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AN ABSTRACT OF THE THESIS OF

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Title WATER LOSS AND UPTAKE IN CLAYEY SUBSOIL MATERIALS

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Abstract approved

B and C horizon samples from twenty four selected profiles along a north-south transect in the Willamette Valley were examined for possible correlation between shrinkage properties and kind of clay minerals present.

Observations of linear shrinkage, weight loss from a condition of maximum plasticity, and changing character of X-ray diffraction patterns were made on 'tablets' of the untreated soil material during drying and subsequent heating at various temperatures to 950^oC. Differential thermal analysis of undried 'whole soil' samples was also made. On the basis of the X-ray diffraction patterns, soil samples were placed in five groups and a pair of B and C horizon samples from a profile representative of each group was selected for characterization of clay mineral suites by conventional X-ray diffraction analysis and differential thermal analysis.

Differences found in clay mineral suites of the five profiles justified the initial grouping and provided a basis for the attempt

to observe correlations between shrinkage behavior and the kind of clay minerals present.

Clays of the two-layer lattice type (kandites) were found dominant in most samples from the Salem Hills. A more detailed distinction of these was made between the red, acid, over-deepened colluvium dominated by kaolinite (with iron and aluminum hydrates associated), and those relatively shallow soils lying on profoundly weathered tuffaceous sediments which were characterized by dominance of poorly crystalline clays of both two-layer and three-layer lattice type (probably hydrated halloysite and smectite of the beidellite-nontronite sequence).

Clays of the three-layer lattice type (micaceous, or showing expansion properties) were dominant in soils on the valley floor. A further distinction of these was made between the silty soils showing micaceous material as well as other material of varying degrees of expansion, and those soils on alluvial clay which appeared to contain most or all of which was smectite (probably of the beidellite-nontronite sequence).

Detailed examination of shrinkage curves for two soil samples containing the same amount of clay, but of different mineralogy (kaolinite vis à vis smectite), failed to reveal differences in shrinkage due to differing lattice type. In general, a difference in shrinkage was not observed between those samples on the transect with dominantly three-layer lattice clays and those with dominantly two-layer lattice clays. Most of the variation in shrinkage could be attributed to variations in particle size and surface area, as

measured by clay content and water loss. The possibility of making distinctions in clay mineralogy on the basis of shrinkage in the field under other circumstances was not excluded.

WATER LOSS AND UPTAKE IN CLAYEY SUBSOIL MATERIALS

by

David Robertson Stannard

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"--- The influence on soil behavior of any one characteristic, or of a variation in any one, depends upon the others in the combination. ---"

p. 7 Soil Survey Manual

WATER LOSS AND UPTAKE IN CLAYEY SUBSOIL MATERIALS

INTRODUCTION

Posing a Question

If one asks a question, quite often the answer is foretold by the manner in which the question is asked. One ought, then, to take great care in formulating questions and illuminate as well as possible the field of their application. The present study is very generally concerned with the question whether clayey soils can be distinguished as to clay mineral type by simple tests of the bulk sample.

In its initial form, the question raised was whether one might assume under field conditions that evidence of shrinkage and cracking would be greater in the case of soils bearing 2:1 lattice(three-layer) clay than in those soils containing the 1:1 lattice(two-layer) type clay minerals. Certainly, it would be an advantage to be able to judge from observations of cracking and shrinkage in soils something about the kind of clay mineral present.

On the face of it, the answer to this question might seem almost obvious, since it is well known that many three-layer clays show considerable expansion upon hydration. For example, hydrated Na^+ saturated montmorillonite is known to swell to as much as eight to ten times its original dry volume (44). In contrast, this is certainly not true of kaolinite. However, the notorious complexity of soil systems suggests caution in trying to form an opinion about the effect on field

behavior of even this extreme range of difference in soil constituents.

Before considering the question of possible influence of differing clay minerals on gross shrinkage behavior in soils, or devising means of examining these relationships, it is important to bring to mind a detailed picture of the internal environment of soil.

One can easily visualize a complex aggregate of various mineral particles ranging in scale from sand size chunks down to small dimensions of the very thin plate-like clay crystals. It is also easy to visualize the open structure of various size pore spaces (both continuous and discontinuous) that develops in such an aggregate as it is constantly pushed and stirred about by the growth and waning of living things whose adhesive remains stabilize the complex of spaces being produced. Movement of water throughout the continuous pore space according to intricate cycles of the moisture regime gives no pause to the imagination, but the ubiquitous importance of water in both living and non-living systems at the earth's surface is so obvious that its unique influence is easily overlooked. One may fairly say that the geological process of weathering and the biological process itself are primarily an expression of the unique characteristics of water (38, 59). It is well, then, to examine in some detail the properties of this water substance so that soil dynamics at the ionic clay lattice scale may take form in the mind's eye.

Review of Hydration Phenomena

Characteristics of Water

Two primary characteristics account for much in the cluster of unique properties of water: a strong tendency toward 'hydrogen bonding', and a very large dipole moment. Both of these characteristics derive from the charge structure of H_2O (which can be roughly described as an oxygen atom with a pair of protons and the non-bonded electrons tetrahedrally oriented at its surface).

In water, each hydrogen atom (being a proton plus an electron) is attached to the oxygen by its single primary valence bond. However, each of the two protons thus exposed at the surface of the oxygen is also attracted to the non-bonded electrons of adjacent oxygen atoms--with a 'bond' strength that is midway between van der Waals forces and that of their primary valence bond. In this way, water can be considered a 3-dimensional net of oxygen atoms each of which is held in tetrahedral orientation to four nearest neighbors by these protonic linkages. Thus, its uniquely high heat capacity, heat of vaporization, surface tension, internal pressure, boiling and freezing points, expansion on freezing, dipole moment, dielectric constant, ionic solution properties, etc. all are expressions of its unusual charge configuration and consequently structured associative tendency (43, p. 6). Examination of reactions in the field of surface chemistry demonstrates the striking consequences of this.

In considering the soil system, where virtually all of the

enormous solid surface area present (many acres of solid-liquid interface in a handful) is expressed as a planar array of oxygen or hydroxyl ions, and where virtually all chemical transformation takes place within aqueous limits (39, p. 66), the overwhelming influence of these peculiar characteristics of water cannot be exaggerated. In fact, adequate emphasis would demand that such an aqueous system be considered as possessed of four major physical states: solid, structured fluid¹, liquid, and gaseous phases. Certainly in this study, which finds itself concerned with hydration phenomena in a primarily colloidal system, such emphasis upon a 'fourth phase' for water is considered essential.

Soil Factors Affecting Hydration

Hydration of the soil system is primarily influenced by the character of particle size distribution; for not only is the surface area available for association with water thus described, but also the character of voids present is thereby determined.

However, the apparent simplicity of the term 'particle size' hides a number of complicating factors. Among particles of sand and silt size, it might be roughly correct to assume that most particles are approximately equilateral in dimension; and that they present charged surfaces to aqueous contact which are roughly similar. In

1

This lattice-ordered state for water ('multi-layers', 'bound water', 'liquid crystal', 'structured water', 'two-dimensional fluid', 'ice', etc.) may extend thousands of angstroms from a solid ionic surface into the surrounding medium (52, p. 14).

any case, the ratio of a particle's solid surface-area to its volume would be relatively so small that variation in its proportions or variation in surface charge density among particles would have little effect on gross properties of the system. Therefore, if the soil contained only sand and silt size particles, hydration phenomena could be fairly simply described and influencing factors would then be confined mainly to particle size distribution and the structure of voids generated by particle aggregation.

But, in the presence of even small amounts of fine colloidal material, hydration phenomena are greatly complicated. With more colloidal material, not only is the absolute amount of solid surface area available very rapidly increased, especially due to the plate-like and laminar nature of clay particles, but also the charge density of these surfaces is often disproportionately increased as a consequence of unsatisfied internal binding forces of the clay lattice. (Increase in hydration capacity due to high surface-to-volume ratio of the clay leaflets is, of course, even more exaggerated in those soil systems containing colloidal material of organic nature since, in this case, the particles are often linear arrays of polar groups.) Furthermore, since the various exchangeable cations found in soils have widely differing hydration tendencies, it would be expected that the particular kind of surface-bound cation also influences hydration processes and consequent dimensional changes in the system(22, p. 21).

Modes of Measurement

Many methods in the study of clays have been devised which measure

associated changes in the system as the state of hydration is varied. Because attention in these studies is usually directed toward identifying and characterizing the various clay minerals present, it is perhaps not at once obvious that many of these methods are dealing with essentially the same hydration phenomenon; and that, therefore, some special advantage might be offered to study of the more complex aspects of a soil system by simultaneously applying several such hydration dependent methods to a single sample.

In the present case, four common methods of analysis were used, in a simplified form, on each field sample chosen for study: 1) X-ray diffraction analysis of basal spacing in the clay lattice, 2) differential thermal analysis (D.T.A.), 3) weight loss curves, and 4) shrinkage curves. X-ray diffraction and shrinkage studies measure changing distances as water is added or removed from between layers of the material. The weight loss and D.T.A. curves both record loss (by heating) of volatile material, primarily lattice-associated water and carbon dioxide: in the former method, loss of weight is recorded; but in the latter, it is the concomitant changes in energy of the system. Furthermore, the X-ray diffraction analysis and D.T.A. may both detect the same phase changes-- since heat induced loss or alteration of crystal structure usually results simultaneously in dimensional and energy changes.

Of the four methods, X-ray diffraction analysis and D.T.A. are clearly most valuable as means of characterizing the kinds of clay minerals present since both measure quantities directly related to the crystal lattice itself. In contrast, shrinkage relates primarily

to changes in spacing between particles and is, like weight loss, a general property of the whole system. Coupling these four methods of study, then, might help to clarify the subsidiary contribution of clay mineral properties to more general behavior of the whole system.

Concerning the Uncertainty PrincipleLaboratory 'Weathering'

Perhaps the greatest (and most subtle) restraint on understanding a dynamic soil system lies in the inevitable uncertainty as to just how an examination will perturb the system. Such concern must be particularly acute in the case of dominantly colloidal systems, since much of the material under examination is 'all surface' and therefore in a state of incipient chemical (structural) change. Under these conditions the uncertainty is minimized, not by preventing perturbation, but by properly gauging its effect. Examination of a single sample in multiple ways offers particularly good hope in this respect.

An excellent example might be the difficulty attending efforts to assess particle size distribution in profoundly weathered soils of high clay content such as those considered in the present study. Samples #7_a-48" and #17-24", both taken from C horizons in the Salem Hills, are strongly weathered tuffaceous material. Standard treatment to determine particle size distribution led to an estimate, in both cases, of about 60 percent sand size particles and five percent clay. This is wildly at variance with other information gathered on these samples: a high total C.E.C., considerable shrinkage, much moisture held at 65°C, and very large D.T.A. endotherms (Appendix, p. 95 and p. 105).

Surely, the concept of particle size distribution is, at best, misleading in cases where gravel and sand size particles are found

to behave like lumps of clay. In such saprolytic material one must take as suspect the image of weathered rock as being composed of adhesive discrete particles. Nor is there any assurance that laboratory separation takes place either between the ghosts of original grains or along new mineral boundaries. Yet there is no doubt that the material possesses a general and relatively stable macro-structure even though it has physical and chemical properties of very clayey material.

The problem was self-imposed in the sense that a simplifying assumption (concept of particle size distribution) was applied to the system when not appropriate and, therefore, the complex condition under study could not survive the attempt to analyze it.

A second example, concerning a more delicate structural condition in the soil system which affects its moisture regime and yet which may disappear under the rigors of examination, is to be found by comparing D.T.A. patterns made from field samples equilibrated under controlled relative humidity with those equilibrated after the soil sample was dried, dispersed, and fractionated (Figures 2_a and 2_b). If the shape and size of first endothermic peaks are studied, it can be readily seen that those of the field equilibrated samples are both larger and sharper than any of the fractionated samples. It has been demonstrated that the area subsumed by the curve of the first endotherm is related to the amount of water physically bound at mineral surfaces (36, p.102). Peak sharpness is a qualitative indication of nearly simultaneous absorption of energy throughout the system. Thus, one may suppose that a high degree of organization

in the colloidal material and associated layers of 'structured fluid' exists in the field which is destroyed when the sample is dried, dispersed, and fractionated; and that this field condition is not readily resumed upon rehydrating the laboratory material. (Comparing X-ray patterns of untreated and treated material also suggests this kind of loss.) Because of this form of uncertainty, it is common practice, then, to equilibrate samples directly from the field when trying to study materials of amorphous or poorly crystalline nature.

Soil Structure

If, as just indicated, the moisture regime can be irreversibly disturbed by altering organization of the soil system at colloidal dimensions, then an equivalent irreversible relation between moisture regime and gross structural organization ought to be even more evident at the visible scale. This relation is, of course, well established; and agricultural practices in the field are strongly affected by consideration of it (4, p. 130-195; 45, p. 423-446; 13, p. 58-64). The point to be made here is that in considering a general property of the soil system (such as shrinkage), one might suspect that its expression would be strongly affected by the existing soil structure. The way in which the present study chose to accommodate itself to this complicating factor can be found in the chapter, which follows, discussing methods of sample selection and procedure.

METHODS

The Selection of Samples

In selecting field samples for this study it seemed appropriate that one seek, within a limited geographic area and uniform climate, a maximum range of clayey soil types. Certainly the range ought to include soils differing widely in kind of clay mineral-- i.e., kandites (two-layer) vis à vis smectites (three-layer fully expanding lattice).

Limiting examination of the soils to those under uniform climate in a restricted area would, of course, reduce the likelihood of encountering samples of the most extreme contrast in shrinkage behavior. For example, the present study includes no soils of dry climate, and consequently contains no examples of Na^+ saturated clay. On the other hand, it seemed likely that comparisons could be made, and the predicates of shrinkage in undisturbed soil could be much more reliably inferred, if one were to select a set of samples out of some natural continuity.

A preliminary plan to select samples from benchmark soil locations situated within the Willamette Valley was revised when an opportunity came in the Summer of 1962 to follow pipeline diggings¹ from Portland to Eugene. In this way it became possible to select samples from a four to six foot deep continuous trench as digging proceeded in a

¹ Southern Pacific Pipelines, Inc.

north-south line down the center of the Willamette Valley. Undisturbed B and C horizons of more than 100 profiles on this transect were sampled. Of these profiles, 24 were subsequently chosen for laboratory examination and use in the thesis. The main criteria for selection were field evidence of high clay content and, to a lesser extent, indications that the profile was fairly representative of its particular class of soils.

Although field notes included topographic features, moist color readings, and major profile characteristics, movement along the transect was too rapid to permit detailed examination of any single profile. For this reason, series names assigned to the sampled profiles (Appendix, #1 through #24) must be taken as generally descriptive of the soils, rather than a confirmed classification of each one. Likewise, the horizon designations are provisional.

On the basis of field observations and some preliminary X-ray analysis and D.T.A., twelve soils along the transect in the Salem Hills were selected in the expectation that their clay fractions would provide dominantly two-layer material (Appendix, samples #5, and #7 through #17). Twelve more sample locations were selected from points along the transect in the valley, both to the north and south of the Salem Hills. These soils, most of them on the uniform silty deposit of the broad valley floor (Willamette silts), could be expected to contain clays primarily of three-layer type lattice; and since about half of them fell into the Dayton series, one could assume from previous X-ray diffraction evidence (59) that some member of the smectite group (perhaps montmorillonite) was well represented in the

sampling.

Thus, 24 profiles were selected at points along the length of the transect over a north-south distance of about 100 miles, extending from the first sampling in colluvial silt on the lower north slope of Bull Mountain, through deep, red, acid soils of the Salem Hills, and to a point in the valley south of Harrisburg where Willamette silts have thinned to a three foot depth. Figure 1 (p. 15) shows the geographic location and elevation of profiles sampled along the transect. (Photographs in Plate I on the opposing page, and encircled sample numbers along the transect diagram refer to five representative profiles out of the 24 which were selected for detailed study through X-ray diffraction analysis and D.T.A. by conventional means.)

SELECTED PROFILES.

#6
(Willamette) →



← #10
(Jory)



↑ #16
(Peavine-like)

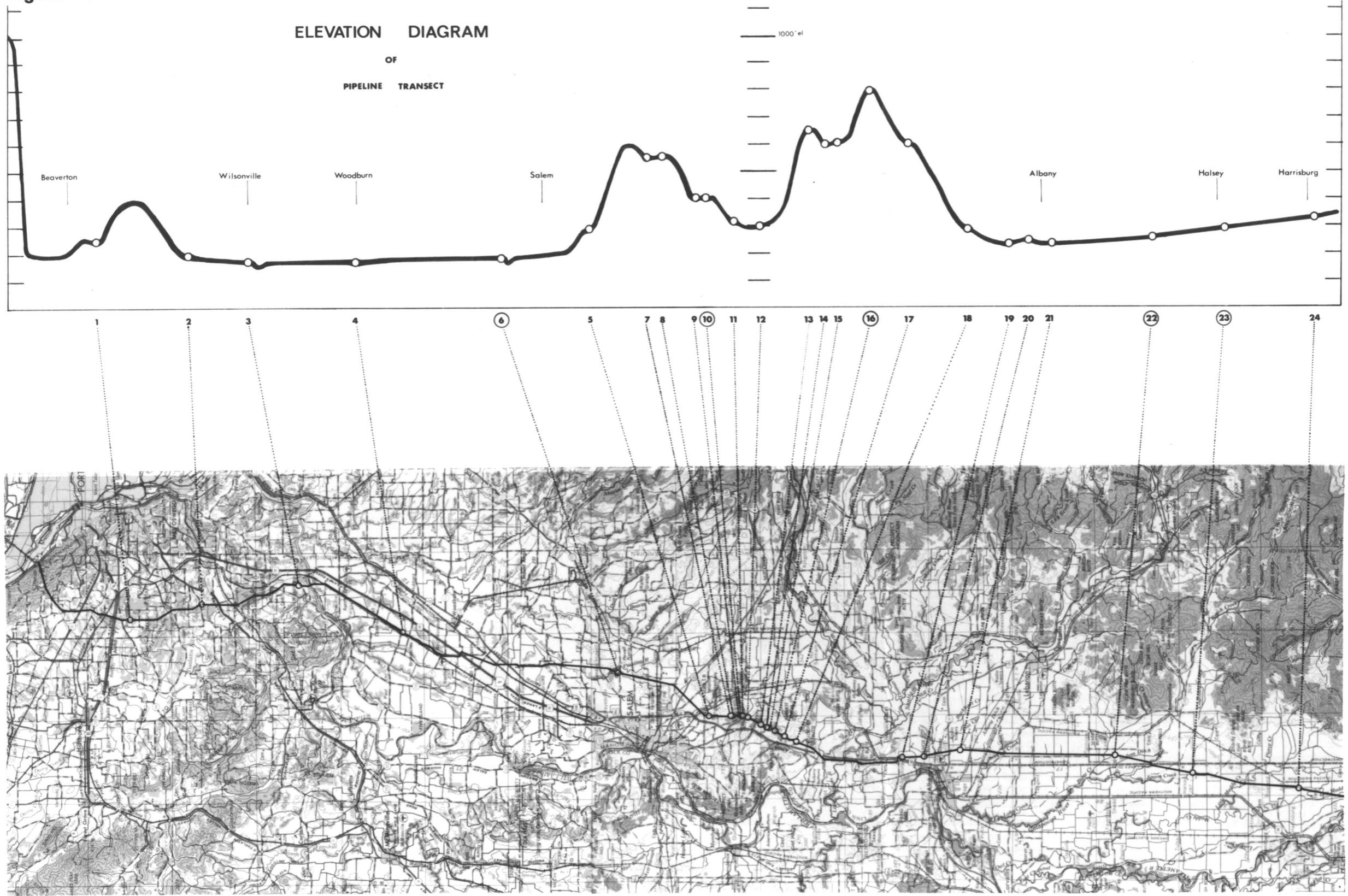


↑ #22
(Cove)



→ #23
(Dayton)

Figure 1



Standard Procedures UsedpH, Exchangeable Bases, and C.E.C.

Considerable evidence is available to show that moisture-dependent conditions in the soil system are profoundly influenced by the ionic state existing at clay surfaces. Grim says: "Adsorbed components may largely control the nature and the extent of oriented water development, and of these inorganic cationic components are probably the most important. ---" (22, p.20). Accordingly, measurements were made on all samples to determine pH, exchangeable bases, and total cation exchange capacity (see Appendix). These measurements were provided by the Oregon State University Soil Testing Laboratory (1).

Mechanical Analysis

Particle size distribution in all samples, both of B and C horizons, was determined for the 24 locations selected. The procedure followed was a slight modification of the Kilmer and Alexander pipette method (34), as currently used in the Oregon State University Soil Physics Laboratory.

A ten gram sample, treated repeatedly with H_2O_2 over a water bath for organic matter removal, is dried overnight at $110^{\circ}C$, weighed, and then dispersed by addition of five percent Calgon with subsequent use of an air jet. The sand fraction is retained on a 300 mesh sieve and washed until the silt-clay suspension reaches a volume of 1130

milliliters. The sedimentation rate is then established under carefully controlled temperature conditions, and a 25 milliliter sample of suspension withdrawn at a moment and depth appropriate for quantitative estimation (by dry weight) of the clay fraction. Silt fraction is calculated as the difference between the total original weight and the weight of sand plus calculated weight of clay.

X-ray Diffraction Analysis

The B and C horizon samples from five profiles were selected for conventional pre-treatment and X-ray diffraction analysis (Table 3, p. 30) and for comparison with results from a 'tablet' technique (Figures 5_a to 9_b, p. 49 - 53). These profiles selected were representative of groups (p. 55) suggested by prior X-ray diffraction patterns obtained through the novel 'tablet' technique (p. 20) for the samples from 24 locations. This grouping corresponds to classification in the field.

For the five pairs of selected samples, the silt-clay Na⁺ saturated dispersions remaining after mechanical analysis were separated by sedimentation and centrifugation (31, p. 101-164) into silt fraction, 2-0.08 μ clay, and <0.08 μ clay. After centrifugation it was noted that, in each case, the 2-0.08 μ clay sediment consisted of two layers. Deposition of opaque light-colored material, thrown down in early stages of centrifugation, was followed with a fairly abrupt transition by deposition of translucent darker-colored material. After drying overnight at 105^oC, separation was made between these

layers with a razor blade. The clay fractions in Table 3 and Figures 2_a to 4_b described as 2-0.08 μ (c) or 2-0.08 μ (f) have reference to this arbitrary division into 'coarse' and 'fine' portions of the 2-0.08 μ clay fraction.

Subsamples of silt and clay fractions were saturated with Ca⁺⁺ and K⁺ cations (14, p. 21-22) and smeared (54) on petrographic microslides. These films of clay, with c-axis of the crystal lattice oriented normal to the microslide, were then examined with the X-ray diffractometer¹ to obtain patterns of basal spacing extant under the various conditions of ion saturation, solvation, and heat treatment used. Major peaks discernable in X-ray patterns from the silt and clay fractions are reported for the following treatments: Ca⁺⁺ saturation and heating to 65°C, Ca⁺⁺ saturation and solvation with ethylene glycol, and K⁺ saturation with sequential heating to 65°C, 150°C, and 550°C (Table 3, p. 30).

Differential Thermal Analysis

Subsamples of the silt and clay fractions which had been separated and Ca⁺⁺ saturated as described above were used for differential thermal analysis. The samples were dried, pulverized to pass through 140 mesh, and then equilibrated for more than two weeks in an atmosphere of about 55 percent relative humidity. This procedure was based upon the suggestion of Mackenzie (36, p. 51).

1

Diffractometer equipment consisted of a Norelco diffractometer with Geiger-Mueller tube, Brown recorder, and used Cu K α radiation.

The instrument used for analysis is one which was designed by M. E. Harward, Oregon State University, in cooperation with O. Kofoid and technicians from Minneapolis-Honeywell Company, and offers the possibility of simultaneously recording the temperature differentials of six unknown samples against the reference inert material of oven-dried, dessicated, 280 mesh alumina. The bell type bottom-loading furnace comes down over a stationary cylindrical Inconel sample block containing eight symmetrically disposed cavities three eighths inch by one half inch deep. Remote-junction, Inconel sheathed, Chromel-Alumel thermocouples are centered in each cavity. Furnace and reference temperatures are measured in cavities filled with the inert standard. A linear heating rate of 10°C per minute is obtained by use of a saturable core reactor and an automatic current proportioning program control circuit. Temperature differentials registered by the six unknowns with respect to the inert standard are recorded independently on the same time base with a Brown potentiometric recorder, up to a temperature of 1000°C .

During each 'run', the six cavities for unknowns were filled with: a 'whole soil' sample equilibrated directly from its moist field condition, four Ca^{++} saturated silt and clay fractions from that same soil, and an inert control sample of dessicated alumina. By a careful routine, cavities were packed to hold approximately one gram of material. All samples from which curves shown in Figures 2_a to 3_b were derived were of similar weight (± 15 percent). Curve D of Figure 4_a and curves C to E of Figure 4_b were derived from considerably smaller quantities, layered between alumina.

New Procedures Used

Preparation of 'Whole Soil' Tablets

In geologic studies, slabs of consolidated material are often cut to suitable dimensions and inserted directly into the sample holder of an X-ray diffractometer. In clay mineralogy studies, orientation of depositional layers in the sample normal to the X-ray beam determines whether the crystal planes are registered on the X-ray patterns, since it is primarily the basal spacings which provide criteria for identification.

Preliminary efforts to apply this technique to horizontal and to vertical cut surfaces of peds taken from the B₂₁ horizon of a Dayton profile did not provide patterns easily read at angles below 14 degrees 2 θ . However, when surfaces were moistened and polished in a single direction, the intensities of basal reflections were considerably improved.

Linear shrinkage studies were made on vertical and horizontal cut surfaces of peds from this same horizon, and also on the surface of a 'mixed' sample that had been kneaded into a uniform mass by squeezing, rolling, and repeated folding. The results suggested that there might be small directional differences in shrinkage of the undisturbed clayey peds, and that they were of the same order of magnitude as differences between the field-oriented and the disoriented (mixed) samples. Therefore, and since indeterminate differences of soil structure might confuse forthcoming evidence of the clay mineral

contributions to shrinkage behavior, it was deemed the better of alternate courses in this study to put aside possible influences of any field orientation and macroscopic structure by subjecting all samples to a uniform mixing treatment and pre-determined moisture content.

Samples taken from the field were air dried, crumbled, and slaked down overnight with distilled water. The mixing (plasticizing) of about 30-40 grams of sample was accomplished by a process of repeatedly (50 times) rolling the moist material into a rod and then folding it. Small additions of water were made, as required, to develop and maintain a clayey mass of uniform and maximum plasticity (3,5323,18). Techniques of measurement are numerous, and somewhat dependent on the use intended. In this study, when the addition of water to the repeatedly extruded clayey mass resulted in an abrupt loss of cohesive strength, that point was recognized as the condition of maximum plasticity. Its limits for reproduction in any given clayey material are surprisingly narrow. It is here called the Plastic Limit, and corresponds to a fairly precise concept: being that condition reached in the progressive wetting of oriented particles when the growing layer of 'bound water' has thickened enough to exhaust available surface forces. With further addition of water, the cohesive dipolar water molecules no longer serve to continue the bridging action between particle surfaces, and the binding forces fall rapidly away.

At the time of mixing each sample and bringing it to its Plastic Limit, an estimate was made of its relative plasticity at that limit. This measure of relative plasticity is similar to the method described

in the Soil Survey Manual (51, p. 132). The method has been made more precise by selecting a specific indication of moisture content and be closely observing the character of rupture (breaking, cracking, or tearing) of the clayey material while it is being folded. These values are recorded in the Appendix as the plastic estimate (Pl. Est.) and defined in Table 1. They were intended only to suggest some relative measure of variation among the samples tested. However, this technique may provide a basis for improving estimates of plasticity in studies of field morphology.

Table 1. Plastic Estimate Values

(-4),(-2)	<u>Nonplastic</u> ; roll scarcely coheres
(-1),(+1)	<u>Slightly plastic</u> ; breaks during folding
(+2),(+3)	<u>Plastic</u> ; cracks during folding
(+4),(+5)	<u>Very Plastic</u> ; tears during folding

Each plasticized roll of soil material, about five centimeters in length, was then thrown repeatedly onto a hard smooth surface (reversing the slab-face each time) until a rectilinear tablet about one centimeter thick had been formed with roughly parallel and planar faces. In the interest of improving the X-ray patterns to be read

from the tablet surfaces, the edge of a petrographic slide was repeatedly drawn across the damp face of the tablet at an acute angle until a flat smooth surface remained. The two arms of a pair of vernier calipers, adjusted five centimeters apart, were pressed into the flat face of the tablet so as to leave indented marks for subsequent shrinkage measurement. These tablets were lined up on coarse paper towels and set aside on a laboratory bench away from noticeable drafts, to be measured and weighed at two hour intervals thereafter.

Shrinkage and Weight Loss Measurements

The accuracy in reading tablet marks with the vernier calipers was about ± 0.1 millimeter, that is, about ± 0.2 percent. Caliper readings were made just prior to weighing each sample, and the same sequential order of readings was maintained during all the occasions of measurement so as to preserve among the samples comparative lengths of time for shrinkage and weight loss. Measurements were continued for some time beyond the point where shrinkage had almost stopped, though at successively longer intervals, until loss of moisture stopped or was reversed.

Air dry tablets were then subjected to successive periods of heat treatment and rehydration as follows: three hours at 65°C , three hours at 150°C , eighteen hours at 65°C and 100 percent relative humidity¹, one hour at 300°C , one hour at 550°C , and one hour at 950°C .

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Samples were sealed off (under initially reduced pressure) in a vacuum drying oven in the presence of a free water surface.

At the end of each heating period the tablets were placed in a desiccator, measured for change in weight and length, and then submitted to X-ray diffraction analysis by direct insertion into the sample holder.

Choices of temperature and heating times were in part based on preliminary X-ray diffraction analysis and studies of shrinkage and weight loss covering more extended periods of heating. None of the heating periods were held to a point of constant weight; but do represent conditions of slow weight loss. One should note the fact that heating temperatures used correspond to intermediary points between major peak areas on the D.T.A. curves (Appendix). The reference condition used in calculating shrinkage and weight loss percentages was 300°C, one common to dehydration studies reported in the literature (e.g., Ross and Hendricks, 44, p. 23). This is a temperature at which most clay minerals are still stable, and little or no 'bound water' remains.

X-ray Analysis and D.T.A. of Untreated Material

The tablets were examined in the X-ray diffractometer at six points in the course of dehydration and heating. The first pattern (labeled 'wet' in Figures 5_a to 10_b, and in the Appendix) was taken at a time near the end of the air drying period. At this point, the edges had dried to a lighter cast, but a central area of the tablet face in purview of the X-ray beam still held its damp, darker cast. This non-equilibrated state of hydration was chosen in

deference to maintaining a relatively uniform condition for drying during the measurements of shrinkage in the tablets. Position was marked in the sample holder in such a way that all later X-ray patterns were obtained from precisely the same area on the tablet face.

In preparation for D.T.A., samples were brought moist from the field, crumbled, and equilibrated in an evacuated desiccator over saturated $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ for about three months before the recording of patterns shown in Figures 10_a and 10_b, and in the Appendix. Analytical procedures were followed as outlined on p. 19, with pairs of B and C horizons from three transect locations in each 'run'.

DISCUSSION

Clay Mineral IdentificationEvidence from Standard Methods

The initial objective was to consider the possible relation between shrinkage phenomena in soil materials and the preponderant clay minerals present. Conventional X-ray diffraction and differential thermal analysis were used to identify the clay minerals in ten samples from the five representative profiles. Table 3 (p.) presents the basal spacings (A°) from peaks evident in the X-ray patterns. The spacings for major peaks have been underlined.

#6 Willamette. (a) Micaceous material is present in the coarse fractions. (b) There appears, in addition, 14A material¹ (suggesting vermiculite or smectite) which in the coarse fractions is expanded beyond 16A when solvated, and fully collapsed to 10A in K^+ saturation at 65°C. As particle size decreases, this material exhibits progressively greater expansion when solvated and less complete collapse in K^+ saturation (suggesting hydroxy interlayering). (c) The 7A peaks that appear in 2-0.08 μ clay fractions of the B horizon (#6-18") would imply the presence of a kandite and/or some chloritic material;

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Most peaks in the 14A region of the patterns, both after standard treatment and from tablets, appeared at between 14.7-15.2A, which is typical for Ca^{++} saturated clays. For convenience and clarity, these peaks will all be referred to as 14A peaks.

the slight shift of peak position in the solvated specimen of the 2-0.08 μ (f) fraction (as though it were a second order reflection of the expanding material) would favor the latter interpretation.

