AN ABSTRACT OF THE THESIS OF

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Title: Composition and Variability of a Willakenzie Map Unit in Yamhill County, Oregon

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The variability in morphologic, chemical, and physical soil properties within the Willakenzie silty clay loam, 2 to 12 percent slopes, map unit in Yamhill County, Oregon was measured.

The objectives of the study included (1) describing the frequency distributions of individual soil properties, (2) measuring the taxonomic composition of the map unit, (3) comparing soil property variability over three separation distances, (4) analyzing the variability of soil properties within single delineations versus the variability of properties between delineations, and (5) diagnosing the major sources of map unit varibility.

One pedon in each of 35 randomly selected delineations was sampled to meet objectives (1) and (2). Samples were taken at 35 m intervals along transects placed within four delineations to meet objectives (3) and (4).

Thirty-seven percent of the morphologic, chemical, and physical properties measured exhibited positively skewed frequency distributions. The median and/or the mode, rather than the mean, were more accurate descriptors of central tendency in two-thirds of these distributions.

CV values were higher for the skewed properties than for the normally distributed properties.

Ranges of all of the soil properties measured, except color hue of the surface horizon, were greater than those described specifically for the Willakenzie silty clay loam, 2 to 12 percent slopes, map unit. Slope gradient and A1 horizon color were mapped correctly most often, whereas texture/character of the C or Cr horizon was mapped correctly least often.

None of the 35 pedons classified exactly as the Willakenzie series, resulting in a 0 percent taxonomic purity. Fifty-seven percent of the sampled pedons were Mollisols. Thirty-one percent of the pedons contained contrasting soil characteristics, which resulted in their designation as dissimilar soils. Sixty-nine percent of the sampled pedons could be managed similar to or more intensively than the Willakenzie.

Soil property variability was compared between three different separation distances along a transect. Chemical properties tended to have higher variances within 70 m distances, and physical properties tended to have higher variances within 105 m distances. Both chemical and physical properties achieved minimum variances within the 35 m distance. Morphologic properties showed no trends.

Delineation mean values were significantly different for sixty-one percent of the properties measured. Management and land use predictions concerning the Willakenzie map unit as a whole can not be applied to every delineation, because of the significant differences in morphologic and physical properties between individual delineations.

Three major sources of observed variability within the map unit were determined. High variability in the underlying geologic strata resulted in a wide range of C horizon textures and rock types, from clays to sandy loams to mudstones to sandstones. Some of the pedons were mapped at elevations low enough to have been affected by lacustrine silts. These pedons contained uniform silt loam horizons, which is not typical for the Willakenzie. The fact that soil mapping in Yamhill County took place in the 1950's under the 1938 Classification system accounted for much of the variability in soil profile features such as mollic epipedons and argillic horizons. These features were not differentiating criteria for the Willakenzie series under the earlier system as they are under the present system.

Composition and Variability of a Willakenzie Map Unit in Yamhill County, Oregon

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TABLE OF CONTENTS

Table of Contents, continued

LIST OF FIGURES

List of Figures, continued

List of Figures, continued

LIST OF TABLES

COMPOSITION AND VARIABILITY OF A WILLAKENZIE MAP UNIT IN YAMHILL COUNTY, OREGON

I. INTRODUCTION

Before an organized soil classification system was developed in the United States in 1899, the differentiation of soils into groups was based on local observations and served local, specific purposes (Baldwin et al., 1938). The divisions between groups were often made on the basis of one attribute, such as color or texture (Baldwin et al., 1938). Through time, the criteria used for classification became more numerous and more precise, as knowledge of soil morphology and genesis increased. In 1899, the United States Department of Agriculture instituted the Soil Survey with the intent of defining and mapping the important soil types throughout the country. The resulting surveys and classification system were applied as a medium for the discussion and extension of knowledge on use, management, productivity, and conservation of different soils (Kellogg, 1963; Riecken, 1962). Modern survey reports include crop suitability groupings, woodland, wildlife, and engineering ratings, and yield predictions for the map units of each soil series identified.

Each innovation in soil description and classification since 1899 has been a response to needs for more quantitative and accurate interpretations of soil landscapes. Yet several studies have indicated that still more improvement is needed in both the mapping accuracy and the quantitative description of map units (Amos and Whiteside, 1975; Powell and Springer, 1965; Beckett and Webster, 1971). These studies also suggest that the reliability of a soil map is fundamentally interrelated with (1) the amount of inherent soil variability present in the landscape, and (2) how accurately the soil variability is described in the accompanying written text.

Early soil surveyors quickly recognized that soils could not be mapped as pure taxonomic entities because of both the amount of natural soil variation present in the landscape and the scale at which the variations occurred. Instead, soils are mapped in terms of soil map units. Map units are named for the dominant soil or soils in them, but they also contain inclusions of other soils that are intimately associated with the dominant soil(s). These inclusions, which can be soils of other series or of unrecognized taxa, occur in areas too small to be identified separately on maps at the scales in common use. The amounts and kinds of inclusions within the map unit can affect the reliability of the soil map and map unit description for predicting land use and soil behavior.

Several kinds of map units have been developed. The most common one for standard soil surveys is the consociation, which consists of a single dominant series plus inclusions of taxadjuncts,[1] other recognized series, and unnamed or unrecognized variants[2] (Adams and Wilde, 1976a). "Guidelines" for the amount of inclusions allowed in

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[1]Taxadjuncts are soils that have properties outside the range of any recognized series, but they differ from a defined series in so small a degree that major interpretations are unaffected.

[2]Variants differ enough in one or more properties from any established series that their behavioral predictions are different; they are potential new series.

consociations were first presented in the 1951 Soil Survey Manual (Soil Survey Staff, 1951):

> ...mapping units named in terms of a single taxonomic unit are bound to include small portions of other taxonomic units and of intergrades with other taxonomic units--say up to 15 percent.

McCormack and Wilding (1969) observed that a 15 percent limit on inclusions within a map unit was not very realistic and that it was not unusual for the amount of inclusions to be underestimated by the soil surveyor. The 1951 "guidelines" were revised and more precisely defined in a later edition by the Soil Survey Staff (1977):

> Soil consociations are mapping units in which only one kind of soil (taxa) or a kind of miscellaneous area dominates each delineation to the extent that three-fourths or more of the soil fits within the taxon that provides the name for the mapping unit or in similar soils.[3] The dominant soil must fall within the range of the taxon providing the name for the mapping unit and must constitute more than one-third of the unit. No one dissimilar soil[4] may make up more than one-tenth of the mapping unit and the total of all dissimilar soils may not exceed one-fourth.

The quality of information within the text of a survey report concerned with describing map unit composition and soil variability also affects the map's reliability. Amos and Whiteside (1975) noted how the detail and refinement of map unit descriptions have decreased with time in relation to the increasing refinement of soil taxa. Survey reports usually do not contain quantitative measurements of map unit variability and do not explain how to recognize dissimilar inclusions

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[3]"Similar soils have differences that are both small in number and in degree. Most differ in no more than two or three criteria that differentiate between soil taxa" (Soil Survey Staff, 1977).

[4]"The differences among dissimilar kinds of soil are either large in number or in degree, or both" (Soil Survey Staff, 1977).

within individual delineations. Detailed information regarding map unit composition and variability could be helpful to the survey user, although gathering the quantitative information might be difficult. For example, the soil surveyor himself may not be able to correctly estimate the range of properties within a map unit, due to his unintentionally-biased sampling of selected, "representative" profiles (Bascomb and Jarvis, 1976; Steers and Hajek, 1979). The soil mapper may have a tendency to see soils which match his preconceived concept of the map unit, and thereby overlook the ones which do not agree. In these instances, the traverses made by the soil scientist in medium-intensity surveys do not provide a clear idea of the proportions of soils comprising the map units (McCormack and Wilding, 1969).

This thesis was undertaken because of the importance of recognizing the way soils actually vary in natural landscapes and of obtaining unbiased information about map unit composition. A map unit of the Willakenzie series was selected for study, because the morphologic variability was known to exhibit unexpected profile features.[5] The specific objectives of the project were:

(1) To quantitatively and qualitatively characterize soil variability within the Willakenzie silty clay loam, 2 to 12 percent slopes, map unit as it is mapped (Otte _et al._, 1974) in Yamhill County, Oregon by

(a) describing map unit composition,

(b) evaluating within delineation variability versus between delineation variability, and

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[5] R. Glasmann and R. Brown. Dept. of Soil Science. Oregon State University, Corvallis, Oregon. Personal Communication.

(c) analyzing the variability of soil properties over distance.

(2) To diagnose the major causes of variation within the map unit.

II. CHARACTERIZATION OF MAP UNIT AND SOIL PROPERTY VARIABILITY

Studies concerned with the improvement of map unit descriptions and soil survey methods have appeared in the literature since the inception of the soil survey itself. These studies have formulated descriptive methods for characterizing and statistical methods for quantifying soil property variability within map units and within map unit delineations. The intent of much of the research has been to maximize the practical applications of soil survey information. This chapter summarizes some of these practical applications and also reviews a number of techniques used in soil variability research.

Utilitarian Aspects of Map Units And Soil Surveys

Potential uses for soil survey reports may be found in many sectors of the economy. Originally, soil surveys were designed to benefit farmers and ranchers, but more recently, home builders, community planners, tax assessors, and highway engineers have all used them effectively (Olson and Marshall, 1968). Klingebiel (1966) boldly states that "a soil survey is an investment that is almost certain to pay for itself--and return a profit within a year."

East Central Florida's experience with regional planning is one example of the value of soil survey information (Doyle, 1966). By superimposing soil survey maps over the existing land-use pattern, areas of predicted urban expansion could be identified based on past growth history. The discovery that previous urban development followed certain trends relative to soil type allowed a much easier prediction of probable future growth areas. Soil map interpretations also enabled the Planning Council to recognize potential use conflict areas, to identify water recharge sites, and to reclassify prime agricultural land. Similarly, farmers in Nebraska increased their crop profits after implementing an improved water management system and a soil reclamation program, both of which were based on soil survey interpretations of the local problem soils (Klingebiel, 1966). In other studies, the use of high intensity surveys yielded considerable savings when applied to road and housing construction projects (Kantey and Williams, 1962; Olson and Marshall, 1968; Thornburn, 1966).

Arnold (1978) describes a practical method for evaluating soil mapping units in relation to specific agricultural planning objectives. A set of soil properties listed as critical for a particular land use is first decided upon, and then limits on the ranges of those properties are established. With the established limits in mind, map units are judged as to their suitability for each use. The range of properties within a map unit may qualify it as "suitable" for one use but "limiting" for a different use. The percentage distribution of all map units within the acreage under consideration is then determined by a point count method. Depending on the percentage of "suitable" map units present, the tract of land is rated for the various possible uses.

The utility of soil survey information also has certain limitations. One limitation concerns the precision with which the kinds of soils actually present in a landscape can be predicted from the mapped representation of that soil landscape. Some people use a soil map to assess relative soil characteristics without first having to visit the area of interest (Bie and Beckett, 1971). This is a good way to get a first approximation of the types of soils and their patterns of occurrence in an area, but the user must be aware that soil conditions cannot always be predicted with exact precision. The scale of the map usually does not allow each soil variation to be represented by delineation boundaries. As a result, inclusions of different soils will be present within most delineations.

Another limitation is the extent to which the taxonomic criteria used to define soil classes are actually significant for agronomic or economic uses (Bie and Ulph, 1972). Gibbons (1961) argues that soil maps based on a general purpose classification have very limited value, because the classification criteria useful for one specific purpose may be entirely different for another land use. He indicated that the only situation in which a soil classification system can be applied generally is when the criteria used for the various purposes are similar or closely correlated. Butler (1964) also criticizes the relevancy of general classifications, because he found no correlation between soil type and crop yield. He concludes that some soil properties important for crop productivity, such as available cations and pH, are not the same as the properties important for the grouping of soils into types. Similarly, Cruickshank and Armstrong (1971) detected little relation between soil series and farm gross profits.

The root of many of the problems associated with grouping soils into coherent classes lies in the inherent nature of the soil population itself. The soil universe is composed of a continuum or a near-continuum of property values, which makes construction of class limits difficult to define and sometimes arbitrary (Bie and Ulph, 1972; Knox, 1965). Soil properties which vary independently of each other compound the problem of designing uniform class concepts. Consequently, pedologists "cannot impose a greater degree of unity on soil classes than the nature of soils permits" (Butler, 1964). This is a limitation that must be accepted and understood before applying soils information to particular land uses.

Purity Of Map Units

The assessment of map purity is one way of quantifying the composition of a map unit. To calculate purity, a sample of profiles is taken from a number of map unit delineations. Each profile is described and compared to the description of the typifying pedon for that unit. The proportion of the profiles which meet the criteria of the defined class gives an estimate of the frequency with which the map correctly predicts the class in that area (Bascomb and Jarvis, 1976). Chittleborough (1978) calls this procedure a measure of "survey success," which may be misleading in some cases. A survey with a low purity rating can still be successful as long as its makers are aware of the degree of variability and can accurately describe it in the text. Some soils are simply too complex in their distributions to achieve high purity ratings. A map unit purity rating can also be misleading for survey users interested in the use and management of a unit. Soil profiles with only a few properties outside the allowable range of characteristics are not considered members of the defined taxonomic class. Hence, the map unit may have a low purity rating, but the differences may be so few or so slight that a high proportion of the soils are similar and can be managed in the same way as the typifying pedon.

Table 1 lists the results of eight studies concerning mapping purity. These values are consistent with the 50 percent average purity estimated by Beckett and Webster (1971) in their comprehensive review on soil variability. Some of the variations in purity between the studies may be explained by disparities in the size of sampling area (only Adams and Wilde [1976a, 1976b] sample from the total geographic extent of the map unit), by differences in the methods of sampling (i.e., random versus systematic), and by differences in the homogeneity of the soil landscape itself.

The purity of a soil mapping unit also depends on the categorical level of the taxonomic unit being mapped. For the same set of observations, Wilding et al. (1965) measured 96 percent map purity at the great group level, 85 percent purity at the subgroup level, 42 percent at the series level, and 39 percent for soil types. McCormack and Wilding (1969) calculated a 74 percent purity for soil orders, 44 percent for great groups, 22 percent for subgroups, and 17 percent for series. Thus, as the classification of the soil becomes more broadly defined, mapping purity increases.

Another factor that affects map unit purity is the scale of the map. Large scales permit more delineation of soil differences observed in the field, whereas small scales necessarily require grouping of

Table 1. Percent Map Purity Reported by 9 Previous Research Studies

Researchers	Sampling Scheme	By Soil Series	By Soil Type
Adams and Wilde, 1980	31 random sites from entire population		58%
Andrew and Stearns, 1963	20 observations in each of 18 small blocks		58%
Bascomb and Jarvis, 1976	30 samples from random placement of grid	60%	
Chittleborough, 1978	7 soil series with total of 1346 samples	37%	
Courtney and Webster, 1973	stratified sampling grid, total of 184 profiles	70%	
McCormack and Wilding, 1969	2 delineations each from 11 map units; total of 220 observations	17%	
Powell and Springer, 1965	transects over 3 map units; total of 518 observations	74%	64%
Ragg and Henderson, 1980	random-stratified sampling of 4 map units	66% 43% 53% 51%	
Wilding, Jones, and Schafer, 1965	10 random observations within each of 24 map delineations	42%	39%
Average Purity		51%	55%

known differences in a single delineation. Hence, map unit purity should increase as the scale of the map increases. Burrough et al. (1971) did in fact find that map purity ranged from 45-63 percent at a 1:63,360 scale and increased to 65-87 percent at a 1:25,000 scale.

The map unit purity to be achieved in a soil survey directly affects both the execution and the economics of the survey. The cost of making the survey (per unit area) increases dramatically with increases in the map purity desired, because the greater accuracy requires closer observations in the field (Bie and Ulph, 1972). Planning intensive land use objectives, such as vegetable or fruit farming, requires map delineations which are relatively pure or uniform, whereas planning for less intensive objectives, such as cattle grazing, can tolerate a lower degree of purity (Arnold, 1978; Riecken, 1962). A higher level of uniformity is difficult to justify if the increased payoff from the closer observations is not greater than the cost of the survey (Bie et al., 1973). Once a soil survey is completed, purity ratings can help elucidate the kinds of land use decisions which are possible for the map units portrayed.

Statistical Description Of Soil Property Variability

There are two reasons for statistically measuring variability in soil properties. First, decisions about appropriate values for class limits or class intervals are made less arbitrary with a knowledge of the extent and nature of variation in the properties (Mulcahy and Humphries, 1967). Second, the user of the resulting classification is provided with a specific measure of property variation within the given class.

Quantification of the variation in specific soil properties can only be done by sampling from the infinite population of pedons in the soil-landscape continuum. Morphological, physical, and chemical data obtained from analyses of the samples can be used to construct frequency distributions of the values for each property, and these in turn are used to calculate statistics which estimate the parameters of the entire population. Many soil property distributions can be approximated by a normal distribution well enough to use normality as the basis for estimating parameters, making predictions, and testing hypotheses (Webster, 1977). Some properties, however, are distinctly non-normal, and to assume normality could lead to serious errors in estimation, prediction, and testing.

Use of the Normal Distribution

Normally distributed soil properties imply a more or less symmetric variation around a mean, or average value. The mean of a normal distribution is an estimate of the most likely occurring value in the population from which the sample was taken (Webster, 1977). Thus, if a soil property is known or can be assumed to be normally distributed, the mean may be used to predict the most frequently occurring value in the population.

