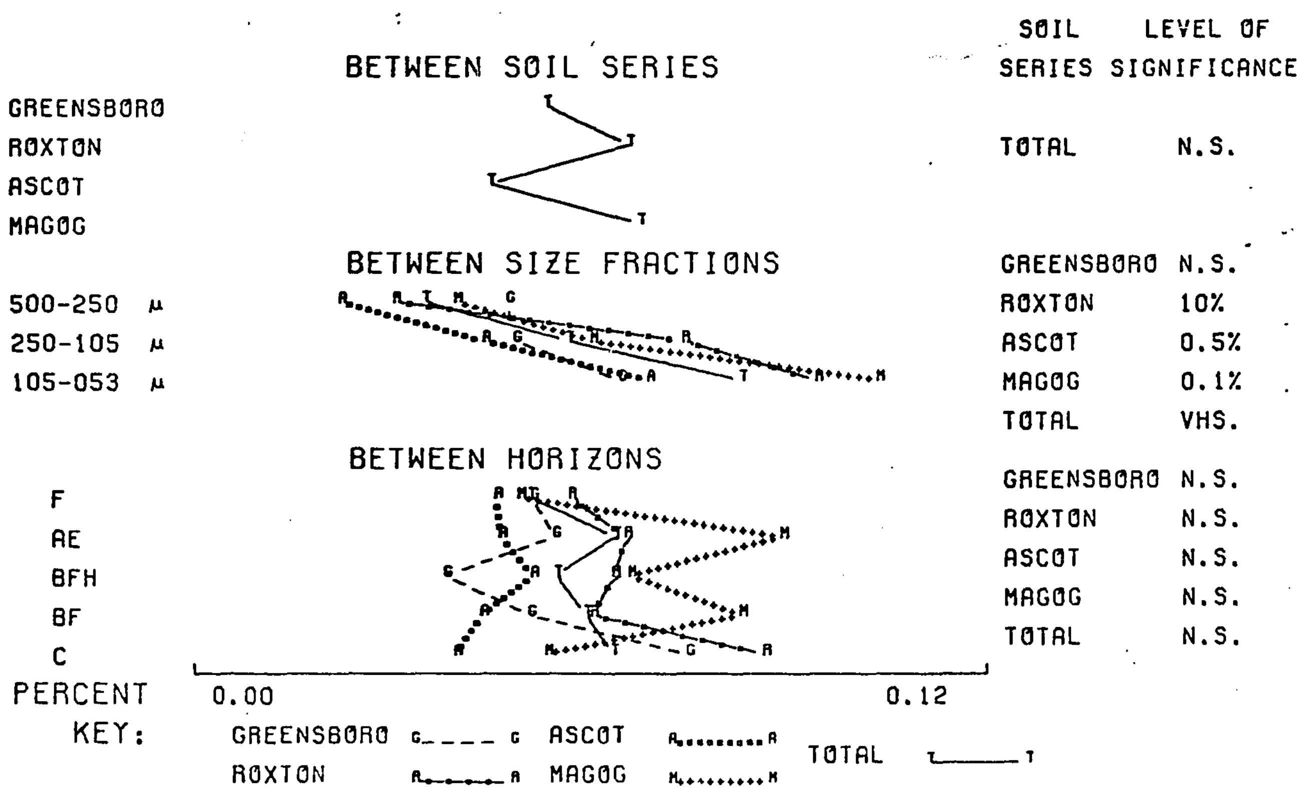


SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	5%
GREENSBORO	0.5%
ROXTON	5%
ASCOT	VHS.
MAGOG	5%
TOTAL	VHS.
GREENSBORO	N.S.
ROXTON	N.S.
ASCOT	N.S.
MAGOG	N.S.
TOTAL	N.S.

ANALYSIS OF VARIANCE TABLE FOR RUTILE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	0.02656	0.00885	2.43	N.S.
PROFILES (REPLICATES)	4	0.01392	0.00348	0.95	N.S.
ERROR	12	0.04380	0.00365		
SIZE FRACTIONS	2	0.11461	0.05730	15.67	VHS.
HORIZONS	4	0.00759	0.00190	0.52	N.S.
SIZE X HORIZON	8	0.05960	0.00745	2.04	5.0%
SIZE X PROFILE	38	0.15950	0.00420	1.15	N.S.
HORIZON X PROFILE	76	0.41160	0.00542	1.48	5.0%
ERROR	152	0.55575	0.00366		