#10 Jory. (a) Kandite is predominant in all fractions. (b) There is evidence of micaceous material in the #10-50" silt fraction, and partially expanding material in the coarse clay fraction, but none at all appears in the finer fractions.

#16 Peavine-like. (a) There is some indication of micaceous material in the silt fraction of the B horizon, but none in any of the clay fractions or in the underlying saprolite (#16-27"). (b) In all clay fractions there is a well expressed peak suggesting three-layer material that collapses in K⁺ saturation much as described in the Willamette clay fractions, but apparently less well crystallized and subject to more complete expansion under solvation. Broad peaks in the fine fractions under K⁺ saturation suggest hydroxy interlayering. (c) Kandite is clearly present in the 2-0.08 μ clay fractions, but not evident in the <0.08 μ clay fractions (which, in the case of the saprolitic C horizon, comprises half the entire sample). (d) A prominent 9A peak, which appears only in the silt fractions, could have reference to the presence of zeolitic material.

#22 Cove. (a) All clay fractions show a major well expressed 14A peak in Ca⁺⁺ saturation which shifts on solvation to 17-19A, and collapses to 10A on K⁺ saturation. The main three-layer material evident shows strong expansion and collapse properties. In this respect, Cove resembles Peavine-like material more than Willamette or Dayton which show significant amounts of non-expanding and partially expanding

material. (b) Kandite (if not chloritic material) is evident in the 2-0.08 μ clay fractions only.

#23 Dayton. (a) Micaceous material appears in the silt and coarser clay fraction, though not in the finer fractions. (b) In addition, there is material with the 14A spacing which has expansion properties parallel to those described for the Willamette samples: expansion to 16A when the silt fraction is solvated, and progressively increasing to 17-19A in the finest fractions. There is chloritic material; there may or may not be kandite. The signs of chloritic material parallel those described for Willamette, though their expression is stronger and appears in silt fractions as well as the 2-0.08 μ clay. (c) It is notable, also, that 7A peaks appear in the Dayton under K⁺ saturation and low temperatures in the absence of any 14A peaks. (This is true of the Cove and Peavine-like samples, as well.) The 2-0.08 μ (f) clay fraction shows a shift of its 7A peak after solvation like that described for the Willamette B horizon sample.

Table #2

	SAND	SILT	CLAY	CLAY FRACTIONS	
	(2mm-50 μ)	(50 μ -2 μ)	(< 2 μ)	(2 μ -0.08 μ)	(< 0.08 μ)
#6-18" WILLAMETTE	7%	65%	28%	21%	7%
#6-54"	18%	68%	14%	10%	4%
#10-30" JORY	16%	29%	55%	36%	19%
#10-50"	17%	34%	49%	33%	16%
#16-14" PEAVINE-LIKE	22%	37%	41%	28%	13%
#16-27"	5%	9%	86%	37%	49%
#22-18" COVE	4%	42%	54%	26%	28%
#22-50"	11%	49%	40%	26%	14%
#23-30" DAYTON	3%	57%	40%	21%	19%
#23-48"	2%	69%	29%	21%	8%

PARTICLE SIZE DATA

and

X-RAY DIFFRACTION DATA →

for ten soil samples (B and C horizons) taken from five selected profiles on the pipeline transect. Values for major peaks (reported as lattice spacings in angstroms) are underlined. * indicates no peak.

Table # 3 (X-RAY DATA FROM STANDARD TREATMENTS)	SILT			2u-0.08u (c)			2u-0.08u (f)			< 0.08u												
	Ca ⁺⁺ 65°C solv.		K ⁺ 65°C 150°C 550°C			Ca ⁺⁺ 65° solv.		K ⁺ 65° 150° 550°			Ca ⁺⁺ 65° solv.		K ⁺ 65° 150° 550°									
	14.9 10.0	16.2 10.0	10.0	10.0	13.9 10.0	14.8 10.1	15-18 10.0	7.2	7.2	14.9 10.2	17.0 10.0	7.5	8.0	n.d.	n.d.	n.d.	15-17	18-22	n.d.	9-15	10-14	
# 6-18" WILLAMETTE (Little Pudding, el. 185')	14.9 10.0	16.2 10.0	10.0	10.0	13.9 10.0	14.8 10.1	15-18 10.0	7.2	7.2	14.9 10.2	17.0 10.0	7.5	8.0	n.d.	n.d.	n.d.	15-17	18-22	n.d.	9-15	10-14	
# 6-54" WILLAMETTE (Little Pudding, el. 185')	14.9 10.0	15.8 10.0	10.1	10.0	13.6 9.9	15.0 10.2	17-19 10.0	10.2	10.0	n.d.	n.d.	n.d.	14.9	17.6	10-15	11-15 10.0	10.0	15.0	18.0	11-17	11.3 10.5	13.7 11.1 10.0 9.9
# 10-30" JORY (Salem Hills, el. 400')	*	*	10.1	10.0	10.0	14.7	17.3 14.3	7.2	7.2	7.2	7.2	*	7.2	7.2	7.3	7.2	*	7.3	7.4	7.7 7.3	7.5	*
# 10-50" JORY (Salem Hills, el. 400')	10.0 7.3	7.3	10.1	10.1	10.0	14.7	16.3 14.7	7.2	7.2	7.3	7.2	*	7.2	7.2	7.3	7.3	*	7.3	7.4	7.4	7.5	*
# 16-14" "PEAVINE-LIKE" (Salem Hills, el. 800')	9.1	18.8 10.1 9.2 7.4	20	10.1	10.2	10.1	14-17	18.5	10.0	10.1	11.0 10.2	15-17	17-19	10-14	10.0	10-15	15.0	18.8	10-14	10.5	10.0	
# 16-27" "PEAVINE-LIKE" (Salem Hills, el. 800')	14-18 9.1	18-20 9.1	10.1	10.2	10.1	14-17	18.5	7.3	7.3	10.0	11.1 10.1	10.2	15-17	17.8	12-15 10.7	10-14 7.4	10.1	15.6	17.7	11-14	10.9 10.4	10.1
# 22-18" COVE (Saddle Butte, el. 260')	*	*	*	*	*	15.0	17-18	7.2	7.2	10.1	10.0	10.1	14.9	17.3	10.7 10.1	11.3 10.2	10.3 9.8	15.5	19.2	12.3 11.0 10-15	10.4	10.1
# 22-50" COVE (Saddle Butte, el. 260')	15.0	17.5	14.5 13.6 10.6 10.1 9.1	10.1	10.1	10.1	15.0	16.7	7.2	10.8 10.0	10.1	10.1	15.0	17.3	10-12 7.3	11.2 10.1	9.9	15.2	17.9	11-18	11.0 10.4	11.1 9.9
# 23-30" DAYTON (Halsey, el. 285')	15.0 10.0	15.8 10.0	10.2	10.2	14.3 10.1	15.0	16.9	7.3	7.3	10.1	10.0	10.1	14.9	17.3	10.3	10.1	10.2	15.5	18.8	10-16	10.6	10.5 9.9
# 23-48" DAYTON (Halsey, el. 285')	14.9 10.0	16.3 10.1	10.2	10.1	14.1 10.1	14.8	17.3	7.3	7.3	10.1	10.0	10.1	14.9	17.5	10.1	10.0	9.9	15.0	17.5	10-17	10.8 10.4	10.0

D.T.A. patterns presented for Jory, Cove, and Dayton in Figures 2_a to 4_b (p. 36 - 38) reinforce the general aspects of the preceding interpretations, and provide some additional information:

Jory. The moderately large first endothermic peak of Ca⁺⁺ saturated clay fractions (arising from loss of water sorbed at the surface or interlayer regions of fine crystalline and amorphous particles) implies that a significant quantity of high surface area material is present in the sample. The presence of appreciable amounts of three-layer type lattice in the clay fractions is excluded, since the X-ray data restricts such material to the silt fraction. Furthermore, the shape of the first endothermic peak is not indicative of Ca⁺⁺ saturated smectites or vermiculite since secondary peaks in the 200°C region are lacking. (See, for example, the Cove patterns in Figures 3_a and 3_b). This peak can then be interpreted either as due to a relatively small proportion of 'amorphous' or crypto-crystalline material, or to a very great proportion of halloysite and/or very fine grained disordered kaolinite.

The size, symmetrical aspect and sharpness of the second endothermic peak (all fractions at 595°C) coupled with the shape, size, and location of the exothermic peak at 930°C¹ suggests that the main clay component is a disordered kaolinite, contaminated by amounts of amorphous material (36, p. 102-127). (In the case of halloysite,

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Temperature of appearance of the exothermic peak, which comes at a time of recrystallization, is considerably lowered in the presence of small amounts of contaminants.

first endothermic peaks would be almost as large as second endothermic peaks; second endothermic peaks have a higher slope ratio; and second endothermic peaks also appear at a lower temperature than obtains for kaolinite, at around 550-570°C.)

A broad endothermic peak in the 300-350°C region, especially evident in curve C of Figure 2_a, indicates the presence of poorly crystalline gibbsite.

Cove. The shape and size of the first endothermic peak, particularly that portion at 230-250°C which is associated with dehydration of the exchangeable Ca⁺⁺ ions, is consistent with the interpretation that smectite dominates in all clay fractions. This portion of the curve would not be easily distinguishable from those for vermiculite, but the X-ray data do not favor such an interpretation. Furthermore, the shape and size of the second endothermic peak which appears, for all fractions, in the region 570-595°C also suggests smectite rather than vermiculite.

Possibly a significant clue to characterization lies in the fact that the main dehydroxylation peak appears in the 550-600°C region, rather than in the 700-900°C region. According to Greene-Kelly (36, p. 148), this is characteristic of all dioctahedral smectites except montmorillonites, in which dehydroxylation is delayed until 700°C or higher:

"It will be noted that all except montmorillonite give their main dehydroxylation peak in the 500°C region and all except montmorillonite owe their silicate layer charge predominately to tetrahedral substitution (cf. the Illites, Chap. VI). It seems logical, therefore, to correlate the two, and more especially since smectites containing little Fe or Mg²⁺ and showing mainly tetrahedral substitution (e.g. Black Jack Mine beidellite) give a main dehydroxylation peak near to that of nontronite."

Greene-Kelly also reports that curves for trioctahedral smectites show their main dehydroxylation peaks at between 800°C and 900°C or above. Therefore, it seems very likely that the Cove samples (with a main peak at 570-595°C and lacking significant endothermic peaks above this temperature) contain dioctahedral, tetrahedrally substituted clay of the beidellite-nontronite sequence as their major constituent. X-ray data compels a similar conclusion, since a test (21) of these samples for expansion under Li^+ saturation and solvation with ethylene glycol showed re-expansion to about 17A.

A very small peak appearing at 325°C in the C horizon clay fractions (Figure 3_b, p. 37) hints at the presence of gibbsite, particularly in the coarser clay fraction.

Dayton. Keeping in mind that curve D of Figure 4_a and curves C-E of Figure 4_b are reported from samples of half or a third the weight of the others shown¹, it is still possible to note some characteristics of interest. Shape and size of first endothermic peaks imply the presence of significant amounts of vermiculite and or smectite. The progression in size of peak area from silt fraction to 2-0.08 μ (c) clay fraction to <0.08 μ clay fraction in the B horizon (#23-30) sample is consistent with the interpretations of X-ray diffraction data (suggesting increase in expansion properties of the material with reduction in particle size).

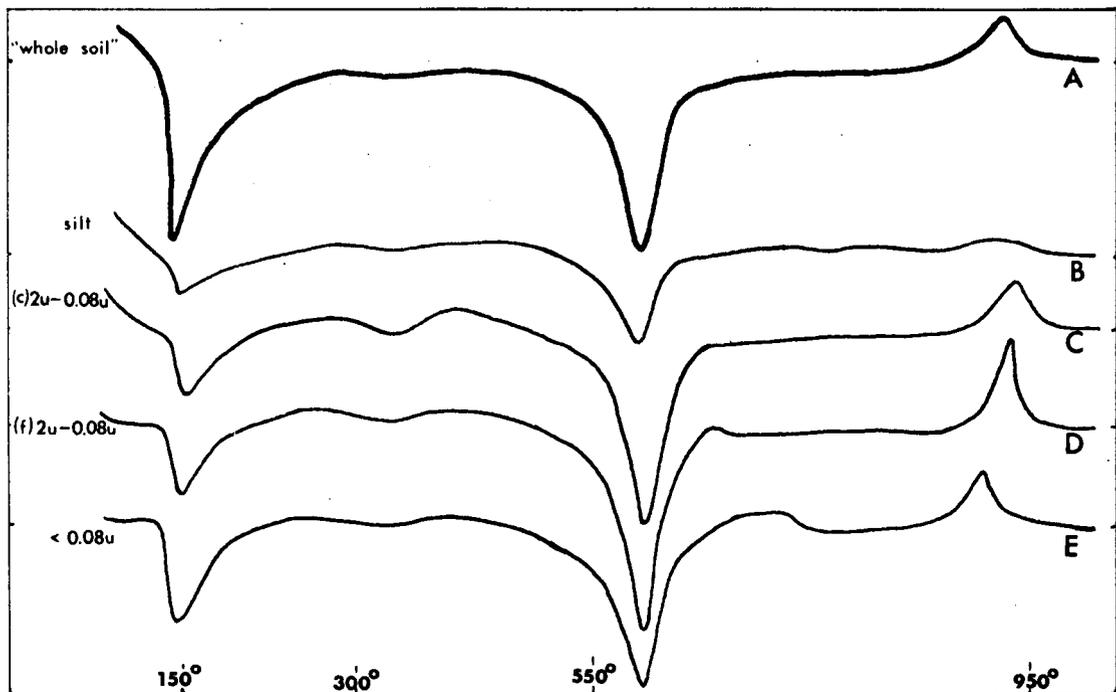
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With these exceptions, all D.T.A. samples from which curves reproduced in the Figures, and the Appendix, were drawn are roughly equivalent amounts: one gram, \pm 15 percent.

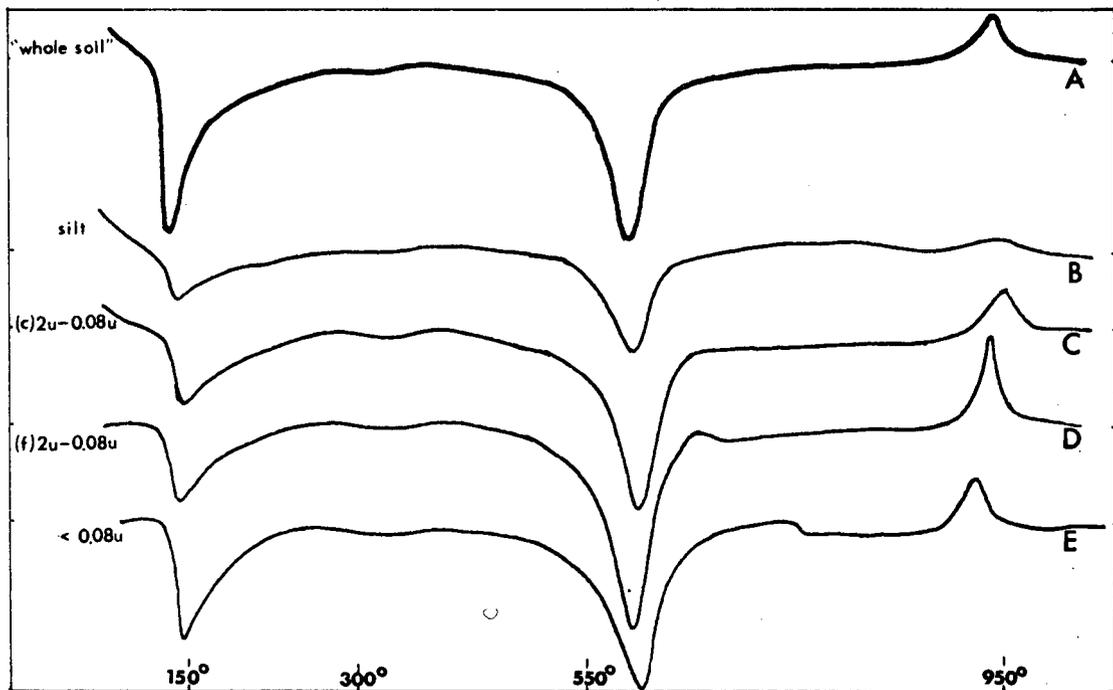
Like diagrams from the Cove, the Dayton patterns are notable in the lack of significant endothermic peaks at temperatures above 600°C. Such information may have particular value as an indication of the kinds of minerals not likely to be present (36, p. 57). The lack of significant endothermic (or exothermic) peaks above 600°C would be unusual for montmorillonites (cf. quotes on p. 32), for most chlorites (36, p. 207-219), and for many micas. Second and third endothermic peaks appear in many "illitic" and "interstratified" three-layer clays in the region between 700-900°C (36, p. 182). However, it is reported that the third endothermic-exothermic inversion does not occur on curves for those "dioctahedral clay micas" with minor replacement of Al⁺⁺⁺ by Mg⁺⁺, Fe⁺⁺, etc. (36, p. 177). Johns and Jonas (33) have suggested that, in the three-layer clays, the appearance of the second endotherm at a lower temperature may be correlated with increasing substitution of Al for Si in the tetrahedral layer.

Thus, in general, the D.T.A. patterns support interpretations of the X-ray diffraction data. When considering both forms of evidence, it seems reasonable to conclude that clay mineral components of the Dayton samples discussed consist mainly of micaceous material which has been heavily weathered and grades, parallel to decreasing particle size, through partially expanded and hydroxy interlayered condition into a considerable fraction of the sample which can be classed as a smectite. Such an indeterminate graduation from one clay mineral into another is consistent with Walker's assertion that it is not now possible to determine the exact point of overlapping in the range of the group of vermiculites of low layer charge (C.E.C. 115

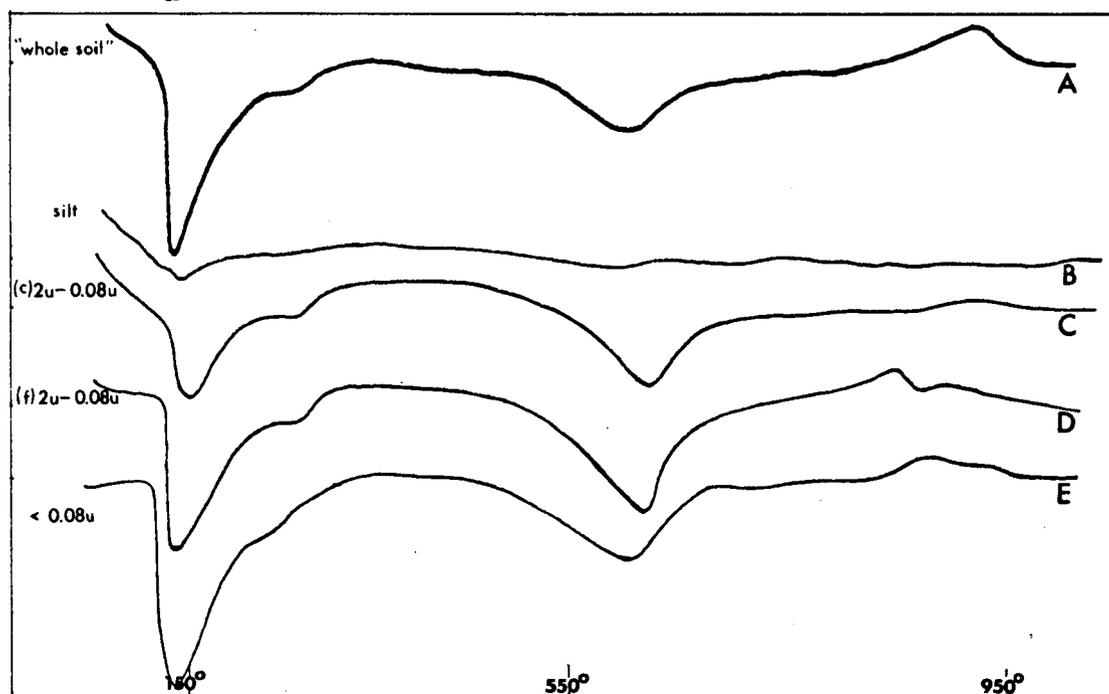
m.e./100g) and the group of smectites of high layer charge (57, p. 314). As with Cove samples, the fine grained clay (possessed of full expansion properties but collapsing readily on K^+ saturation) is referred to as beidellite.

Figure 2_a.

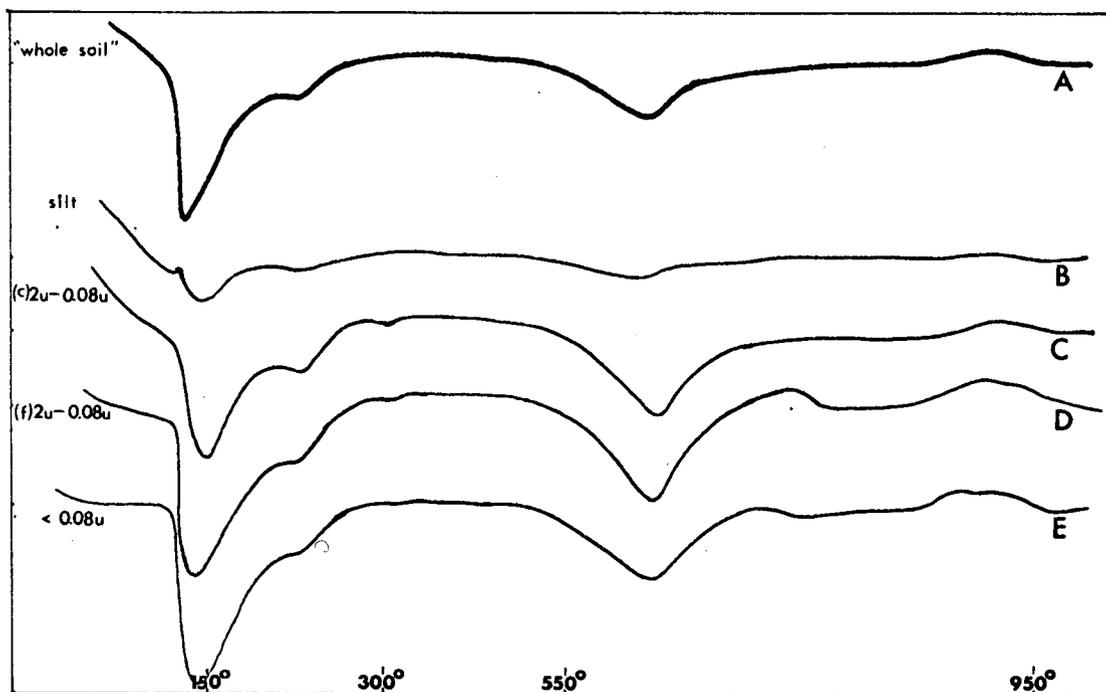
Sample #10-30" (Jory, B horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

Figure 2_b.

Sample #10-50" (Jory, C horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

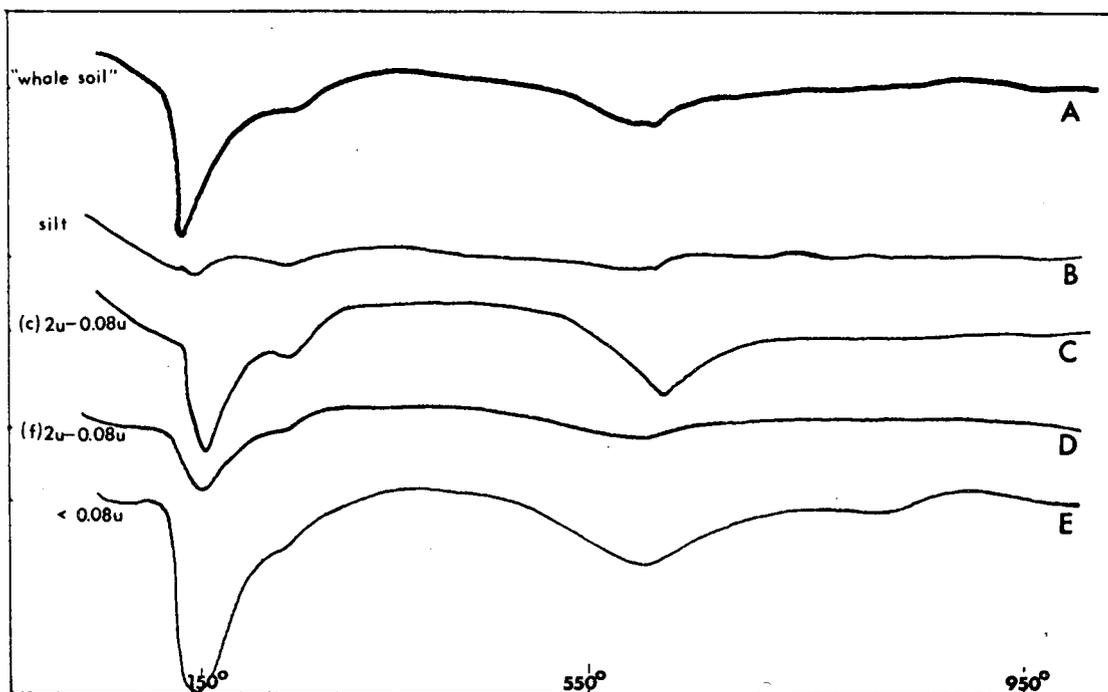
Figure 3_a.

Sample #22-18" (Cove, B horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

Figure 3_b.

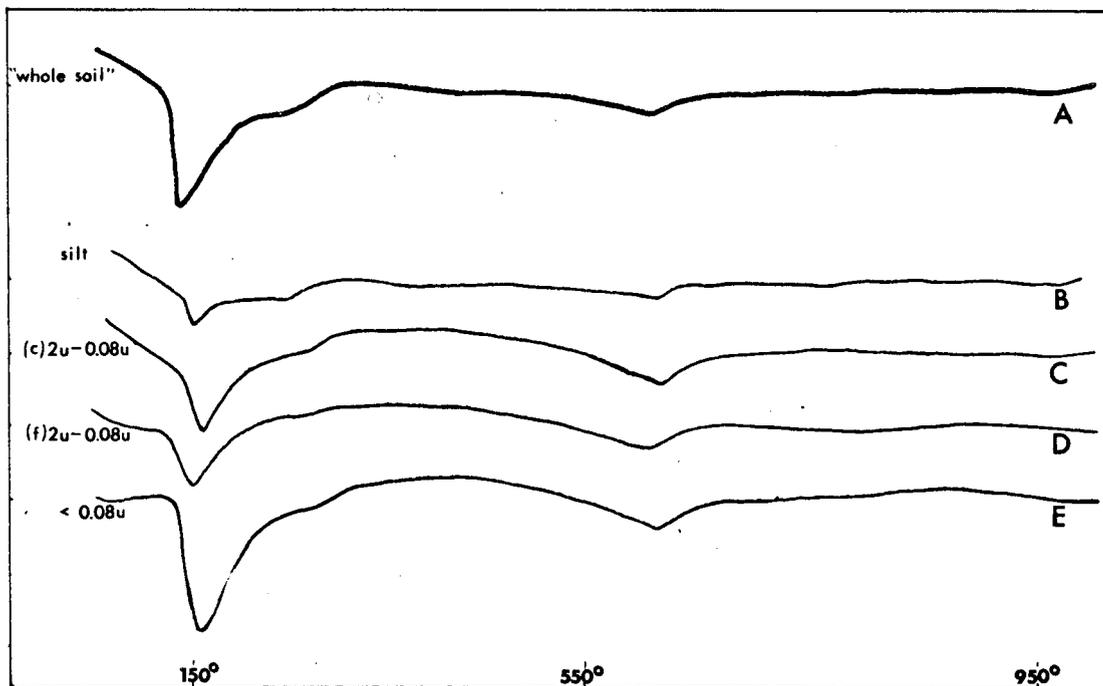
Sample #22-50" (Cove, C horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

Figure 4a.



Sample #23-30" (Dayton, B horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

Figure 4b.



Sample #23-48" (Dayton, C horizon). D.T.A. patterns: (A) equilibrated field sample of the soil material; (B-E) Ca^{++} saturated fractions.

Supporting Evidence from Untreated Material

If the preceding interpretations are fundamentally correct, then the X-ray and D.T.A. patterns drawn from 'whole soil' material (Figures 5_a to 10_b, p. 49-54) of the same samples may be shown to hold potential value. The tablet method is not suggested as an equivalent of standard treatments since it is a less discriminating approach. Rather, it is suggested that, beyond its value as a cursory indicator, it might also be of use in attempting a better estimate of the field condition of colloidal material in soils prior to their possible alteration during more intensive laboratory examination.

In evaluating the patterns drawn from 'whole soil' material, it is worth noting that all samples from the valley (#1 to #6 and #18 to #24) are essentially Ca⁺⁺-Mg⁺⁺ saturated, while the remaining samples, from the hill soils, may be supposed to be largely H⁺ and Al⁺⁺⁺ (25, 32) saturated. (See the pH and Base Exchange data in the Appendix.) A comparative examination among the five profiles of X-ray data from 'whole soil' tablets supports the same major conclusions that were drawn from conventional data: (a) Willamette and Dayton samples seem to contain three-layer clay material of micaceous as well as of peculiar expansion and collapse characteristics. There is more expansion and less pronounced and irreversable collapse in the Dayton material than the Willamette, particularly in B horizons. Patterns also give evidence of chloritic material, and possibly some kandite as well. (b) Cove samples seem to be primarily smectite with some possibility of kandite. (c) Jory appears to consist largely of kandite

with micaceous material present and perhaps some of the material showing partial expansion properties. (d) Peavine-like samples give patterns which reveal characteristics some of which are similar to Jory and some to Cove.

Detailed examination of the patterns from tablets revises and extends the previous interpretations to some extent.

Inspection of curves for the Willamette and Dayton samples (p. 49 and 53) will show: (a) Material expanding to 14A at 65°C, or beyond when wet, undergoes virtually complete collapse at 150°C even though these are dominantly Ca⁺⁺-Mg⁺⁺ saturated. (b) In contrast to Dayton, re-expansion of the Willamette material was largely inhibited during rehydration¹ after its initial collapse at 150°C. In this respect, it is notable that the presence of exchangeable K⁺ was in excess of other samples on the transect (Appendix, p. 93). (c) Except for the Dayton B horizon (Figure 9_a), samples give much less indication of large amounts of smectite (Figures 5_a, 5_b, and 9_b) than they did after dispersion and separation. (d) The shape and position of the peaks are consistent with the idea that products of weathering are greater in B horizons than C horizons (and greater in Dayton than Willamette). (e) In all four samples there is an apparent intensification of a 14A peak after heating to 550°C. This reinforces implications of the presence of chloritic material. It could be interpreted as incomplete collapse after the rehydration, but patterns drawn at

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As with the 'wet' procedure, rehydration was not an equilibrium condition, but samples may be presumed to have all been subjected to comparable hydrating conditions.

150°C mitigate against this interpretation.

The above observations, particularly (a) and (b), are reminiscent of the behavior of micaceous materials studied by Rich and Cook (41). They have shown that the weathering of dioctahedral soil micas, both natural and in the laboratory, results in the formation of mixtures of vermiculite and interstratified mica-vermiculite. These laboratory 'weathered' micas of low layer charge had a great affinity for K^+ to the extent that they would extract minute quantities from surrounding, supposedly 'pure', solution and were easily collapsed to 10A on K^+ saturation (41, p. 96-106).

Minor differences in clay mineral interpretation between the two methods used in the present study could be resolved by assuming that clay forming material and weathering processes similar to that described above are present in the Willamette and Dayton soil samples. If patterns for the Dayton B horizon (Figure 9a) are compared with those for its C horizon (Figure 9b), it will be seen that both horizons exhibit a major proportion of material which was expanded to 14A at 65°C and collapsed to 10A at 150°C. In the case of the B horizon material, much of it expanded well beyond 14A when rehydrated and would be considered a smectite, whereas material in the C horizon re-expanded on hydration only to 14A, as would be expected of vermiculite. (This contrast between B and C horizons was characteristic of all the micaceous valley soil samples on the transect.) No such contrast between Dayton B and C horizon patterns was evident in the silt or clay fractions subjected to pre-treatments. Furthermore, fractions of the pre-treated material showed the main peak expanding on solvation to

about 16A in the silt, 17A in the 2-0.08 μ (c) clay, more than 17A in the 2-0.08 μ (f) clay, and about 18A in the <0.08 μ clay. This trend toward increase in expansion with decreasing particle size was equally apparent in both horizons. (See Table 3, p. 30).