The dispersion, or spread of the values in the frequency distribution, is calculated as an average of the squares of the deviations from the mean. This statistic is the variance, and its square root is the standard deviation. The standard deviation has a certain amount of predictive value in that approximately two-thirds of the values in a normal population lie within ± 1 standard deviation of the sample mean, and approximately 95 percent of the population values fall within ± 2 standard deviations of the sample mean. The standard deviation can also be considered as an indicator of the reliability of the mean for predicting values of new observations (Morse and Thornburn, 1961). Large standard deviations denote wide dispersions around the mean, which in turn, make the mean less accurate for prediction. The opposite is true for small standard deviations.

The mean and standard deviation can be used together for calculating other useful quantities such as confidence and prediction intervals. Confidence intervals predict the range within which the true population mean lies, and prediction intervals predict the range within which a specific property value lies. Both intervals are determined at a specified degree of probability. Jansen and Arnold (1976) and Protz _et al_. (1968) used confidence intervals to define inclusions within landform units. The soil pedons whose property values fell outside the calculated confidence intervals were designated as the inclusions. A calculation similar to that for determining confidence intervals has been used by a number of researchers (Adams and Wilde, 1976a; Mader, 1963; Mausbach _et al_., 1980; McCormack and Wilding, 1969; Wilding _et al_., 1965) to plan sampling intensities. In this procedure, the number of samples needed for estimating a population mean at a specified level of confidence is determined from a limit of accuracy curve.

A statistic used extensively in soils research is the coefficient of variation (CV), which is the standard deviation divided by the mean, expressed as a percentage. Its utility is derived from the fact that the standard deviation tends to vary with the mean (Snedecor and Cochran, 1967). Many scientists find this statistic a useful means of expressing the relative variation between soil properties, while others believe it to be "an unnecessary simplification" of data and prefer to look at the mean and standard deviation separately (Wright and Wilson, 1979). The advantages to using the CV are twofold; it is a fast and easy statistic to compute, and it is independent of the units involved. No other statistic, for example, can compare variations between soil properties such as percent clay and milliequivalents of calcium. One disadvantage of the CV is that it can sometimes be a misleading representation of property variability. For example, a soil property may have the same variance, s^2, in two separate areas, but may have different mean values, $\bar{x}$ and $2\bar{x}$, respectively, for each area. By use of the CV, it would be concluded that the property in area one is twice as variable as it is in area two. In other cases, if the sample distribution is significantly skewed, the CV may be an inappropriate statistic, because the calculation assumes normality.[6]

Trends in the CV values of soil properties have become evident in the recent literature (Table 2). For instance, properties more apt to be affected by management practices (e.g., exchangeable Ca^{++} and Mg^{++}) are consistently more variable than those that are not (Adams and Wilde,

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[6] R. Peterson. Dept. of Statistics. Oregon State University, Corvallis, Oregon. Personal Communication.

Table 2. Selected CV Values (Expressed as a Percentage) for Surface Soils

Researcher	Sampling Scheme	Thickness of A Horizon	Sand	Silt	Clay	O.M.	Depth to $CaCO_3$	pH	K^+	Ca^{++}	Mg^{++}	CEC
		--cm---	----------%			----------	-cm--		-----meq/100 g-----			
Andrew and Stearns, 1963	random sampling of soil series		17	5	19							
Crosson and Protz, 1974	grid sampling of 2 map units (several delineations)	53		63	51	34	62					
		37		36	54	20	42					
Bascomb and Jarvis, 1976	random sampling of map unit	18		16	12	15	21	9				15
Wilding, Schafer, Jones, 1964	sampling only typical profiles of 2 series	14	25	10	25	32	12	9				
		14	37	11	17	30	14	9				
Adams and Wilde, 1976a	random sampling of map unit	17						10	66	40	33	19
Nelson and McCracken, 1962	sampling only typical profiles of 2 soil series	37	10	51	45	31		6	25	39	82	33
		33	17	45	50	50		2	83	71	48	41
Jeyaseelan and Matthews, 1956	sampling only typical profiles of soil series		22	21	31	40			5	38	41	39
McCollum and McCaleb, 1954	random sampling of 2 soil series		8		30	21		3	21	29	41	
						21		9	55	51	88	
	Average CV	28	19	29	33	29	30	7	42	45	55	29

1976b; Bascomb and Jarvis, 1976; Beckett and Webster, 1971). Indeed, the CVs for available Mg^{++}, Ca^{++}, and K^{+} in Table 2 tend to be greater than those for physical properties such as percent sand and silt, which are relatively unaffected by management. It is also possible that these differences in CV values are due to differences in the properties' frequency distributions. Chemical properties often have positively skewed value distributions (Webster, 1977). In other studies, chemical properties were found to vary more in A horizons than in B horizons, although Table 2 does not illustrate this point (Adams and Wilde, 1976b; Chittleborough, 1978; Dawud, 1979; Mausbach et al., 1980). This observation may be due to the effects of management on the surface layer.

Some researchers have compared the CV values for morphologic properties with those for chemical properties, but their results are mixed. Bascomb and Jarvis (1976), Wicherski (1980), and Adams and Wilde (1976b) found the CVs of chemical properties to be greater than those of morphologic ones, whereas Dawud (1979) indicated the opposite for his observations. Mausbach et al. (1980) found no significant differences between the CVs of these sets of properties.

Non-normal Distributions

When soil property values are not normally distributed, most of the common statistical techniques for quantitatively describing their dispersion and central tendency may become misleading, if not invalid (McIntyre and Tanner, 1959). In these cases, transforming the scale of measurement into one that is normally distributed can be beneficial. Log and square root transformations are a common means of doing this, especially for soil chemical and hydrologic properties (Nielsen et al., 1973; Webster and Butler, 1976; Webster, 1977).

The mean may be a poor measure of central tendency if the frequency distribution for the values of a soil property is skewed. In its place, McIntyre and Tanner (1959) recommend using the geometric mean, which is derived by taking the arithmetic mean of the logarithms of the raw values and transforming back. Snedecor and Cochran (1967) suggest reporting the median, because it seems to represent people's concept of an average better than the mean.

Other ways to quantitatively describe non-normal distributions are with the coefficients of skewness and kurtosis. Skewness refers to the degree of symmetry of the property distribution. A peak of values at the lower, or left end, of the distribution signifies a positive skewness and is represented by a positive coefficient. When the distribution has a long tail at the left end of the scale, the coefficient is negative, and the distribution is considered negatively skewed. Kurtosis is a measure of the distribution's peakedness. Leptokurtic distributions have a higher than normal percentage of values occurring close to the mean, and platykurtic distributions have a flatter peak than normal (Adams and Wilde, 1980). Together, the coefficients can effectively describe degrees of departure from a normal curve and aid in the comparison of property distributions.

Analysis of Within and Between Class Variance

As early as 1919, soil scientists (Lipman, 1919; Pendleton, 1919) discovered high variabilities in soil properties and behavior within classes of the same soil type and began to question the validity of the classification and mapping procedures for grouping soils into these types. More recently, Beckett and Webster (1971) reviewed a number of variability studies and concluded that the variability of soil properties within soil classes was frequently as great as that between them. Kristof and Zachary (1974) encountered a similar situation in mapping soils from multispectral scanner data. They found that variations in spectral signatures within a soil series were greater than variations between soil series. In cases like these, the time and cost spent on mapping and classifying soils into their types may be fruitless, if the grouping of soils does not result in classes which can be differentiated from each other (Chittleborough, 1978).

Analyses of variance and F tests have been used in soil variability studies to analyze and test for soil property homogeneity within and between soil classes (Andrew and Stearns, 1963; Bascomb and Jarvis, 1976; Chittleborough, 1978; Mader, 1963; McCormack and Wilding, 1969; Webster and Butler, 1976; Wilding et al., 1965). Webster and Beckett (1968) suggested that the within-class variance be a regular feature in soil survey reports. A nested or hierarchical sampling design, in which the population is divided into several classes that contain additional subdivisions, is most conducive to analysis of variance of soils data (Webster, 1977). This method reveals how variable the groups are at each sampling level, and what proportion of the total variance is attributed to within class variability versus between class variability.

The results of these kinds of studies are diverse. Some authors (McCormack and Wilding, 1969; Wicherski, 1980) found that morphologic properties such as depth to mottling, solum thickness, IIB horizon thickness, color value and chroma, and thickness of the A horizon were more variable within mapping delineations than between delineations. Conversely, Wilding _et al_. (1965) found that properties such as depth to mottling, A and B horizon thickness, and color value and chroma were _less_ variable within delineations than between. These conflicting observations may be the result of differences in parent material, landscape, vegetation, and/or climate between the authors' study sites.

Spatial Variability of Soil Properties

Three major sources of variation cause observed differences in soil properties: spatial variability, seasonal fluctuations, and experimental error. Of these, spatial variability affects the applicability of soil test results to a much greater extent than variations due to either experimental error or seasonal fluctuation (Ball and Williams, 1968; Cline, 1944; Raupach, 1951). Differences of a whole pH unit, for example, were found within a three by four foot area, and differences of up to 0.6 pH unit existed between adjacent samples one foot apart (Downes and Beckwith, 1951). Seasonal fluctuations within the same three by four foot area were comparably slight. Soil properties such as organic matter, percent clay, and exchangeable cations have shown relatively wide variations over distances as short as six inches; the variations in every case were statistically significant when compared to the experimental error involved (Raupach, 1951). This complex spatial pattern of soil variation, both laterally and with depth, influences the effectiveness of predictions based on the average values of soil properties computed from field-sampled data (Peck and Melsted, 1967), An understanding of how and why soil properties vary with distance is integral for use and management decisions as well as for research sampling purposes.

Factors of Variation

Properties of soil landscapes vary spatially for many reasons. At a very small scale, the presence of worm holes and castings, soil pores, roots, bacteria, fungi, etc., and the localization of chemical and physical processes on the surface of soil particles accounts for some differences in soil property values. In cultivated fields, the local effects of row cultivation, fertilizer placement, mole hills, small animals, and even cow pats contribute to variability (Beckett, 1967; Buol et al., 1973; Grava et al., 1961). Spatial variations of litter-fall (Zinke, 1962) and tree throw phenomena (Armson and Fessenden, 1973) affect soil property distributions in forest environments.

Parent materials may be a major cause of lateral soil variation, because they can vary irregularly over distances of meters (Beckett and Webster, 1971). Abrupt changes sometimes result from irregular deposition of materials by glacial or fluvial actions. Robinson and Lloyd (1915) note that soils formed on transported material are often more variable than soils derived from the in situ weathering of bedrock. On the other hand, geochemical gradients present at the time of deposition can cause regional variations in an otherwise uniform sedimentary stratum, resulting in clear-cut soil differences (Ulrich, 1949). The morphology of an Oregon soil, the Elkins Road Paleosol, derives much of its variability from short range variations in the underlying formation (Glasmann, 1979), which Hoover (1963) ascribed to the lateral interfingering of different rock types.

Other variations in soil properties can be attributed to the effects of slope, aspect, and topography. Soils on north-facing slopes generally have greater accumulations of organic matter than soils on south slopes (Klemmedson, 1964; Losche, 1967), whereas soils on south-facing slopes tend to have more clay and more pronounced argillic horizons than soils on north slopes (Losche, 1967). On the loess and drift landscapes in Iowa, Walker et al. (1968b) found that as slope concavity increased, A horizon thickness increased and mottling occurred closer to the surface. Solum thickness was directly related to slope gradient by Norton and Smith (1930) on similar loess landscapes. Because topographic features are immediately detectable to the eye, it is much easier to account for them during sampling and mapping than for subsurface parent material factors.

Measuring Variation

Numerous techniques have been devised for measuring the spatial variability of soil properties. Most of them have arisen from the general desire for more accurate statements about the potentialities of a mapped soil, and are therefore involved in predicting property values. Others stem from a more academic propensity for simply exploring the character of soils. These methods concentrate on the quantitative description of property distributions over the landscape.

(1) Effect of Distance One measurement of soil variability that has been discussed extensively in the recent literature concerns the relationship betwen variability and distance. One school of thought holds that the variability of soil property values increases as the sampling area increases (Beckett, 1967; Beckett and Bie, 1976; Beckett and Webster, 1971). The other (Wright and Wilson, 1979) holds that property variability does not necessarily increase with distance and that maximum variation may occur within relatively short distances. Experimental data can be mustered to defend both viewpoints.

Beckett (1967) proposes several hypothetical curves which describe how the variance of a property increases with the area, or with the square of the distance. The shapes of the curves vary, depending on the types of hypothetical periodicities that might occur in parent material or topography. Some of the curves increase rapidly at first and level off with increasing area; in others, the variance increases gradually with increasing area. Beckett and Bie (1976) sampled several different-sized areas by transects and looked at how the pooled variance of a property varied with the distance between sampling points. Within the individual transects, the variances of soil properties did not always increase with distance, but when transects from all the different-sized areas were compared to each other, the pooled variances of soil properties generally increased. A similar conclusion was reached by Beckett and Webster (1971). They found that the CV values and variances of soil properties increased with area, although they also stressed that one-half of the variance in a field could occur within any square meter of it.

The opposite conclusion, i.e. that the variance doesn't necessarily increase with the size of the sample area, is revealed by Wright and Wilson (1979). Their graphs of variance versus area show no trends in these variables. They also offer mathematical proof that no theoretical statistical reasons exist for Beckett's (1967; and Bie, 1976; and Webster 1971) claims of increasing variance with increasing area. In addition, their results illustrate that different variabilities may occur within areas of equal size. Keogh and Maples (1967) showed that differences in the sizes of their study areas did not appreciably affect CV values, and Cipra et al. (1970) found that pedons spaced 90 m apart commonly varied as much in fertility levels as pedons spaced either 8 or 145 km apart. Wicherski (1980) reported no direct relationship between the variation of soil properties and sampling distance.

Despite these conflicts in opinion and theory, most researchers do concur on one point--that a great deal of the total variation in one area can be attributed to variability over relatively small distances (Beckett and Webster, 1971; Cameron et al., 1971; Dawud, 1979; Downes and Beckwith, 1951; Wright and Wilson, 1979). This variability, though, is rarely uniformly dispersed throughout the area (Cameron et al., 1971), and it is more complex for some soil properties than others (Webster and Butler, 1976). It is this intricate distribution of property values that makes an accurate, detailed description of soil variability almost impossible.

(2) Computer Models Statistics used in most soil variability studies, such as pooled variances, CVs, and ANOVA models, are all fairly conventional and easily calculated. Another set of methods utilized by some authors involves complicated computer programs that offer promising new ways to describe continuous soil properties and to predict property values. These techniques include trend surface analysis, autocorrelation, and kriging.

Trend analysis is an adaptation from the statistical theory of linear regression. The trend surface itself is an equation of the form: $Y = b_0 + b_1x_1 + b_2x_2 + b_3x_1^2 + b_4x_2^2 + b_5x_1x_2 + \cdots + b_mx_n^p + E_i$ where Y is a dependent property linearly regressed on two independent geographic coordinates, x_1 and x_2 (Davis, 1973; Campbell, 1977). Best fit surfaces of increasing complexity, starting with a plane, are fitted to the data using polynomials of successively higher order according to the least squares criterion. The positions of the points are defined with reference to a rectangular grid. Campbell (1977) used this method to describe the areal distribution of pH and percent silt across the boundary between two soil series. Isoplethic maps of each property revealed how the properties varied gradually over the landscape. Davies and Gamm (1970) also used this model to describe and explain pH differences in calcareous and non-calcareous soils. The method's predictive value was recognized by Walker et al. (1968a), who were able to estimate values for certain soil properties not otherwise measured within their sampled area. Their observations of statistically significant trends led them to conclude that most of the soil properties within the area were not randomly distributed, but varied systematically over the landscape.

One disadvantage of trend surface analysis is that the equations become extremely complex for highly variable property fluctuations, especially over a large area. Additionally, it is very unlikely that a specific equation could apply to more than one region (Webster and Cuanalo, 1975). Webster and Cuanalo (1975) suggest that, in cases like these, an alternative method of examining relationships between points be used, called autocorrelation analysis. Unlike trend analysis, which defines property values based on their absolute position within a grid, autocorrelation measures relationships between sampling points as a function of the distance separating them. Thus, a transect scheme containing equally spaced intervals is required. During the process of autocorrelation, the entire sequence of point values along the transect is compared with itself at different lags. A lag is the distance of one spacing interval. At zero lag, all points, x_n, along the transect are compared with each other; when the lag = 1, x_1 is correlated with x_2, x_2 with $x_3, \ldots, x_{n-1}$ with x_n; for lag = 2, x_1 is correlated with x_3, x_2 with $x_4, \ldots, x_{n-2}$ with x_n, etc. (Vieira, 1980). This self-comparison process determines the degree of similarity or dissimilarity at every position along the transect for each chosen lag. For transects with some degree of spatial dependence, there will be lags in which autocorrelation values vary between 0 and 1, with values above 0.4 generally considered significant (Vieira, 1980). Examination of an autocorrelogram (lag vs. autocorrelation) reveals intervals of space at which the sequence has a repetitive or periodic nature, and further discloses the distance at which variables become statistically independent of each other. Webster and Cuanalo (1975) used this technique for detecting geologic periodicities in the landscape, and subsequently, for aiding in soil boundary location. Petrova (1978) also used autocorrelograms in a field experiment to determine the minimum spacing of soil moisture sensors. In other studies, the process was employed for determining whether a particular property distribution was random or if a spatial dependence existed between them (Campbell, 1977; Vieira, 1980).