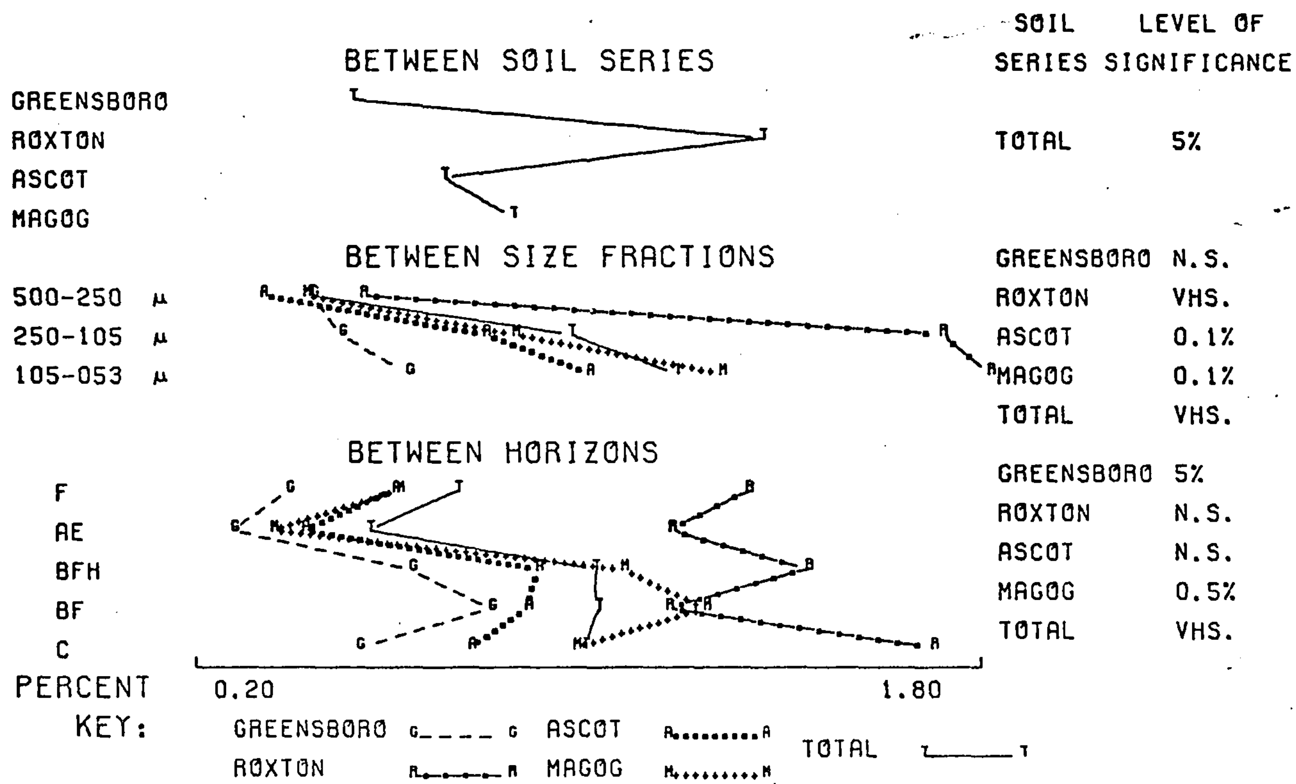
PLOT OF THE VARIATION OF THE RUTILE CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR ENSTATITE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	28.12366	9.37455	5.46	5.0%
PROFILES (REPLICATES)	4	4.53166	1.13291	0.66	N.S.
ERROR	12	20.60291	1.71691		
SIZE FRACTIONS	2	29.13553	14.56776	40.48	VHS.
HORIZONS	4	9.81269	2.45317	6.82	VHS.
SIZE X HORIZON	8	2.10541	0.26318	0.73	N.S.
SIZE X PROFILE	38	32.30048	0.85001	2.36	0.1%
HORIZON X PROFILE	76	42.18214	0.55503	1.54	5.0%
ERROR	152	54.70099	0.35987		