It is suggested that this discrepancy between clay mineral interpretations from the two methods is an indication of laboratory "weathering" due to the treatment of these interstratified, micaceous, vermiculitic samples with concentrated H₂O₂ during the process of organic matter removal (cf. p. 16) prior to particle separation and clay saturation procedures. It has been demonstrated that concentrated H₂O₂ is a "particularly effective" (remark of Walker, 57, p. 297) chemical exfoliating agent. By way of example, an African vermiculite¹ (known to be actually a complex interstratified 'hydro-biotite') which shows a minor first endothermic peak and a highly elaborate but reproduceable pattern of second and third endothermic peaks in the 700-900°C region, was repeatedly treated with concentrated H₂O₂ over a water bath for several days. (The frothing action never diminished.) The D.T.A. pattern for this treated sample was completely altered: showing the first endothermic peak height and area to have been approximately doubled, and also recording disappearance of the dehydration peaks in the 700-900°C region. Thus, one may suppose that the material in Dayton samples which shows partial expansion is subject to further, irreversable expansion by the exfoliative action of H₂O₂ as oxygen is evolved--- catalyzed, perhaps, by manganese or organic matter lodged in the interlayer positions (16, 23).

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Perlite Company, Portland, Oregon

Comparing interpretations reached through conventional methods with those from the 'whole soil' tablets led to a suggestion that the expanding clay minerals in the micaceous Willamette and Dayton samples may have suffered some degradation from their original field condition. A similar comparison of patterns from the two methods for the saprolitic Peavine-like or Cove samples also implies alteration from the original field condition during pre-treatments, but having the effect of an improved organization of the colloidal material present.

For example, collapse of the Cove peaks (Table 3) from 14A to 10A upon K^+ saturation and heating results in a sharply expressed peak at 10A. On the other hand, examination of patterns from the tablet (Figure 8_b) shows a major 14A peak at 65°C which disappears when heated to 150°C without the concomitant appearance of a 10A peak, although rehydration readily brings back the orientation (as demonstrated by the reappearance of a well organized peak at 17A after rehydration). Two explanations seem pertinent. At lattice dimensions, one might assume that clay in the field is extensively and non-uniformly blocked in its interlayer positions in such a way that, although expanded layers can assume an oriented parallel relation to each other, when collapse occurs the parallel arrangement of lattice planes is disturbed by intervening hydroxy groups and the synergetic basal reflections disappear. On a larger scale, one might suppose that clay particles in the weathered rock¹ are oriented in its field

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Field observations of the Cove C horizon suggest a coarse sandy alluvial deposit, but microscopic examination discloses these grains to be ghostly pseudomorphs composed of argillaceous material. (Personal communication from Joel Norgren).

field state in a fairly random way. The pre-treatments then result in disruption of the consolidated material, dispersion, and reorganization of the colloidal complex.

Examination of Figures 5_a to 9_b will show that an additional source of distinction between mineral character of the Willamette and Dayton samples as opposed to those of the Peavine-like, Cove, or Jory samples is available on the basis of differing recrystallization tendencies of the various samples at elevated temperature. Comparison of patterns made at 65°C with those made after heating at 950°C will give some indication of the kind and extent of recrystallization that has taken place. In both the Cove and Peavine-like samples it is evident that extensive recrystallization has taken place, whereas the Willamette and Dayton samples are seen to be virtually unaltered at this temperature.

Cristobalite can be identified on these patterns by the appearance of a major peak in the region near 4.1A; the peaks at 2.69A and 2.51A are associated with the growth of anhydrous crystal forms of iron and aluminum (e.g. hematite and γ -alumina); mullite ($3Al_2O_3 \cdot 2SiO_2$) is indicated by a major pair of peaks in the region 3.38-3.42A and lesser peaks at 2.51A and 2.54A; and the 3.18A peak which appears in the pattern from the Peavine-like C horizon probably arises from the growth of some crystal form (e.g. enstatite) of a magnesium silicate.

Recognition of such recrystallization products does not give unequivocal information about the initial clay minerals and other material that might have been present, since variation in degree of order

in the crystal lattice, nature of adsorbed and substituted ions, rates of heating, etc. all contribute to variability in the kind and amount of recrystallization that takes place at any given temperature (28, 42, 55, 56). On the other hand, knowledge of the recrystallizing tendencies of pure clays would offer some basis for assessing more complex systems.

Wahl and Grim (56) have compared phase transformations in kaolinite, halloysite, illite, and montmorillonite at elevated temperatures (to 1450°C) and report the advance or retardation effects of several chemical impurities on the temperature of structural transition. They found that Mg^{++} and Ca^{++} lowered the temperature of formation of mullite and β -cristobalite from kaolinite by 50-200°C. Potassium was found to inhibit the formation of β -cristobalite in illite, kaolinite, and montmorillonite. In general, the mineralizing ions (e.g. Mg^{++} , Ca^{++} , P^{5+}) were found to have a more pronounced influence on phase changes in the two-layer than the three-layer clay minerals.

Bohor (7) notes in illites the retardation of mullite formation by adsorbed ions in their order of effectiveness-- $K > Na > Li > Ca > NH_4 > Mg$; and postulates that the speed and degree of crystallization is proportional to electronegativity and ionic potential of the adsorbed ions. Tlapek and Kellor (55) postulated the increasing thermal stability of three-layer phyllosilicates with increasing electronegativity of lattice substitutions, Al for Si and Mg for Al; and showed anhydrous clay lattice thermal stability in the increasing order-- pyrophyllite < montmorillonite (also nontronite and saponite) < illite < muscovite. This suggestion is consistent with, rather

than antagonistic to, Bohor's postulate, since the strength of the cation-oxygen bond in the case of substituted ions is directed toward preservation of the structure and in this sense would be in competition with the adsorbed ions external to and disruptive of the lattice. (For a theoretical discussion of the relation between thermal stability and electronegativity of substituting ions, see, Hans Ramberg's paper, 40).

In the case of pure clays, it has been shown that the anhydride structure of illite persists above 1000°C . In contrast, kaolinite is known to begin development of γ alumina at 900°C , mullite at 950°C , and cristobalite at 1100°C (42). Halloysite, however, begins to form mullite only above 1100°C , and in the absence of contaminating ions, does not form β cristobalite at all (42). The work of Insley and Ewell (29), as reported by Hyslop (28) showed that the appearance of mullite in co-precipitated Al-Si gels follows that of γ alumina, as in kaolinite, but that it begins to form at a lower temperature than is the case for kaolinite.

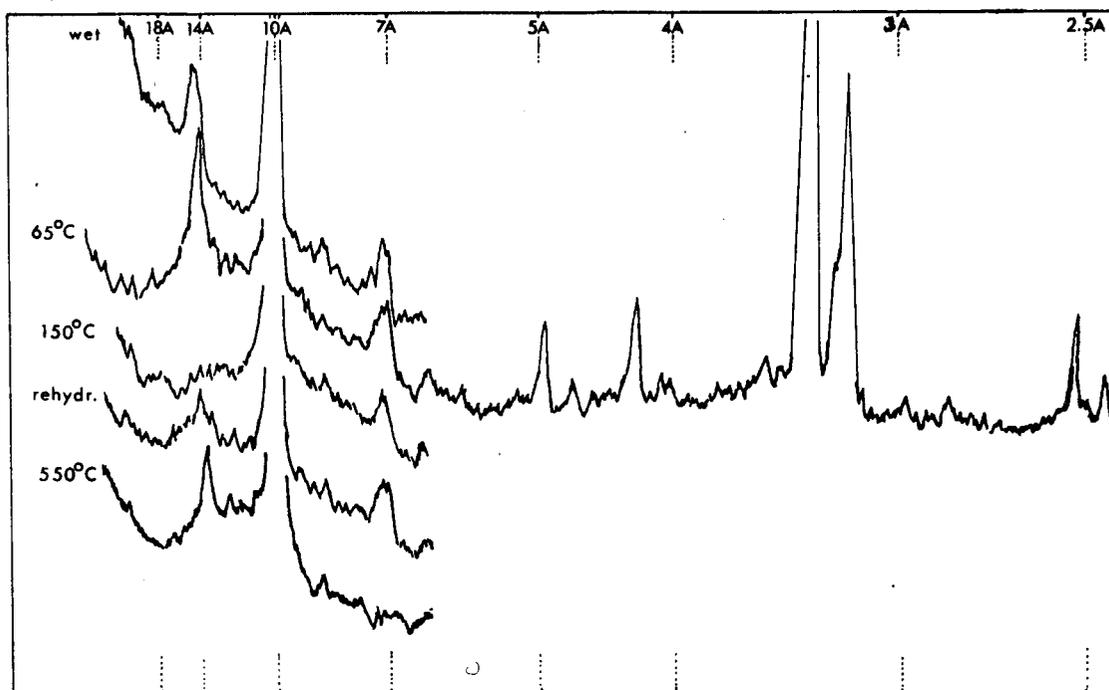
In looking at patterns in the present case (Figures 5_b to 9_b), it is evident that it is in just those C horizon samples where X-ray patterns at low temperatures indicate poor crystallinity in the clay colloids that the pattern at 950°C shows the greatest degree of recrystallization (i.e., Peavine-like Cove Willamette, Dayton). The extensive development of cristobalite under these conditions not only suggests a crypto-crystalline state for much of the material of the Peavine-like sample but also reinforces assumptions of the dominant presence of Ca^{++} - Mg^{++} interlayered smectite (and lack of

inhibiting potassium ions) in both the Peavine-like and the Cove samples. However, indications of the possible presence of kandite (and hydrates of iron and aluminum) in the Peavine-like C horizon sample are also strengthened by observation of the 950°C patterns of the growth of mullite, and of crystal forms of iron and aluminum oxide.

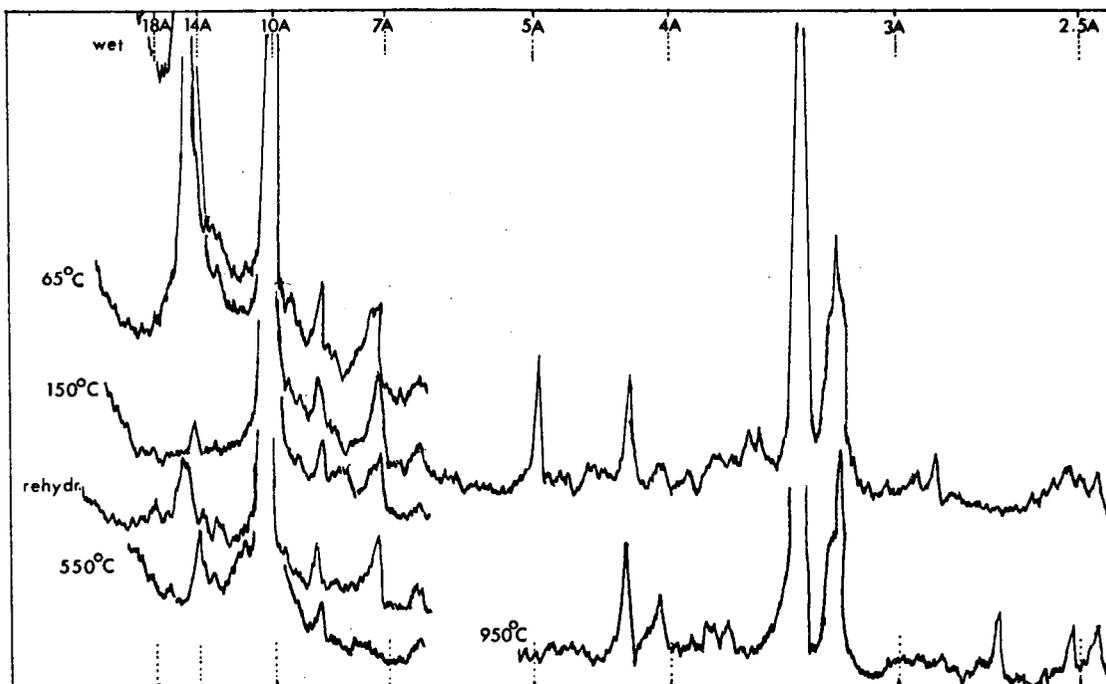
As would be expected from earlier evidence of the dominance of kaolinite (in association with significant amounts of crypto-crystalline iron and aluminum hydrates), an equivalent pattern for the Jory pattern (Figure 6_b) shows much more extensive growth of mullite and peaks associated with the iron and aluminum oxides, although the development of cristobalite seems not so great.

One region on the X-ray diffraction patterns from tablets of the samples may be worth brief discussion as a means of distinguishing between kaolinite and halloysite in the two-layer clays. As with the Peavine-like samples, the patterns for Jory drawn at 65°C show bands at about 4.4\AA and 3.5\AA , regions where peaks may appear both in the case of kaolinite and of halloysite. Brindley asserts (10, p. 87-88) that the relative intensities and sharpness of peaks in these regions are valuable in distinguishing presence or relative amounts of the two forms of kandite. In neither the Jory nor the Peavine-like samples is it possible, by this means, to exclude potential presence of halloysite. (Other samples from the transect, containing kandite as a clay mineral component, give more certain indications, by this means, of the presence of halloysite.) Interpretation of position, intensity, and sharpness of peaks in this region for the Jory sample strengthens

previous interpretations of the presence of kaolinite.

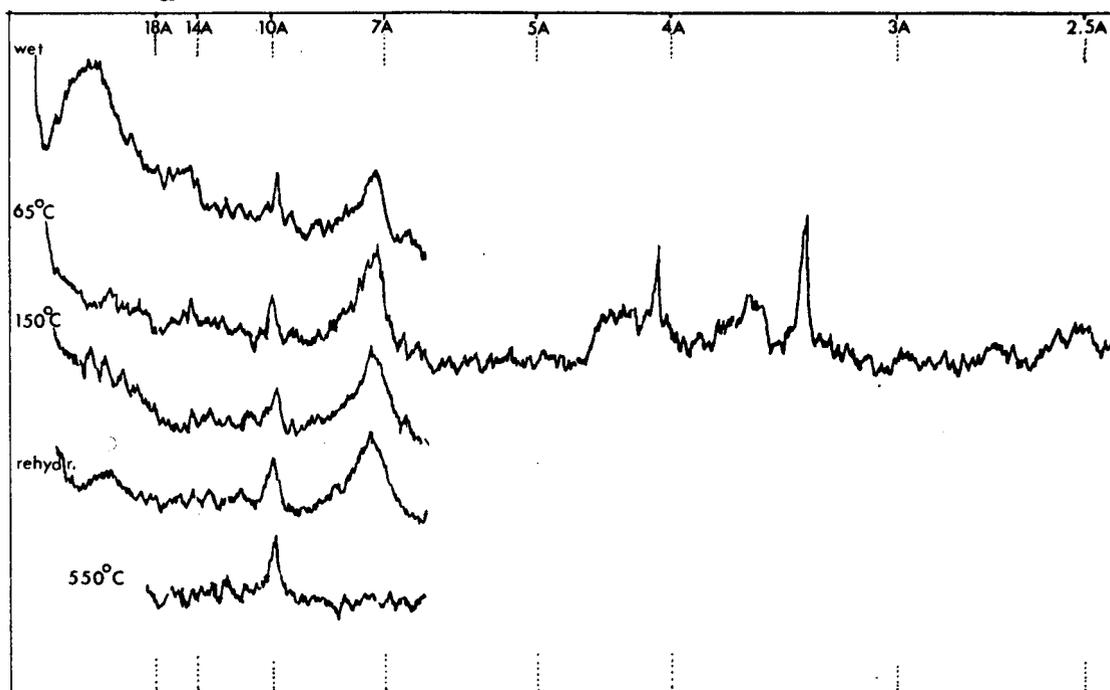
Figure 5a.

Sample # 6-18'' (Willamette, B horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 5b.

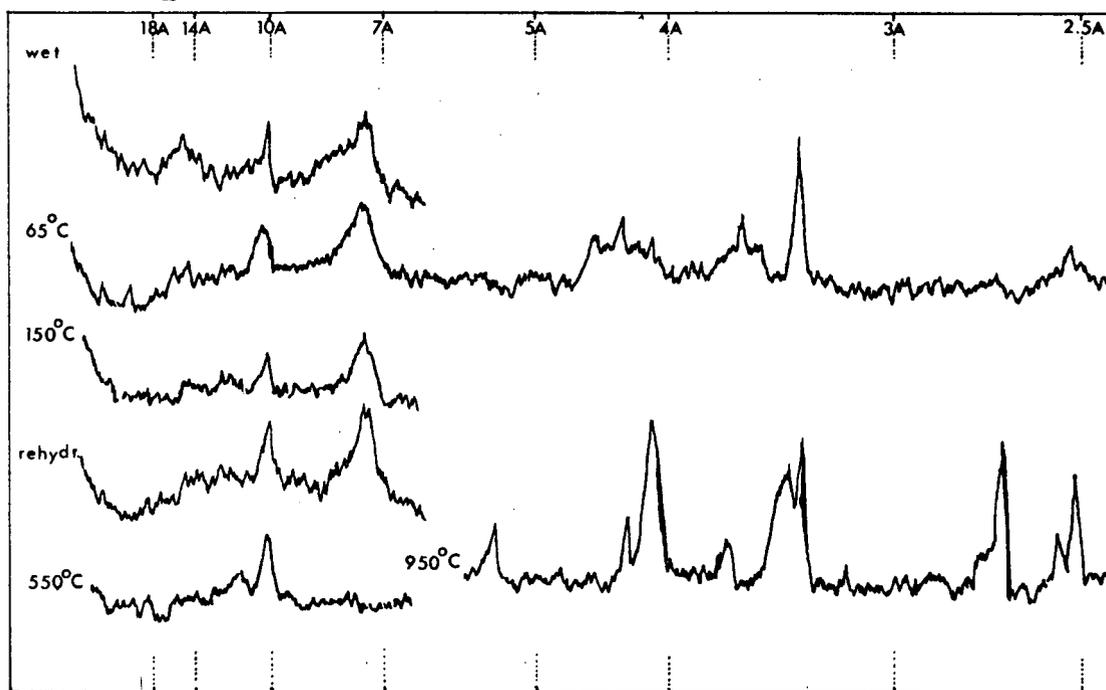
Sample # 6-54'' (Willamette, C horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 6a.

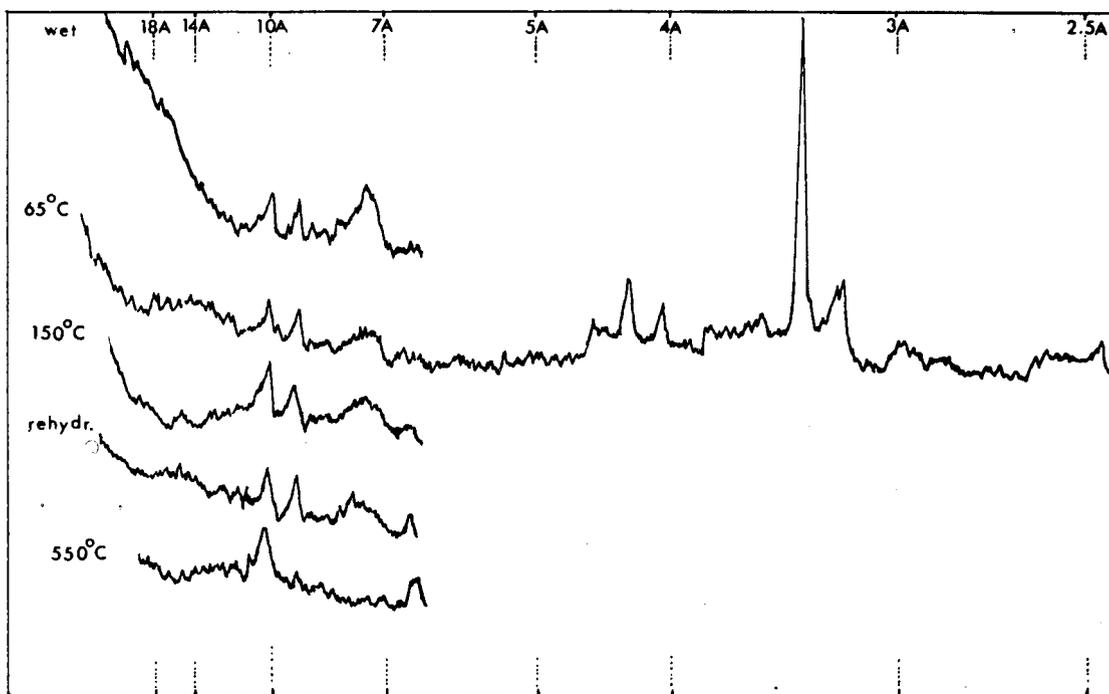


Sample #10-30" (Jory, B horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

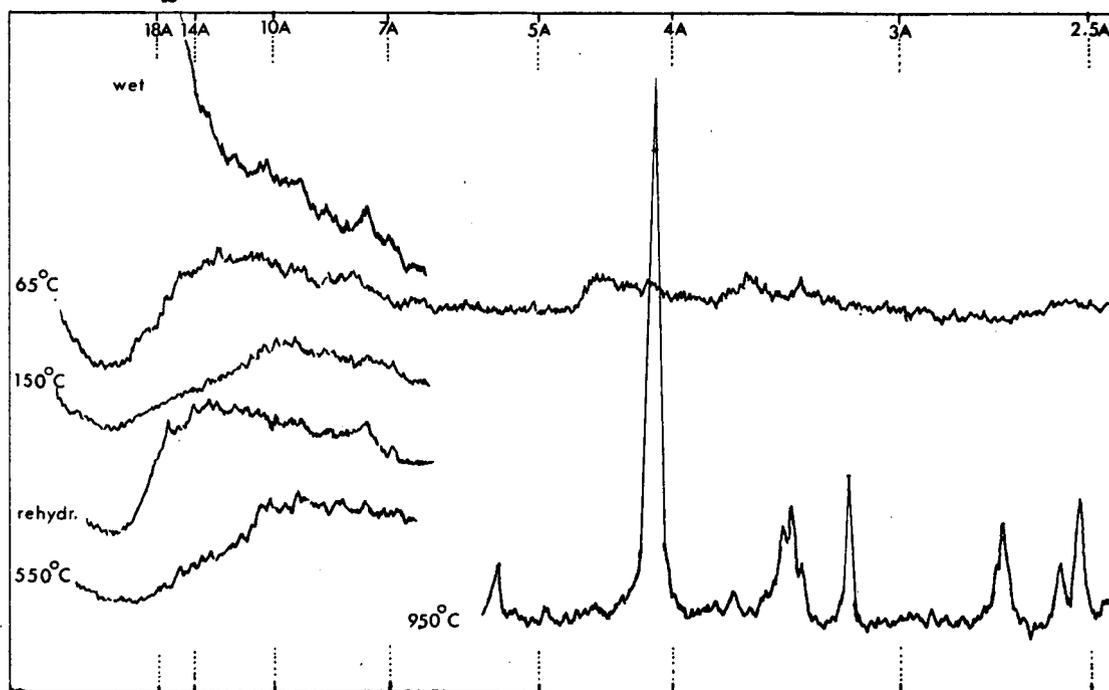
Figure 6b.



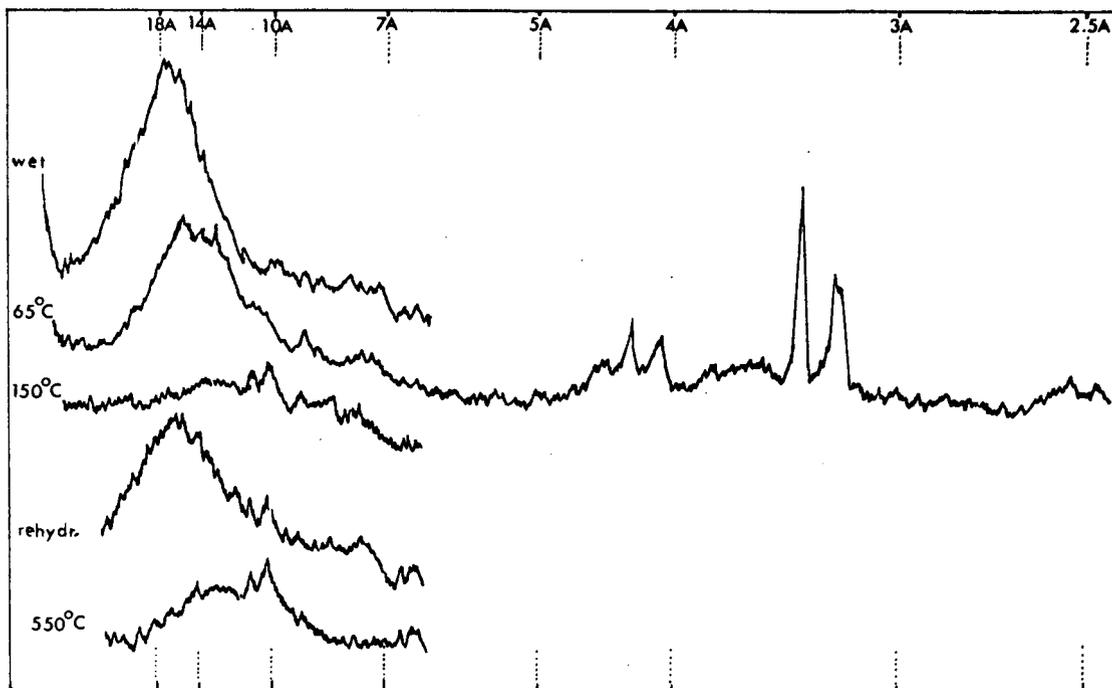
Sample #10-50" (Jory, C horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 7_a.

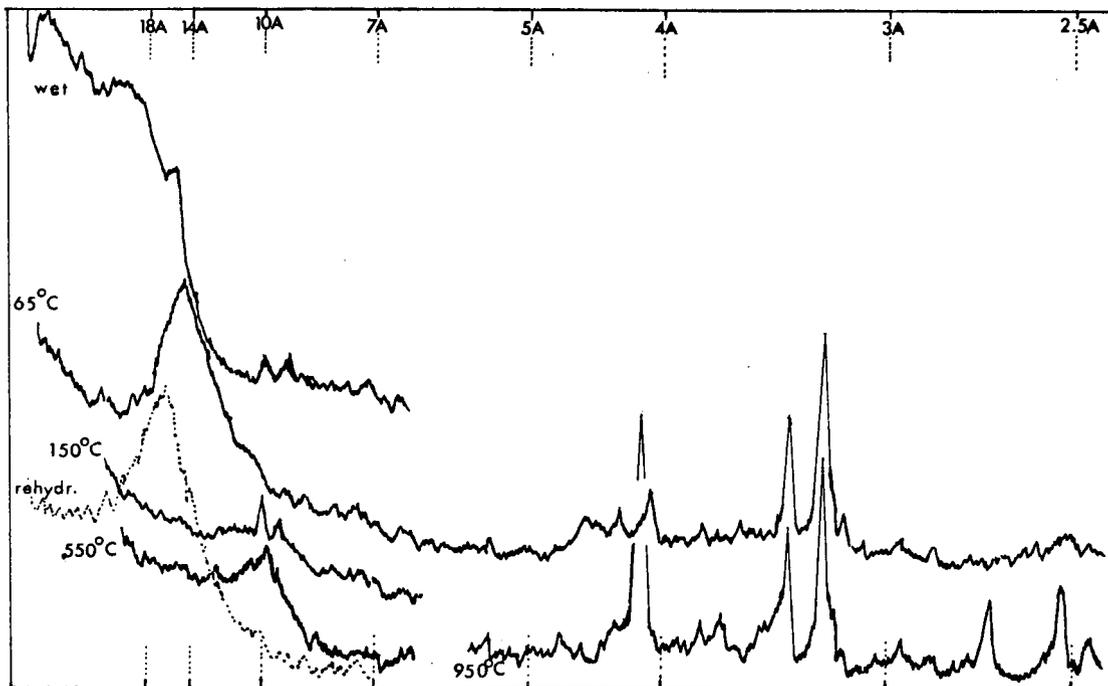
Sample #16-14'' (Peavine-like, B horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 7_b.

Sample #16-27'' (Peavine-like, C horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

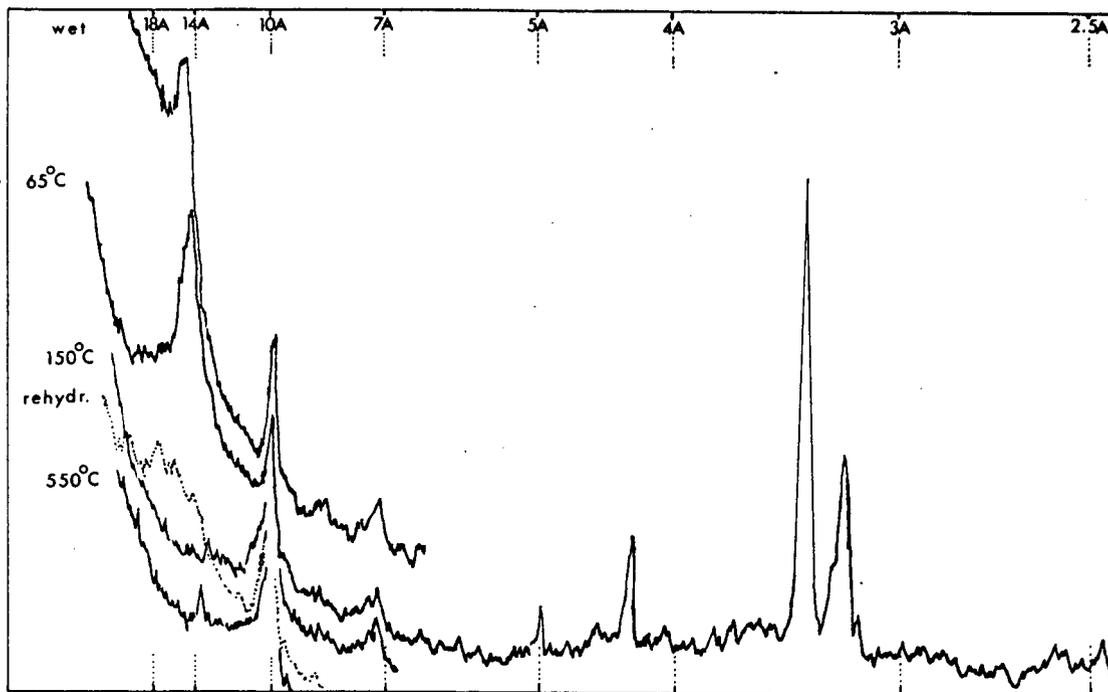
Figure 8_a.

Sample #22-18" (Cove, B horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 8_b.

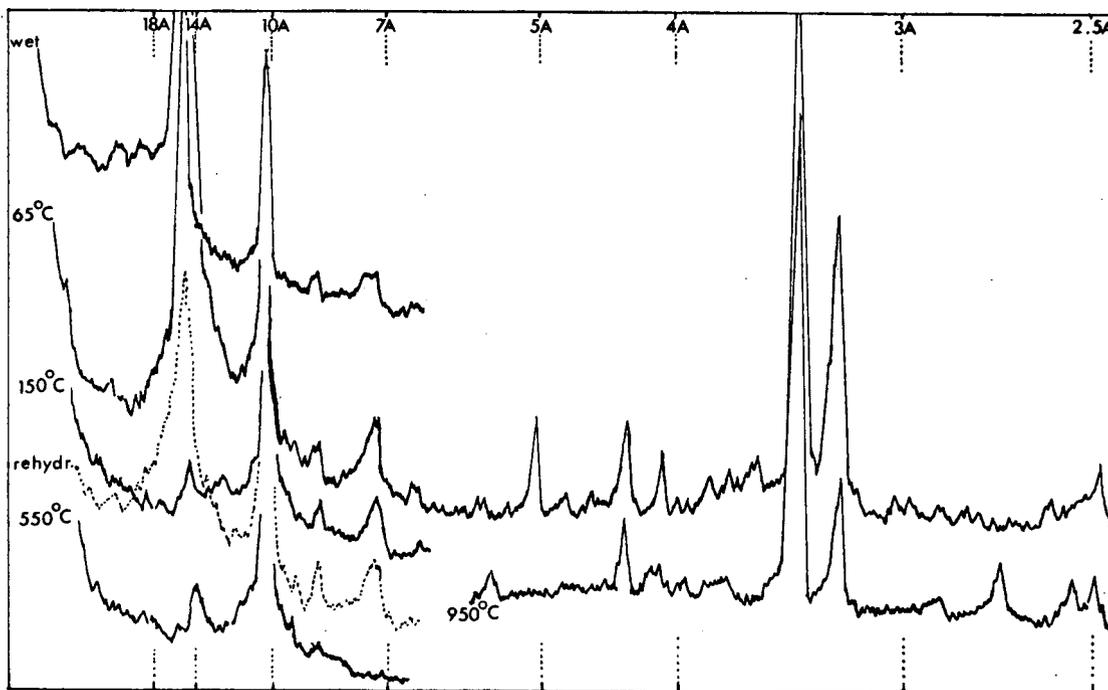
Sample #22-50" (Cove, C horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 9a.