If through these methods, a soil property exhibits spatial dependence; i.e., it does not show a random distribution at a specified sampling distance, the application of Regionalized Variable Theory may prove instrumental in describing and predicting unsampled properties. This theory has the advantage of being able to deal with variables having geographic variations too complex to be represented by ordinary, workable functions (Campbell, 1978; Davis, 1973). The kriging technique, derived from this theory, weights all data values within the study area and not only attempts to estimate unknown values, but also gives the probable error associated with each estimated value (Matheron, 1963; Webster, 1977). The technique assumes that the influence of nearby points is probably greater than the influence of more distant points, and that the degree of influence might be different in different directions (Davis, 1973). Even though very few researchers have bothered with this kind of analysis, Webster (1977) sees a very practical use for it in sampling and estimation procedures, as well as in isoplethic mapping of soil properties. Campbell (1978) expresses the hope that basic relationships between soil variables, which could be determined by kriging techniques, might be applicable to other areas of similar soils. In this way, a few intensive studies of selected sites could represent a range of soil taxa, without the surveyor having to make detailed analyses of every individual soil body.

III. DESCRIPTION AND SAMPLING OF THE STUDY AREA

Background For The Study

The following section provides a setting for the study and a rationale for some of the initial decisions which were made during the planning phase. The decisions involved selecting a map unit and research area that were relatively close to Corvallis, and which were already mapped by the Soil Conservation Service. Background information concerning the geology and geography was aquired through geologic maps, journal articles, private conversations, and through the text of the Yamhill Area Soil Survey Report (Otte et al., 1974).

Selection of the Map Unit and Study Area

Recent work (Glasmann, 1979; Glasmann et al., 1980) affiliated with a soil erosion study in rolling foothills adjacent to the major terraces of the Willamette Valley indicated that many soil profiles exhibited marked lateral and vertical variability as a function of geologic and/or geomorphic influences. Among the observed profiles were several pedons similar to the Willakenzie series, a moderately deep member of the fine-silty, mixed, mesic family of Ultic Haploxeralfs. The soil investigations showed the C horizon to range from clay to loam to siltstone bedrock at highly variable depths.[7] In contrast, the published description of the Willakenzie series

[7] R. Brown. Unpublished Soils Map of Elkins Road Watershed. Oregon State University, Corvallis, Oregon.

(Otte et al., 1974) describes the Willakenzie as overlying "hard, fractured siltstone bedrock" at a depth of 50 to 100 cm. Brown[8] and Glasmann (1979) concluded that short-range variation in bedrock mineralogy and texture affected the character of the C horizon from place to place throughout the study site. This observation raised the initial interest in the Willakenzie series as the object for a study on soil variability.

Glasmann et al. (1980) also found that geomorphic factors affected soil profile variability within the study area. During the Pleistocene epoch, lake waters repeatedly filled and drained from the Willamette Valley, depositing lacustrine sediments in the process (Baldwin, 1964). The last flood left a layer of silt that covered the valley below 122 m (Baldwin, 1964), which Balster and Parsons (1969) defined as the Greenback Member of the Willamette Formation. At the Polk County study site (Glasmann, 1979; Glasmann et al., 1980) the Greenback Member mantles either a partially eroded paleosol, bedrock, or the Irish Bend Member of the Willamette Formation. The Irish Bend Member occurs on the lower slopes of the study site below 80 m (Glasmann, 1979). Glasmann et al., (1980) determined soil types on the various geomorphic surfaces associated with the lacustrine deposits and underlying bedrock geology and found profiles similar to the Willakenzie both above and below the 122 m elevation on the Dolph and Brateng surfaces, respectively. The Willakenzie was not mapped on the Bethel surface (below the 80 m elevation), because the surface was underlain primarily by Mollisols

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[8] R. Brown. Dept. of Soil Science, Oregon State University, Corvallis, Oregon. Personal Communication.

(Glasmann et al., 1980). In Yamhill County, the Willakenzie was mapped between the elevations of 75 and 245 m, which presumably could include the Bethel, Brateng, and Dolph surfaces. Whether or not the profile morphology of the Willakenzie pedons in Yamhill County would be affected by their elevational position was another consideration contributing to the decision to focus this study on a map unit of the Willakenzie series.

The economic value of the Willakenzie became a third factor in the selection of a soil series to study. The landscape position, texture, and drainage conditions associated with the series make it a prime site for rural housing, pasture land, and grain, fruit, and nut production.

Six different phases of the Willakenzie series have been recognized in four Oregon counties, based on differences in slope and depth to bedrock. Of these, the Willakenzie silty clay loam, 2 to 12 percent slopes, was chosen because of its wider extent and higher agricultural value as compared to either the shallow (20-30 inches to bedrock) or the steeper phases.

Yamhill County was chosen as the site for the study because it is the only one of the four counties to have a published soil survey, and the type location for the Willakenzie series is found in Yamhill County.

Geography and Geology of Yamhill County

Yamhill County is located on the west side of the middle portion of the Willamette Valley. Its area extends to within 15 miles of Portland on the northeast side and to within 30 miles of Corvallis on the southern boundary. It is bounded on the west by the Coast Range and on the east by the Willamette River. Over 95 percent of the county drains eastward into the Willamette River, primarily through the forks of the Yamhill River and Chehalem Creek (Otte et al., 1974).

The area has a diverse physiography and climate. From the hilly and mountainous relief of the Coast Range on the north and west boundaries, the landscape gradually levels to the smooth, wide floodplains of the Yamhill and Willamette Rivers in the southern and eastern parts of the county. This gradation in elevation accounts for three major climatic zones: those associated with the valley floor, the foothills of the Coast Range, and the Coast Range itself. Like all of western Oregon, most of the rain falls between October and March. The amount of rainfall, however, increases sharply westward in the county, with yearly averages of 109, 157, and 323 cm, respectively, for each zone (Otte et al., 1974).

The bedrock geology of Yamhill County is highly variable, due to the great number of sedimentary depositions associated with the transgressions and regressions of the sea during the Tertiary period (Baldwin, 1964). Scattered intrusions of igneous rocks also have shaped parts of the landscape. The oldest rocks exposed are the Paleocene and early Eocene Siletz River Volcanics, which constitute part of the Coast Range in western Yamhill County. The youngest sediments are the alluvial deposits along the Willamette and Yamhill Rivers. Formations of Eocene, Oligocene, Miocene, and Pleistocene age lie between them.

A major part of central Yamhill County is underlain by a series of marine sedimentary rocks of Eocene age. The oldest formation within these strata has been named the Yamhill formation, and it surfaces in the southwestern portion of the county along the S. Yamhill River (Baldwin et al., 1955). It consists of tuffaceous siltstone and dark-gray shales overlain by sandstone and fine-grained, micaceous siltstones and mudstones. The siltstone and shale weather to small blocky fragments, which appear reddish-brown when exposed at the surface.

Younger Eocene strata were deposited after the Yamhill sediments were folded and eroded. Like the Yamhill, the members within this formation are texturally variable. They are comprised of tuffaceous shale and siltstone, thin-bedded sandstones, and some intercalated pillow basalts, breccias, and tuffs (Baldwin et al., 1955). Schlicker (1962) correlates the interbedded shale and sandstone members of this unit with the Spencer formation exposed in the southern Willamette Valley. With the exception of a thin strandline of Spencer sandstone mapped by Schlicker (1962) in central Yamhill County, the other lithologic units of the formation have not been differentiated. Baldwin et al. (1955) identify this entire sequence as the Nestucca formation, because it correlates lithologically and faunally with the type formation mapped in coastal sections.

As many as three formations of lower through upper Oligocene age surface in the eastern section of the county. These undifferentiated mapping units are grouped as tuffaceous sedimentary rocks by Baldwin et al. (1955) and include beds of basaltic sandstones overlain by tuffaceous sandstones and shales. The uppermost member is described by Schlicker (1962) as predominantly silty and tuffaceous. Fragments of volcanic ash are abundant throughout the beds and indicate the presence of volcanoes during the time of deposition.

Columbia River Basalt caps the Oligocene formations in isolated areas of eastern Yamhill County (Baldwin, 1964). These Miocene flows form the Chehalem Hills and the Red Hills of Dundee.

Along the Willamette and Yamhill River valleys lie silty sediments deposited during the late Pleistocene Epoch. Balster and Parsons (1969) have named them the Willamette Formation, because they consist of four depositional units of differing morphology. The four members, from youngest to oldest, are the Greenback, Malpass, Irish Bend, and Wyatt. They have not been differentiated for any portion of Yamhill County, and their elevational extent onto the surrounding foothills has been difficult to determine (Baldwin *et al*., 1955). However, Allison (1953), Gelderman (1970), and Glasmann (1979) have shown the upper limit of Greenback silt deposition to be 122 m in areas just south of Yamhill County.

Distribution of the Willakenzie Delineations

There are 336 delineations of the Willakenzie silty clay loam, 2 to 12 percent slopes, map unit (WeC) in Yamhill County. They cover approximately 11,300 acres, which is about two percent of the survey area's total acreage. The size distribution of the delineations is shown in Figure 1. Fifty-five percent of them are less than 10 acres in size, whereas only seven percent are greater than 60 acres. These few large delineations, however, account for half of the total WeC acreage in the survey area.

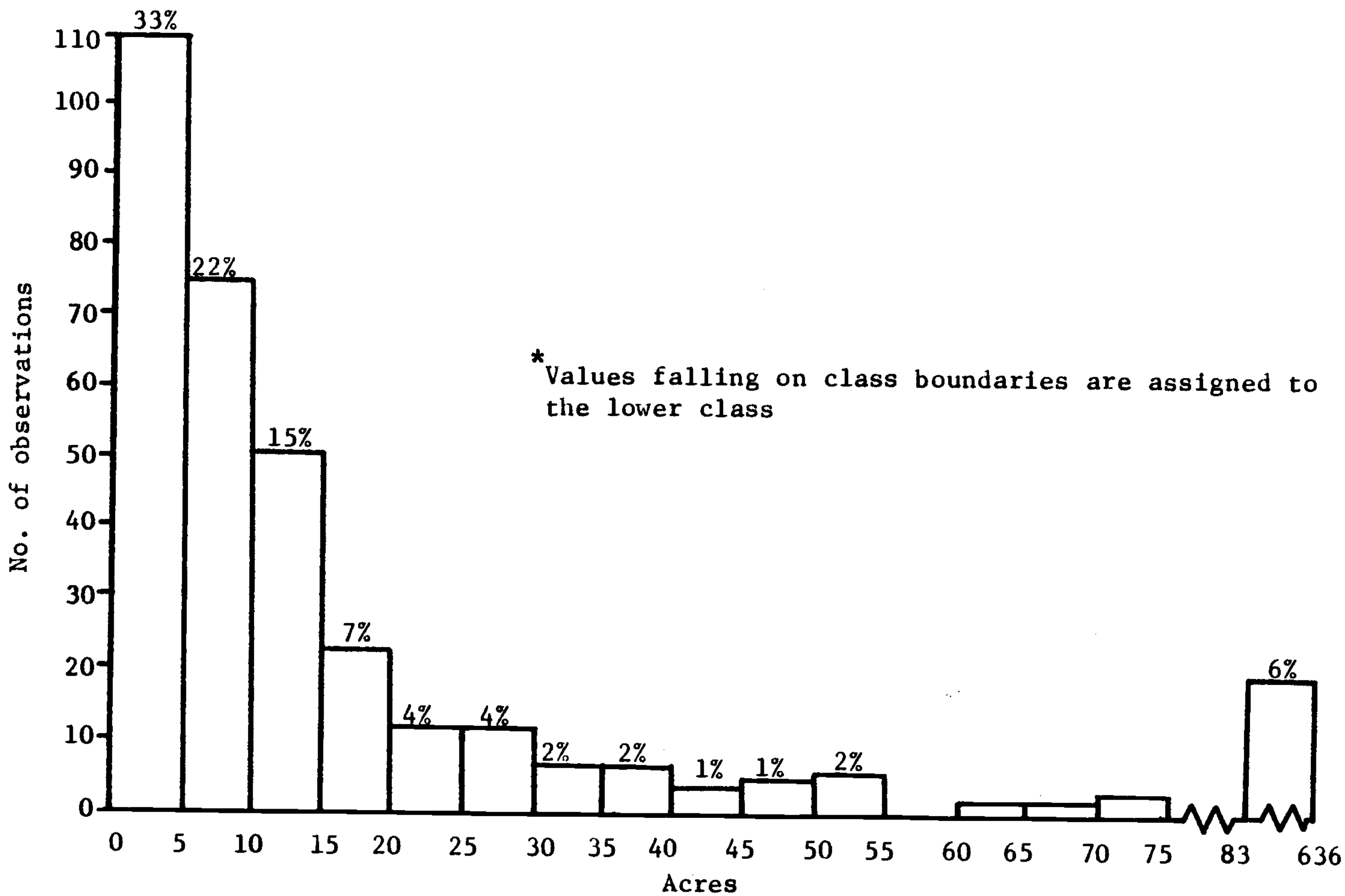

FIGURE 1: Size distribution of Willakenzie silty clay loam, 2 to 12 percent slopes, delineations.

Geographically, WeC delineations are found on the footslopes of the Coast Range and on ridgetops and side slopes of low hills surrounding the Yamhill and Chehalem River valleys. These three positions are most often underlain by the Nestucca and Oligocene tuffaceous sedimentary formations, although a few delineations are underlain by the Yamhill and Willamette Silt formations (Baldwin et al., 1955; Baldwin and Roberts, 1952; Warren et al., 1945). This geological variability is one of the most probable reasons for the variability observed within the Willakenzie map unit.

Sampling And Laboratory Procedures

The accuracy with which data collected from a set of soil samples can be used to estimate parameters of a whole population is a function of several factors: (1) the inherent variabiltiy of the soil population, (2) the number of sampling units drawn, and (3) the kind of sampling scheme used to collect the samples (Cline, 1944). This last factor is of particular importance when considering a population as spatially heterogenous as soils. Indeed, the question of random versus systematic sampling has been a prominent one in the soils literature and should be considered before commencing any sampling program.

There are advantages and disadvantages to both schemes. In random sampling, each unit of the population under investigation has an equal and independent chance of being included in the sample. This procedure is the only sure method for avoiding sampling bias (Webster, 1977). Conversely, a systematic sampling scheme can introduce bias into the sample population if the points of observation coincide with a regular periodicity in the landscape (Bourdeau, 1953; Webster, 1977). The period of variation and its direction, however, are usually obvious, and the spacing of observations can be adjusted to correct for this. The major draw-back to systematic sampling is that it does not give an entirely accurate measure of the sampling error. Statistical estimates of error are based on the assumption that all sampling units have been chosen independently and at random (Bourdeau, 1953; McClave and Dietrich, 1979). Webster (1977) believes that this disadvantage is offset by the more efficient coverage resulting from systematic sampling. Grid or transect samples are also generally easier to select and locate in the field than a random sample. Bourdeau (1953) suggests utilizing a stratified random sampling to obtain the advantages associated with both sampling schemes.

Sampling in Soils Research

Soil scientists have approached the sampling of landscapes in many different ways, depending upon the study's specific objectives. When the goal is to obtain a representative sample from a very large population (e.g., the total geographic extent of a map unit), a simple random sampling may be the most efficient and reliable method (Adams and Wilde, 1976a; 1976b). It may be the only practical scheme in cases where the sampling pool is irregularly distributed over several regions.

A grid pattern is commonly employed for selecting points of observation when the objective is to obtain a representative sample from a small area. This system is more likely to include the variations within an area compared to random sampling (Bourdeau, 1953). Some authors (Andrew and Stearns, 1963; Courtney and Webster, 1973; Crosson and Protz, 1974; Nielsen et al., 1973) have used grid sampling for measuring soil property variability in single fields or delineations. It is the most promising system of sampling for assessing soil trends over distance (Campbell, 1978; Webster, 1977), particularly with the kriging technique (Vieira, 1980) and in trend analysis (Walker et al., 1968a).

A third kind of scheme, transect sampling, has been used for measuring map unit composition (Powell and Springer, 1965; Steers and Hajek, 1979) and for analyzing the variance of soil properties over distance (Beckett and Bie, 1976; Webster and Cuanalo, 1975; Wright and Wilson, 1979). The use of transects for the latter purpose has been previously discussed. Powell and Springer (1965) describe the point-intercept method for estimating the amount of map unit inclusions. In this method, diagonal transects are laid out across a selected number of 160-acre blocks of land. (The sampling area may vary depending on the density of the mapping delineations). Soils are then examined and taxonomically classified at regular intervals along the transect. The number of sites assigned to each kind of soil is proportional to the area of each kind of soil within the study area. Steers and Hajek (1979) use a similar procedure in their study area to determine the number of transects needed to "adequately" define the composition of map units. The validity of this method has been substantiated mathematically by Chayes (1956) for petrographic work, but White (1966) questions its practicality for soil survey operations.

Both random and systematic sampling schemes were considered for the study in Yamhill County. Two different methods were used based on the three areas of interest to be examined. These sampling objectives were:

(1) to describe map unit composition,

(2) to evaluate within delineation variability versus between delineation variability, and

(3) to analyze the variability of soil properties over distance.

Sampling to Determine the Composition of the WeC Map Unit

It was the desire in this study to sample as many WeC delineations as possible so that an accurate measure of the total range in characteristics within the map unit could be gained. The 336 delineations of WeC in Yamhill County were irregularly distributed throughout a wide area; thus a systematic sampling scheme did not appear feasible. On the other hand, a random sampling of the delineations would produce an unbiased set of observations that could be statistically analyzed for variability and sampling error.

Every individual within the population must have an equal chance of being drawn in order to sample soils randomly. Therefore, all delineations of WeC were identified and numbered on the soil survey maps within the Yamhill County survey report (Otte et al., 1974). Thirty-five of the 336 delineations were randomly selected, by use of a random numbers table, to represent the WeC population. Figure 2 shows their location within the county, and Table 3 gives their legal locations.