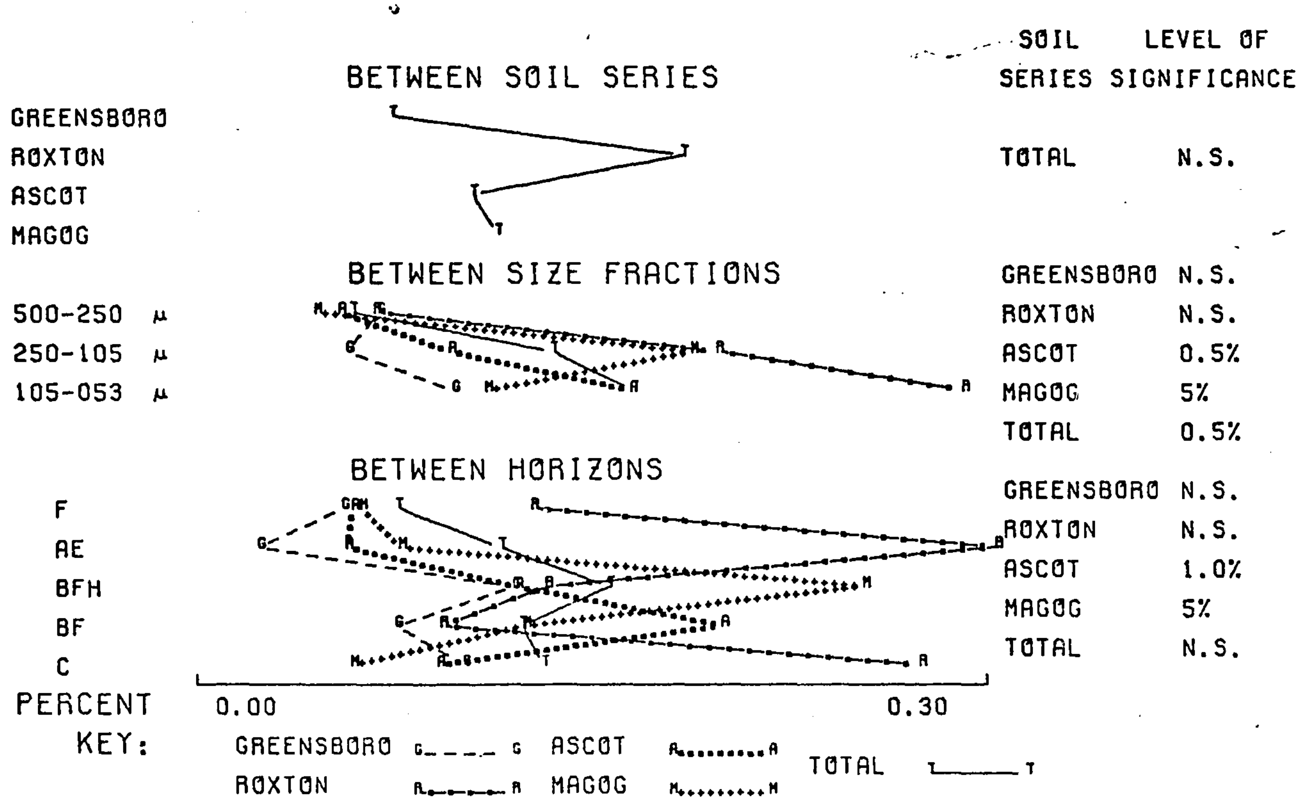
PLOT OF THE VARIATION OF THE ENSTATITE CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR AUGITE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	0.38318	0.12773	0.65	N.S.
PROFILES (REPLICATES)	4	0.26601	0.06650	0.34	N.S.
ERROR	12	2.34939	0.19578		
SIZE FRACTIONS	2	0.58173	0.29086	5.82	0.5%
HORIZONS	4	0.16249	0.04062	0.81	N.S.
SIZE X HORIZON	8	0.20587	0.02573	0.51	N.S.
SIZE X PROFILE	38	3.66325	0.09640	1.93	0.5%
HORIZON X PROFILE	76	5.18033	0.06816	1.36	10.%
ERROR	152	7.59850	0.04999		