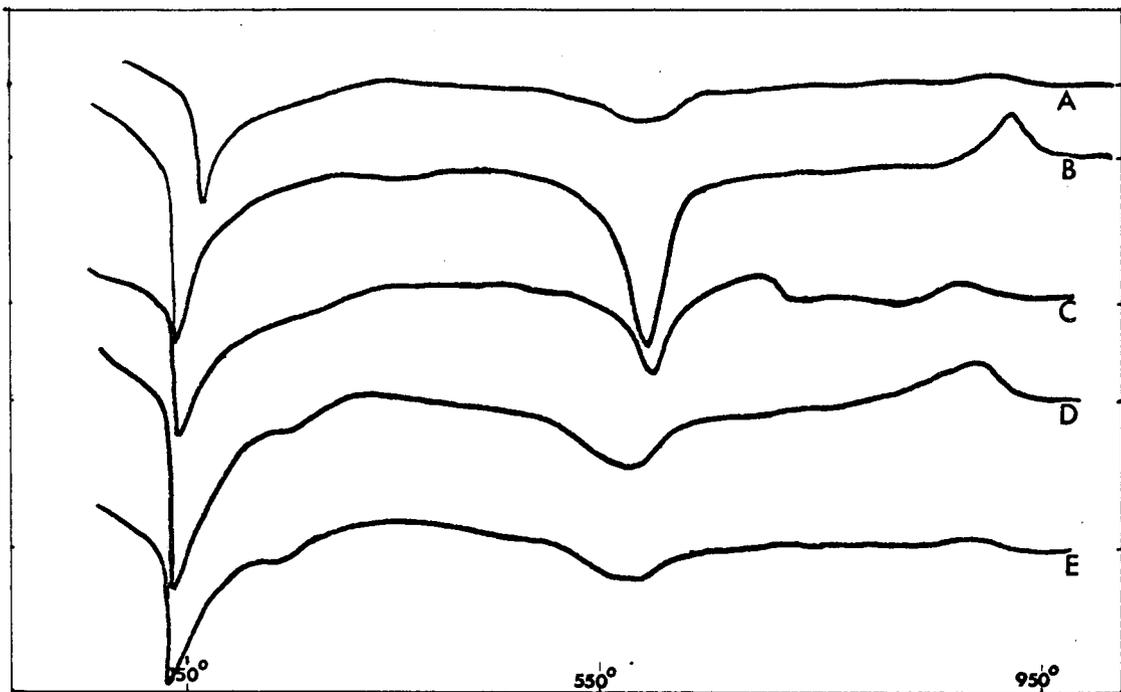
Sample #23-30'' (Dayton, B horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 9b.



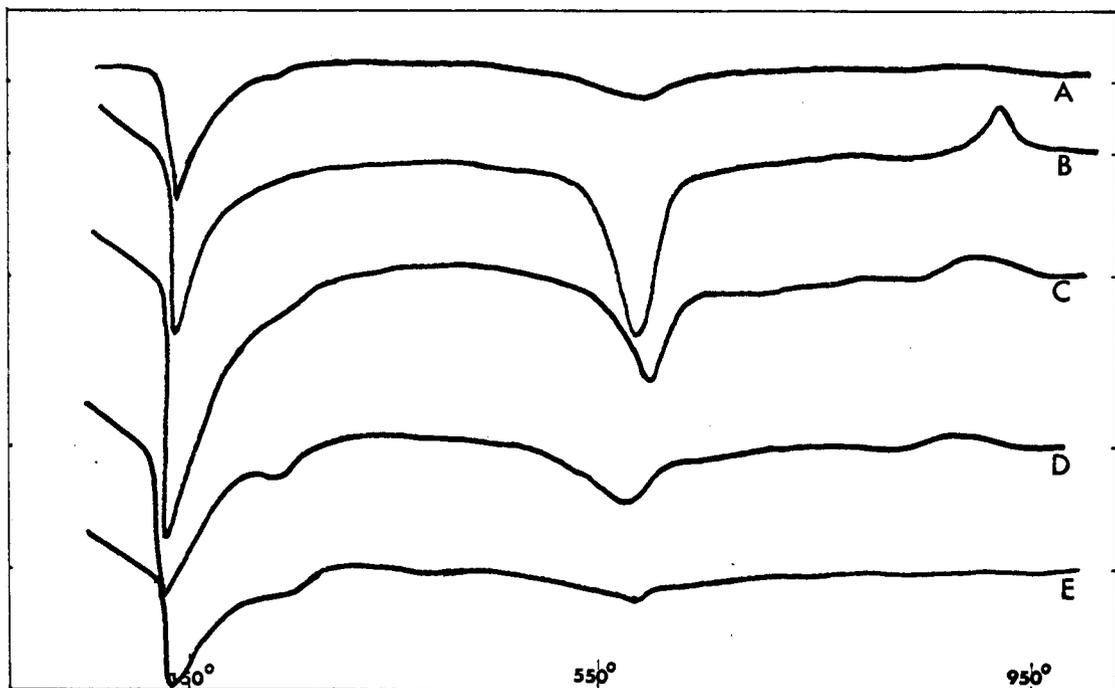
Sample #23-48'' (Dayton, C horizon). X-ray diffraction patterns from a tablet of the untreated soil material.

Figure 10a.



D.T.A. patterns from equilibrated field samples of B horizons: (A) Willamette, #6-18"; (B) Jory, #10-30"; (C) Peavine-like, #16-14"; (D) Cove, #22-18"; (E) Dayton, #23-30".

Figure 10b.



D.T.A. patterns from equilibrated field samples of C horizons: (A) Willamette, #6-54"; (B) Jory, #10-50"; (C) Peavine-like, #16-27"; (D) Cove, #22-50"; (E) Dayton, #23-48".

Working Assumption of Clay Mineral Suites

On the basis of the preceding interpretations, and data presented in the Appendix for all 24 soil locations on the transect, the assumption is made that there are represented in the soil samples at least three, perhaps four, extremes in the range of clay mineral components present. Most of the soils sampled are believed to contain a clay mineral suite of intermediate and overlapping character, relative to the extremes encountered in some cases.

In the hill soils sampled two main categories may be invoked:

(a) apparently older soils which are like the Jory in the sense of containing a major component of well crystallized kaolinite (possibly disordered) which is contaminated with both weathered micaceous material of aeolian origin¹ and with significant amounts of amorphous or poorly crystalline iron and aluminum hydrates; and (b) those in which a primary component is crypto-crystalline and poorly crystalline smectite of the beidellite-nontronite sequence (e.g., Peavine-like C horizon sample) of fully weathered tuffaceous sediments, although there is some possibility that significant amounts of halloysite type clay mineral are also forming². The B horizons in this category are sometimes more like the Jory in clay mineral content and

1

The evidence available shows 10A peaks reduced or lacking in the lower horizons, relative to the higher.

2

For example, compare the peaks and bands at about 4.4A and 3.5A in the case of samples #7 (Jory) or #8 (Willakenzie-like), in Appendix.

sometimes, at lower elevations, more like the micaceous clays of the valley floor Willamette silts.

In the soils of the valley floor, again, two main categories are defined: (a) those, primarily of the Willamette silts, in which the clay fraction is assumed to be dominated by weathering products of dioctahedral mica with a range from 10A material (probably illite) through interlayered vermiculite to interlayered smectite (probably beidellite); and (b) soils of alluvial origin which seem to almost entirely consist of poorly crystalline hydroxy interlayered dioctahedral smectite of the beidellite-nontronite sequence with signs of contamination by kandite. The clay mineral investigations, and field observations, suggest a relation in origin between soils of this latter category and soils from weathered tuffaceous sediments as represented by the Peavine-like C horizon sample.

The following section involves a wider comparison of clay mineral components among samples from the transect. Data from the field and laboratory study have been arranged in Tables 4 and 5 by placing samples from the transect study in groups based on estimates of their dominant clay mineral characteristics.

Table #4. DATA FOR B HORIZON SAMPLES ARRANGED BY CLAY MINERAL GROUPS

Parent Material Position Elevation	Samples	Clay Minerals	Index Ratio	C.E.C. Clay meq/100g	Sand %	Clay %	Linear Shrinkage		Weight Loss		Plastic Estimate	Hue	Base Sat. %	pH
							P.L. -300°C %	300-550°C %	65-300°C %	300-550°C %				
Willamette Silts on Valley Floor El. <325'	#6 (Willamette)	illite vermiculite smectite chloritic	1.1	60	7	28	10.6	36.8	2.7	2.4	+3	10YR	77	5.1
	#4 (Dayton)	smectite vermiculite illite chloritic	1.7	100	20	30	14.4	43.8	4.1	2.4	+3	2.5Y	90	5.4
	#3 (Dayton-like)		2.1	90	17	38	11.2	45.8	6.1	2.9	+4	10YR	91	5.7
	#2 (Amity-like)		1.8	80	17	31	11.4	37.1	4.3	2.4	+4	10YR	105	6.0
	#1 (Scholl)		2.0	70	20	43	12.1	39.1	4.5	2.2	+4	10YR	108	6.9
	#24 (Dayton)		1.8	70	2	44	12.4	40.3	4.8	2.7	+4	2.5Y	111	6.6
	#23 (Dayton)		1.8	70	3	40	12.4	40.3	4.8	2.7	+4	10YR	98	5.8
	#21 (Dayton)		1.6	70	6	40	12.9	39.3	4.5	2.8	+4	10YR	89	5.9
#19 (Dayton)	1.9		70	8	50	13.9	49.9	5.7	3.1	+4	2.5Y	95	5.6	
Alluvial Clays on Valley Floor El. <325'	#18 (Wapato)	smectite	1.7	80	14	44	12.6	44.9	5.3	3.1	+4	2.5Y	109	7.1
	#22 (Cove)		1.7	80	4	54	13.4	52.4	7.6	4.5	+4	10YR	92	6.3
	#20 (Holcomb)		1.8	80	4	52	14.2	51.4	6.4	3.6	+4	7.5YR	96	6.4
Weathered Tuffaceous Sediments on Hill Tops El. 540'-800'	#17 (Hazelair-like)	poorly crystalline	2.1	80	26	52	12.9	51.8	7.0	3.3	+5	2.5Y	89	5.0
	#8 (Willakenzie-like)	crystalline	1.3	40	3	89	27.6	79.6	8.4	6.4	-1	2.5YR	40	4.8
	#16 (Peavine-like)	smectite and kandite	1.5	60	22	41	11.1	47.3	5.2	3.5	+3	5YR	82	5.5
Deep, Red, Acid Colluvium on Hill Slopes El. 375'-575'	#7 (Jory)	kaolinite amorphous material illite	0.95	30	21	41	11.4	48.3	6.7	7.1	-1	2.5YR	45	5.4
	#9 (Jory)		0.74	30	18	45	12.6	52.2	5.8	7.9	-2	5YR	36	5.4
	#10 (Jory)		0.72	30	16	55	13.4	49.8	5.4	7.5	-1	10YR	45	5.5
	#14 (Jory)		0.79	40	22	47	10.4	42.5	5.8	7.4	+3	2.5YR	66	5.6
	#15 (Jory)		0.78	20	13	53	11.6	48.7	5.7	7.3	+1	2.5YR	34	5.4
Silty Clay over Basalt Hill Top El. 630'	#13 (Nekia-like)	illite	1.1	30	14	50	11.4	42.7	7.1	6.4	+3	2.5YR	54	5.5
Alluvium and Colluvium near Valley Floor El. <325'	#12 (Alpin)	vermiculite smectite	0.97	50	17	42	8.5	40.7	6.4	6.6	+2	5YR	40	5.4
	#11 (Nekia)	smectite chloritic	0.98	70	14	36	8.2	40.4	4.7	4.8	+2	10YR	62	5.5
	#5 (Jory)	chloritic	1.5	60	17	32	8.7	39.3	5.5	5.5	+3	3.5YR	64	5.8

Table #5. DATA FOR C HORIZON SAMPLES ARRANGED BY CLAY MINERAL GROUPS

Parent Material Position Elevation	Samples	Clay Minerals	Index Ratio	C.E.C. Clay meq/100g	Sand %	Clay %	Linear Shrinkage %	P.L.-300°C %	Weight Loss 65-300°C %	300-550°C %	Plastic Estimate	Hue	Base Sat. %	pH
Willamette Silts on Valley Floor El. < 325'	#6 (Willamette)	illite vermiculite smectite chloritic	1.4	140	18	14	6.4	32.4	2.8	2.0	+1	2.5Y	109	5.8
	#4 (Dayton)		2.4	170	30	16	9.4	35.2	3.6	1.5	+2	2.5Y	104	6.5
	#3 (Dayton-like)		1.5	170	42	15	7.5	33.7	3.1	1.9	+2	2.5Y	109	7.3
	#2 (Amity-like)		2.0	100	20	20	10.4	35.0	3.0	1.7	+2	2.5Y	114	7.0
	#1 (Scholl)		2.0	70	11	41	10.4	35.6	4.3	2.2	+3	2.5Y	106	7.1
	#24 (Dayton)		1.5	80	7	38	12.4	39.0	4.2	2.8	+4	2.5Y	118	7.2
	#23 (Dayton)		1.6	90	2	29	9.4	36.3	3.4	2.2	+2	2.5Y	108	6.6
	#21 (Dayton)		1.3	110	6	20	8.5	33.4	2.7	2.0	+2	2.5Y	119	6.6
#19 (Dayton)	1.4	130	12	20	9.4	38.4	3.3	2.4	+2	2.5Y	96	6.4		
Alluvial Clays on Valley Floor El. < 325'	#24 (IIC)	smectite	1.6	70	8	59	12.1	39.9	5.3	3.4	+5	5YR	98	7.0
	#22 (Cove)		1.5	100	4	40	13.4	47.8	6.0	3.9	+4	10YR	111	7.5
	#20 (Holcomb)		1.7	150	7	25	13.1	45.3	5.1	3.0	+3	10YR	107	6.8
	#18 (Wapato)		2.1	90	26	47	12.4	46.8	6.0	2.9	+4	2.5Y	103	7.3
Saprolite Tuffaceous Sediments on Hill Tops El. 540'-800'	#17 (Hazelaire-like)	poorly crystalline smectite and kandite	1.3	1100	66	4	11.1	56.8	5.4	4.2	+1	2.5Y	88	5.6
	#16 (Peavine-like)		1.4	50	5	86	18.8	77.6	8.3	5.9	+4	2.5YR	69	4.5
	#8 (Willakenzie-like)		-	60	1	75	27.6	88.7	6.1	-	-2	2.5YR	27	4.6
Deep, Red, Acid Colluvium on Hill Slopes El. 375'-575'	#7a (Jory)	kaolinite illite	0.67	240	59	5	4.2	44.7	5.6	8.4	-4	7.5YR	31	5.8
	#14 (Jory)		0.62	50	18	49	12.1	58.8	5.6	9.0	+4	5YR	61	6.0
	#9 (Jory)		0.71	30	17	44	11.4	53.9	5.4	7.6	-4	5YR	19	5.4
	#10 (Jory)		0.91	30	17	49	13.4	55.3	5.8	6.4	+1	2.5YR	27	5.0
	#15 (Jory)		0.72	20	14	53	12.9	53.2	5.3	5.3	+1	2.5YR	23	5.0
Alluvium and Colluvium near Valley Floor El. < 325'	#12 (McAlpin)	illite vermiculite smectite chloritic	1.2	70	21	25	8.2	41.9	6.4	5.4	+2	10YR	53	5.8
	#11 (Nekia)		1.2	80	16	19	12.1	49.9	6.1	5.2	+3	5YR	66	5.8

Relation of Clay to the Soil SystemClay Minerals and an Index Ratio

For practical purposes, several degrees of association are commonly ascribed to water in the soil system (e.g., capillary and hygroscopic) and are concerned with cohesive and surface binding forces that are weak relative to assumed stability of the particles involved; but, aside from direct practical value, the sharpest distinction in kind which can be made lies between this water which is held at the surface of particles, and that water which is actually a constituent in the crystal lattice. The latter is, of course, present in the form of hydroxyl ions and its absolute amount is determined by the particular kind of crystal lattice.

The hydroxyl ion forms lattice associations neither with cations of low nor of high ionic potential, but rather, with those of intermediate surface charge density¹ such as Al^{+++} , Fe^{++} , and Mg^{++} . Of these, the mineral structures of three-layer type like the micaceous clays would have (by weight) proportionately fewer hydroxyl groups present than the two-layer kandites, and they, in turn, less than the single-layered gibbsite-goethite-brucite type lattice. Since the cation-hydroxyl bond is less stable than the cation-oxygen bond, it is not surprising to note that, although the geometry of the system is also a controlling factor, thermal stability of such hydrous

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i.e., those which tend to form insoluble hydrates under the near neutral acid-base conditions common at the earth's aqueous surface (38)

minerals is inversely proportional to their hydroxyl content. Relative positions of their dehydroxylation peaks in D.T.A. illustrate this, and also help to distinguish among them.

With the two-layer clays, in which hydroxyl loss occurs over a restricted temperature range near 550°C , the actual amount of dehydroxylation serves to measure the quantity of mineral present (36, p. 63-97). In contrast, the loss of hygroscopic water bears a much closer relation to the character and amount of surface area of the particles than to their lattice character, and so is a gauge of quantity mainly in certain cases where lattice character is known. For example, three-layer clays such as vermiculite or smectite contain a great deal of surface area by virtue of their expansion characteristics (and therefore also have a high capacity to contain hydrating cations) and as a consequence, they usually hold very large amounts of hygroscopic water. On the other hand, those that do not expand, such as illite, hold much less.

Thus, a measure of weight loss in the region (150°C) where hygroscopic water is driven off, and another in the 550°C region where dehydroxylation commonly occurs, could serve to distinguish dominant kinds of the common clay minerals. Berkelhamer (6) tested nearly a hundred clays by this means and established a simple laboratory test for typing clay samples¹.

Similar information is available from weight loss values (recorded

1

He followed a two hour dehydration of duplicate samples with a two hour rehydration period at 65°C for one sample and two hours at 600°C for the other.

as percent change relative to 300°C, Appendix) for soil samples used in the present study. The value for 65°C includes exchangeable cation hydration moisture as well as that which was held by surfaces of amorphous and crystalline material, and also probably includes hydroxyl water from amorphous material and some or all of the lattice water from single-layer minerals like gibbsite. The value for 550°C, judging by D.T.A. patterns (Appendix), includes some crystal lattice water from smectites as well as from kandites.

Actual amount of clay present in any particular sample from the transect may be as much as 20 to 90 percent of the total, and both weight loss values should reflect such variation. However, the ratio between them should be relatively independent of this variation in clay content and, thus, might be useful in comparing the kinds of clay mineral present. This ratio of weight lost between 65°C and 300°C to weight lost between 300°C and 550°C is the Index Ratio (see Figure 11a).

Whether the main form of clay mineral present is two-layer or three-layer would be, in most cases, indicated by the actual value of percentage weight loss between 300°C and 550°C. Given an appreciable clay fraction in the sample, a large weight loss value indicates the former, while a small or negligible value suggests the latter. To the extent that individual minerals within both the two- and three-layer mineral groups are ranged in a sequential array relative to their increasing degree of crystallinity and decreasing surface area (e.g., smectite < vermiculite < illite, and hydrated halloysite < disordered kaolinite < kaolinite), their corresponding Index Ratio would decrease in value.

In the event that samples were to contain but a single clay mineral component, the utility of the Index Ratio would be unequivocal. The index for three-layer clays would range in number from values near one for the relatively low surface area micas to Index Ratio numbers of two and more for fine grained smectites and the vermiculites of high C.E.C. Index Ratios of the two-layer clays would range from values near one for very fine grained hydrated halloysite to fractional numbers increasingly smaller as the degree of crystal order increased from disordered kaolinite to more ordered forms.

In this way, for samples from the transect, an Index Ratio of appreciably more than one would indicate the dominant presence of expanding lattice material, while a fraction appreciably less than one would appear only in the event that the major component was kaolinite or one of its more ordered forms. Index numbers near to one would be less easily interpreted, as they might represent nonexpanding three-layer clays, poorly crystalline clays, or multi-component two- and three-layer clay mineral suites.

Some differentiation among these three last mentioned categories could be made if the percent weight loss through dehydroxylation from a sample is considered in terms of its Index Ratio. For example, Figure 11_a lists the Index Ratios for all B horizon samples on the transect. Figure 11_d graphs the relative percentages of "hygroscopic water" and "lattice water". It will be seen that, for the most part, loss of the latter form of water is less than three or four percent in samples from the valley, while it is usually at least five percent and more in samples from the Salem Hills. The Index

Ratio for most of the valley soils stands above 1.5, while that for most of the hill soils is a fraction less than one.

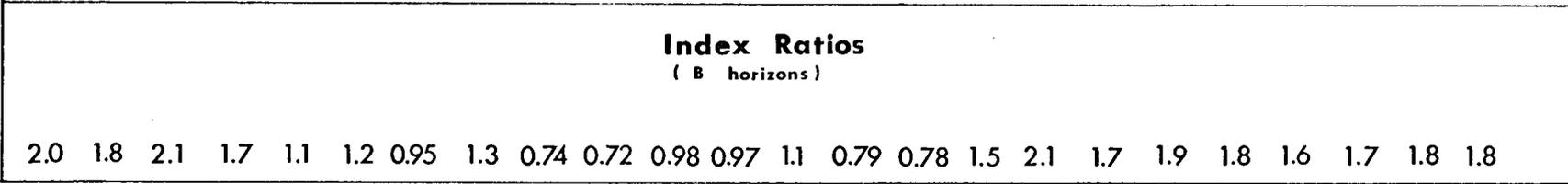
There are, however, several samples whose Index Ratio lies near one. Consideration of their percentage "lattice water" in terms of the Index Ratio makes the distinction between those dominant in non-expanding three-layer clays and those containing significant amounts of two-layer clay mineral. For example, both samples #6 and #13 have an Index Ratio of 1.1 for their B horizon. Reference to the percentage "lattice water" lost in each case will make a satisfactory distinction.

For B horizons, Index Ratios greater than 1.5 are restricted to valley alluvial soils with primarily vermiculite and smectite clay mineral components. Fractional values of less than 0.8 have reference to the over-deepened red colluvial hill soils (usually called Jory) with kaolinite a major component. B horizons with an Index Ratio near to one include: the illitic sample #6 (Willamette); alluvial and colluvial samples at the foot of the Salem Hills (#5, #11, #12) which appear to contain significant amounts of both two- and three-layer clay minerals; and the shallow, apparently truncated, soils overlying basalt or weathered tuffaceous sediments at well drained positions on the exposed ridges (#8, #13, #16), which appear to contain both two- and three-layer minerals of a poorly crystalline nature. (To be included in this last named group is #17, a dense clay sample with exceptional Index Ratio of 1.7).

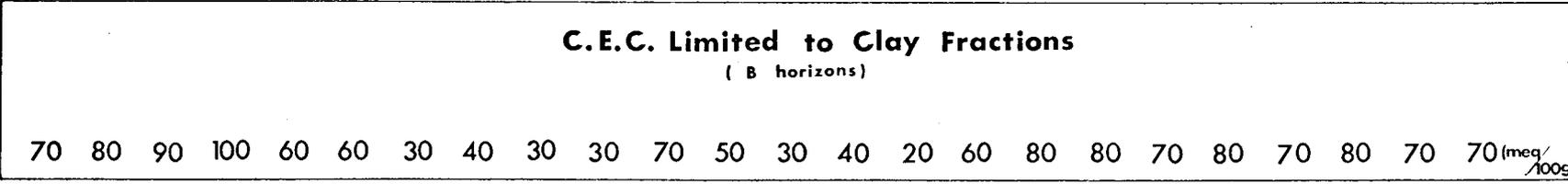
When calculations are made (for B horizons) on the C.E.C. that was observed in the whole soil sample, in order to limit it only to

the clay fraction, it is seen that the estimated values follow the same grouping (Figure 11_b). With one possible exception (#11), calculated values greater than 60meq/100g of clay are found only in the alluvial valley soils, values of 30meq/100g of clay or less are confined to those samples judged to hold kaolinite as the primary component, and various intermediate expressions of C.E.C. from 40 to 60meq/100g of clay are found in the other samples (in the relative quantities expected from assumptions upon which the Index Ratio was based.)

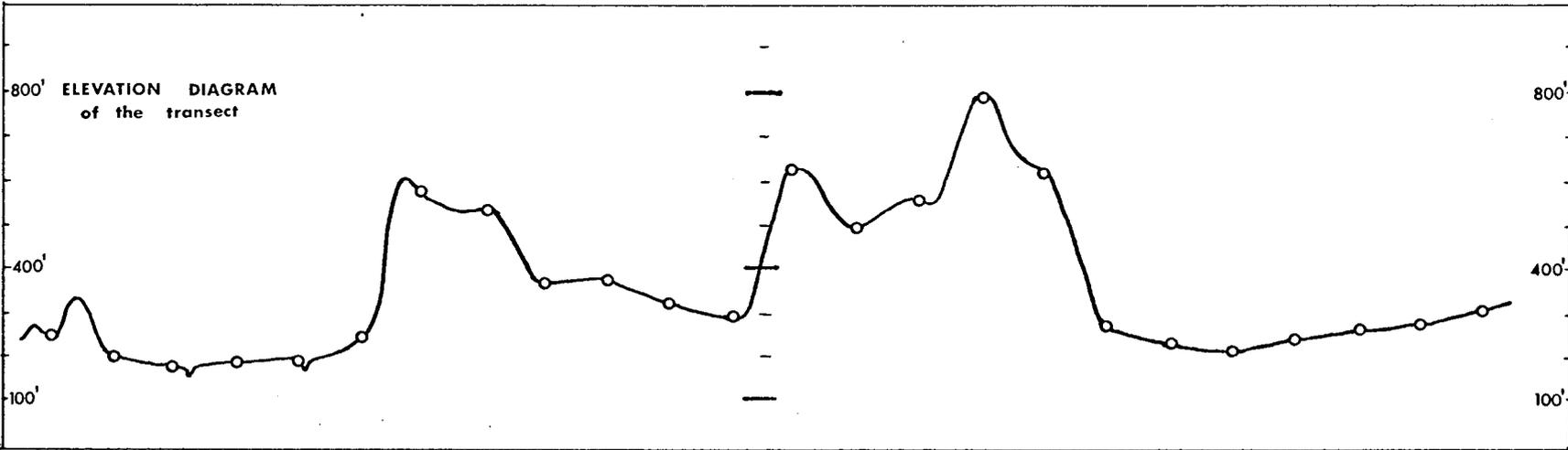
Figure 11a



11b



11c



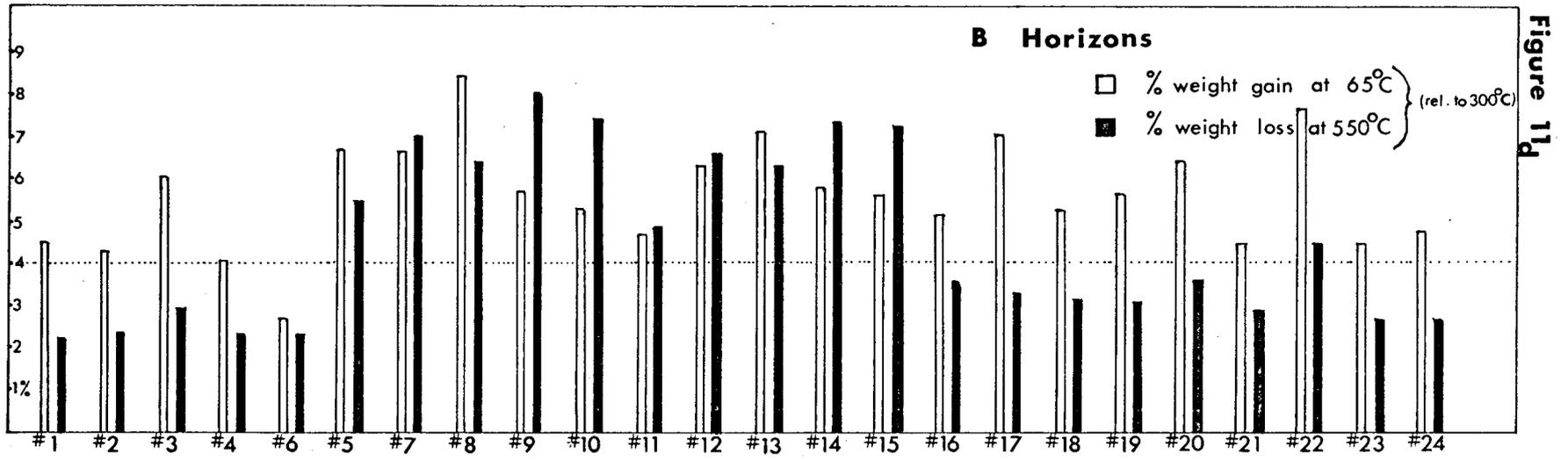
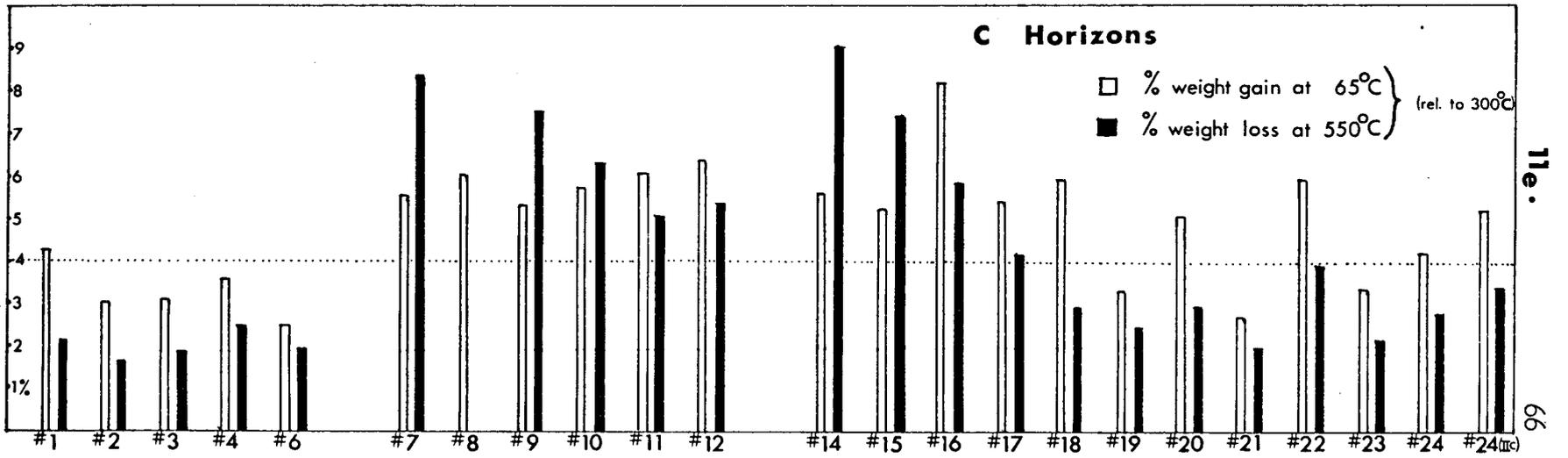


Figure 11a



11e
66

Relation of Shrinkage, Percent Clay, and Plastic Limit

Discussion of the Index Ratio has centered attention on use of "hygroscopic water" as a crude form of specific surface-area measurement in differentiating the clay minerals. The direct relation between available surface area and water held at the Plastic Limit has also been discussed (p. 21-22). This dependence is quantitatively shown in the coincidence of values between percent of moisture held at the Plastic Limit and percent of clay present in B horizons sampled (Figure 12_a).