The random selection of an observation point within each delineation was accomplished through a method suggested by Peterson and Calvin

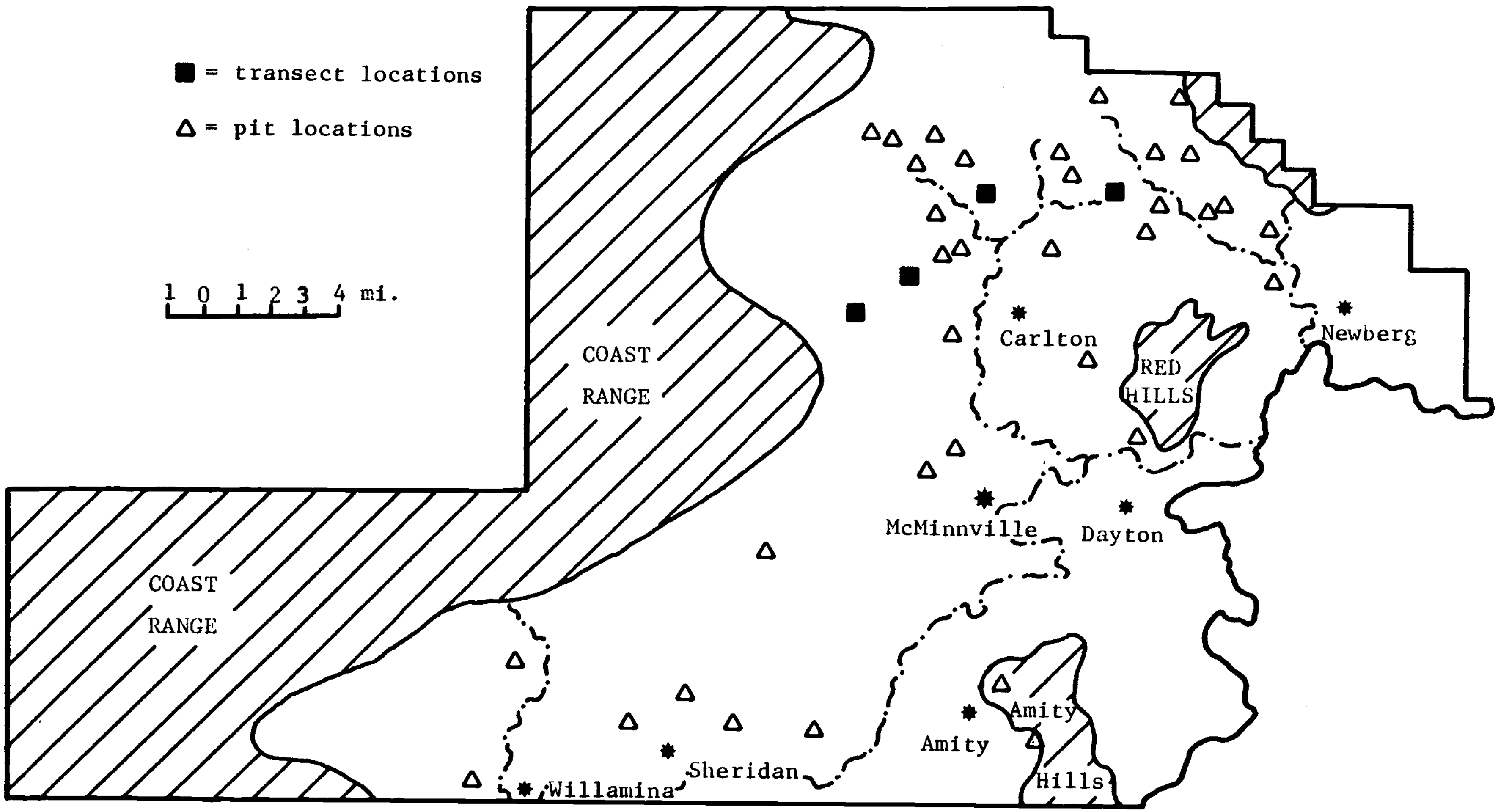

Figure 2: Locations of the 35 randomly sampled pedons and 4 delineations containing transects in Yamhill County

Table 3. Locations of Sample Delineations

Del. No.	Location
26	NE1/4 SE1/4 Sec.13 T2S R4W
31	SE1/4 SW1/4 Sec.23 T2S R5W
32	SE1/4 SW1/4 Sec.23 T2S R5W
34	NE1/4 NW1/4 Sec.25 T2S R5W
35	SE1/4 NE1/4 Sec.26 T2S R5W
41	SW1/4 SE1/4 Sec.36 T2S R5W
43	SW1/4 NW1/4 Sec.29 T2S R4W
49	SW1/4 NW1/4 Sec.29 T2S R4W
68	NE1/4 NW1/4 Sec.30 T2S R3W
69	SE1/4 SW1/4 Sec.19 T2S R3W
84	SE1/4 SE1/4 Sec.29 T2S R3W
93	NE1/4 SW1/4 Sec.27 T2S R3W
98	NE1/4 SW1/4 Sec.17 T2S R3W
107	SW1/4 NE1/4 Sec. 7 T3S R4W
108	SE1/4 NW1/4 Sec. 7 T3S R4W
110	SE1/4 NE1/4 Sec.13 T3S R5W
120	NE1/4 SE1/4 Sec.10 T3S R4W
126	NW1/4 NW1/4 Sec. 1 T3S R4W
128	NE1/4 NE1/4 Sec.12 T3S R4W
135	SE1/4 NE1/4 Sec. 5 T3S R3W
142	SE1/4 NW1/4 Sec. 4 T3S R3W
143	NW1/4 SW1/4 Sec. 4 T3S R3W
145	NE1/4 SW1/4 Sec. 3 T3S R3W
161	NE1/4 NW1/4 Sec.15 T3S R3W
173	NW1/4 SE1/4 Sec.23 T3S R5W
191	SW1/4 SW1/4 Sec.20 T3S R4W
199	NE1/4 SW1/4 Sec.36 T3S R4W
220	SW1/4 NW1/4 Sec.12 T4S R5W
223	SE1/4 SW1/4 Sec. 1 T4S R5W
234	NE1/4 SW1/4 Sec. 5 T4S R3W
242	NE1/4 SE1/4 Sec.25 T4S R6W
261	SW1/4 NW1/4 Sec.12 T5S R7W
292	SW1/4 SW1/4 Sec.16 T5S R4W
311	NE1/4 NW1/4 Sec. 2 T6S R7W
314	SW1/4 NW1/4 Sec.28 T5S R6W
318	NW1/4 SW1/4 Sec.23 T5S R6W
319	NW1/4 NE1/4 Sec.25 T5S R6W
322	SW1/4 NW1/4 Sec.19 T5S R5W
328	NW1/4 SE1/4 Sec.27 T5S R4W

(1965). A rectangle was drawn around the delineation so that all parts were included within its area. The southwest corner of the rectangle represented the origin, as in an x, y coordinate system. From this point, a random distance was selected for each axis. The point at which the two distances intersected within the rectangle became the reference point for the delineation. This point was located in the field. If the x and y distances did not intersect within the delineation, they were both discarded and new random distances chosen.

The possibility of introducing bias into the sampling scheme was present while locating the reference point in the field, because the exact location of the point had to be estimated from its relative position to features appearing on the aerial photograph. Therefore, another set of random numbers was drawn, in which the first specified the number of paces to be walked in an easterly or westerly direction from the reference point, and the second specified the number of paces to be walked in a northerly or southerly direction. The direction was decided by a flip of the coin. Again, if the number or direction of paces resulted in a point outside the delineation, a new set of random numbers was chosen and the process repeated. The point reached by this pacing process was the point at which a soil pit was dug for characterization and sampling.

This system worked well for identifying sample points within the larger delineations. It was far less useful in the very small delineations because of difficulties measuring short distances on the map and transferring them accurately to the field. For these small delineations, therefore, a slightly different method was developed. Instead of measuring a random number of meters to the north and east of the southwest origin, a random number of paces in these directions was chosen. Pacing was done in the field using the origin as the starting reference point. The second step was not included this time, because the first step produced an unbiased, random location.

Sometimes the sample site was obviously not located on the Willakenzie soil type, but on another type exhibiting poorer drainage or a contrasting texture. These areas were not disregarded, because the object of the study was to look at all the variations within the map unit as it was mapped, including both mapping inclusions and mismapped delineations. In other instances, barns or houses were situated on the selected site, so that a new set of random numbers or a new delineation had to be selected. Sites on fence lines or under trees were simply moved to the nearest adjacent open spot.

Sampling for Spatial Variability Within Delineations of the WeC Map Unit

Sampling objectives (2) and (3) were approached together through a single sampling scheme. A statistical analysis of variance comparing the variability of soil property values within delineations to variability between delineations required several sampling points, or replicates, to be located within each of a number of delineations. At the same time, an analysis of soil property variability over distance, utilizing Beckett and Bie's (1976) pooled variance procedure, required a set of points to be sampled at equal intervals along a straight line. It appeared that a transect containing four or five equidistant sampling sites, placed within each study delineation, would satisfy the sampling requirements of both objectives.

Four delineations between one and ten acres in size were randomly drawn to represent the WeC population. This specific size range was chosen as the sampling pool, because it accounted for more than half of the total number of WeC delineations (Figure 1). Placement of a transect within each of these delineations was a "purposive" process (Webster, 1977), not a random one. An attempt was made to orient the transect across the most variable, yet representative, part of the landscape. This usually meant locating the transect up and down the slope rather than across the slope, because variability in soil properties such as moisture status and solum thickness, was expected to be greater in the former orientation. Using these placement criteria, the within delineation variability was maximized, but more thoroughly represented than it would be by a random placement of the transect.

The decision concerning the length of the sampling interval along the transect was reached after checking for landscape periodicities within, and measuring the width of each delineation to be sampled. A minimum of four observations was desired in order to obtain a workable number of degrees of freedom for statistical analyses. A sampling interval of 35 m met these landscape and statistical considerations. The end observations were placed several meters inwards from the borers to avoid sampling areas on the boundary of the WeC delineation. The transect was placed at equal distances from each border, so that the end observations could be located objectively.

Delineation no.'s 49, 110, and 173 contained transects which crossed the landscape in a downslope direction, whereas the transect within delineation no. 126 ran perpendicular to the major slope gradient. Smaller scale undulations were present in this delineation, which resulted in placing the transect over them in the across-slope direction, instead of between them in the downslope direction (Figure 3). Five observation points were located along this transect due to its comparatively greater length. All other transects consisted of four equidistant sampling sites.

Soil Profile Characterization

The primary objective in sampling both the 35 randomly located sites and the 4-5 sites along the transects was to get as clear a view of the soil horizonation as possible, so that each profile could be described morphologically and classified taxonomically. Soil pits were dug by shovel or backhoe until bedrock or the C horizon was reached. In pits where massive clay layers or soil depth prevented digging to bedrock, a three inch-diameter bucket auger was used to collect deeper samples. Samples from the soil profile itself were taken from the center of each major horizon along a strip parallel to the horizon boundary. This latter technique was recommended by Piper (1942) for obtaining a representative horizon sample. Parameters recorded at each site included thickness of the A1 and B2 horizons, thickness of the mollic epipedon, if present, color of the A1 and B1 horizons, depth to B2t horizon, depth to Cr or C horizon, depth to mottling, amount and color of mottles, and presence of clay skins.

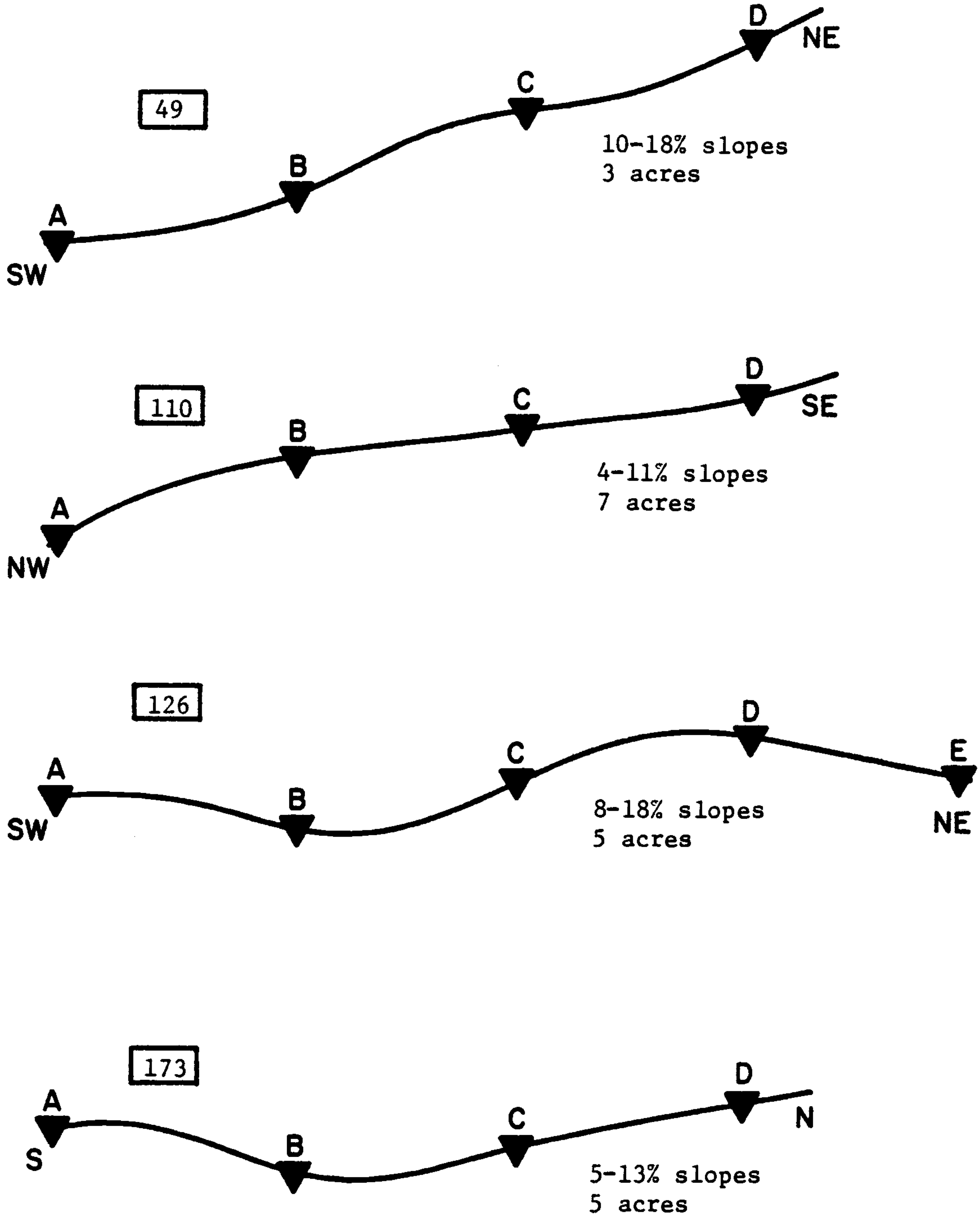

Figure 3: Slope profiles of transects within delineation no.'s 49, 110, 126, and 173

Any unusual profile characteristics such as abrupt textural or color boundaries, silt coatings on ped faces, slickenslides, or deep, wide cracks were also noted. Each site was characterized in terms of slope position, convexity or concavity, gradient, elevation (by pocket altimeter), vegetation, and disturbance of the soil by man or erosion.

Soil samples were taken to the lab and allowed to air dry for two weeks. Afterwards, they were crushed manually with a rolling pin and passed through a 2 mm sieve in preparation for physical and chemical analyses. The pippette method as described by Day (1965) was used on samples from the A1, B2 or AC, B3 and/or C horizons to give percent composition of sand, silt, and clay. Organic matter was removed with 30 percent hydrogen peroxide in the presence of 5 ml of acetic acid. Samples were then dispersed with sodium pyrophosphate, allowed to sit overnight, and air jetted for 5 minutes before beginning the actual pipetting.

Chemical analyses on the same major horizons included pH, exchangeable hydrogen, postassium, calcium, and magnesium. The exchangeable cations were used to calculate percent base saturation and CEC by the summation procedure. On some selected samples of A1, A3, and B1 horizons, organic matter (Walkley-Black method) and cation exchange capacity (ammonium acetate method) were performed. A total of 107 samples from the 35 randomly located pits, and a total of 46 samples from the 17 pits along the transects were analyzed. All procedures followed the methods outlined for the OSU Soil Testing Laboratory (Berg and Gardner, 1978a).

The morphologic and chemical properties measured for each soil pit were chosen for several reasons. They were properties which could be compared between sample pits and with the typifying pedon described for the Willakenzie series. In addition, many of them were needed for classifying the profiles into taxonomic groups. Third, the morphologic properties were readily measurable in the field and could be used to assess management needs for each site.

IV. COMPOSITION AND VARIABILITY OF THE WILLAKENZIE MAP UNIT

Data collected from all 35 randomly sampled delineations (Tables 4 and 5) were used to characterize the entire Willakenzie map unit both in terms of its soil property variability and in terms of its similarity to the defined taxonomic unit. Property values were statistically described and then compared to the range of characteristics listed for the Willakenzie series. Map unit purity was also determined by classifying each of the pedons into a family category. Several hypotheses were then explored to explain the sources of variability occurring within the map unit.

Frequency Distributions Of Soil Property Values

Both the variability in and the ranges of soil property values can be visualized easily by constructing frequency distributions, or histograms, from the data. Histograms also provide immediate visual estimates of the extent to which frequency distributions depart from normality. Figures 4-8 show the frequency distributions of values for soil morphologic and physical properties; histograms of chemical property values are shown in Figures 9-12. Class intervals for each histogram were calculated by subtracting the minimum value of the property from the maximum value and dividing by 4, 5, or 6, depending on the number of classes which best illustrated the data. Values falling on a class boundary were assigned to the lower class.