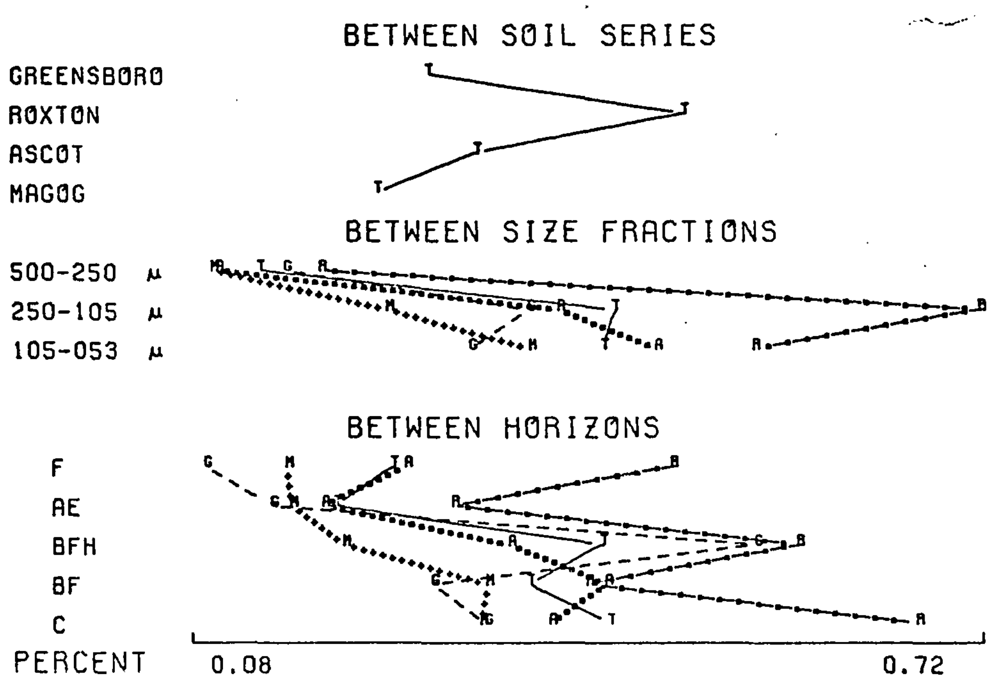
PLOT OF THE VARIATION OF THE AUGITE CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR MAGNETITE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	2.49361	0.83120	1.30	N.S.
PROFILES (REPLICATES)	4	0.82589	0.20647	0.32	N.S.
ERROR	12	7.70071	0.64173		
SIZE FRACTIONS	2	5.15074	2.57537	23.86	VHS.
HORIZONS	4	2.25449	0.56362	5.22	0.1%
SIZE X HORIZON	8	0.44469	0.05559	0.51	N.S.
SIZE X PROFILE	38	6.53830	0.17206	1.59	5.0%
HORIZON X PROFILE	76	9.50535	0.12507	1.16	N.S.
ERROR	152	16.40768	0.10795		

PLOT OF THE VARIATION OF THE MAGNETITE CONTENT OF THE SAND



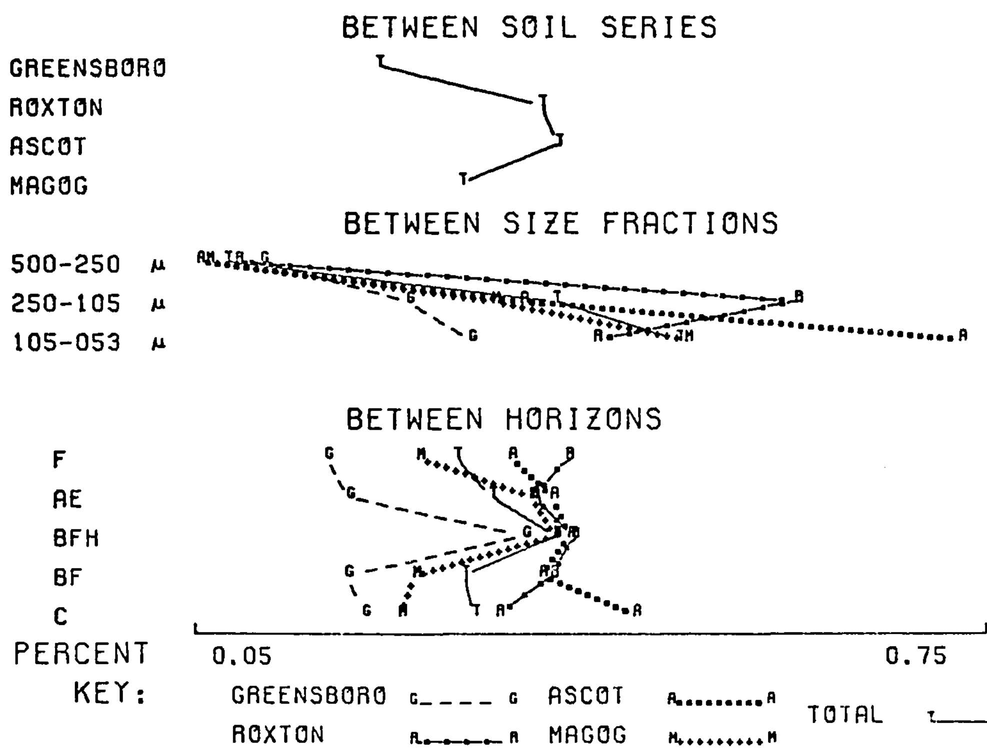
SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	N.S.
GREENSBORO	1.0%
ROXTON	1.0%
ASCOT	0.1%
MAGOG	0.1%
TOTAL	VHS.
GREENSBORO	0.1%
ROXTON	N.S.
ASCOT	N.S.
MAGOG	5%
TOTAL	0.1%