The somewhat reduced amounts of moisture held by two-layer clays in contrast to three-layer clays due to their differing geometry, lesser surface charge, and fewer adsorbed hydrating ions, is also perhaps evident in Figure 12_a, as indicated by the tendency of Plastic Limit values of Hill soils to fall below figures for percent clay.

Slight but consistent deviations between the percentage values for Plastic Limit and percent clay in valley samples from the transect north of the Salem Hills, in contrast to those south of the Salem Hills, suggests the presence of internal surface in sand and silt particles as determined by the mechanical analysis. The foundation for this opinion is greatly strengthened by analysis of much larger deviations in samples from C horizons on the transect (Figure 12_b). The most extreme discrepancies between percent clay measured and the amount of water held are found in samples #7_a and #17. Both of these samples were, in fact, taken from their field location in a consolidated form. Sample #7_a was a fully weathered

rock fragment at four feet in a Jory profile of deep colluvium. Sample #17 was saprolite from weathered tuffaceous sediments. In such cases, it seems obvious that the concept of a clay fraction as being composed of an aggregate of discrete, separable particles breaks down, and standard estimates by mechanical analysis of percent clay become irrelevant. Sample #11 is another example of such material. On this basis, most of the C horizon samples contain sand and silt size particles with internal surface, and it is perhaps accurate to view a large proportion of them as sponge-like particles holding considerable $<2\mu$ material which is not released by dispersion procedures-- or, perhaps, simply revealing a large internal surface area on their own account. As might be expected, shrinkage values in these extreme examples are considerably smaller than would be anticipated from their demonstrated moisture holding capacity or the large amounts of clay that are suggested by D.T.A. Under these circumstances, moisture holding capacity or surface area measurements would probably be a more useful indication of "clay content" than would results from mechanical analysis.

Figure 12_a shows that, in general, linear shrinkage and amount of water held at the Plastic Limit are closely related to the amount of clay present. No indications of a difference in linear shrinkage due to differences in kind of clay mineral are apparent among these samples. Figure 12_b shows that shrinkage values for the transect samples can be more closely related to differences in the amount of water held than to the amount of clay measured by mechanical analysis.

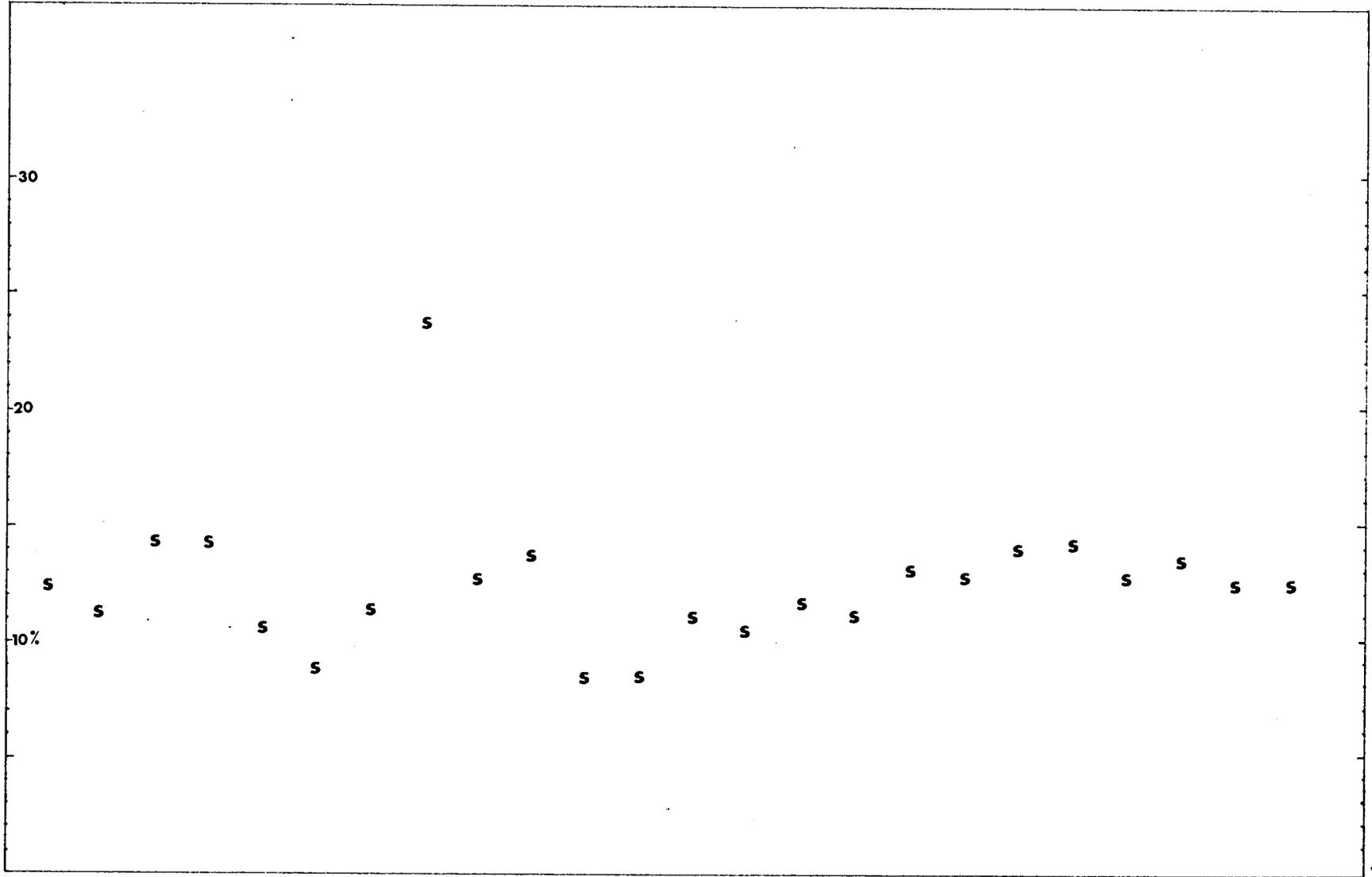
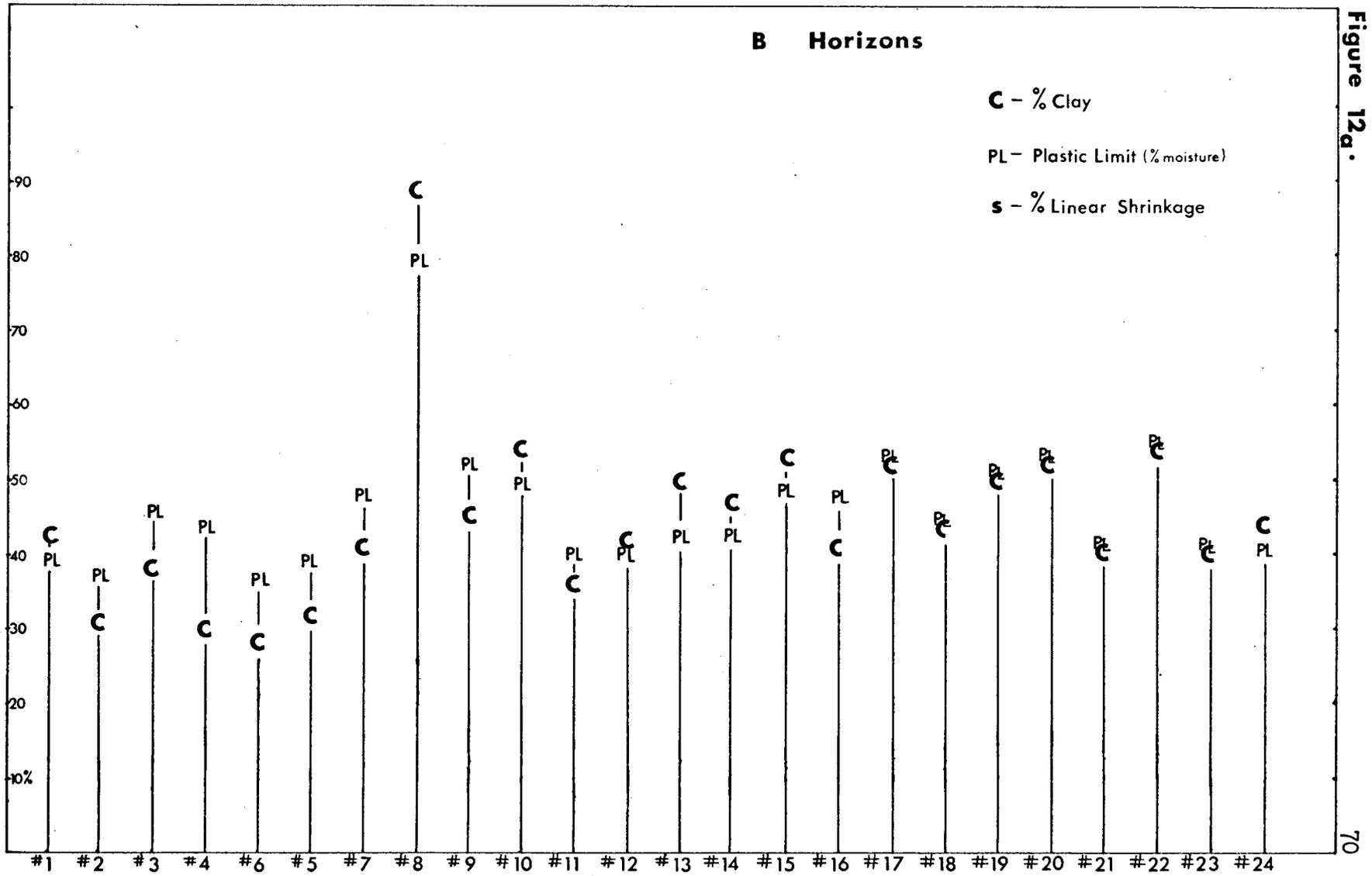
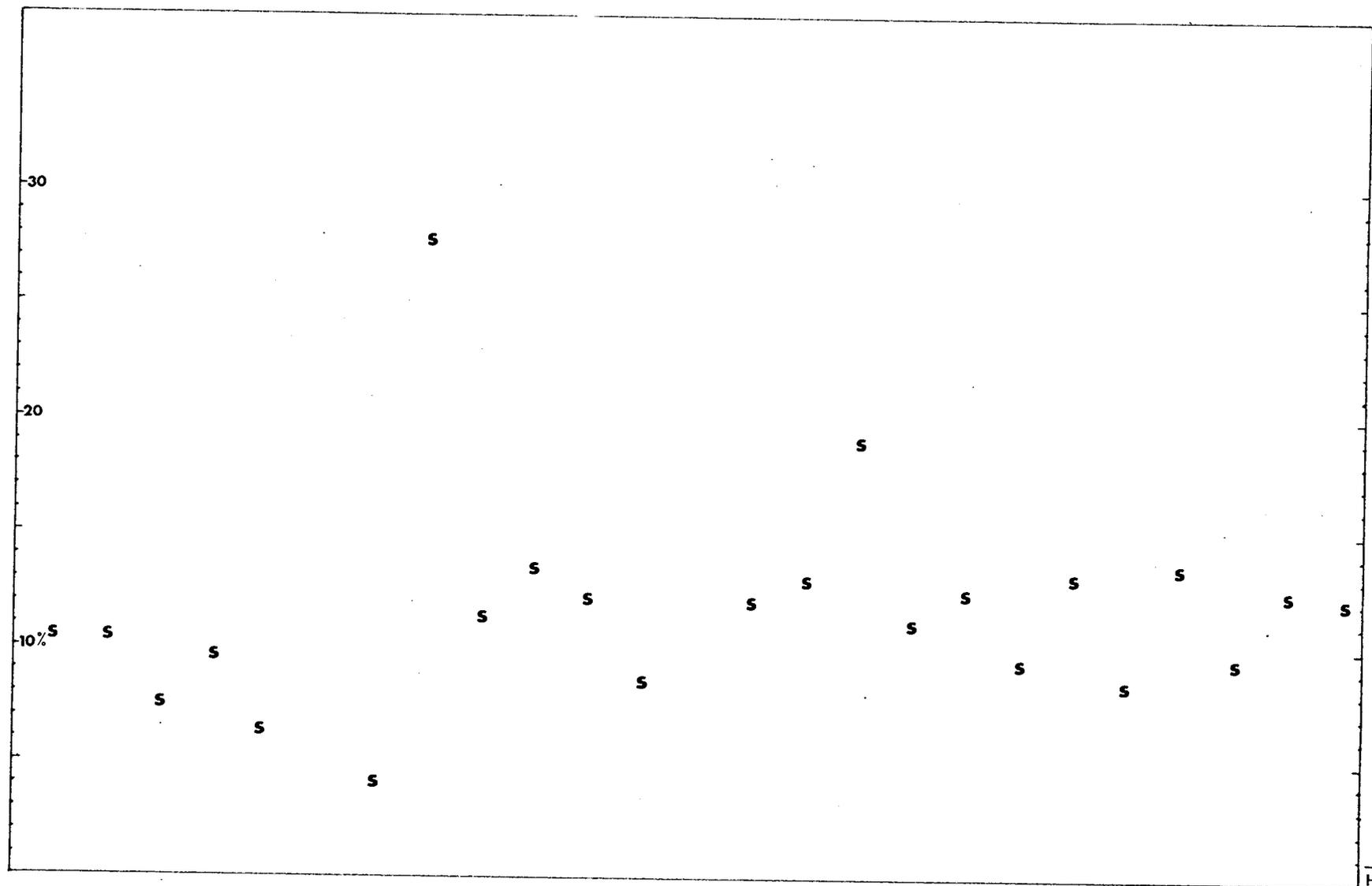


Figure 12a.





C Horizons

C - % Clay

PL - Plastic Limit (% moisture)

s - % Linear Shrinkage

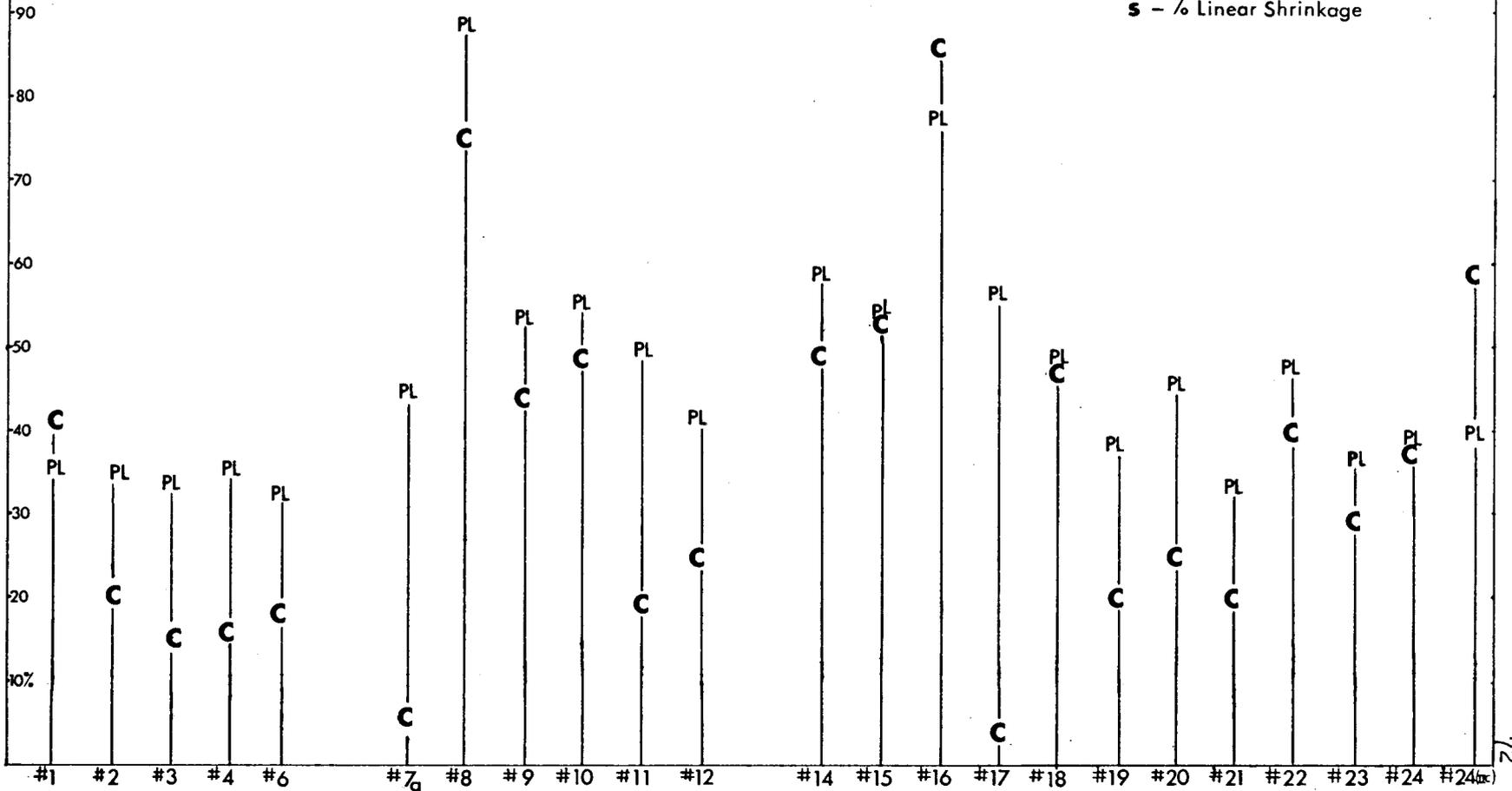


Figure 12b.

Shrinkage and Weight Loss through Time

Considerable attention has been paid to the effect of water on clayey systems. Comprehensive reviews have been published in the interest of agriculture (4), the ceramic industry (26, 19), and foundations engineering (58).

Dimensional change in an unrestrained clayey system upon loss of water is governed by particle size distribution and the character of hydrophyllic materials present (e.g. nature of organic matter, hydration tendencies of exchangeable ions, compressibility and shape of particles, state of particle aggregation, etc.). The general features of such a system, starting from a plastic state where all the particles are surrounded by a hydrous film continuous throughout the system, were pointed out by Haines (24).

Characteristic modes of shrinkage relative to moisture loss have been concisely described by Holdridge (26, p. 82-5), who says:

"---As the water is removed during drying, the initial tendency is for these films to become attenuated and for the surface tension to draw particles closer together. During this stage...[A, Figure 13], the volume of the sample decreases by the volume of water removed from the system, so that, if the weight of the sample is plotted against the volume, a straight-line graph is obtained having a slope of 45 degrees. Eventually some of the particles come into contact and a pore system starts to form. Water continues to escape from the pores, but the contraction of the piece as a whole is restricted by the fact that some of the particles are already in contact. Volume contraction is hence no longer proportional to the loss of moisture but gradually tails off (stage B) into the final stage when the system is comparatively rigid (stage C). A slight contraction occurs in stage C owing to the compacting of the structure through the surface tension of the remaining water films and the gradual dehydration of the colloidal material; there is some evidence for a final slight expansion when the material is finally dried out..."

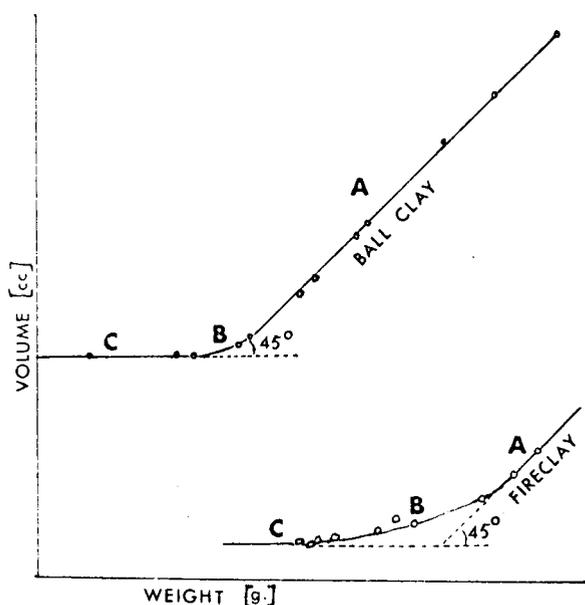


Figure 13. Volume changes in different types of clay during drying.
 (from Holdridge, 26)

"... The whole phenomenon appears to be closely bound up with particle size: the finer the grain size and the higher the colloid content, the more water this system will hold, the longer becomes stage A and the shorter stage B, since the system will be relatively close-packed at the end of A. With a higher proportion of relatively large particles stage A is shortened and the subsequent smaller contraction in stage B extended as the coarse particles adjust themselves under the pull of the surface tension of the water films and the finer particles are drawn into the relatively large pores."

Franklin reports (19), from the work of Fisher (18) and Sherwood (46-49), three rate controlling steps in the drying of granular masses or porous bodies: (a) evaporation of liquid at the surface of the body (resistance to internal diffusion is small in comparison with resistance to removal of water at the surface), (b) evaporation at the solid surface when internal resistance is large compared with resistance to the removal of vapor at the surface (a "Falling Rate Period" (46) where decrease in rate is dependent on the rate at which

the area of wetted surface diminishes), and (c) evaporation within the interior of the solid as the drying surface steadily recedes into the interior of the body (resistance to internal diffusion is great compared with the total resistance to removal of water vapor).

Curves for shrinkage and weight loss through time for B horizons of the five profiles (Figure 14_a, p. 76) may be considered in two parts: an initial period of about 17 to 19 hours during which the shrinkage and weight loss were large and rapid, relative to a second period when shrinkage slowed down or stopped and moisture loss continued at a reduced rate. In the terms of Holdridge's description of volume loss relative to water loss (quoted on p. 73-74), the fairly abrupt end of the initial period of shrinkage corresponds to the end of stage A (Figure 13) when some of the particles have come into contact and contraction is no longer proportional to moisture loss, but tails off through stage B to stage C (Figure 13).

This initial period of relatively rapid loss shown in Figures 14_a and 14_b corresponds to that termed the "Falling Rate Period" (see (b) on p. 74) when water evaporates at the wetted surface at a rate not yet primarily determined by internal forces, since contraction still continues without restriction. Thereafter, upon the formation of pore space as particles come in contact and begin to resist further reduction in total volume, water leaves at a slower rate, controlled by the processes of internal conduction in a capillary system.

Figure 14a.

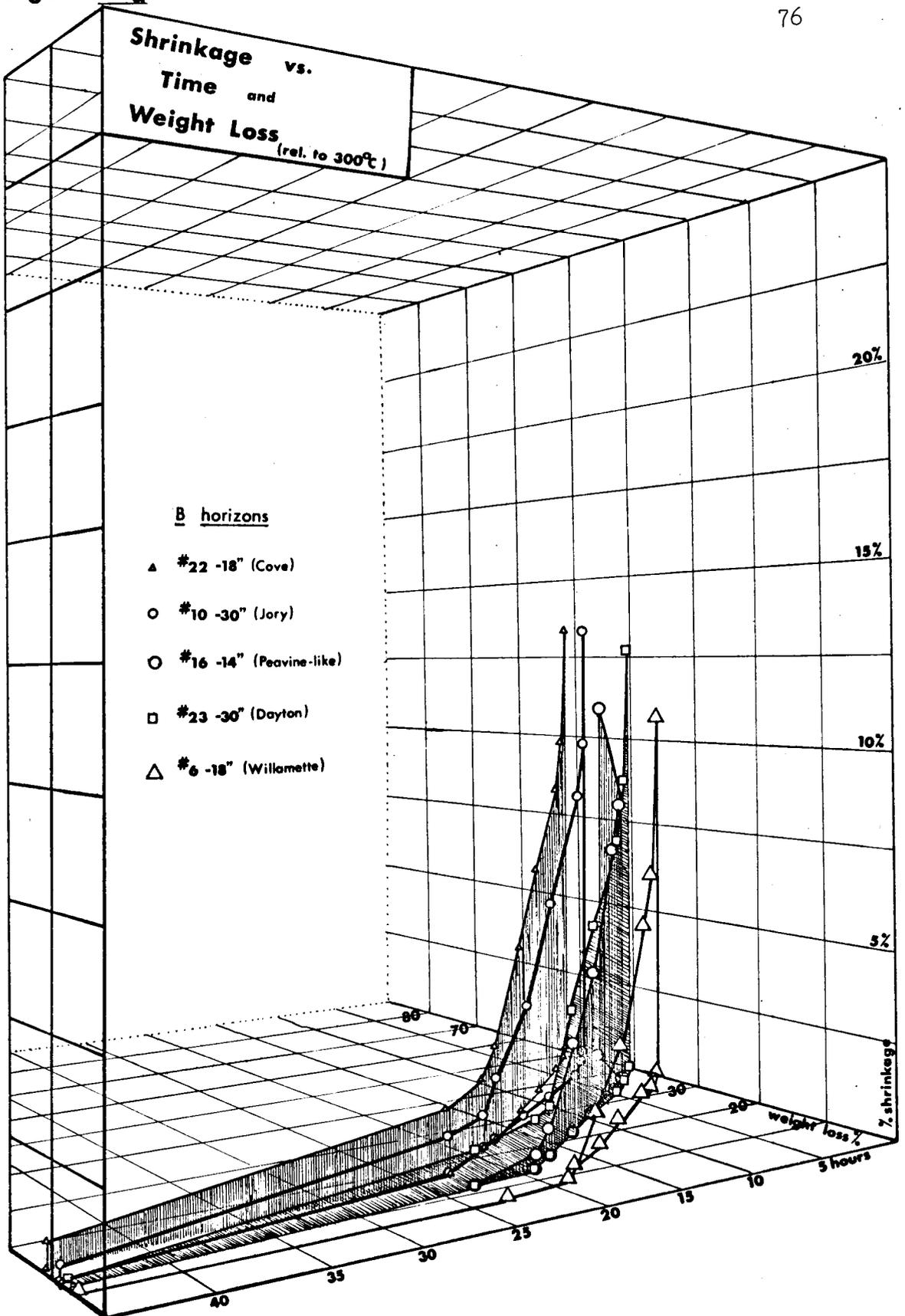
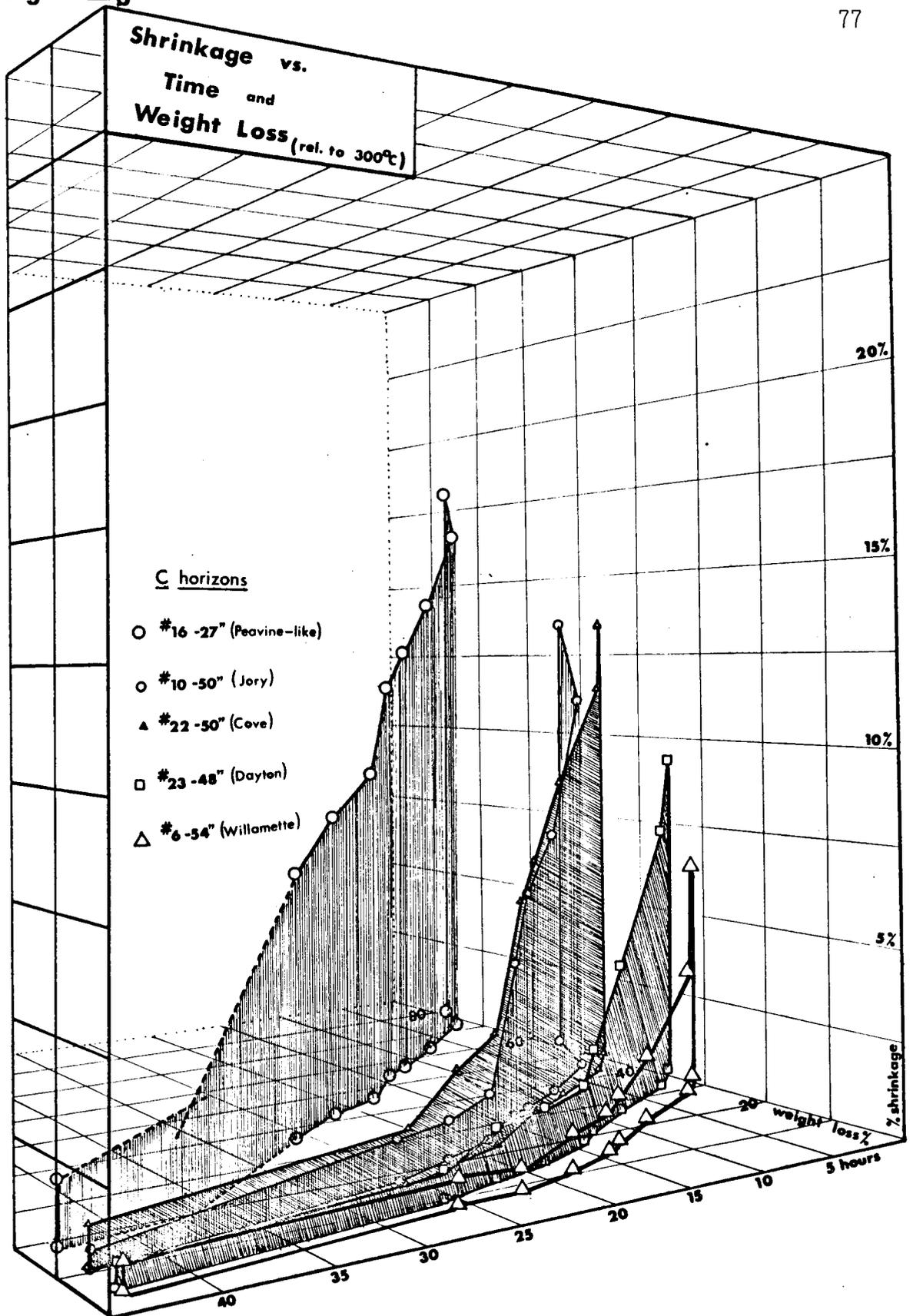


Figure 14_b.



Haines pointed out that this latter, slow, period of "residual shrinkage" (24) varies a good deal in amount. While noting that the total shrinkage has been linked with clay content (53), he suggested that the "residual shrinkage depends upon the extent of ultrafine colloidal material presumed to "pad" the solid particles. (He observed a several percent increase in "residual" shrinkage of kaolin upon addition of a small fraction of one percent of silica gel.)

As might be expected of silty material in comparison to soils containing fine clay and/or amorphous material, Figure 15 shows the Willamette B horizon sample as lacking in "residual" shrinkage, in contrast to Cove and Jory. It is also apparent that "residual"

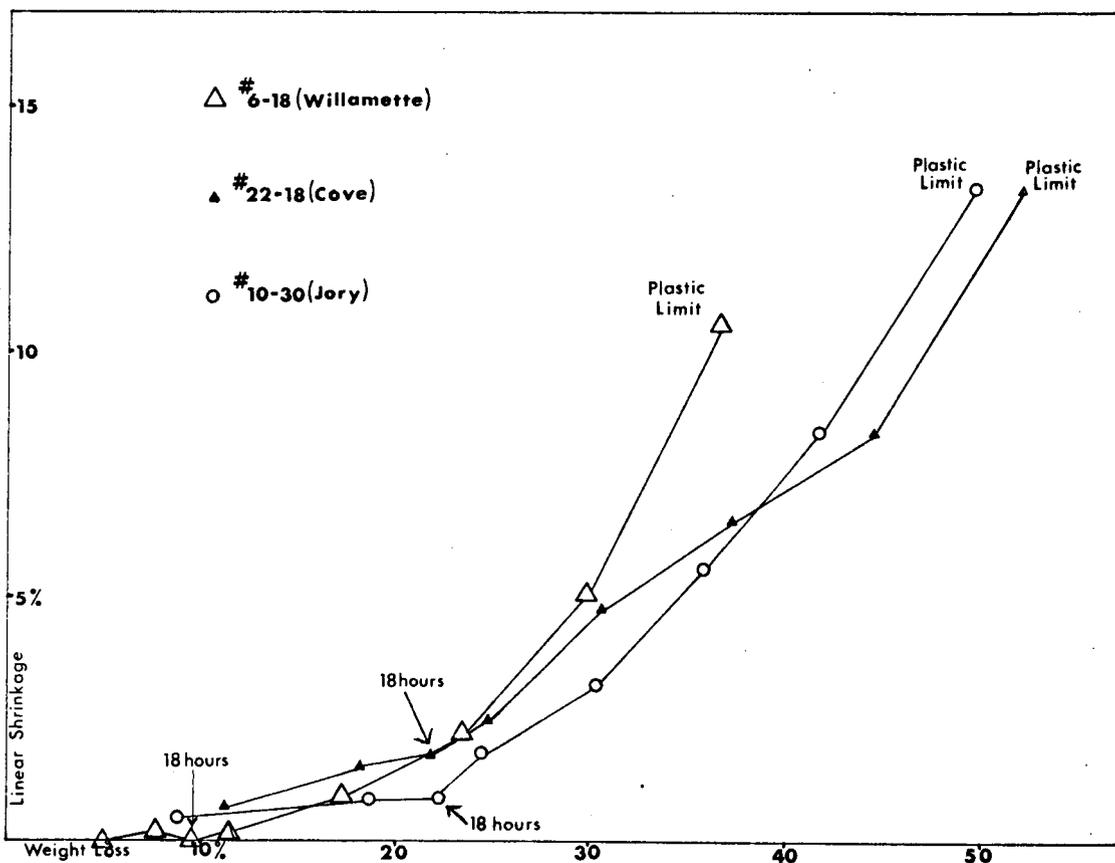


Figure 15. Linear Shrinkage and weight loss for selected B horizon samples (relative to 300°C).

shrinkage was greater in the case of the Cove sample than the Jory. Thus, the values for "residual" shrinkage taken from curves in Figure 15 show Willamette < Jory < Cove. The abrupt aspect of the transition region (stage B) in the curve for Jory suggests that, of the three samples shown in Figure 15, it may contain the highest proportion of ultra-fine colloidal (i.e., amorphous) material even though its "residual" shrinkage is less than that of Cove.