Table 4. Site and Profile Data for the 35 Randomly Located Pedons

Del. No.	Slope: Gradient	Slope: Position†	Slope: Elevation	Thickness: A1	Thickness: Mollic	Thickness: B2	Depth to: B2	Depth to: C/Cr	Kind of C. Hor.*	Argillic Horizon	Depth to Mottling	Drainage**
	---%----		----m----	-----------------cm---------							---cm---	
26	10	x-x	110	18	--	18	63	124	ss	yes	--	w
31	8	v-v	150	48	48	28	48	76	sic	no	74	mw
32	9	x-x	122	30	30	27	55	101	sis/ms	yes	--	w
34	9	v-x	110	25	38	31	25	66	sl	no	--	w
35	7	x-x	76	43	--	48	43	91	sicl	no	0	swp
41	8	x-x	91	25	--	15	38	53	sis	yes	--	w
43	10	x-x	85	13	--	18	20	38	sis	yes	0	swp
68	7	x-x	72	9	41	46	41	107	sicl	yes	41	swp
69	5	v-l	81	40	73	33	40	73	sil	no	--	w
84	6	x-x	186	20	--	?	76	?	?	yes	56	mw
93	3	x-x	207	15	--	46	56	?	?	yes	--	w
98	8	x-x	123	8	--	38	28	90	sicl	yes	66	mw
107	30	x-v	59	23	69	21	48	89	sis	no	--	w
108	9	x-x	61	20	20	55	49	129	sicl	no	--	w
120	11	x-x	88	25	--	20	76	114	l	yes	--	w
128	18	x-v	116	46	--	28	56	84	ss	no	--	w
135	5	x-v	100	20	--	36	43	107	c	yes	79	mw
142	14	x-x	107	14	--	15	23	58	ss/sis	no	--	w
143	11	x-x	117	10	--	45	34	96	c	yes	--	w
145	5	x-x	90	38	38	30	74	?	?	no	74	mw
161	10	x-x	65	20	46	38	46	?	?	no	63	mw
191	13	x-x	90	25	18	--	--	81	sic	no	25	swp
199	11	x-v	73	28	51	35	51	?	?	no	43	swp
220	10	x-x	50	96	96	23	96	119	sil	no	--	w
223	8	x-x	119	15	53	36	53	127	sicl	no	89	mw

Table 4. Continued

Del. No.	Slope: Gradient	Slope: Position†	Elevation	Thickness: A1	Thickness: Mollic	Thickness: B2	Depth to: B2	Depth to: C/Cr	Kind of C. Hor.*	Argillic Horizon	Depth to Mottling	Drainage**
	---%----		----m----	------------------cm----------							---cm---	
234	14	x-x	62	18	--	51	63	?	?	yes	--	w
242	10	x-x	134	28	28	25	28	53	sis/ss	no	--	w
261	8	x-x	102	24	24	?	48	?	?	no	--	w
292	14	x-x	160	21	21	26	21	47	basalt	no	--	w
311	9	x-x	119	20	--	22	36	58	c	yes	36	swp
314	14	x-v	120	36	--	24	36	60	sic	no	0	p
318	19	x-x	207	26	26	31	26	57	c	no	57	swp
319	15	x-x	76	10	41	12	41	53	c	yes	41	swp
322	9	x-x	91	20	53	23	53	76	sis	yes	--	w
328	6	x-x	145	15	30	18	30	48	sis/ss	no	--	w

†x = convex; v = concave; l = linear.

*l = loam; sl = sandy loam; sil = silt loam; sicl = silty clay loam; sic = silty clay; c = clay; ss = sandstone; sis = siltstone; ms = mudstone.

**w = well drained; mw = moderately well drained; swp = somewhat poorly drained; p = poorly drained.

? = unknown.

Table 5. Profile Data of A, B, and C Horizons in the 35 Randomly Located Pedons

Del. No.	Horizon	Sand	Silt	Clay	K^{+}	Ca^{++}	Mg^{++}	CEC	B.S.	pH	Color	
											Moist	Dry
		--------%--------			---------meq/100 g---------				-%--			
26	A1	7	69	24	0.62	5.7	1.5	20	38	5.4	7.5YR3/2	10YR5/4
	B2	6	52	42	0.25	6.8	6.1	26	51	5.4		
	B3	3	36	61	0.50	12.1	12.0	43	57			
31	A1	7	57	36	0.44	15.4	4.2	34	59	5.8	7.5YR3/2	10YR5/3
	B2	7	58	35	0.25	9.6	5.0	22	67	6.1		
	C	7	52	41	0.25	9.8	5.5	25	62	5.8		
32	A1	5	58	37	1.39	12.3	4.5	34	53	5.9	10YR3/2	10YR5/3
	B2	4	51	45	0.74	5.8	5.7	30	40	5.3		
	B3				0.50	8.2	7.0	29	53			
34	A1	17	55	28	0.50	14.3	6.0	32	65	6.0	7.5YR3/2	10YR3/2
	B2	37	43	20	0.27	17.9	10.0	38	74	6.2		
	C	68	26	6	0.11	22.3	11.0	41	81	6.4		
35	A1	5	62	33	1.04	5.2	2.3	27	31	5.2	10YR3/2	10YR5/3
	B2	5	67	28	0.46	5.6	3.0	19	47	5.3		
	C	4	62	34	0.29	8.1	4.0	23	53	5.2		
41	A1	18	56	26	0.49	11.2	2.5	30	48	5.4	10YR3/2	10YR6/3
	B2	17	53	30	1.39	9.4	2.6	23	59	6.1		
43	A1	5	47	48	0.95	15.2	9.0	39	65	5.8	10YR3/3	10YR6/3
	B2	3	33	64	0.72	20.8	14.0	54	66	5.2		

Table 5. Continued

Del. No.	Horizon	Sand	Silt	Clay	K^+	Ca^{++}	Mg^{++}	CEC	B.S.	pH	Color	
											Moist	Dry
		--------%--------			--------meq/100 g--------				-%--			
68	A1	14	61	25	0.71	8.6	3.3	23	55	5.7	10YR3/2	10YR5/4
	B2	10	49	41	0.51	18.1	7.0	37	69	5.7		
	C	13	56	31	0.33	14.1	6.0	26	77	6.0		
69	A11	14	68	18	1.18	11.1	1.9	27	52	5.8	10YR2/2	10YR4.5/2
	A12	13	71	16	1.29	10.7	2.0	27	52	5.8		
	B2	8	66	26	1.03	11.4	2.7	25	61	6.1		
	C	9	73	18	1.00	9.4	2.4	15	85	6.4		
84	A1	29	53	18	0.30	3.2	1.2	11	43	5.5	7.5YR3/3	10YR5.5/4
	B2	22	31	47	0.22	5.8	4.4	21	50	5.3		
93	A1	15	61	24	1.07	5.1	1.2	26	28	4.9	7.5YR2/2	7.5YR4/4
	B2	21	41	38	0.21	6.8	5.0	25	47	5.5		
	B3				0.20	9.4	7.0	31	53			
98	A1	18	60	22	1.06	7.3	3.1	20	57	5.7	7.5YR3/2	10YR5/4
	B2	9	54	38	0.54	8.9	6.0	25	62	5.4		
	B3	6	54	40								
	C	8	57	35	0.32	12.5	11.0	32	74	5.2		
107	A1	3	68	29	1.06	9.4	3.5	27	52	5.8	10YR3/2	10YR5/3
	B2	8	61	31	0.49	13.0	5.4	32	58	5.8		
	B3				0.61	18.7	9.0	42	67			
108	A1	4	73	23	0.29	6.1	1.8	23	36	5.5	10YR3/2	10YR5/2
	B2	2	72	26	0.34	14.8	6.0	28	75	6.3		
	C	1	67	32	0.30	15.1	6.0	24	89	6.8		

Table 5. Continued

Del. No.	Horizon	Sand	Silt	Clay	K^+	Ca^{++}	Mg^{++}	CEC	B.S.	pH	Color Moist	Color Dry
		-------%--------			--------meq/100 g--------				-%--			
120	A1	25	52	23	1.02	4.9	1.8	16	47	6.0	7.5YR3/2	10YR6/3
	B2	25	35	40	0.24	3.7	3.9	18	43	5.1		
	C	43	38	19	0.19	6.1	6.0	24	51	5.2		
128	A1	43	32	25	0.41	3.1	1.0	14	33	5.1	7.5YR4/4	10YR6/4
	B2	43	37	20	0.22	4.2	2.2	12	57	5.5		
135	A1	17	65	18	0.38	6.8	2.0	25	37	5.5	7.5YR3/2	10YR5/3
	B2	17	51	32	0.45	4.1	4.4	17	51	5.5		
	C	12	35	53	0.38	6.8	10.0	32	54	5.1		
142	A1	39	40	21	1.14	4.9	1.6	14	56	5.9	7.5YR3.5/4	10YR5/4
	B2	41	36	23	0.80	10.3	4.2	23	68	5.8		
143	A1	37	40	23	0.63	8.3	2.2	21	53	5.9	7.5YR3/2	10YR4/4
	B2	30	28	42	0.40	9.8	3.8	22	62	5.4		
	C	32	27	41	0.31	13.0	7.0	34	59			
145	A1	7	68	24	0.33	12.8	5.1	23	79	6.1		
	B2				0.28	11.3	4.6	24	68			
161	A1	12	71	17	0.37	6.5	1.9	22	39	5.5	10YR2/2	10YR5/3
	B2	12	66	22	0.21	7.4	4.1	22	53	5.7		
	B3				0.28	9.8	5.3	26	58			
191	A1	13	58	29	0.23	10.7	6.0	29	59	5.9	10YR3/2	10YR5/2
	AC	4	24	72	0.36	18.2	15.0	52	65	4.5		
	C	7	40	53	0.20	10.3	9.0	33	59	4.7		

Table 5. Continued

Del. No.	Horizon	Sand	Silt	Clay	K^+	Ca^{++}	Mg^{++}	CEC	B.S.	pH	Color Moist	Color Dry
		--------%--------			--------meq/100 g--------				-%--			
199	A1	21	57	22	0.24	4.3	0.9	15	37	5.6	10YR3/3	10YR5/3
	B2	18	65	17	0.19	3.3	1.6	15	35	5.6		
	B3				0.08	7.1	4.5	20	58			
220	A1	5	65	30	0.26	9.9	4.5	25	59	6.2	10YR2/2	10YR5/3
	A1b	6	66	28	0.20	10.4	4.6	26	58	6.3	10YR3/1	10YR5/3
	B2b	6	69	25	0.15	9.7	4.8	23	64	6.4		
	C	5	70	25	0.18	9.7	5.0	20	74	6.5		
223	A1	18	52	30	1.07	9.6	2.6	30	45	5.7	10YR2/2	10YR4/3
	B2	16	55	29	0.26	10.6	4.4	23	67	6.2		
	C	14	58	28	0.22	10.8	5.3	23	70	6.7		
234	A1	11	65	24	0.54	5.7	1.4	18	41	5.8	10YR2/2	10YR6/4
	B2	14	48	38	0.44	7.0	4.3	21	55	5.7		
	B3				0.43	8.9	4.9	24	38			
242	A1	14	51	35	0.60	17.5	8.9	41	66	5.9	10YR3/2	10YR4/3
	B2	15	46	39	0.29	18.9	10.0	39	74	6.0		
261	A1	19	41	40	0.80	25.0	8.3	54	63	5.5	10YR3/3	10YR4/4
	B21	23	38	39	0.47	29.2	8.5	53	72	6.1		
	B22	29	36	35	0.59	30.8	9.6	56	74	6.1		
292	A1	15	53	32	0.80	10.2	2.2	25	53	6.3	7.5YR3/2	7.5YR4/4
	B2	15	55	30	0.75	7.3	3.2	22	52	6.2		

Table 5. Continued

Del. No.	Horizon	Sand	Silt	Clay	K^+	Ca^{++}	Mg^{++}	CEC	B.S.	pH	Color: Moist	Color: Dry
		%	%	%	meq/100 g	meq/100 g	meq/100 g	meq/100 g	%			
311	A1	5	56	39	0.57	5.2	3.3	32	29	5.5	7.5YR3/2	10YR5/4
	B2	2	35	63	0.49	6.3	8.0	35	42	5.4		
	C	3	22	75	0.55	6.2	9.0	46	34	5.1		
314	A1	5	59	36	0.60	6.4	3.0	34	30	4.7	10YR4/1	10YR6/3
	B2	5	59	36	0.41	7.1	5.2	28	45	5.5		
	C	6	53	41	0.45	7.5	6.0	25	55	5.3		
318	A1	7	43	50	1.28	16.8	7.2	42	60	5.8	10YR3/2	10YR5/2
	B2	11	32	57	0.75	14.7	9.4	49	51	5.3		
	C	3	26	71	0.66	13.0	10.2	51	47	5.2		
319	A1	6	57	37	0.90	14.0	5.3	36	57	5.7	10YR3/2	10YR5/2
	B2	8	44	48	0.42	14.6	9.0	39	62	5.4		
	C	4	31	65	0.48	22.5	13.0	53	68	4.8		
322	A1	15	54	31	1.67	10.7	10.0	36	62	5.7	7.5YR2/2	10YR5/4
	B2	17	46	37	0.33	9.4	13.0	39	57	5.6		
328	A1	15	45	50	1.36	8.2	2.3	30	39	5.5	10YR2/2	7.5YR4.5/4
	B2	13	40	47	0.79	7.1	3.9	24	49	5.8		

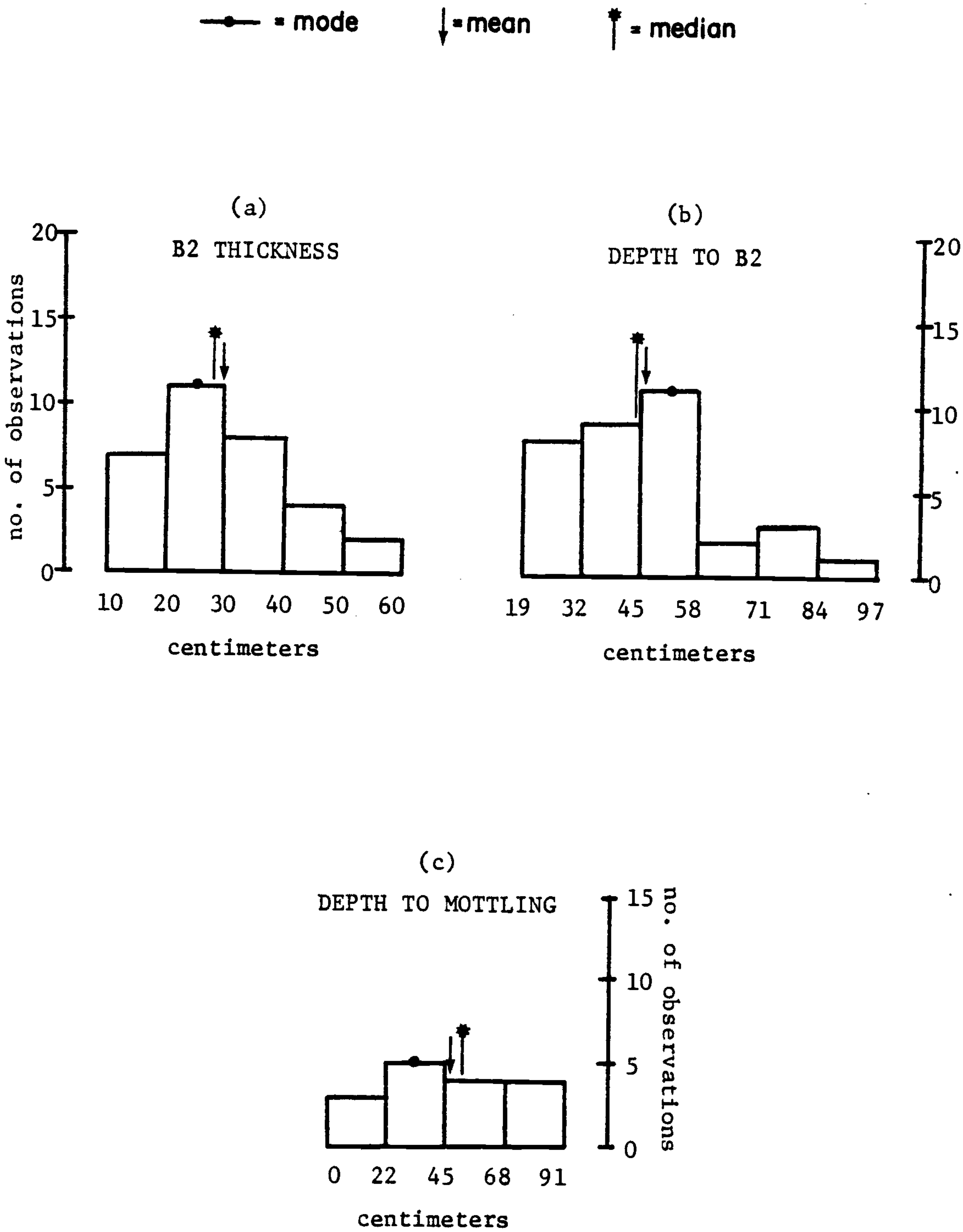

Figure 4: Frequency distributions of (a) B2 horizon thickness, (b) depth to the B2 horizon, and (c) depth to mottling