KEY: GREENSBORO G----G ROXTON R-•-•-R ASCOT A••••••A MAGOG M••••••M TOTAL T——T

ANALYSIS OF VARIANCE TABLE FOR ILMENITE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	1.17102	0.39034	1.79	N.S.
PROFILES (REPLICATES)	4	0.45524	0.11381	0.52	N.S.
ERROR	12	2.61857	0.21821		
SIZE FRACTIONS	2	8.48941	4.24470	93.61	VHS.
HORIZONS	4	0.29116	0.07279	1.61	N.S.
SIZE X HORIZON	8	0.29214	0.03652	0.81	N.S.
SIZE X PROFILE	38	5.99386	0.15773	3.48	VHS.
HORIZON X PROFILE	76	5.31548	0.06994	1.54	5.0%
ERROR	152	6.89253	0.04535		

PLOT OF THE VARIATION OF THE ILMENITE CONTENT OF THE SAND

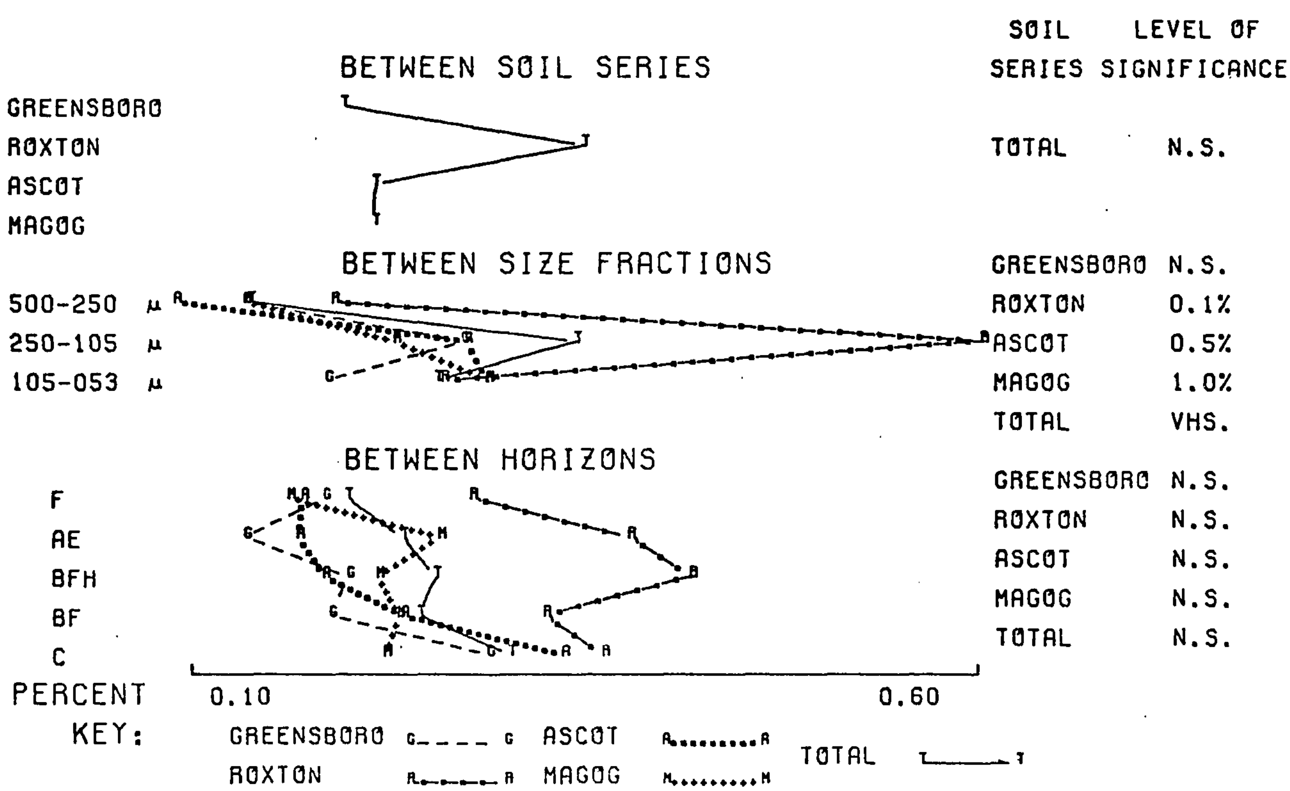


SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	N.S.
GREENSBORO	0.1%
ROXTON	VHS.
ASCOT	VHS.
MAGOG	VHS.
TOTAL	VHS.
GREENSBORO	5%
ROXTON	N.S.
ASCOT	N.S.
MAGOG	5%
TOTAL	N.S.