Complexity of Shrinkage Factors

If significant differences in shrinkage behavior between samples could be directly related to the kind of clay mineral present, then one would expect to be able to distinguish the Cove and Jory samples in Figure 15 (and in Figure 14_a) on that basis, since mechanical analysis indicated the same percentage of clay present in both samples. However, total shrinkage from the Plastic Limit is seen to be the same.

One might, then, note the slight amount of additional water held by Cove at the Plastic Limit, or its greater "residual" shrinkage as compared with Jory, and suppose this to be due to a difference between kaolinite and smectite in their association with water. Or, one might suppose that the additional water and higher "residual" shrinkage in the Cove sample could be attributed to a difference in kind and amount of hydrating cations present, since Cove may be assumed to have two to three times the number of exchange sites present than are in Jory clay and to have most of them filled by Ca^{++} or Mg^{++} (Appendix). On the other hand, the observed differences might be thought to be evidence of a difference in the dominant kind of accessory amorphous material present, such as iron and aluminum hydrates in the Jory vis à vis silica gel in the Cove. However, if a close look is taken at particle size distribution in Table 2 (p. 29) it will be seen that about one third of the clay fraction in the Jory sample is $<0.08\mu$ size, whereas about half of the Cove clay fraction

is $<0.08\mu$ material. Thus, surface area alone might account for the ⁸¹ differences observed.

It seems likely that each of these sources of potential difference between the two samples influences the resultant shrinkage behavior and water holding capacity to some extent. (For example, it would be very surprising if significant changes in these bulk properties did not occur were the Ca^{++} - Mg^{++} ions filling exchange sites in the Cove smectite to be replaced with either Na^+ or K^+ .) Nevertheless, the resultant effect of all these inter-related factors serves to conceal any possible relation between clay mineral type and shrinkage behavior in the 'whole soil' samples.

Figure 12_a illustrates the correlation of shrinkage values for B horizon samples along the transect with values for water held at the Plastic Limit and, in most cases, for clay content. Figure 11_d presents dehydroxylation data (loss 300-550°C) for the same array of B horizon samples along the transect. A comparison of the two sets of bar graphs fails to show any significant difference in shrinkage behavior relative to clay content (or Plastic Limit values) for that group of samples dominant in kandite clay (#5 through #15) as opposed to the rest of those on the transect which are dominant in three-layer clays. Additional data, as well as data presented on these figures, are summarized, according to mineral groups, in Tables 4 and 5 (p. 57 and 58).

It is possible that a close analysis of shrinkage curves for all the transect samples might show differences in "residual" shrinkage relative to their clay mineral content, but the total shrinkage values for 'whole soil' samples do not reveal their differing clay mineral

content. This does not, however, deny the possibility that soils of a more extreme range of difference in clay mineral content might be differently affected in shrinkage properties. In particular, one might expect differences to be apparent if the clay mineral differences were not obscured by poor crystallinity and contaminating amorphous material, or if the exchangeable cations present displayed more extreme hydration tendencies.

The failure in this study to observe differences in total shrinkage relative to their known differences in clay mineral content does not deny the possibility that the character of shrinkage in the field could show differences related to the clay mineral content, since the macro-structure of the field material was destroyed before making the shrinkage studies. Study of possible correlation between kind of macro-structure developed and kind of clay minerals present in the soil would be an interesting investigation, but beyond the scope of the present work.

BIBLIOGRAPHY

1. Alban, L. A. and Mildred Kellogg. Methods of soil analysis as used in the OSC Soil Testing Laboratory. Corvallis, Oregon State College Agricultural Experiment Station, 1959. 9 p. (Miscellaneous Paper No. 65)
2. Allen, Victor T. Formation of bauxite from basaltic rocks of Oregon. *Economic Geology* 43:619-626. 1948.
3. Atterberg, Albert. Die plastizitat der tone. *Internationale Mitteilungen fur Bodenkunde* 1:10-43. 1911.
4. Baver, L. D. Soil physics. 3d. ed. New York, Wiley, 1956.
5. Baver, L. D. and G. M. Horner. Water content of soil colloids as related to their chemical composition. *Soil Science* 36: 329-353. 1933.
6. Berkelhamer, Louis H. Rehydration study of clays. *Journal of the American Ceramic Society* 26:120-126. 1943.
7. Bohor, Bruce F. High temperature phase development in illitic clays. In: *Proceedings of the Twelfth National Conference on Clays and Clay Minerals*, ed. by W. F. Bradley. Oxford, Pergamon Press, 1964. p. 233-246
8. Bradley, W. F. (ed.). *Proceedings of the Twelfth National Conference on Clays and Clay Minerals*. Oxford, Pergamon Press, 1964. 691 p.
9. Bradley, W. F. and R. E. Grim. Mica clay minerals. In: *The X-ray identification and crystal structures of clay minerals*. London, Mineralogical Society (Clay Minerals Group), 1961. p. 209-241
10. Brindley, G. W. Kaolin, serpentine, and kindred minerals. In: *The X-ray identification and crystal structures of clay minerals*. London, Mineralogical Society (Clay Minerals Group), 1961. p. 51-131
11. Brindley, G. W. and D. M. C. MacEwan. Structural aspects of the mineralogy of clays and related silicates. In: *Ceramics: A symposium*, ed. by A. T. Green and Gerald H. Stewart. Stoke-on-Trent, British Ceramic Society, 1953. p. 15-59
12. Brown, George (ed.) *The X-ray identification and crystal structures of clay minerals*. London, Mineralogical Society (Clay Minerals Group), 1961. 543 p.

13. Buckman, Harry O. and Nyle C. Brady. The nature and properties of soils. 6th ed. New York, Macmillan, 1960. 567 p.
14. Carstea, Dumitru Dumitru. Conditions of Al, Fe, and Mg inter-layer formation in montmorillonite and vermiculite. Master's thesis. Corvallis, Oregon State University, 1965. 73 num. leaves.
15. Correns, C. W. The experimental weathering of silicates. Clay Minerals Bulletin 4(26):249-264. 1961.
16. Drosdoff, M. and E. F. Miles. Action of hydrogen peroxide on weathered mica. Soil Science 46:391-395. 1938.
17. Ervin, Guy, Jr. and E. F. Osborn. The system $Al_2O_3 \cdot H_2O$. Journal of Geology 59:381-394. 1951.
18. Fisher, E. A. Some moisture relations of colloids. I. A comparative study of the rates of evaporation of water from wool, sand, and clay. Proceedings of the Royal Society of London 103A:139-161. 1923.
19. Franklin, C. E. L. Changes in the theory and practice of drying, 1900-1950. In: Ceramics: A symposium, ed. by A. T. Green and Gerald H. Stewart. Stoke-on-Trent, British Ceramic Society, 1953. p. 315-362
20. Green, A. T. and Gerald H. Stewart (eds.) Ceramics: A symposium. Stoke-on-Trent, British Ceramic Society, 1953. 870 p.
21. Greene-Kelly, R. The identification of montmorillonoids in clays. Journal of Soil Science 4:233-237. 1953.
22. Grim, Ralph E. Organization of water on clay mineral surfaces and its implications for the properties of clay-water systems. In: Water and its conduction in soils (An international symposium). Washington, D. C., National Research Council, 1958. p. 17-23 (Highway Research Board Special Report No. 40)
23. Groves, R. C. Exfoliation of vermiculite by chemical means. Nature 144:554. 1939.
24. Haines, W. B. The volume changes associated with variations of water content in soil. Journal of Agricultural Science 13: 296-310. 1923.
25. Harward, M. E. and N. T. Coleman. Some properties of H- and Al-clays and exchange resins. Soil Science 78:181-188. 1954.

26. Holdridge, D. A. The colloidal and rheological properties of clays. In: *Ceramics: A symposium*, ed. by A. T. Green and Gerald H. Stewart. Stoke-on-Trent, British Ceramic Society, 1953. p. 60-93
27. Holdridge, D. A. and F. Vaughan. The kaolin minerals (kandites). In: *The differential thermal investigation of clays*, ed. by Robert C. Mackenzie. London, Mineralogical Society (Clay Minerals Group), 1957. p. 98-139
28. Hyslop, J. F. The action of heat on clays. In: *Ceramics: A symposium*, ed. by A.T. Green and Gerald H. Stewart. Stoke-on-Trent, British Ceramic Society, 1953. p. 186-200
29. Insley, Herbert and Raymond H. Ewell. Thermal behavior of the kaolin minerals. *Journal of Research of the National Bureau of Standards* 14:615-627. 1935.
30. Jackson, M. L. Weathering sequence of layer silicates. *Soil Science Society of America Proceedings* 16:306. 1952.
31. _____ . Soil chemical analysis: Advanced course. Madison, University of Wisconsin, published by the author, 1956. 991 p.
32. _____ . Aluminum bonding in soils: A unifying principle in soil science. *Soil Science Society of America Proceedings* 27:1-10. 1963.
33. Johns, William D. and Edward C. Jonas. Some observations on the relation between isomorphism and properties of clays. *Journal of Geology* 62:163-171. 1954.
34. Kilmer, Victor J. and Lyle T. Alexander. Methods of making mechanical analysis of soils. *Soil Science* 68:15-24. 1949.
35. Libby, F. W., W. D. Lowry, and R. S. Mason. Feruginous bauxite deposits in northwestern Oregon. Salem, Oregon, 1945. 97 p. (Oregon Department of Mineral Industries. Bulletin 29)
36. Mackenzie, Robert C. (ed.) *The differential thermal investigation of clays*. London, Mineralogical Society (Clay Minerals Group), 1957. 456 p.
37. Mackenzie, R. C. and B. D. Mitchell. Differential thermal analysis: A review. *The Analyst* 87: 420-434. 1962.
38. Mason, Brian Harold. *Principles of geochemistry*. 2d. ed. New York, Wiley, 1958. 310 p.
39. _____ . Oxidation and reduction in geochemistry. *Journal of Geology* 57:62-72. 1949

40. Ramberg, Hans. A theoretical approach to the thermal stabilities of hydrous minerals. I. General principles as revealed by studies of hydroxides and oxyacids. *Journal of Geology* 62 (4):388-398. 1954.
41. Rich, C. I. and M. G. Cook. Formation of dioctahedral vermiculite in Virginia soils. In: *Proceedings of the Tenth National Conference on Clays and Clay Minerals*, ed. by Ada Swineford. New York, Macmillan, 1963. p. 96-106 (Earth Science Series, Monograph No. 12)
42. Richardson, H. M. Phase changes which occur on heating kaolin clays. In: *The X-ray identification and crystal structures of clay minerals*, ed. by George Brown. London, Mineralogical Society (Clay Minerals Group), 1961. p. 132-142
43. Rodebush, Worth H. and Arthur M. Buswell. Properties of water substance. In: *Water and its conduction in soils (an international symposium)*. Washington, D.C., National Research Council, 1958. p. 5-13 (Highway Research Board Special Report No. 40)
44. Ross, Clarence S. and Sterling B. Hendricks. Minerals of the montmorillonite group. U. S. Geological Survey Professional Paper 205B:23-77. 1945
45. Russell, E. Walter. *Soil conditions and plant growth*. 9th ed. London, Longmans, 1961. 687 p.
46. Sherwood, T. K. The drying of solids. I-II. *Journal of Industrial and Engineering Chemistry* 21:12-16, 976-980. 1929.
47. _____ . The drying of solids. III. *Journal of Industrial and Engineering Chemistry* 22:132-136. 1930.
48. _____ . The drying of solids. IV. *Journal of Industrial and Engineering Chemistry* 24:307-310. 1932.
49. _____ . The drying of solids. V-VI. *Journal of Industrial and Engineering Chemistry* 25:311-316, 1134-1136. 1933.
50. Smith, Joseph V. (ed.) *Index to the X-ray powder data file*. Philadelphia, American Society for Testing and Materials, 1962. (Special Technical Publication No. 48-L)
51. Soil Survey Staff. *Soil survey manual*. 1962. 503 p. (U.S. Department of Agriculture. Soil Conservation Service. Handbook No. 18)

52. Szent-Gyorgyi, Albert. Water structure and bioenergetics. In: Water and its conduction in soils (an international symposium). Washington, D.C., National Research Council, 1958. p. 14-16 (Highway Research Board Special Report No. 40)
53. Tempany, H. A. The shrinkage of soils. Part I. The relationship between contraction and water loss. Part II. The relationship between contraction and the percentage of colloidal clay. *Journal of Agricultural Science* 8:312-337. 1917.
54. Theisen, A. A. and M. E. Harward. A paste method for preparation of slides for clay mineral identification by X-ray diffraction. *Soil Science Society of America Proceedings* 26:90-91. 1962.
55. Tlapek, John W. and W. D. Kellor. Stabilities of three-layer phyllosilicates related to their ionic-covalent bonding. In: *Proceedings of the Twelfth National Conference on Clays and Clay Minerals*, ed. by W. F. Bradley. Oxford, Pergamon Press, 1964. p. 249-266
56. Wahl, F. M. and R. E. Grim. High temperature D.T.A. and X-ray diffraction studies of reactions. In: *Proceedings of the Twelfth National Conference on Clays and Clay Minerals*, ed. by W. F. Bradley. Oxford, Pergamon Press, 1964. p. 69-81
57. Walker, G. F. Vermiculite minerals. In: *The X-ray identification and crystal structures of clay minerals*. London, Mineralogical Society (Clay Minerals Group), 1961. p. 297-324
58. Winterkorn, Hans F. (ed.) Water and its conduction in soils (an international symposium). Washington, D.C., National Research Council, 1958. 338 p. (Highway Research Board Special Report No. 40)
59. Young, J. L. and R. A. Cattani. Mineral fixation of anhydrous NH_3 by air-dry soils. *Soil Science Society of America Proceedings* 26:147-152. 1962.

APPENDIX

Abbreviations Used in the Appendix

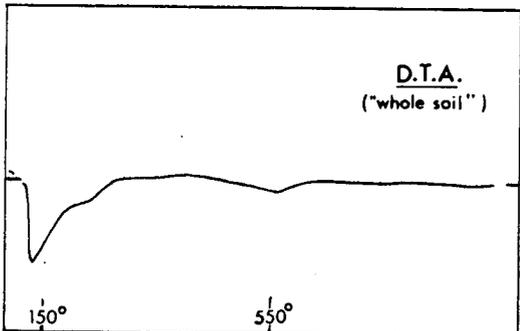
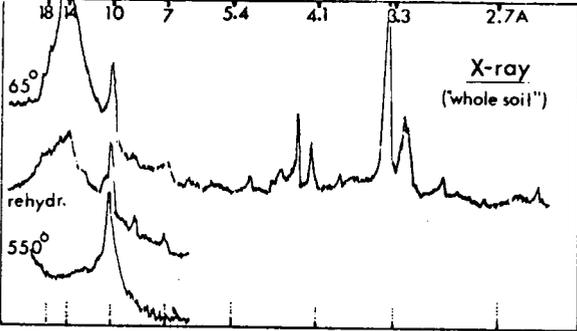
Base Sat.	quantity of exchangeable cations present
brn	brown
cr.	creek
dk	dark
E	east
g	gram
Gf	gravelly, breaking to ultra-fine when pressed
gry	gray
Imp.	imperfectly
lt.	light
meq	milliequivalents
Mtn.	mountain
N	north
nr.	near
Pl. Est.	Plastic Estimate
R.	river
rel.	relative
S	south
SE	southeast
th	thixotropic
W	west
v	very

Scholls. Poorly drained silt. 89
 N slope, Beaverton Cr. drainage. El. 240'

#1-24" B horizon 10YR 3/1 (v dk gry) Pl. Est. : +4
 pH 6.9 C.E.C. (meq/100g) 31 Base Sat. (meq/100g)

Na	K	Ca	Mg
1.3	0.5	18	14

% Sand	Silt	Clay
20	37	43



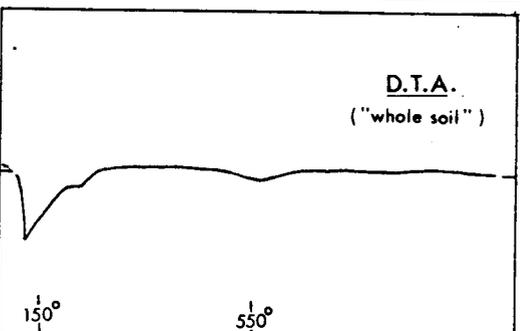
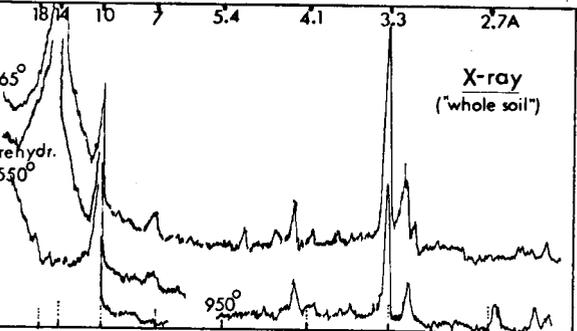
Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length				
2.0		weight	39.1	4.5	0.6	4.8	-2.2

Remarks:

#1-46" C horizon 2.5Y 3/2 (v dk gry brn) Pl. Est. : +3
 pH 7.1 C.E.C. (meq/100g) 30 Base Sat. (meq/100g)

Na	K	Ca	Mg
1.3	0.5	17	13

% Sand	Silt	Clay
11	48	41

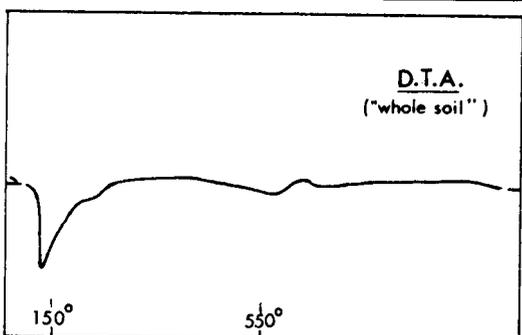
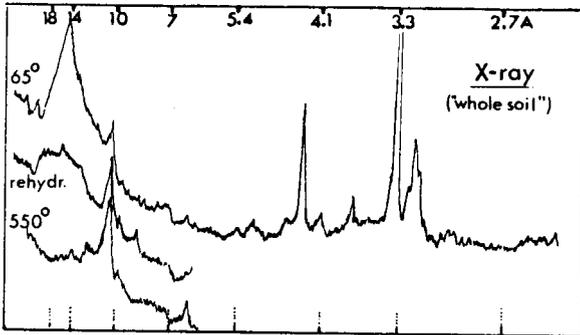


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length					
2.0		weight	35.6	4.3	0.5	6.0	-2.2	-7.7

Remarks:

Amity-like. Imp. drained colluvium from silts. El. 200'
 S slope Bull Mtn., Tualatin R. drainage.

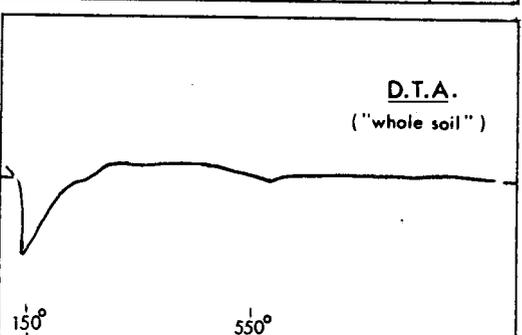
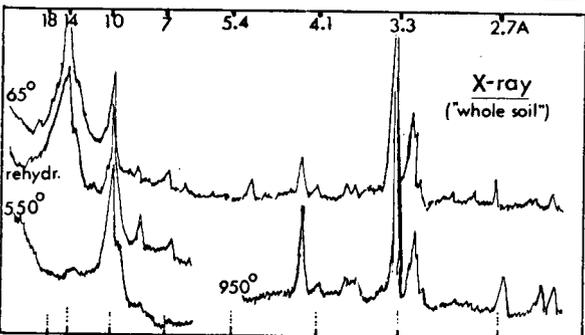
# 2-26" B ₂₁ horizon 10YR 3.5/1.5 (dk gry) Pl. Est. : +4										
pH	C.E.C. (meq/100g)	26	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
6.0				0.8	0.4	14	11	17	52	31



Index Ratio	1.8	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
				11.4				
			weight	37.1	4.3	0.7	4.8	-2.4

Remarks:

# 2-53" C horizon 2.5Y 3.5/1 (v dk gry) Pl. Est. : +2 th										
pH	C.E.C. (meq/100g)	24	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
7.0				0.9	0.4	14	11	20	60	20

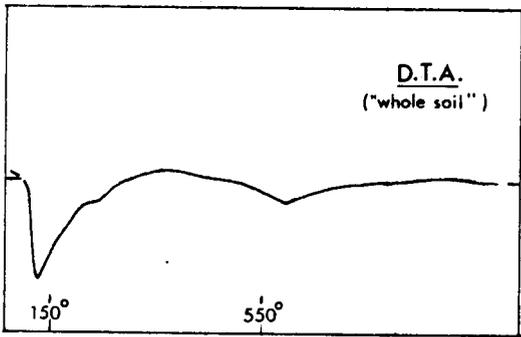
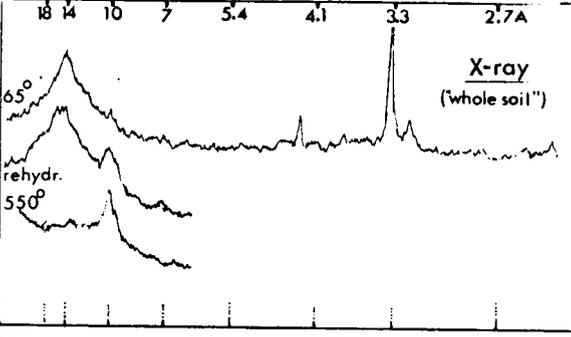


Index Ratio	2.0	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
				10.4					
			weight	35.0	3.0	0.5	4.8	-1.7	-6.6

Remarks:

Dayton-like. Imp. drained Willamette silts. El. 170'
 3/4 mi. N of Willamette R. (nr. Wilsonville)

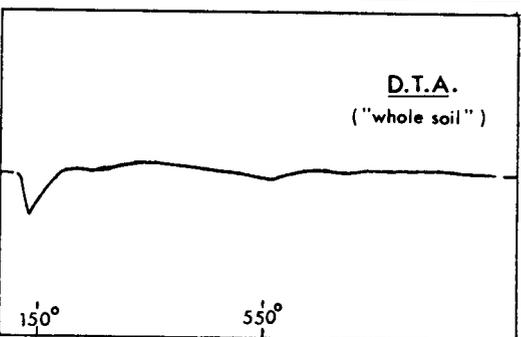
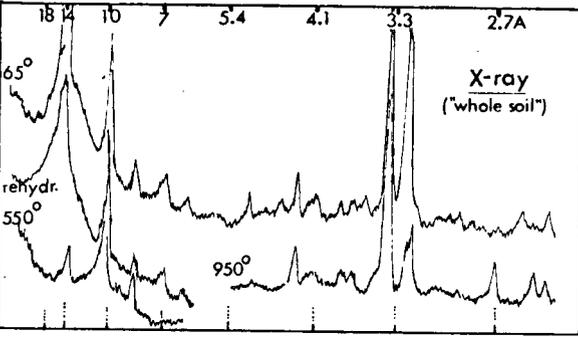
3-18" B₂₁ horizon 10YR 4/1 (dk gry) Pl. Est. : +4
 pH 5.7 C.E.C. (meq/100g) 34 Base Sat. (meq/100g) 0.5 Na 0.5 K 16 Ca 14 Mg % Sand 17 Silt 44 Clay 38



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	14.4			
2.1		weight	45.8	6.1	1.1	6.7	-2.9

Remarks :

3-40" C horizon 2.5Y 4.5/3 (olive brn) Pl. Est. : +2
 pH 7.3 C.E.C. (meq/100g) 26 Base Sat. (meq/100g) 1.0 Na 0.3 K 15 Ca 12 Mg % Sand 42 Silt 43 Clay 15

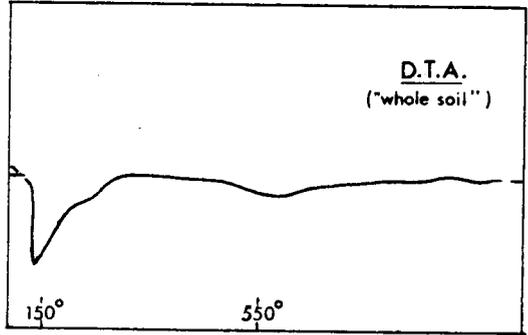
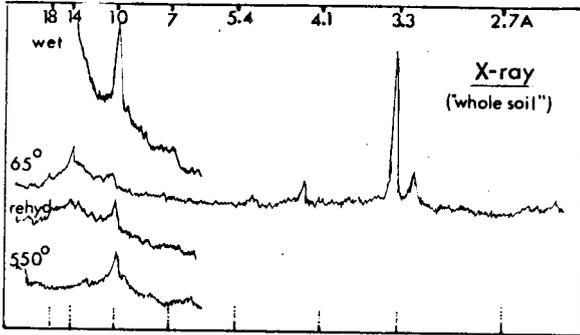


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	7.5				
1.5		weight	33.7	3.1	0.4	5.2	-1.9	-5.4

Remarks :

Dayton. Poorly drained Willamette silts. El. 174'
 nr. Broadacres, W fork, Mill Cr. drainage.

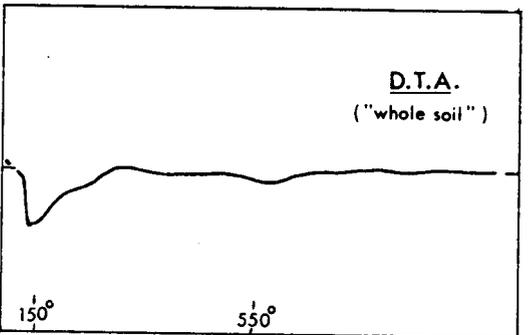
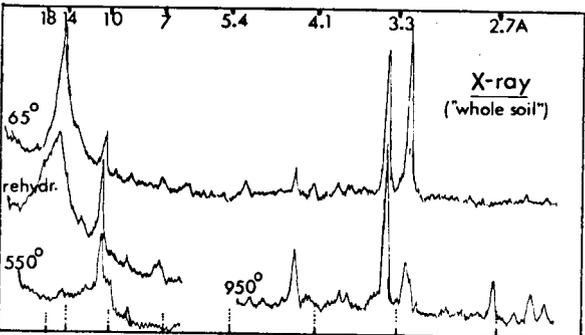
#4 -20" B horizon 2.5Y 4/1 (dk gry) Pl. Est. : +3 th
 pH 5.1 C.E.C. (meq/100g) 31 Base Sat. (meq/100g) 0.5 Na 0.5 K 17 Ca 10 Mg
 % Sand 20 Silt 50 Clay 30



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	14.4			
1.7		weight	43.8	4.1	0.7	5.0	-2.4

Remarks:

#4 -43" C horizon 2.5Y 3/4 (olive brn) Pl. Est. : +2
 pH 6.5 C.E.C. (meq/100g) 27 Base Sat. (meq/100g) 0.5 Na 0.4 K 17 Ca 10 Mg
 % Sand 30 Silt 54 Clay 16

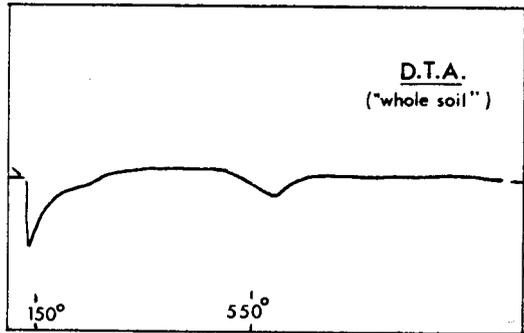
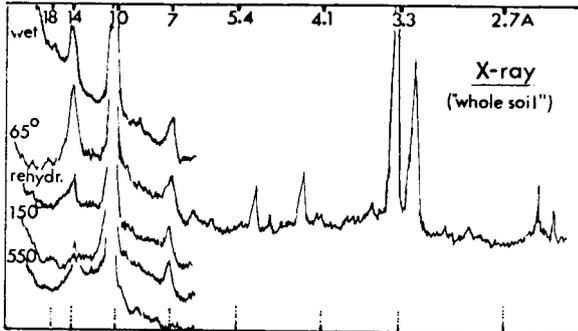


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	9.4				
2.4		weight	35.2	3.6	0.7	5.4	-1.5	

Remarks:

Willamette. Well drained Willamette silts. El. 175'
 N bank of Little Pudding R. (nr. Fruitland).

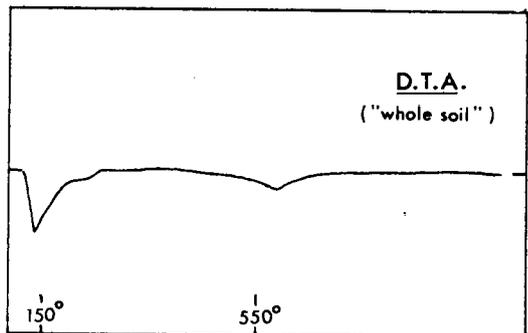
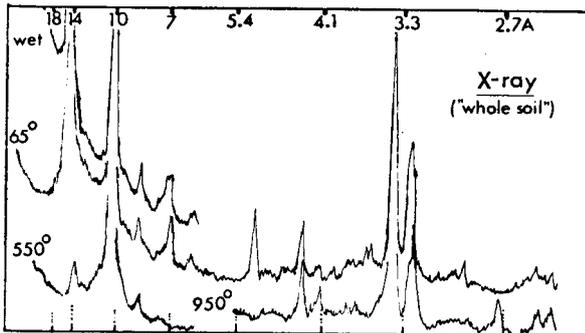
#6 -18" B horizon 10YR 4/4 (dk y brn) Pl. Est. : +3
 pH 5.1 C.E.C. (meq/100g) 17 Base Sat. (meq/100g) 0.3 Na 0.8 K 8 Ca 4 Mg 4
 % Sand 7 Silt 65 Clay 28



Index Ratio	% Change (rel. to 300°C)	Plastic Limit	65°C	150°C	rehydrate	550°C	
			length	weight	length	weight	length
1.1		10.6	36.8	2.7	0.5	3.6	-2.4

Remarks: clayskins (5YR 3/4). Clay Minerals: discrete illite, vermiculite, interlayered, beidellite, chlorite, kandite(?).