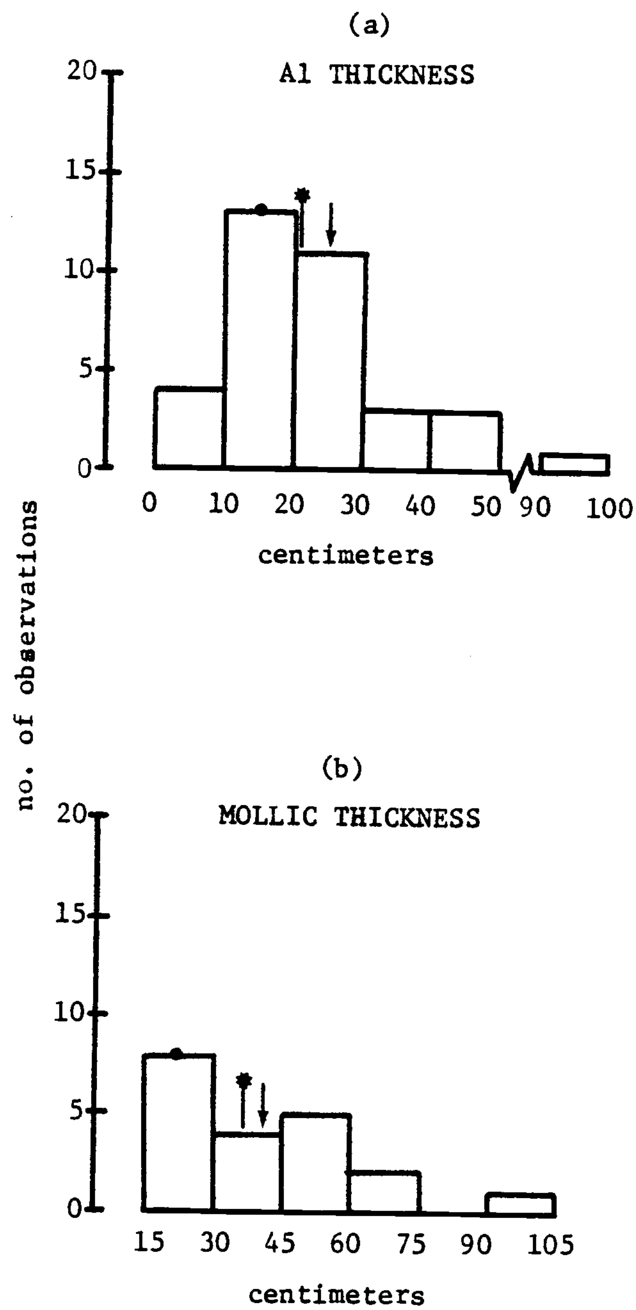

Figure 5: Frequency distributions of (a) A1 horizon thickness and (b) mollic thickness

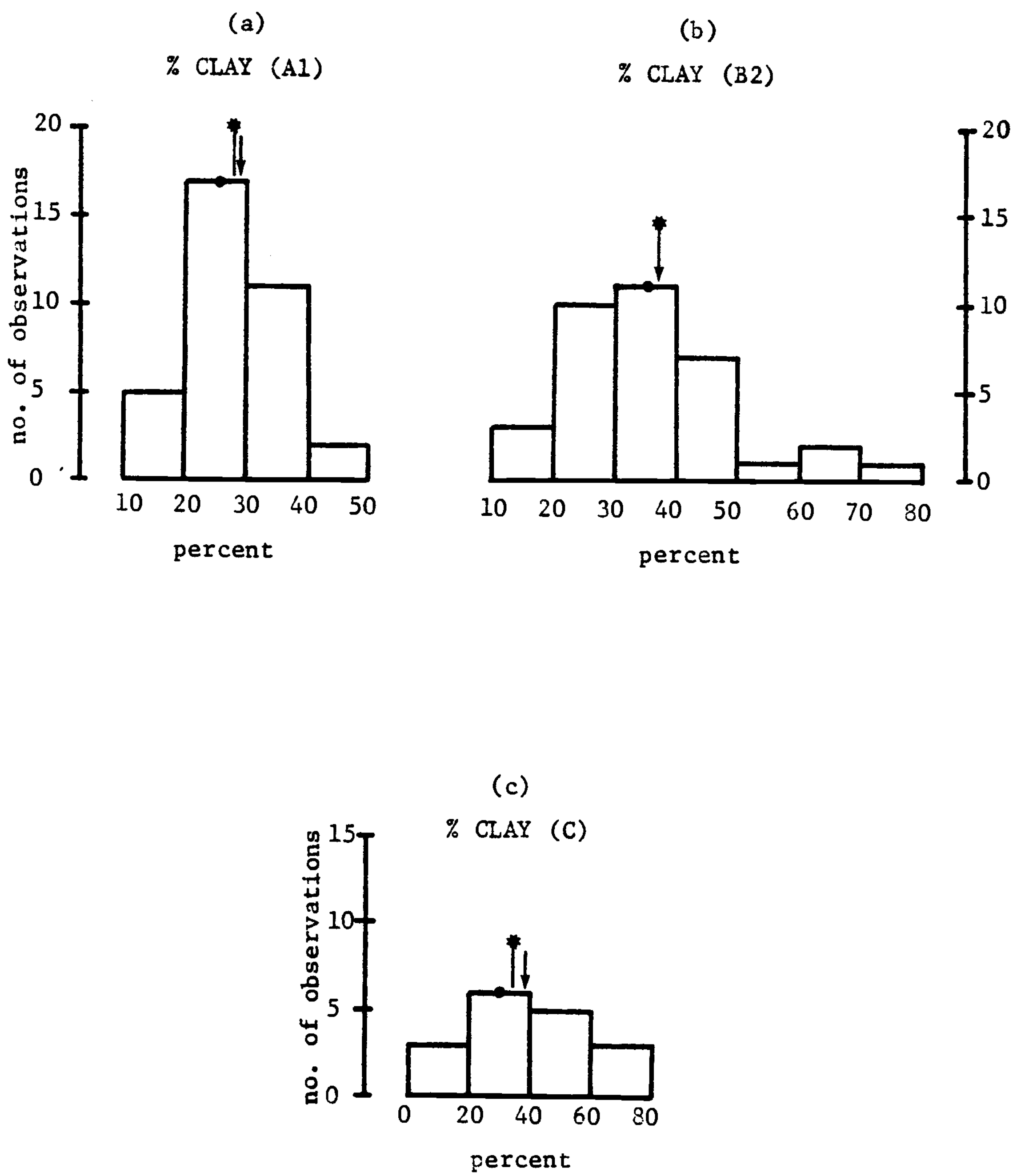

Figure 6: Frequency distributions of clay content in the (a) A1 horizon, (b) B2 horizon, and (c) C horizon

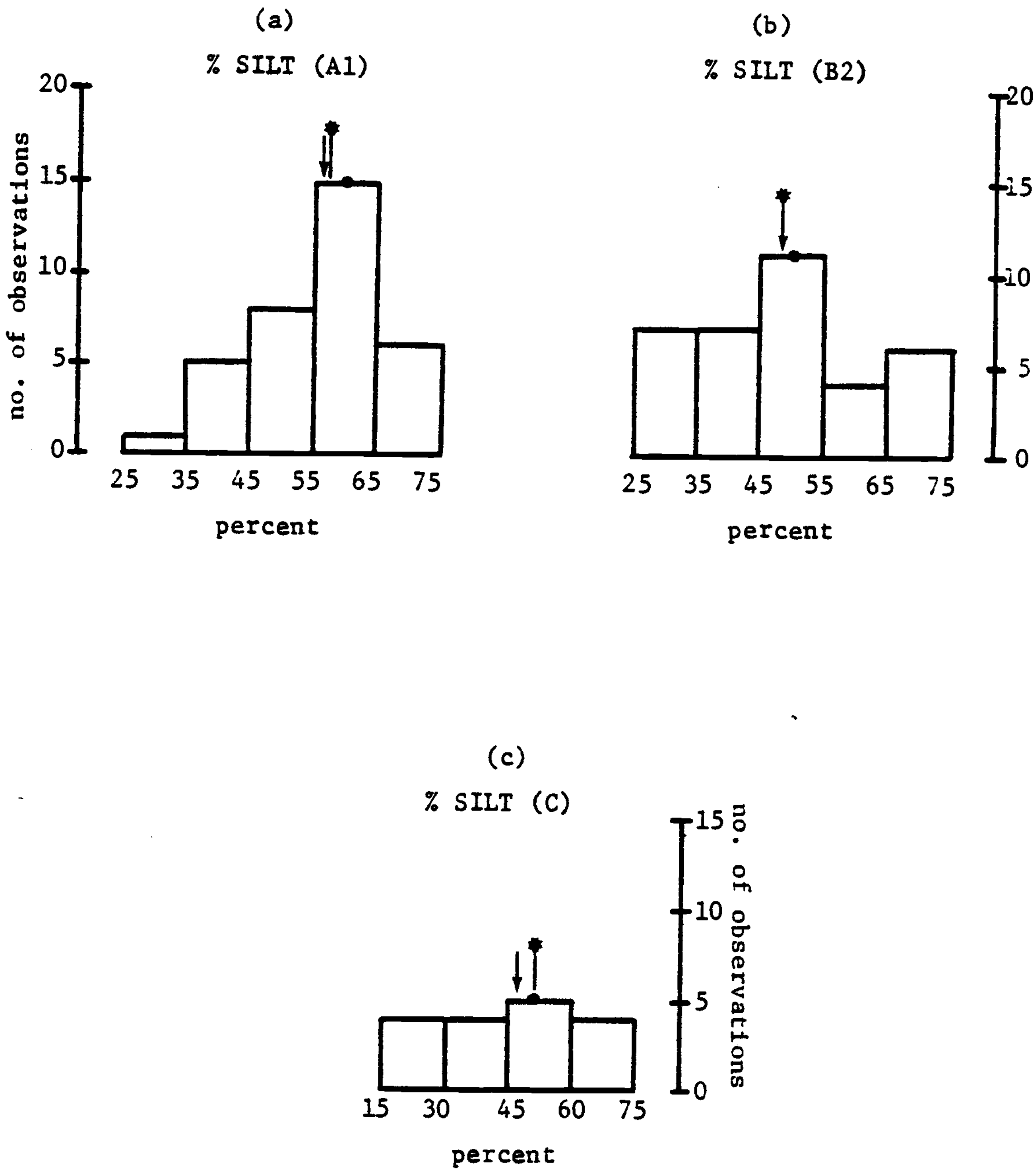

Figure 7: Frequency distributions of silt content in the (a) A1 horizon, (b) B2 horizon, and (c) C horizon

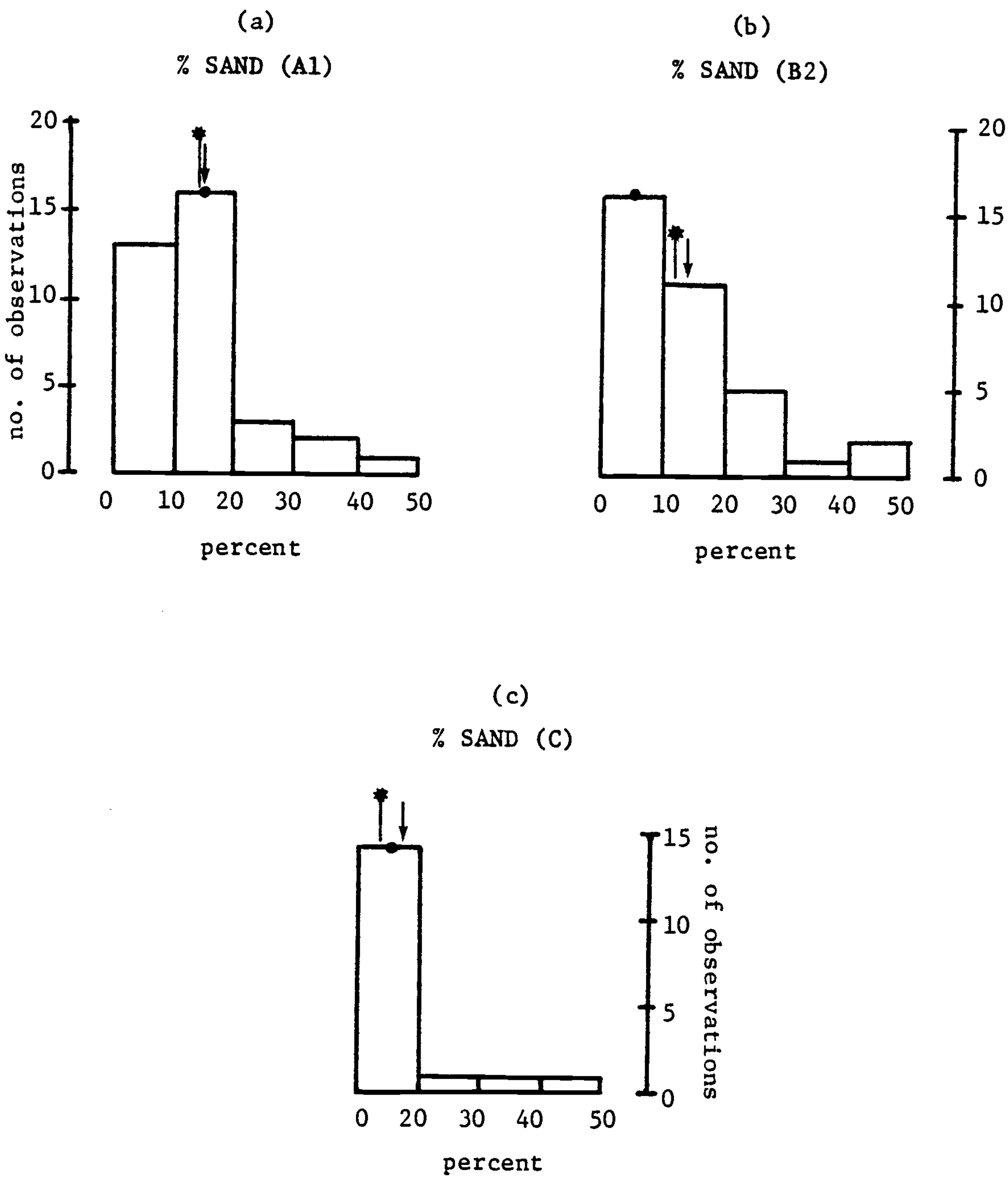

Figure 8: Frequency distributions of sand content in the (a) A1 horizon, (b) B2 horizon, and (c) C horizon

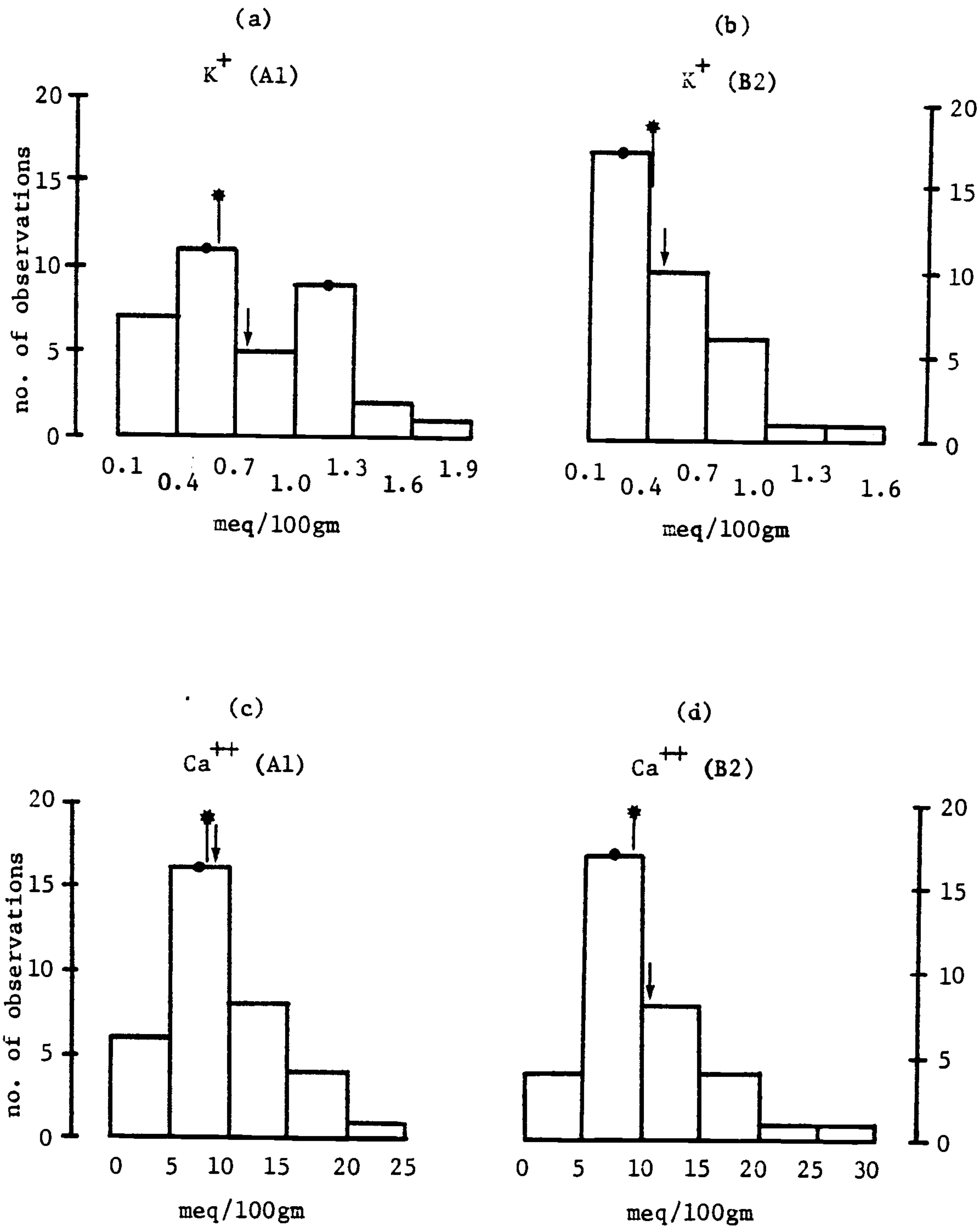

Figure 9: Frequency distributions of exchangeable K^+ in the (a) A1 horizon and (b) B2 horizon, and exhangeable Ca^{++} in the (c) A1 horizon and (d) B2 horizon