ANALYSIS OF VARIANCE TABLE FOR GARNET

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	0.99905	0.33302	2.29	N.S.
PROFILES (REPLICATES)	4	0.42423	0.10606	0.73	N.S.
ERROR	12	1.74418	0.14535		
SIZE FRACTIONS	2	2.23490	1.11745	25.53	VHS.
HORIZONS	4	0.31461	0.07865	1.80	N.S.
SIZE X HORIZON	8	0.20190	0.02524	0.58	N.S.
SIZE X PROFILE	38	4.50415	0.11853	2.71	VHS.
HORIZON X PROFILE	76	4.89906	0.06446	1.47	5.0%
ERROR	152	6.65394	0.04378		

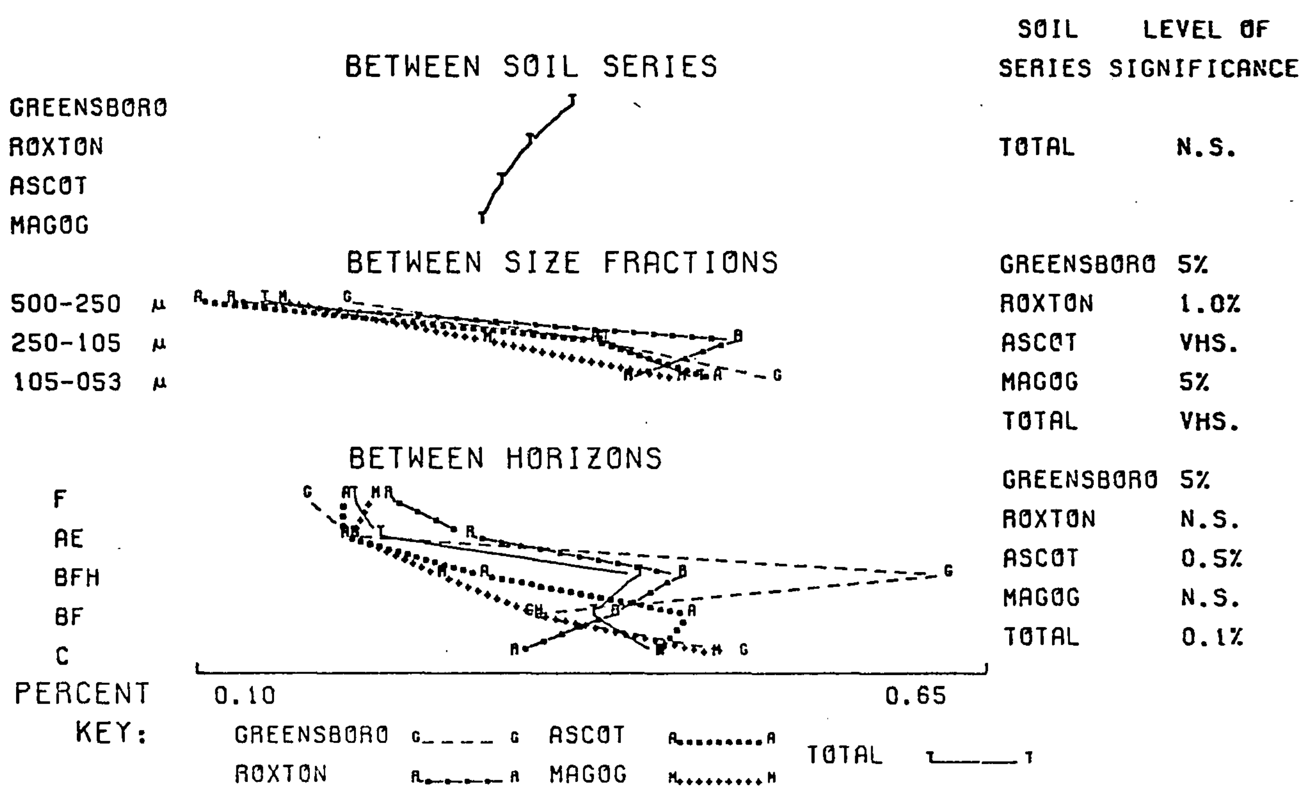
PLOT OF THE VARIATION OF THE GARNET CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR EPIDOTE