#6 -54" C horizon 2.5Y 4/3 (olive brn) Pl. Est. : +1
 pH 5.8 C.E.C. (meq/100g) 20 Base Sat. (meq/100g) 0.5 Na 0.4 K 16 Ca 5 Mg 5
 % Sand 18 Silt 68 Clay 14

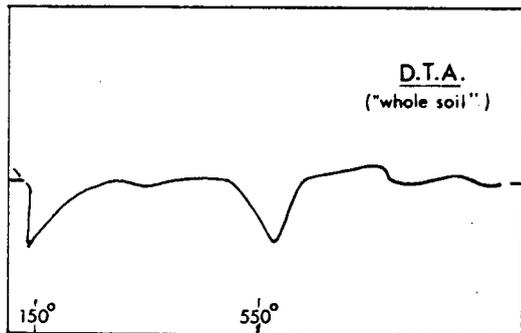
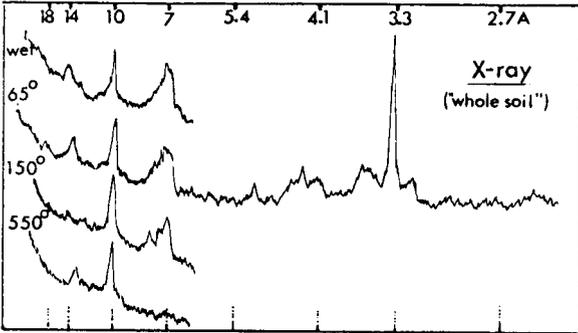


Index Ratio	% Change (rel. to 300°C)	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	weight	length	weight	length
1.4		6.4	32.4	-2.8	0.6	4.2	-2.0

Remarks: note low Mg and high K rel. to X-ray evidence of chlorite, and collapse. Clay Minerals: discrete illite, vermiculite, interlayered, beidellite, chlorite.

Jory. Imp. drained colluvium over basalt. El. 250
 Foot of N slope of Salem Hills.

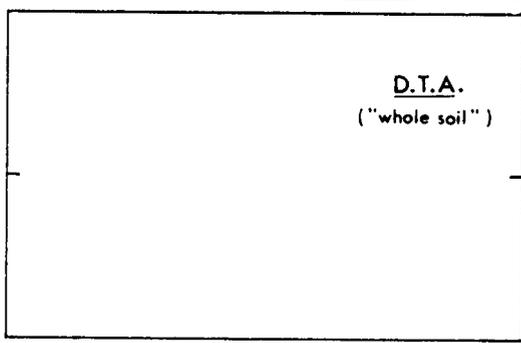
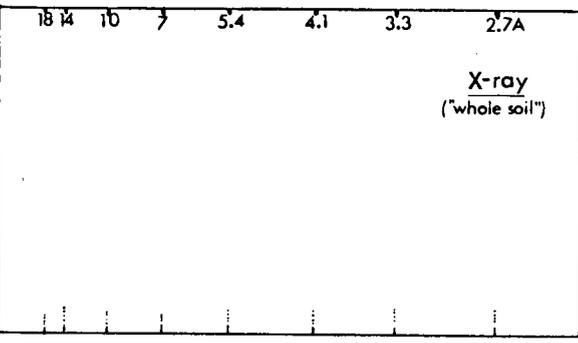
5-36" solum 3.5YR 3/5 (dk red) Pl. Est. : +3
 pH 5.8 C.E.C. (meq/100g) 18 Base Sat. (meq/100g) 0.3 Na 0.3 K 7 Ca 4 Mg 4
% Sand 17 Silt 51 Clay 32



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			1.2	8.7			
		weight	39.3	6.7	2.0	6.5	-5.5

Remarks:

Pl. Est. :
 pH C.E.C. (meq/100g) Base Sat. (meq/100g) Na K Ca Mg % Sand Silt Clay

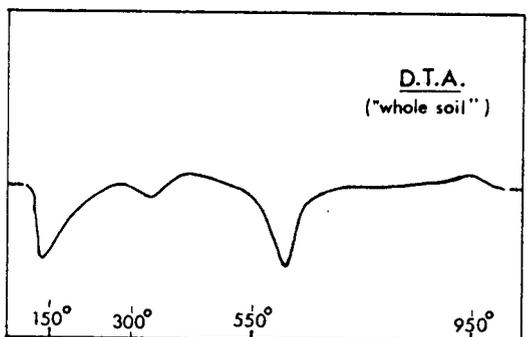
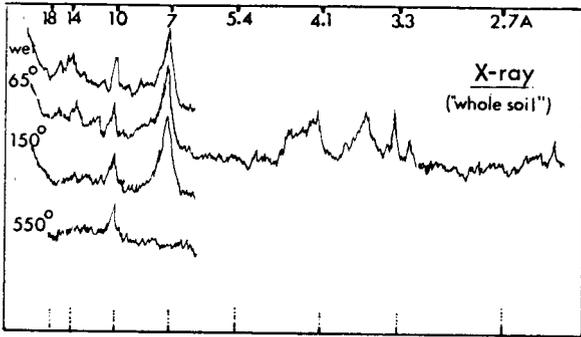


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
		weight						

Remarks :

Jory. Well drained colluvium over basalt. El. 575'
 Salem Hills, S slope of northernmost ridge.

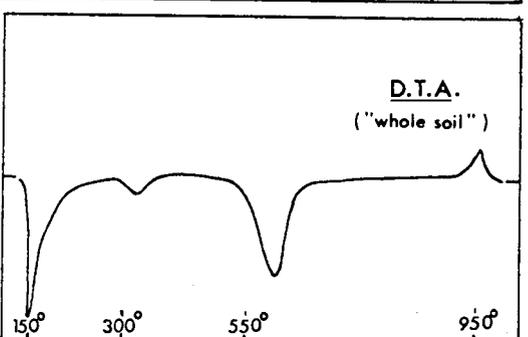
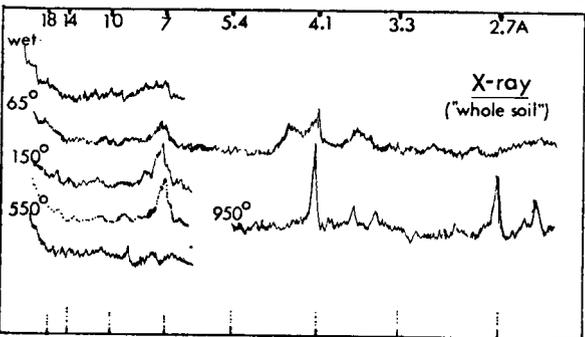
#7-48" solum 2.5YR 3/8 (dk red)							Pl. Est. : -1		
pH 5.4	C.E.C. (meq/100g) 12	Base Sat. (meq/100g) 0.4	Na -	K 3	Ca 2	Mg 2	% Sand 21	Silt 38	Clay 41



Index Ratio 0.95	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	11.4			
		weight	48.3	6.7	1.4	5.8	-7.1

Remarks: matrix.

#7a-48" solum 7.5YR 5.5/8 (strong brn)							Pl. Est. : -4 th Gf		
pH 5.8	C.E.C. (meq/100g) 12	Base Sat. (meq/100g) 0.6	Na 0.1	K 2	Ca 1	Mg 1	% Sand 59	Silt 36	Clay 5

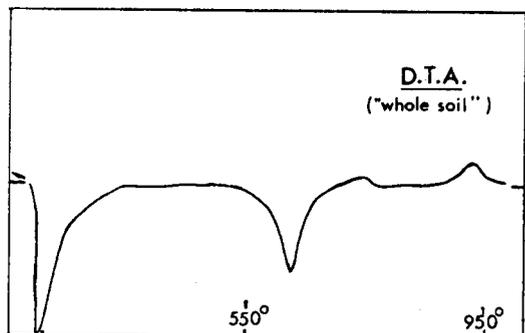
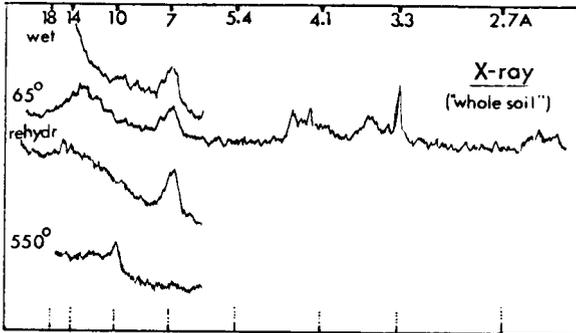


Index Ratio 0.67	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	4.2				-7.9
		weight	44.7	5.6	0.9	5.4	-8.4	

Remarks: 6" diam. weathered rock fragment.

Willakenzie-like. Well drained tuffaceous sediments. El. 540'
 Salem Hills, N of Battle Cr.

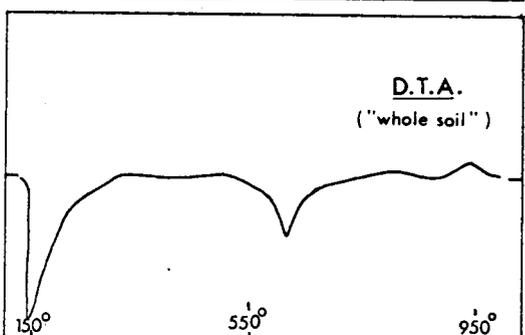
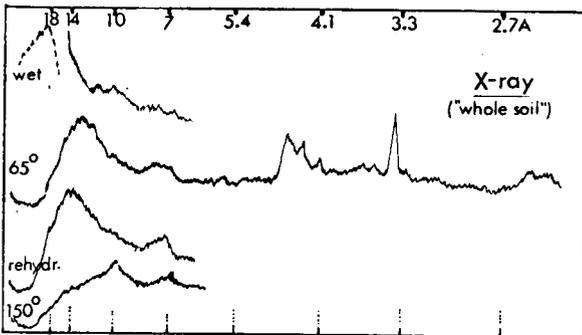
#8 -18"		B horizon 2.5YR 3/8 (dk red)				Pl. Est. : -1			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
4.8	37	0.3	0.6	7	7		3	8	89



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	23.8			
1.3			79.6	8.4	1.5	8.7	-6.4

Remarks:

#8 -36"		(C) horizon 2.5YR 6.5/4 (lt red brn)				Pl. Est. : -2 th			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
4.6	48	0.4	0.7	5	7		1	24	75

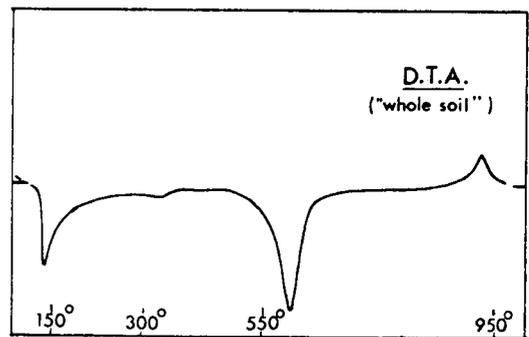
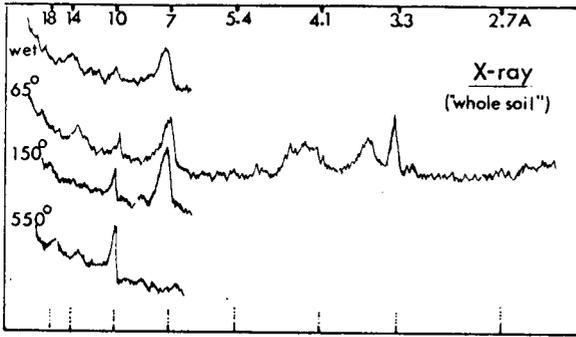


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	27.6				
			88.7	6.1	-			

Remarks :
 weathered bedrock.

Waldo-like. Imp. drained colluvium from weathered basalt. El. 375'
 S slope, Battle Cr. drainage.

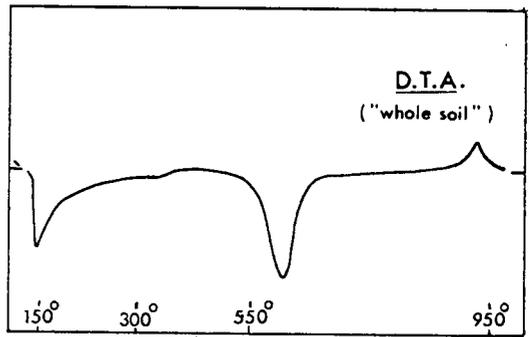
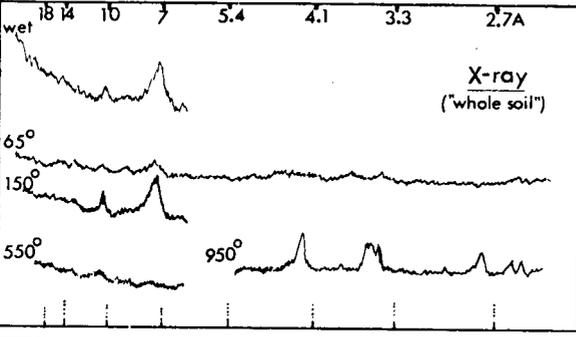
#9-30"	B21 horizon	5YR 4/6 (y red)	Pl. Est. :	-2					
pH 5.4	C.E.C. (meq/100g) 12	Base Sat. (meq/100g) 0.3	Na	K	Ca	Mg	% Sand	Silt	Clay
			0.3	-	2	2	18	37	45



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	52.2	5.8	1.3	5.7

Remarks:

#9-40"	B22 horizon	5YR 4/8 (y red)	Pl. Est. :	-4 th GF					
pH 5.4	C.E.C. (meq/100g) 12	Base Sat. (meq/100g) 0.3	Na	K	Ca	Mg	% Sand	Silt	Clay
			0.3	-	1	1	17	39	44



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	53.9	5.4	1.2	7.3	-7.6

Remarks:

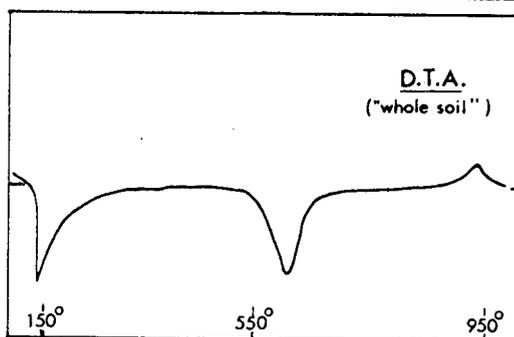
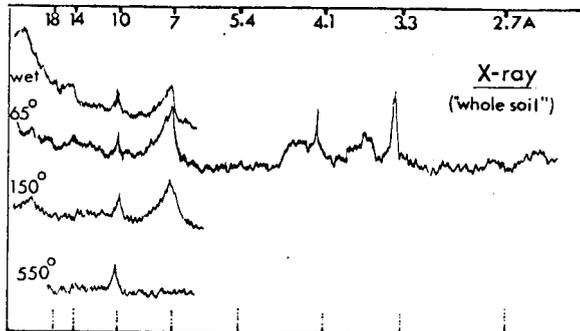
Jory. Well drained colluvium from weathered basalt.

El.

S slope, Battle Cr. drainage.

380'

#10 -30"	B ₂₁ horizon	10R 3/8 (dk red)	Pl. Est. :	-1					
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.5	15	0.3	0.4	3	3		16	29	55



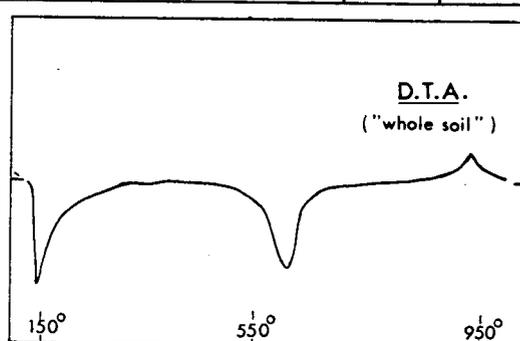
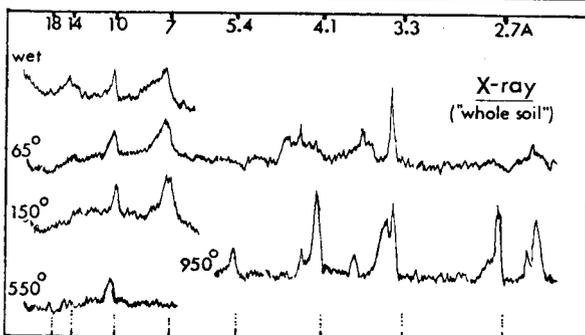
Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	13.4			
0.72		weight	49.8	5.4	0.6	6.0	-7.5

Remarks:

300 yds. N of #11.

Clay Minerals: kandite, illite(?), smectite(?).

#10 -50"	B ₃ or C horizon	2.5YR 3/7 (dk red)	Pl. Est. :	+1					
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.0	17	0.4	0.1	2	2		17	34	49



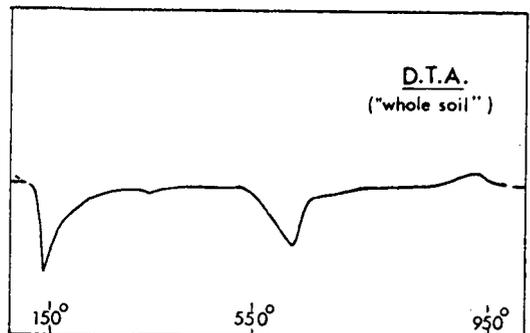
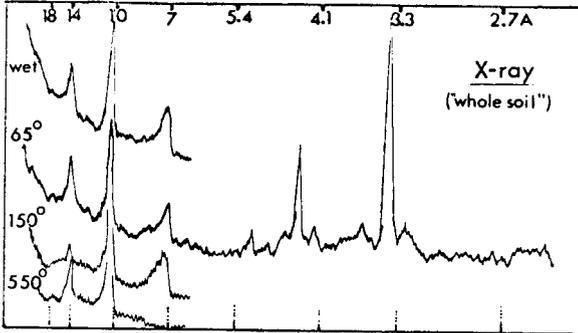
Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	13.4				
0.91		weight	55.3	5.8	1.8	8.3	-6.4	-25.0

Remarks :

Clay Minerals: kandite, illite(?).

Nekia. Moderately well drained colluvium. El. 325'
 50' N of Turner-Sunnyside junction.

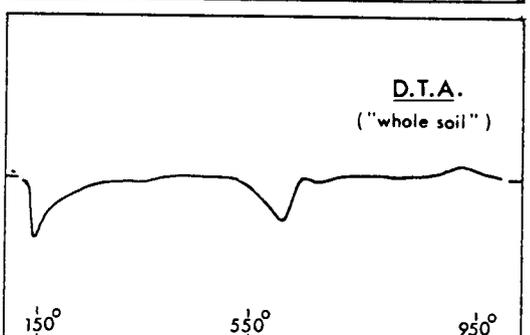
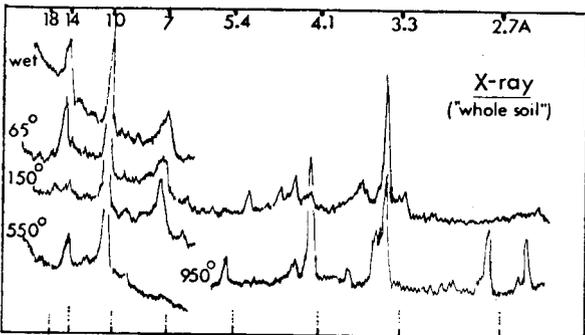
#11-24"		B horizon 10YR 5/6 (y brn)				Pl. Est. : +2			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.5	25	0.3	0.3	8	7		14	50	36



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	40.4	4.7	0.7	4.8
0.98			8.2				

Remarks:
black ped surfaces.

#11-36"		C horizon 5YR 4/6 (y red)				Pl. Est. : +3			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.8	16	0.3	0.2	6	4		16	66	19

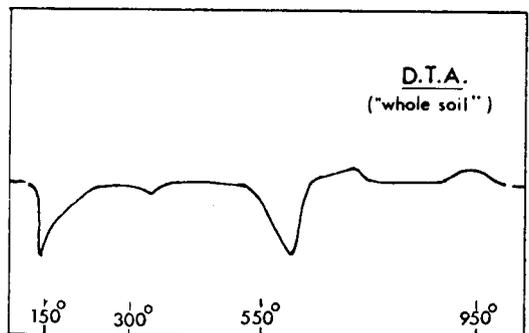
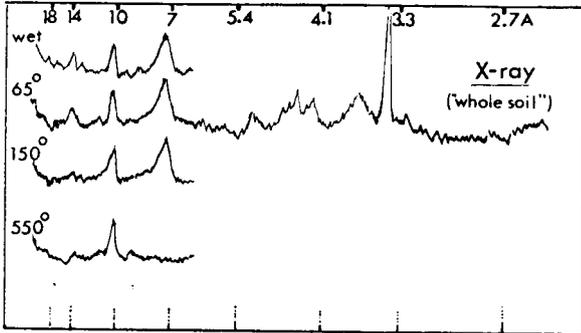


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	49.9	6.1	1.1	7.4	-5.2
1.2			12.1					

Remarks :

McAlpin. Mod. well drained alluvium from Salem Hills. El. 300'
 Battle Cr. flood plain.

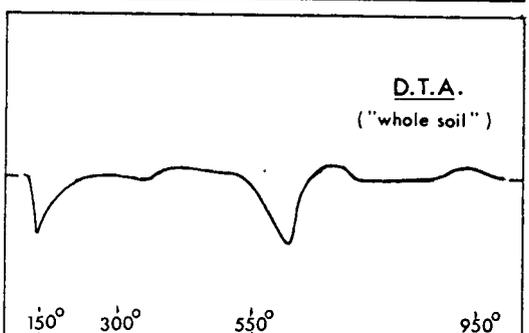
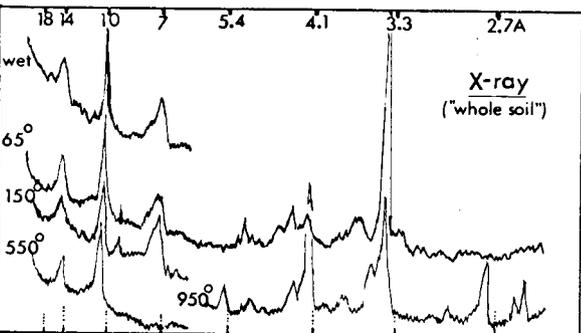
#12-30" B₂ horizon 5YR 3/8 (y red) Pl. Est. : +2
 pH 5.4 C.E.C. (meq/100g) 21 Base Sat. (meq/100g) 0.3 Na 0.2 K 5 Ca 3 Mg 3
 % Sand 17 Silt 41 Clay 42



Index Ratio 0.97	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	40.7	6.4	0.6	5.8

Remarks:
black ped surfaces.

#12-50" C horizon 10YR 4/6 (dk y brn) Pl. Est. : +2
 pH 5.8 C.E.C. (meq/100g) 18 Base Sat. (meq/100g) 0.3 Na 0.2 K 5 Ca 4 Mg 4
 % Sand 21 Silt 54 Clay 25

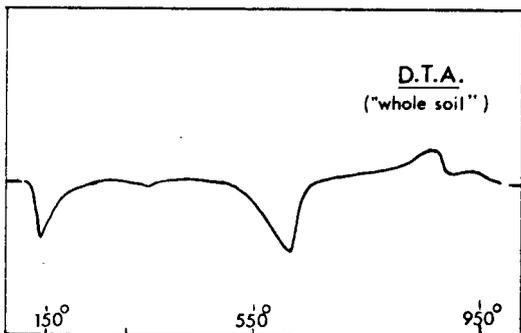
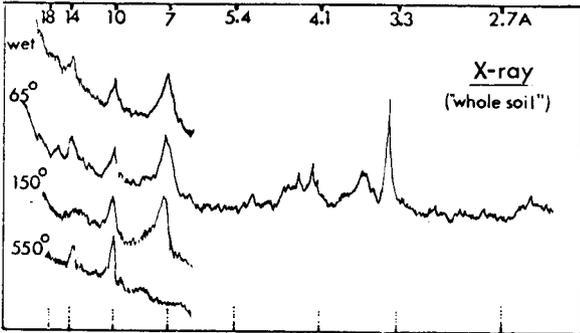


Index Ratio 1.2	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	41.9	6.4	1.2	7.0	-5.4

Remarks :

Nekia-like. Shallow colluvium overlying basalt. El. 630*
 Hill top S of Battle Cr.

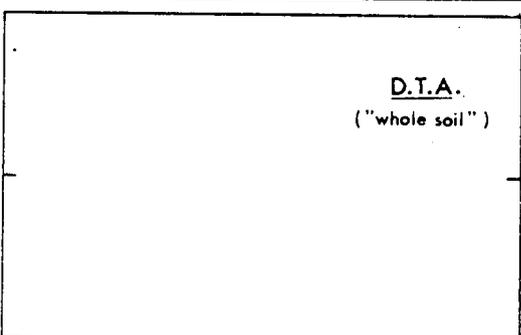
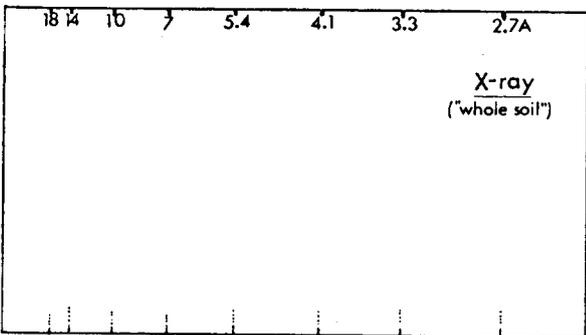
# 13-24		solum. 2.5YR 2/6 (dk red)				Pl. Est. : +3			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.5	16		0.3	0.4	5	3	14	36	50



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	42.7	7.1	1.5	8.4

Remarks:
500 yds. N of Ilahee School-Cloverdale School road.

#						Pl. Est. :			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay

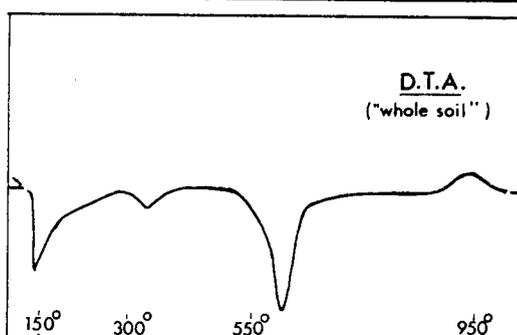
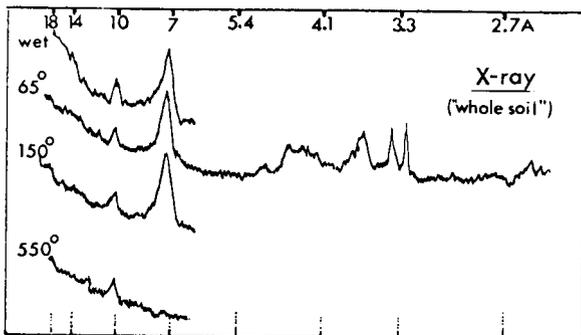


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight					

Remarks :

Jory-like. Imp. drained colluvium over tuffaceous sediments. El. 500'
 S slope, Rogers Cr. drainage.

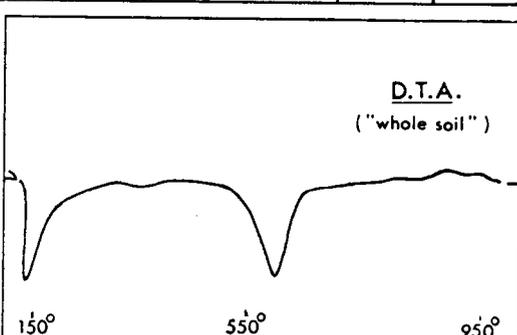
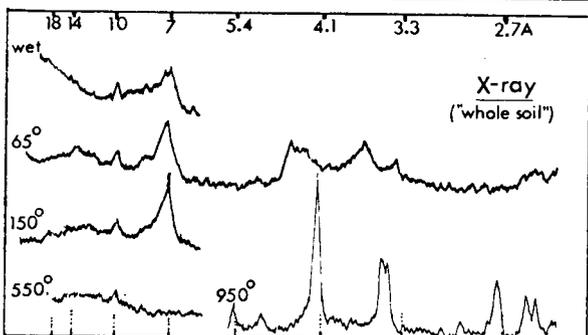
#14-43" (B) horizon 2.5YR 3/8 (dk red)		Pl. Est. : +3				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na K Ca Mg	% Sand	Silt	Clay
5.6	19	0.3	0.2 7 5	22	32	47



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
0.79			10.4				
		weight	42.5	5.8	1.1	7.4	-7.4

Remarks:
 dense gravelly clay @ 5-6'.

#14-74" (C) horizon 5YR 5/8 (y red)		Pl. Est. : +4				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na K Ca Mg	% Sand	Silt	Clay
6.0	24	0.4	0.3 8 6	18	33	49

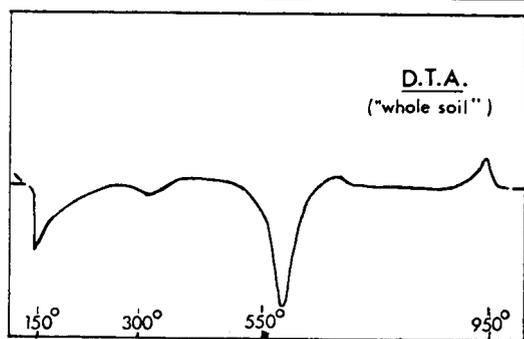
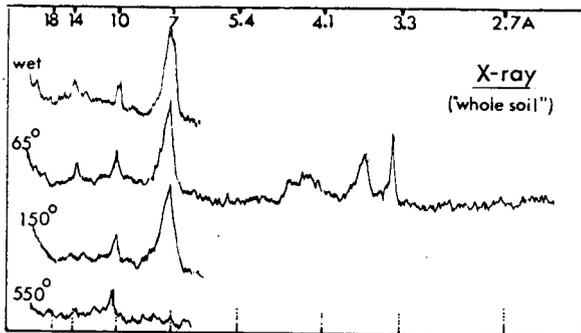


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
0.62			12.1					-28.7
		weight	58.8	5.6	1.3	8.0	-9.0	

Remarks :

Jory. Dense clay over tuffaceous sediments. El. 575'
 1/4 mi. S of Ilahee School-Cloverdale School road.

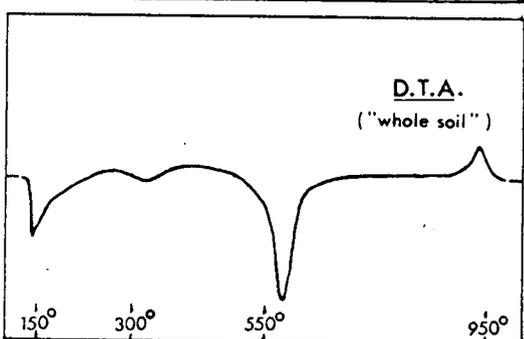
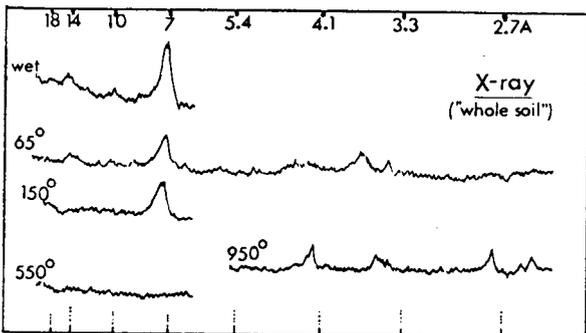
#15 -24" (B) horizon 2.5YR 3/6 (dk red)							Pl. Est. : +1			
pH	C.E.C. (meq/100g)	10	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.4				0.3	0.1	2	1	13	29	53



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	48.7	5.7	1.2	6.1
0.78							

Remarks:
black ped surfaces.