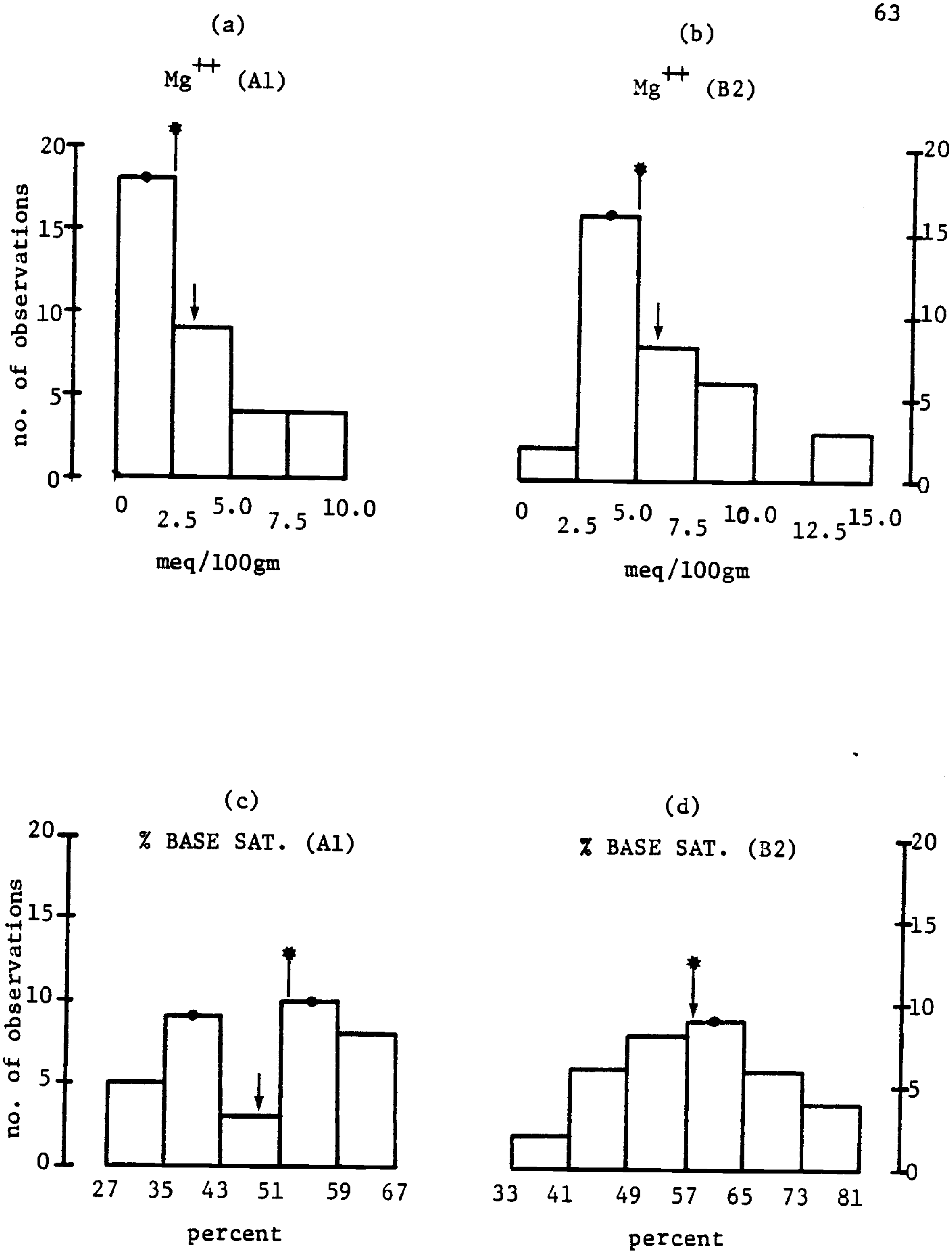

Figure 10: Frequency distributions of exchangeable Mg^{++} in the (a) A1 horizon and (b) B2 horizon and base saturation (sum) in the (c) A1 horizon and (d) B2 horizon

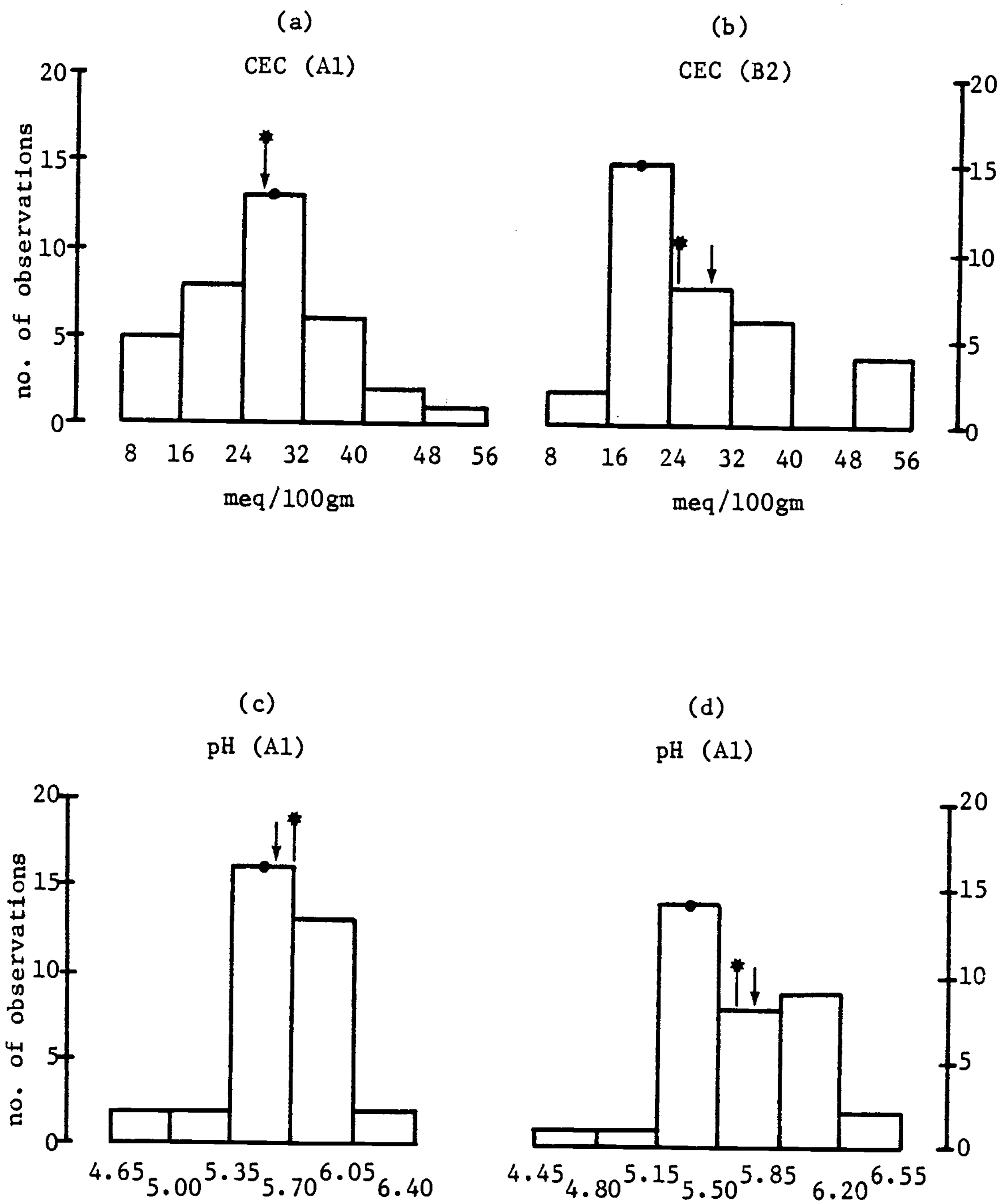

Figure 11: Frequency distributions of CEC in the (a) A1 horizon and (b) B2 horizon and pH in the (c) A1 horizon and (d) B2 horizon

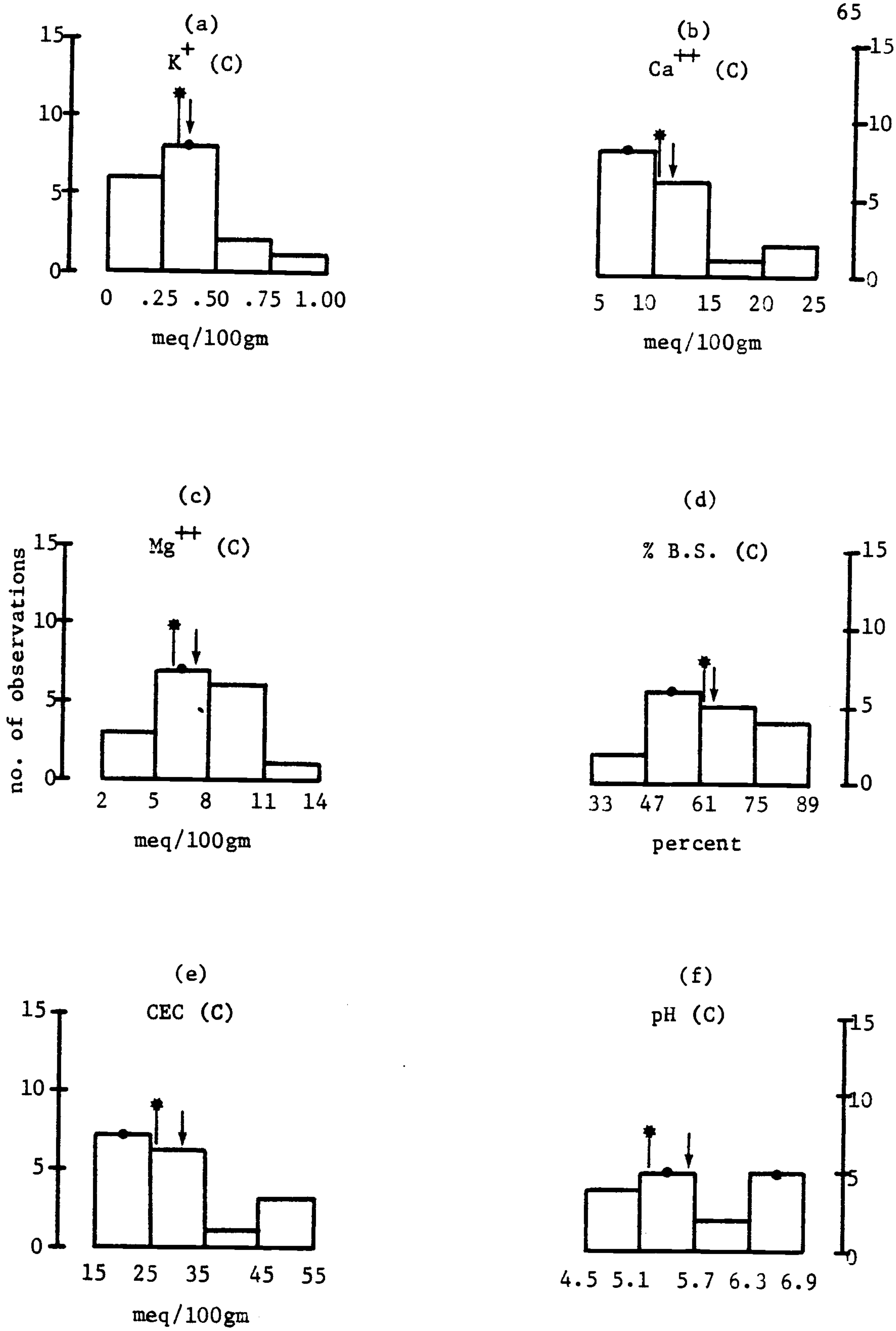

Figure 12: Frequency distributions of C horizon chemical properties: (a) K^+, (b) Ca^{++}, (c) Mg^{++}, (d) base saturation, (e) CEC, and (f) pH

Table 6. Statistical Data for Selected Morphologic Soil Properties

Soil Property	n	$\overline{X}$	Median	Mode	S	CV	Range	Kurt.	Skew
I. Normally Distributed Data									
B2 Thickness (cm)	32[†]	30	28.0	25.0	11.4	.38	12-55	2.76	0.14
Depth to B2 (cm)	34	46	44.5	51.5	17.6	.38	20-96	3.44	0.75
Depth to Mottling (cm)	16	46	49.5	33.5	28.7	.62	0-89	2.09	-0.43
A1 Color Value (moist)	35	2.8	3	3	0.52	.19	2-4	--	--
(dry)	35	5.0	5	5	0.61	.12	4-6	--	--
A1 Color Chroma (moist)	35	2.2	2	2	0.58	.26	1-4	--	--
(dry)	35	3.2	3	3	0.73	.23	2-4	--	--
II. Skewed Data									
A1 Thickness (cm)	35	25	21.0	15.0	16.0	.64	8-96	11.85	2.59*
after removal of outlier	34	23	20.5	15.0	10.5	.45	8-48	2.95	0.76
Mollic Thickness (cm)	20	42	39.5	22.5	20.0	.47	18-96	3.79	1.06*
after removal of outlier	19	39	38.0	22.5	15.9	.41	18-73	2.52	0.56

[†] Of the 35 profiles, one contained an AC horizon, two had unknown B2 thicknesses.

* Distribution is significantly skewed at 1% level.

Table 7. Statistical Data for Physical Soil Properties

Soil Property		n	$\overline{X}$	Median	Mode	S	CV	Range	Kurt.	Skew
I. Normally Distributed Data										
% clay	A1 horizon	35	29	28	25	8.5	.29	17-50	2.79	0.64
	B2 horizon	35	37	37	35	13.0	.35	17-72	3.41	0.84
	C horizon	17	39	35	30	19.0	.49	6-75	2.43	0.36
% silt	A1 horizon	35	56	57	60	10.0	.18	32-75	2.77	-0.35
	B2 horizon	35	49	49	50	13.2	.27	24-72	1.96	0.03
	C horizon	17	47	52	52	17.0	.36	22-73	1.60	0
II. Skewed Data										
% sand	A1 horizon	35	15	14	15	10.0	.69	3-43	4.16	1.25*
	B2 horizon	35	14	12	5	10.7	.75	2-43	3.86	1.20*
	C horizon	17	14	7	10	17.7	1.26	1-68	6.37	2.07*

*Distribution is significantly skewed at 1% level.

Table 8. Statistical Date for Chemical Soil Properties

Soil Property	Horizon	n	$\bar{X}$	Median	Mode	S	CV	Range	Kurt.	Skew
I. Normally Distributed Data										
K^+ (meq/100 g)	A1	35	0.76	0.63	0.55, 1.15	0.38	.50	0.23-1.67	2.28	0.44
Ca^{++} (meq/100 g)	C	17	11.6	10.3	7.5	4.89	.42	6.1-22.5	3.52	1.11
Mg^{++} (meq/100 g)	C	17	7.4	6.0	6.5	2.91	.39	2.4-13.0	2.10	0.25
% Base Saturation (by summation)	A1	35	48	52	39,55	11.8	.24	28-66	1.73	-0.19
	B2	35	58	58	61	11.0	.19	35-79	2.22	-0.22
	C	17	64	62	54	14.8	.23	34-89	2.34	-0.11
CEC (meq/100 g) (by summation)	A1	35	27	27	28	9.2	.34	11-54	3.57	0.59
	C	17	31	26	20	11.0	.35	15-53	2.53	0.75
pH	A1	35	5.6	5.7	5.52	0.33	.06	4.7-6.3	4.13	-0.82
	B2	35	5.7	5.2	5.40, 6.60	0.71	.13	4.7-6.8	1.62	0.38
II. Skewed Data										
K^+ (meq/100 g)	B2	35	0.46	0.41	0.25	0.26	.56	0.15-1.39	5.32	1.45*
	C	17	0.37	0.31	0.37	0.22	.59	0.11-1.00	5.35	1.58*
Ca^{++} (meq/100 g)	A1	35	9.2	8.3	7.5	4.80	.52	3.1-25.0	4.50	1.19*
	B2	35	10.6	9.4	7.5	5.80	.55	3.3-30.0	4.77	1.28*
Mg^{++} (meq/100 g)	A1	35	3.5	2.5	1.25	2.54	.72	0.9-10.0	3.30	1.19*
	B2	35	6.0	5.0	3.75	3.29	.55	1.6-15.0	3.77	1.20*
CEC (meq/100 g)	B2	35	29	25	20	11.0	.38	12-54	3.11	0.96*

*Distributions are significantly skewed at 1% level.

Frequency distributions can be characterized quantitatively by calculating measures of central tendency, dispersion, and shape. Measures of central tendency include the mean, the median, and the mode. Measures of dispersion include the variance, the standard deviation, the range, and the coefficient of variation. Measures of shape include the skew and the kurtosis. Data for these statistics are given in Tables 6-8. The C horizon data include fewer observations (n=17) because of unsampled horizons or profiles containing bedrock.

The shape statistics are useful because they provide quantitative measures of the extent to which distributions depart from normality. Significant departures from a normal curve affect the validity of further calculations of central tendency and dispersion, which are based on normal distributions. The skew statistic measures the degree of asymmetry of a distribution. For the data in this study, skew values of $\pm$ 0.92 and $\pm$ 1.19 for n=35 and n=17 observations, respectively, represent significantly skewed distributions at a .99 confidence level. Twelve of the 32 property distributions, as listed in Part II of Tables 6-8, are significantly skewed in a positive direction. The remaining 20 property distributions are approximately normal.