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	0.17095	0.05698	0.12	N.S.
PROFILES (REPLICATES)	4	1.07298	0.26825	0.58	N.S.
ERROR	12	5.51578	0.45965		
SIZE FRACTIONS	2	4.97009	2.48505	23.48	VHS.
HORIZONS	4	2.28024	0.57006	5.39	0.1%
SIZE X HORIZON	8	0.97195	0.12149	1.15	N.S.
SIZE X PROFILE	38	3.04212	0.08006	0.76	N.S.
HORIZON X PROFILE	76	13.38235	0.17608	1.66	0.5%
ERROR	152	16.09012	0.10586		

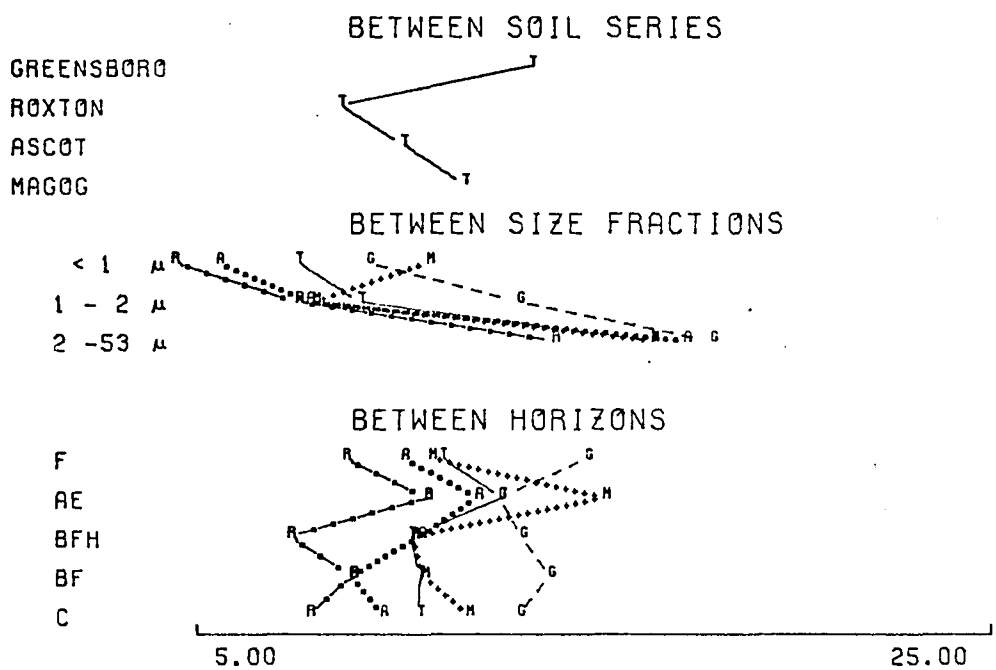
PLOT OF THE VARIATION OF THE EPIDOTE CONTENT OF THE SAND



ANALYSIS OF VARIANCE TABLE FOR QUARTZ (SILT AND CLAY SIZES)

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	1961.3	653.76	1.97	N.S.
PROFILES (REPLICATES)	4	4046.8	1011.7	3.05	10.%
ERROR	12	3977.8	331.48		
SIZE FRACTIONS	2	3683.1	1841.5	13.83	VHS.
HORIZONS	4	1240.7	310.18	2.33	10.%
SIZE X HORIZON	8	1055.0	131.88	0.99	N.S.
SIZE X PROFILE	38	3688.8	97.074	0.73	N.S.
HORIZON X PROFILE	76	24931.	328.04	2.46	VHS.
ERROR	152	20247.	133.20		