#15 -48" (C) horizon 2.5YR 3/6 (dk red)							Pl. Est. : +1			
pH	C.E.C. (meq/100g)	10	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.0				0.3	-	1	1	14	33	53

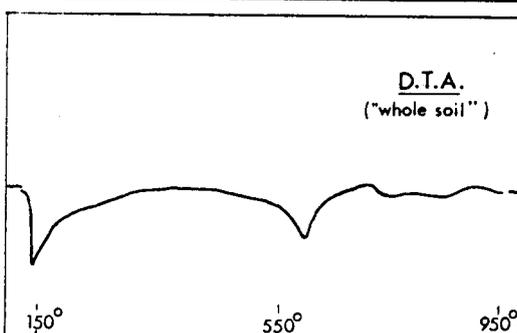
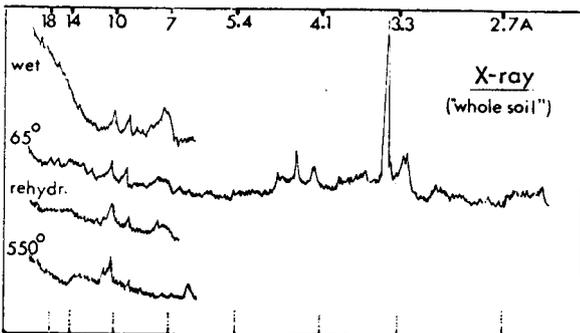


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	53.2	5.3	1.5	11.6	-7.4
0.72								

Remarks :

Peavine-like. Well drained truncated soil on tuff. sediments. El. Ridgetop, Salem Hills (100yds. SE of NW corner of Sec. 12). 800'

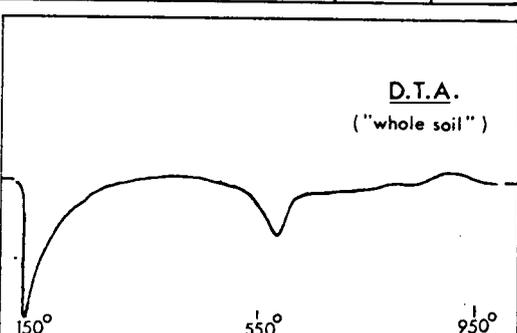
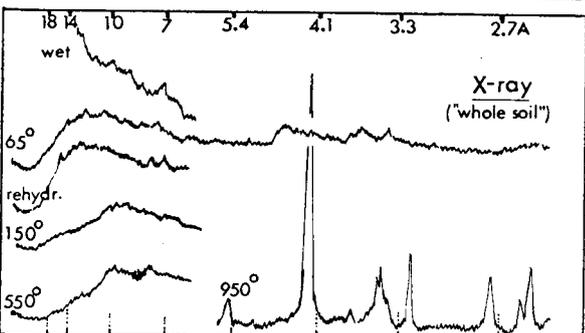
#16 -14"	B horizon	5YR 3/6	(y red)	Pl. Est. :	+3				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
5.5	25		0.4	0.2	13	7	22	37	41



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	11.1			
1.5		weight	47.3	5.2	1.0	6.7	-3.5

Remarks: 9.1A peaks are confined to silt fraction. Clay Minerals: discrete illite, interlayered, beidellite, kandite

#16 -27"	C or D horizon	2.5YR 5/4	(brn)	Pl. Est. :	+4				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
4.5	47		0.8	0.8	17	14	5	9	86

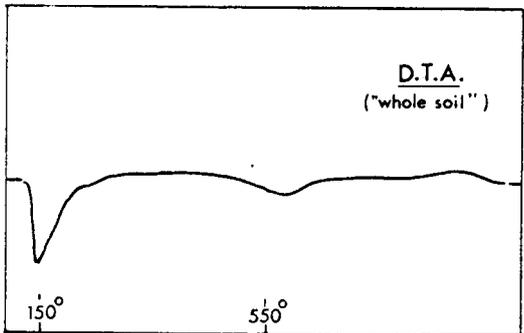
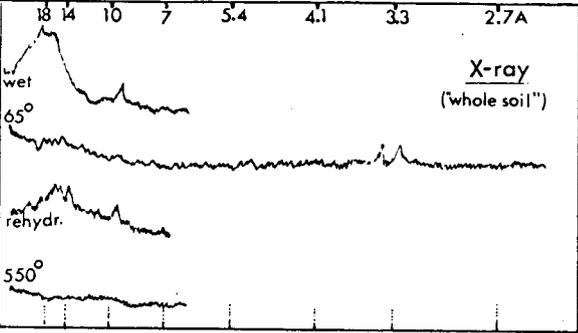


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	18.8				
1.4		weight	77.6	8.3	0.6	13.1	-5.9	

Remarks : saprolite. Clay Minerals: interlayered, beidellite, kandite

Hazelaire-like. Dense clay over tuffaceous sediments. El. 625'
 S slope of Salem Hills.

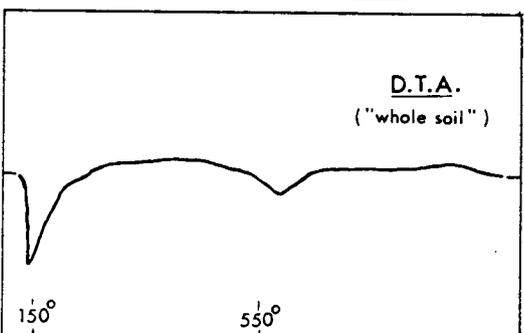
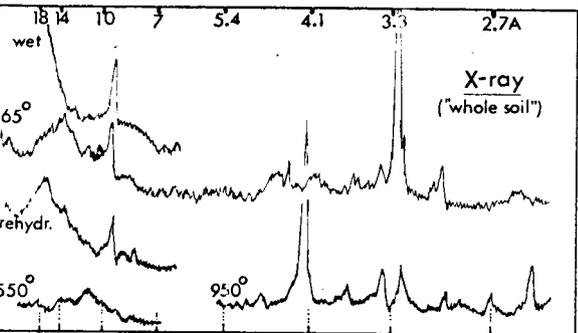
#17-18" (B) horizon 2.5Y 5/3 (lt olive brn) Pl. Est. : +5
 pH 5.0 C.E.C. (meq/100g) 43 Base Sat. (meq/100g) 1.6 Na 0.6 K 24 Ca 12 Mg 12 % Sand 26 Silt 22 Clay 52



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	12.9			
2.1		weight	51.8	7.0	1.4	9.7	-3.3

Remarks: very dense clay.

#17-24" C horizon 2.5Y 7/6 (yellow) Pl. Est. : +1 th GF
 pH 5.6 C.E.C. (meq/100g) 43 Base Sat. (meq/100g) 1.4 Na 0.6 K 25 Ca 11 Mg 11 % Sand 66 Silt 30 Clay 4

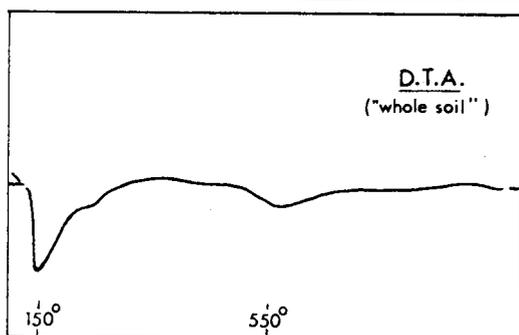
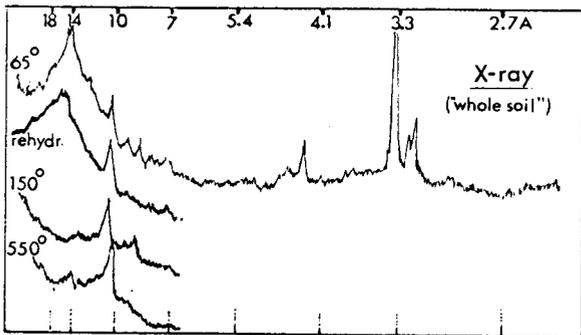


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	11.1				
1.3		weight	56.8	5.4	0.5	10.2	-4.2	-4.9

Remarks: saprolite. Unidentified 9.0A peak.

Wapato. Alluvial from weathered tuffaceous sediments. El. 275'
 S foot of Salem Hills.

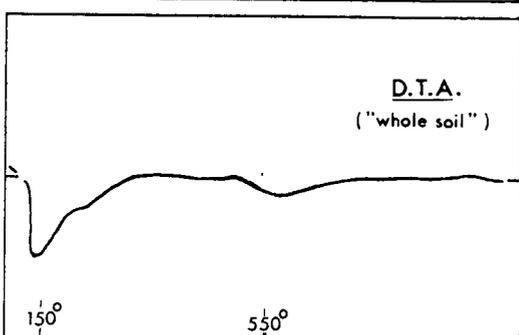
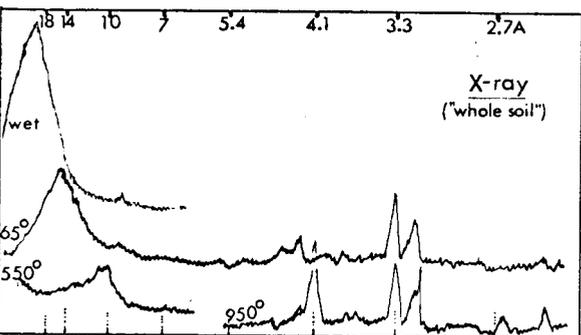
#18-24" (B) horizon 2.5Y 3/1 (v dk gry) Pl. Est. : +4
 pH 7.1 C.E.C. (meq/100g) 37 Base Sat. (meq/100g) Na 1.8 K 0.6 Ca 24 Mg 14 % Sand 14 Silt 43 Clay 44



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	12.6			
1.7		weight	44.9	5.3	1.0	7.6	-3.1

Remarks:

#18-36" (C) horizon 2.5Y 4/3 (olive brn) Pl. Est. : +4
 pH 7.3 C.E.C. (meq/100g) 44 Base Sat. (meq/100g) Na 2.5 K 0.6 Co 26 Mg 16 % Sand 26 Silt 27 Clay 47

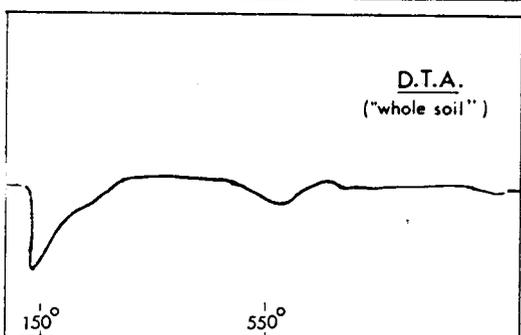
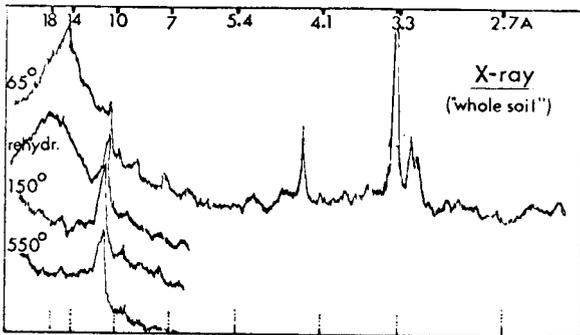


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	12.4				
2.1		weight	46.8	6.0	0.8	10.3	-2.9	-4.9

Remarks:

Dayton. Imp. drained Willamette silts. El. 235'
 NW of Knox Butte. 500 yds. SE of freeway.

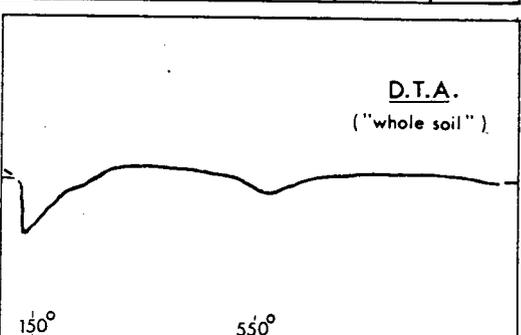
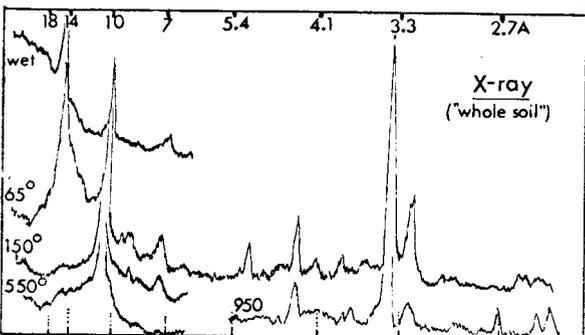
#19-24" B horizon 2.5Y 4/1 (dk gry) Pl. Est. : +4
 pH 5.6 C.E.C. (meq/100g) 34 Base Sat. (meq/100g) 0.6 Na 0.6 K 19 Ca 12 Mg
 % Sand 8 Silt 42 Clay 50



Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
			length	13.9			
1.9		weight	49.9	5.7	1.0	7.1	-3.1

Remarks:

#19-45" C horizon 2.5Y 5/4 (lt olive brn) Pl. Est. : +2
 pH 6.4 C.E.C. (meq/100g) 26 Base Sat. (meq/100g) 0.6 Na 0.4 K 15 Ca 9 Mg
 % Sand 12 Silt 68 Clay 20

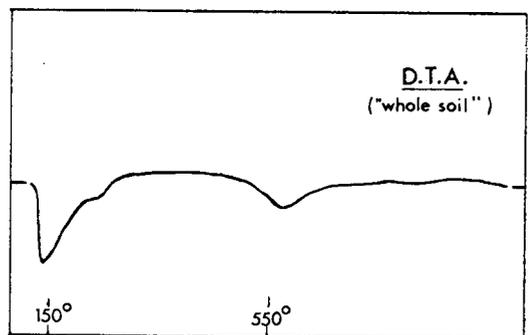
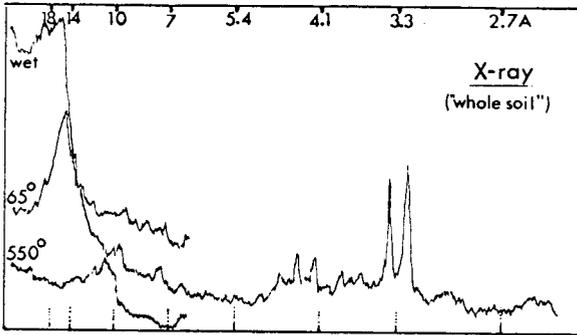


Index Ratio	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			length	9.4				
1.4		weight	38.4	3.3	0.4	6.2	-2.4	-7.4

Remarks:

Holcomb. Alluvium over Willamette fine silts. El. 215'
 W of Albany. 150' N of Knox Butte road.

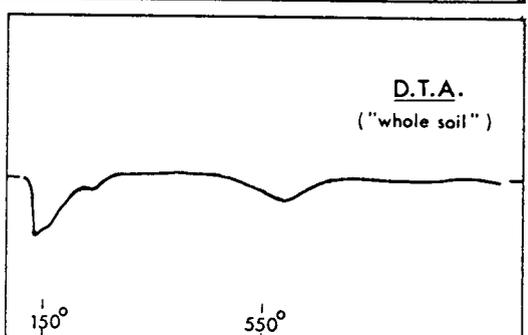
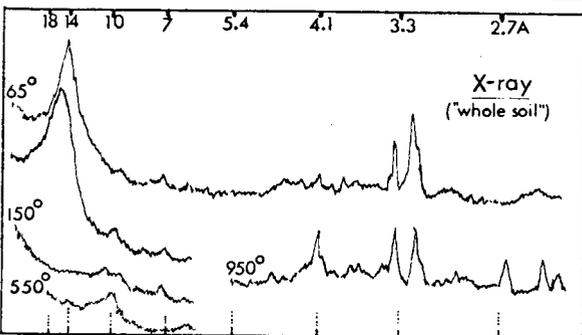
#20-36"		B horizon 7.5YR 4/2 (brn)				Pl. Est. : +4			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
6.4	42		0.9	0.5	23	16	4	43	52



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			weight	14.2			
1.8			51.1	6.4	0.9	7.8	-3.6

Remarks:

#20-53"		C horizon 10YR 4/6 (dk y brn)				Pl. Est. : +3			
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
6.8	38		1.3	0.4	24	15	7	68	25

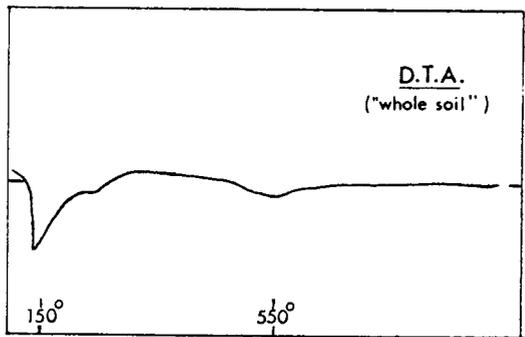
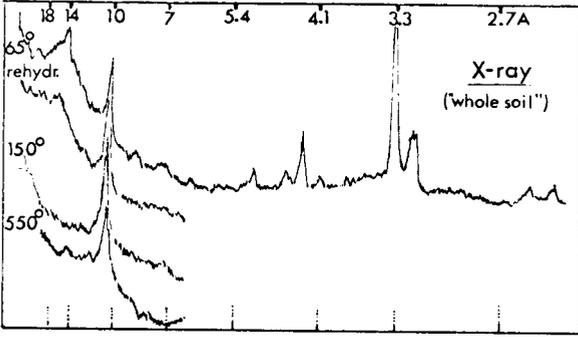


Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			weight	13.1				
1.7			45.3	5.1	0.5	10.3	-3.0	-8.6

Remarks:

Dayton. Imp. drained Willamette silts. El. 240'
 SE of Albany, Cox Cr. drainage.

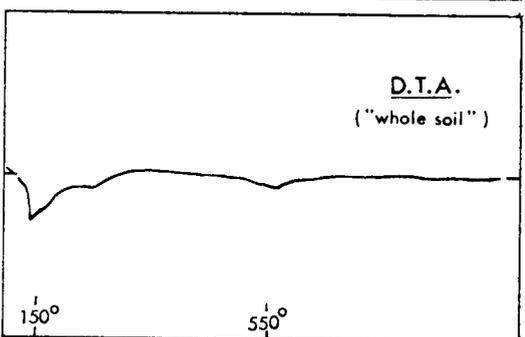
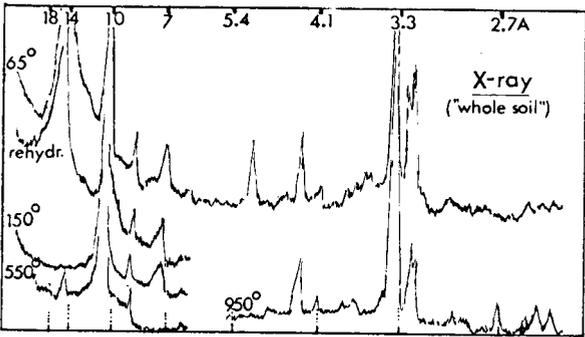
#21-28" B horizon 10YR 4/0 (dk gry) Pl. Est. : +4
 pH 5.9 C.E.C. (meq/100g) 28 Base Sat. (meq/100g) 0.6 Na 0.4 K 14 Ca 10 Mg 10 % Sand 6 Silt 54 Clay 40



Index Ratio	% Change (rel. to 300°C)		Plastic Limit				
			length	65°C	150°C	rehydrate	550°C
1.6		length	12.9				
		weight	39.3	4.5	0.9	5.8	-2.8

Remarks:
 N side of road SE from Albany to Lebanon.

#21-60" C horizon 2.5Y 5/4 (lt olive brn) Pl. Est. : +2 th
 pH 6.6 C.E.C. (meq/100g) 21 Base Sat. (meq/100g) 0.6 Na 0.4 K 14 Ca 10 Mg 10 % Sand 6 Silt 73 Clay 20

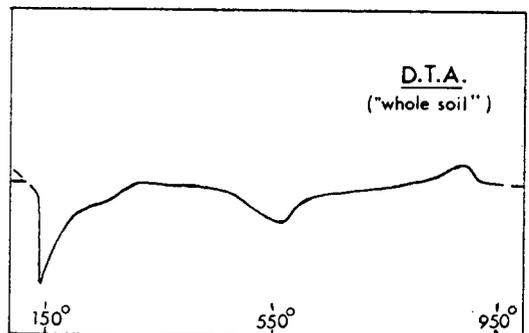
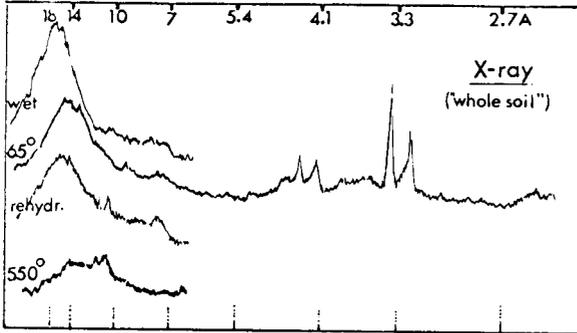


Index Ratio	% Change (rel. to 300°C)		Plastic Limit					
			length	65°C	150°C	rehydrate	550°C	950°C
1.3		length	8.5					-8.2
		weight	33.4	2.7	0.3	5.5	-2.0	

Remarks :

Cove. Dark clay over highly weathered sand. El. 265'
 NE of Saddle Butte, 200' S of Butte Cr.

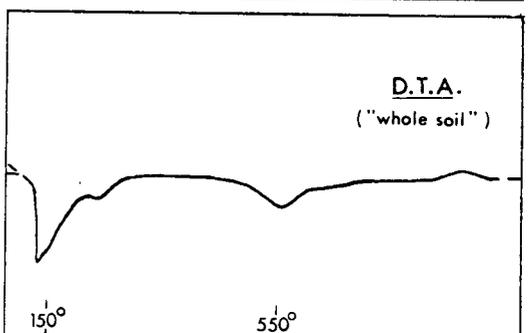
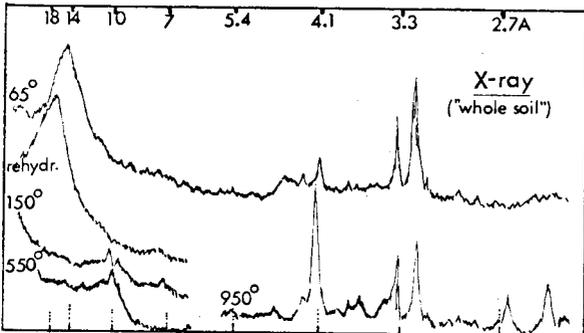
#22 -18" B horizon 10YR 2/1 (black)						Pl. Est. : +4				
pH	C.E.C. (meq/100g)	41	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
6.3				1.9	0.7	22	14	4	42	54



Index Ratio	1.7	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C
				length	13.4			
			weight	52.4	7.6	1.8	8.4	-4.5

Remarks: Clay Minerals: beidellite, kandite.

#22 -50" (C) horizon 10YR 4/2 (dk gry brn)						Pl. Est. : +4				
pH	C.E.C. (meq/100g)	40	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
7.5				2.1	0.4	26	16	11	49	40

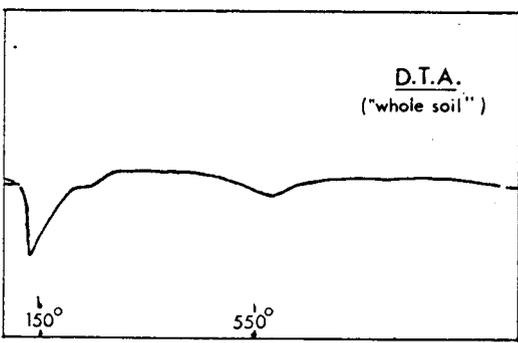
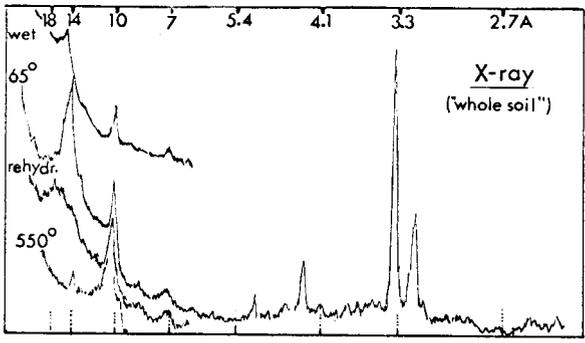


Index Ratio	1.5	% Change (rel. to 300°C)		Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
				length	13.4				
			weight	47.8	6.0	0.5	9.9	-3.9	

Remarks: looks like sand, but only ghosts remaining. Clay Minerals: beidellite, kandite.

Dayton. Poorly drained Willamette silts. El. 288'
 1 mi. S of Halsey-Brownsville road, Spoon Cr. drainage.

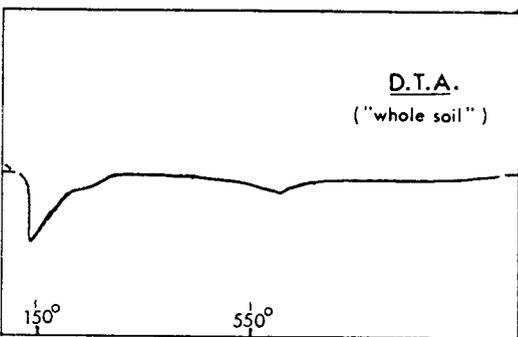
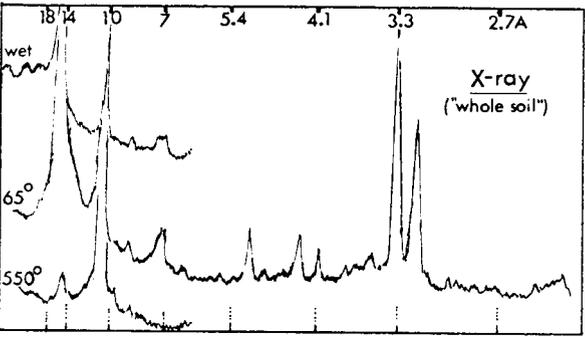
<input type="checkbox"/> #22-30"	B horizon 10YR 4/1.5 (dk gry)	Pl. Est. : +4							
pH 5.8	C.E.C. (meq/100g) 28	Base Sat. (meq/100g)	Na 0.8	K 0.5	Ca 14	Mg 12	% Sand 3	Silt 57	Clay 40



Index Ratio 1.8	% Change (rel. to 300°C)	length	Plastic Limit 12.4	65°C	150°C	rehydrate	550°C
			weight 40.3	4.8	1.3	5.9	-2.7

Remarks: Clay Minerals: discrete illite, vermiculite, interlayered(?), beidellite, kandite/chlorite(?).

<input type="checkbox"/> #23-48"	C horizon 2.5Y 5.5/4 (lt y brn)	Pl. Est. : +2							
pH 6.6	C.E.C. (meq/100g) 26	Base Sat. (meq/100g)	Na 0.8	K 0.4	Ca 15	Mg 12	% Sand 2	Silt 69	Clay 29



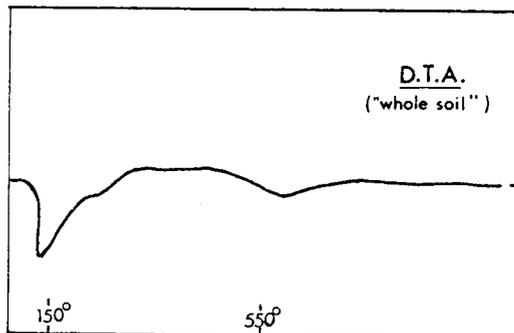
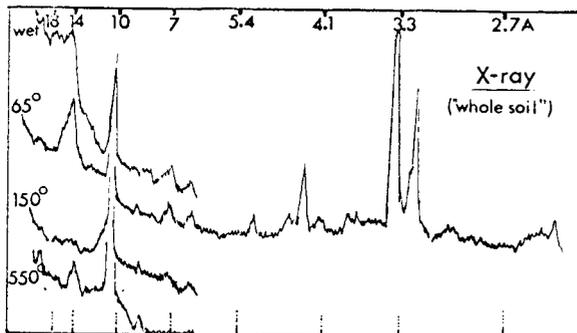
Index Ratio 1.6	% Change (rel. to 300°C)	length	Plastic Limit 9.4	65°C	150°C	rehydrate	550°C	950°C
			weight 36.3	3.4	0.4	5.8	-2.2	-8.6

Remarks: Clay Minerals: discrete illite, vermiculite, interlayered(?), kandite/chlorite(?).

Dayton. Poorly drained Willamette silts overlying dense
gravelly clay at 45".
E of Harrisburg, Muddy Cr. drainage.

Ei.
320'

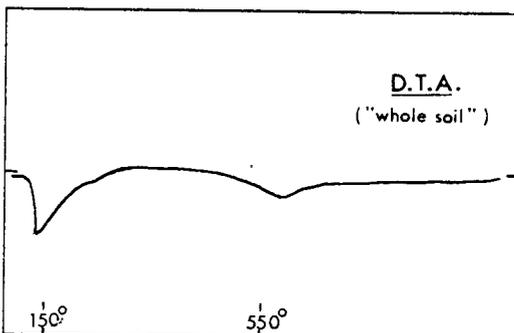
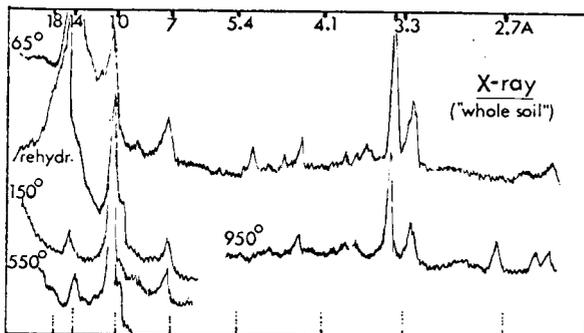
# 24 -14"	B horizon	2.5Y 3/1	(v dk gry)	Pl. Est. :	+4				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
6.6	29	0.7	0.4	18	13		2	54	44



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			1.8	12.4			
		weight	40.3	4.8	1.3	5.9	-2.7

Remarks :

# 24 -40"	C horizon	2.5Y 5/4	(lt olive brn)	Pl. Est. :	+4				
pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay
7.2	31	1.0	0.5	20	15		7	55	38



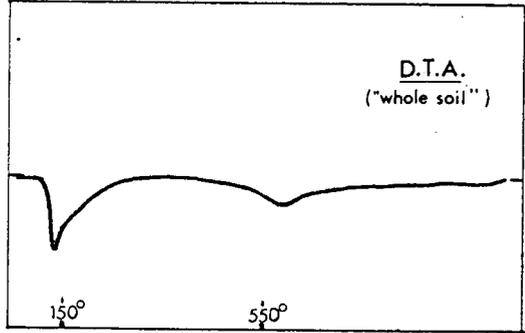
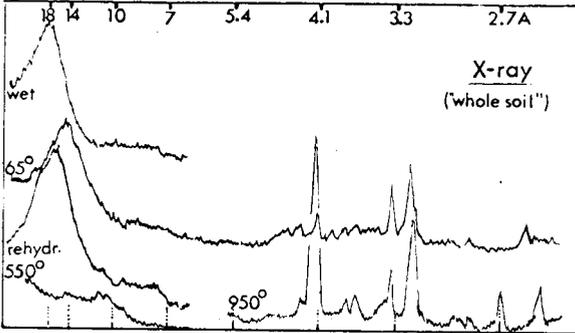
Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
			1.5	12.4				
		weight	39.0	4.2	0.3	6.2	-2.8	

Remarks :

El.

24-55" IIG horizon 5YR 4/2 (dk red gry) Pl. Est. : +5

pH 7.0	C.E.C. (meq/100g) 39	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand 8	Silt 33	Clay 59
			1.0	0.4	20	17			

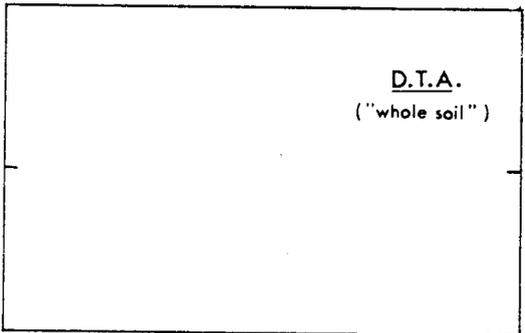
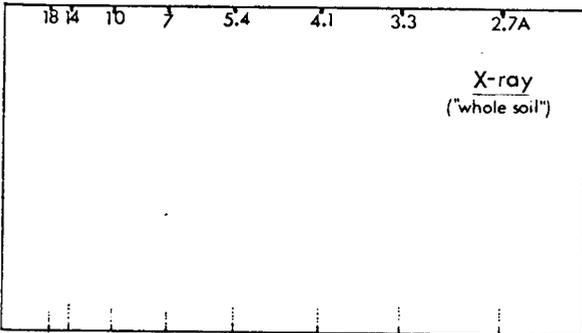


Index Ratio 1.6	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C
			12.1				
		weight	39.9	5.3	0.8	10.4	-3.4

Remarks:
dense gravelly clay under
2-3' of Willamette silts.

Pl. Est. :

pH	C.E.C. (meq/100g)	Base Sat. (meq/100g)	Na	K	Ca	Mg	% Sand	Silt	Clay



Index Ratio	% Change (rel. to 300°C)	length	Plastic Limit	65°C	150°C	rehydrate	550°C	950°C
		weight						

Remarks :