PLOT OF THE VARIATION OF THE QUARTZ CONTENT OF THE FINES



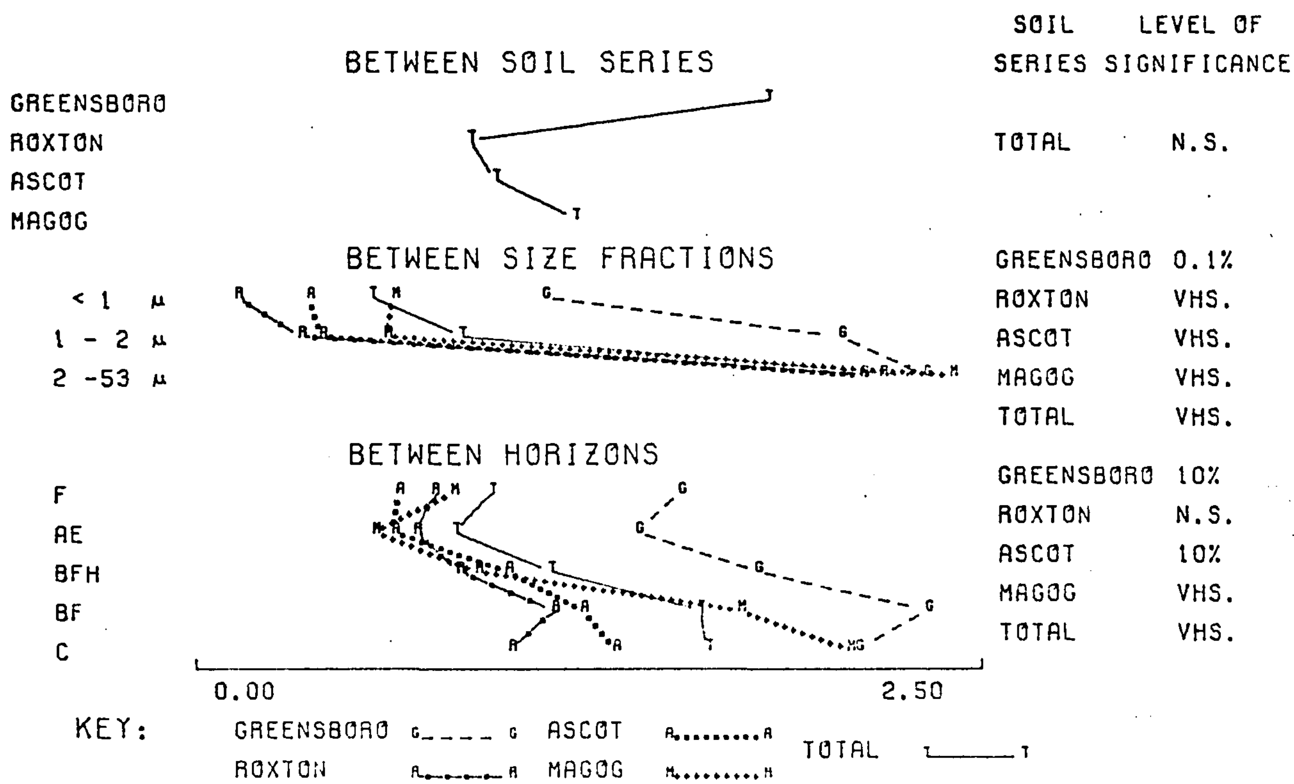
SOIL SERIES	LEVEL OF SIGNIFICANCE
TOTAL	N.S.
GREENSBORO	VHS.
ROXTON	VHS.
ASCOT	VHS.
MAGOG	VHS.
TOTAL	VHS.
GREENSBORO	N.S.
ROXTON	VHS.
ASCOT	5%
MAGOG	VHS.
TOTAL	10%

KEY: GREENSBORO G----G ASCOT A.......A TOTAL T——T
ROXTON R-.-.-R MAGOG M.......M

ANALYSIS OF VARIANCE TABLE FOR PLAGIOCLASE (SILT AND CLAY SIZES)

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	29.931	9.9771	1.50	N.S.
PROFILES (REPLICATES)	4	33.998	8.4996	1.28	N.S.
ERROR	12	79.559	6.6299		
SIZE FRACTIONS	2	193.67	96.834	80.76	VHS.
HORIZONS	4	80.561	20.140	16.80	VHS.
SIZE X HORIZON	8	33.599	4.1998	3.50	0.1%
SIZE X PROFILE	38	98.352	2.5882	2.16	0.1%
HORIZON X PROFILE	76	395.61	5.2055	4.34	VHS.
ERROR	152	182.25	1.1990		

PLOT OF THE VARIATION OF THE PLAGIOCLASE CONTENT OF THE FINES



ANALYSIS OF VARIANCE TABLE FOR ORTHOCLASE (SILT AND CLAY SIZES)

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F RATIO	LEVEL OF SIGNIFICANCE
SOIL SERIES	3	36.339	12.113	14.64	0.1%
PROFILES (REPLICATES)	4	1.8880	0.47199	0.57	N.S.
ERROR	12	9.9263	0.82719		
SIZE FRACTIONS	2	15.352	7.6760	10.56	VHS.
HORIZONS	4	2.4258	0.60646	0.83	N.S.
SIZE X HORIZON	8	2.2101	0.27626	0.38	N.S.
SIZE X PROFILE	38	60.640	1.5958	2.19	0.1%
HORIZON X PROFILE	76	71.398	0.93945	1.29	10.%
ERROR	152	110.51	0.72705		

PLOT OF THE VARIATION OF THE ORTHOCLASE CONTENT OF THE FINES