Seven of the twelve significantly skewed distributions are for chemical properties. These include exchangeable Ca^{++} and Mg^{++} in the A1 horizon (Figures 9c, 10a), exchangeable K^{+}, Ca^{++}, Mg^{++}, and CEC in the B2 horizon (Figures 9b, 9d, 10b, 11b), and exchangeable K^{+} in the C horizon (Figure 12a). The peaks of these distributions fall within the average range in levels for the properties measured in western Oregon soils (Berg and Gardner, 1978b). The extreme values in the tails of the distributions were at first thought to be the result of heavy fertilization at a few of the sites; however, field notes showed that only a small percentage of these sites had been plowed or fertilized in recent years. The pedons containing the extreme values tended to be those underlain by consolidated bedrock (delineation no.'s 32, 41, 43, 142, 242, 292, 322, 328). The bedrock underlying these delineations was composed of tuffaceous shales, siltstones, and sandstones (Baldwin _et al._, 1955; Warren _et al._, 1945), which are characteristically high in a variety of weatherable minerals. This suggests that the in situ weathering of geologic strata has produced the unusually high chemical values. Adams and Wilde (1976b), Webster and Butler (1976), and Wicherski (1980) also found chemical properties to be skewed, but no explanations for the distributions were given.

Other properties such as percent sand in the A1, B2, and C horizons, thickness of the A1 horizon, and thickness of the mollic epipedon also exhibited significantly skewed distributions (Figures 8a,b,c, 5d, 6d). The skewness of the latter two properties was reduced drastically by the removal of one outlier value. The outlier value was measured in pedon no. 220, which was located at the foot of a steeply sloping ridge. The old surface horizon had been buried, resulting in both an A1 horizon and mollic epipedon thickness of 96 cm. This high value of 96 cm differed from all other thickness values by several frequency classes (Figure 5a,b). Skewness values were no longer statistically significant for both properties after the outlier was omitted from the calculations (Table 6, Part II). The extremely high skewness value for sand content in the C horizon was due to three unusually sandy textures in delineation no.'s 34, 120, and 143. These profiles probably were formed over a weathered, coarse-grained geologic stratum.

The kurtosis statistic measures the peakedness or flatness of the property distribution. Kurtosis values greater than 3.00 signify distributions containing an excess of values near the mean; values less than 3.00 describe distributions with flatter peaks than normal. Tables listing significant levels of kurtosis values are not available for sample sizes of 35 (Snedecor and Cochran, 1967) and thus, the values calculated can be used only for comparison purposes. Eight of the 32 soil properties had relatively high (>4.00) kurtosis values. These included thickness, pH, sand content, and exchangeable Ca^{++} of the A1 horizon, exchangeable K^{+} and Ca^{++} in the B2 horizon, and exchangeable K^{+} and sand content in the C horizon (Figures 5a, 8a,c, 9b,c,d, 11c, 12a). All of these properties had a high proportion of values occurring in one or two frequency classes, and all except pH in the A1 horizon were significantly skewed. Properties with relatively low kurtosis values (<2.00) included base saturation in the A1 horizon, silt content in the B2 horizon, and pH and silt content in the C horizon. These property distributions were either bimodal (Figure 10c, 12f) or had fairly uniform frequency class sizes (Figures 7b,c).

The mean, median, and mode describe the central tendency of the soil property distributions. All three are indicated for each property on the frequency distributions themselves (see Figure 4 for symbol legend). The mode is defined for individual properties as the midpoint of the frequency class containing the largest relative frequency. This definition of the mode is more appropriate for these particular data than the alternative measure based on the most frequently occurring raw score value, because the continuous nature of the data results in 0-4 modes for some properties when the latter method is used.

Traditionally, soil scientists (Protz _et al._, 1968) have described "typifying pedons" or "modal profiles" as a means of characterizing the central concept of a soil series. This practice suggests that the mode may be a more appropriate statistic for describing and predicting the most likely occurring property values in soil taxonomic classes, yet most statistical tests performed on soil samples are actually concerned with estimating the means of property values (Adams and Wilde, 1976a; Mader, 1963; Mausbach _et al._, 1980; Wilding _et al._, 1965). This situation results primarily from the fact that most statistical techniques are based on the means of samples and not on their modes. As long as soil properties follow normal distributions, in which the mean, median, and mode all coincide, there is no conflict between the soil scientist's modal concept and the statisticians dependence on an arithmetic mean. But for skewed distributions, the median or the mode may be a better measure of central tendency than the mean.

The data collected from the 35 Willakenzie delineations indicate that for three properties, exchangeable K^+ of the A1, base saturation of the A1 horizon, and pH of the C horizon (Figures 9a, 10c, 12f), the mode produces a closer estimate of the central values of the distribution than either the mean or the median. This is due to the bimodal nature of the distributions. The mean falls either in the trough between the two peaks of the distribution, or it lies just adjacent to it; the median occurs in one peak or the other. Thus, the mode is a more accurate measure of central tendency in these three cases.

The median and/or the mode may estimate central tendency more accurately than the mean in about two-thirds of the significantly skewed data. For these particular property distributions, which include A1 horizon thickness, mollic thickness, exchangeable Mg^{++} in the A1 horizon, sand content, CEC, and exchangeable K^{+}, Ca^{++}, and Mg^{++} in the B2 horizon (Figures 5a, 6a, 8b, 9b,d, 10a,b, 11b), the mean does not fall in the modal frequency class. Instead, the mean falls in the higher, adjacent class, because it is influenced by the extreme values in the tail of the skewed distribution.

It is difficult to judge which of the three measures most accurately estimates the central tendency in the remaining soil property distributions. The mean, median, and mode all occur in the same frequency class for fifteen of the properties, both skewed and normal. When one measure is clearly not a "better" statistic for describing and predicting central tendency, it is generally more useful to report the mean, because the mean can be used to calculate other statistical measures.

Coefficients of variation (Tables 6-8) are used frequently as a means of comparing the variability of soil properties (Adams and Wilde, 1976a, 1976b; Ball and Williams, 1968; Bascomb and Jarvis, 1976; Dawud, 1979; McCormack and Wilding, 1969; Wicherski, 1980; Wilding _et al_., 1964, 1965). They may be a misleading descriptor of relative variability, however, if some of the data being compared are highly skewed.[9] Unusually high CV values, particularly those above 100 percent, are symptomatic of skewed property distributions (Bascomb and Jarvis, 1976; Beckett and Webster, 1971). In this study, skewed and normally distributed properties were compared separately. CVs were compared between properties having different sample sizes, even though sample size may affect the value of the property variance. The sample sizes in this study were large enough to minimize any such effect in comparison to other possible effects on the sample variance (e.g., shape of the property distribution). Concern over differences in sample sizes when comparing CVs has not been expressed in the literature (Adams and Wilde, 1976a, 1976b; McCormack and Wilding, 1969) or by professional statisticians.[10]

The most variable of the normally distributed properties (CV values >.45) included A1 horizon thickness (with outlier removed), depth to mottling, exchangeable K^{+} in the A horizon, and clay content and exchangeable Ca^{++} in the C horizon. McCormack and Wilding (1969) and Wilding et al. (1964, 1965) also found that horizon thicknesses, depth to mottling, and fine clay content had high CVs of similar magnitude. Exchangeable cations had the highest CV values in studies by Adams and Wilde (1976b) and Mader (1963).

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[9] R. Peterson. Dept. of Statistics, Oregon State University, Corvallis, Oregon. Personal Communication.

[10] D. Thomas. Dept. of Statistics, Oregon State University, Corvallis, Oregon. Personal Communication.

Soil properties with the lowest CV values (values $<.26$) were percent base saturation and pH in the A1, B2, and C horizons, and silt content, color value and color chroma in the A1 horizon. Low CV values for pH reflect the fact that pH is a log function, which reduces the perceived amount of variability in H^+ ion concentration. For example, the CV for pH in the C horizon would be 1.06, if the H^+ concentration values are expressed in moles/liter. This is in comparison to a CV value of .13 when the values are expressed as pH. The low values for color chroma and value can be attributed to the relatively narrow scale of possible values presented by the classification system (Munsell Soil Color Chart) as well as to its discrete nature. Therefore, the CVs of pH and soil color may be misleadingly low. It is best to compare CVs only between those properties with similar scales, i.e., with all continuous or all discrete variables. The same holds for logarithmic versus linear scales.

The CVs of the positively skewed data can be compared to each other, because the property values share a similar kind of distribution. Among the skewed distributions, sand content in the A1, B2, and C horizons, and exchangeable Mg^{++} in the A1 horizon had the highest CVs (values $>.68$), and CEC in the B2 horizon had the lowest CV, with a value of .38. The high variability in surface horizon Mg^{++} levels may be due to the effects of weathering on Mg^{++} release from bedrock or to differences in fertilizer applications between the pedons. The variability in sand content between the pedons may be a function of the wide range in observed parent material particle sizes.

Statistics derived from frequency distributions also can be used to calculate limit of accuracy curves. These curves graphically illustrate the number of samples needed to estimate the map unit property mean within a desired limit of accuracy. They often have been used as a means of estimating preliminary sampling intensities within an area (Adams and Wilde, 1976a; McCormack and Wilding, 1969; Wilding et al., 1965). The calculation assumes a random sampling and a normal distribution; thus, only the normally distributed properties are characterized by this method. The equation is $N = \frac{t^2 s^2}{L^2}$, in which N represents the number of samples required to obtain a population mean within $\pm$ a desired number of units (L); t is the critical limit of student's t distribution at n-1 degrees of freedom and at a chosen confidence level (n=the number of samples collected), and s^2 is the sample variance (Snedecor and Cochran, 1967). The equation can be rearranged so that L becomes the dependent variable and N the independent. The graphs are commonly shown with N being the independent variable (Adams and Wilde, 1976a; McCormack and Wilding, 1969; Wilding et al., 1965).

Figures 13-18 show limit of accuracy curves for the normally distributed properties. As an example of their use, an estimate of the population, or map unit, mean for percent clay in the A1 horizon (Figure 15a) within $\pm$ 4 percentage points at the 95 percent confidence level would require about 20 samples randomly located throughout the 336 Willakenzie delineations. Over 60 samples would be needed to estimate the map unit mean within $\pm$ 2 percentage points. Although differences exist in the number of samples required to establish the various property means with the same degree of precision and confidence, in

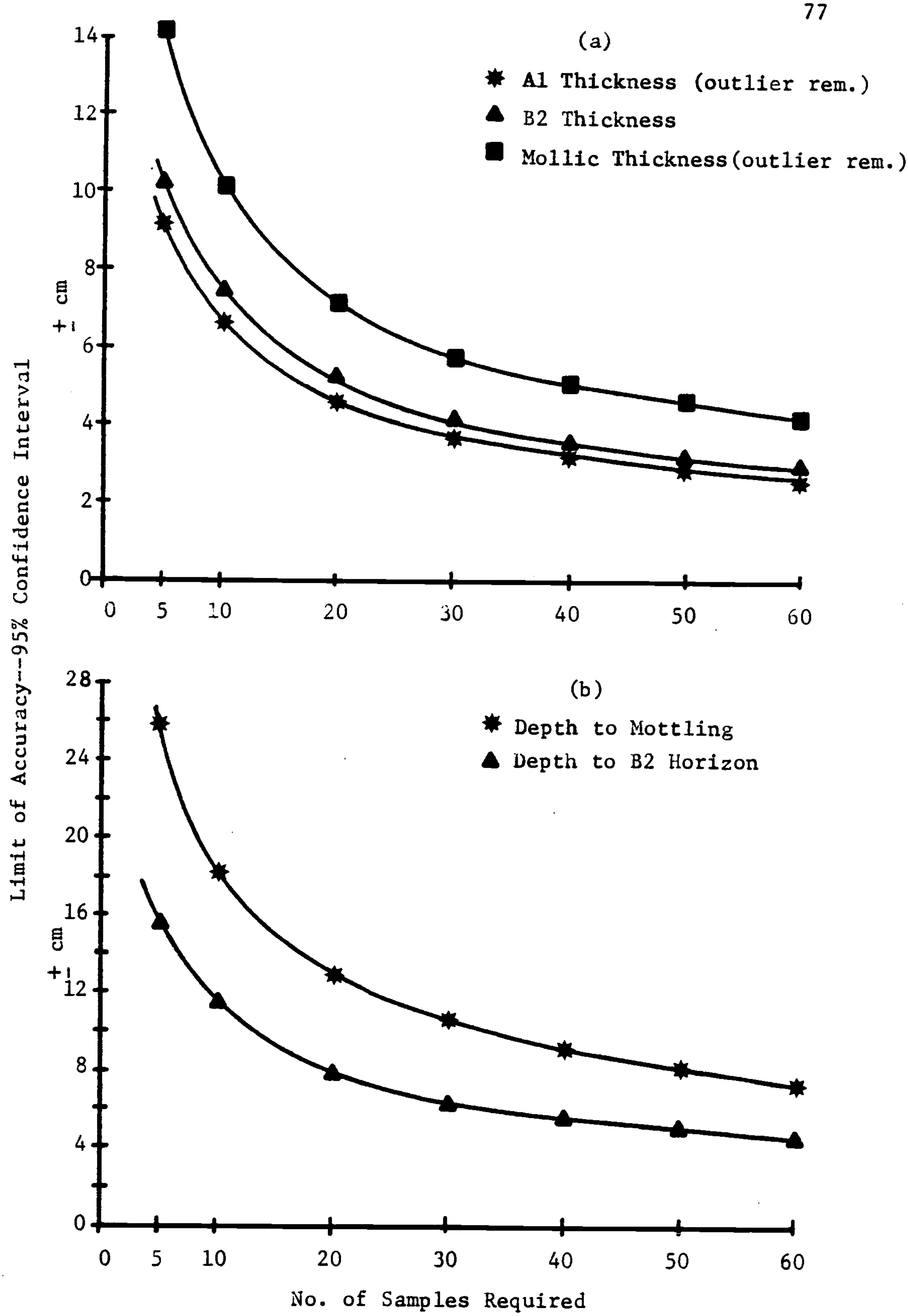

Figure 13: Limit of accuracy curves for morphologic properties: (a) Al, B2, and mollic thicknesses, and (b) depth to mottling and to the B2 horizon

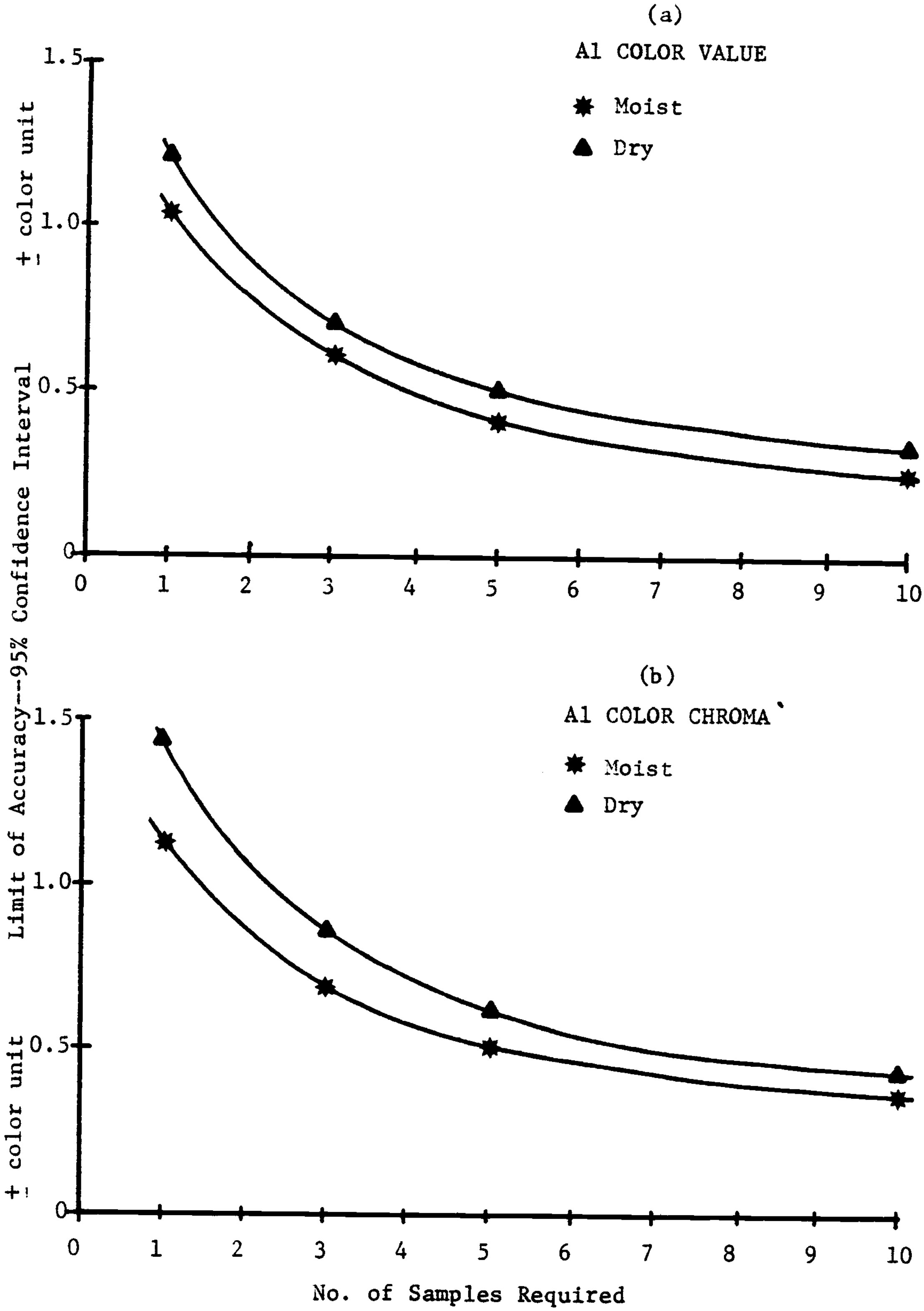

Figure 14: Limit of accuracy curves for surface horizon color (a) value and (b) chroma

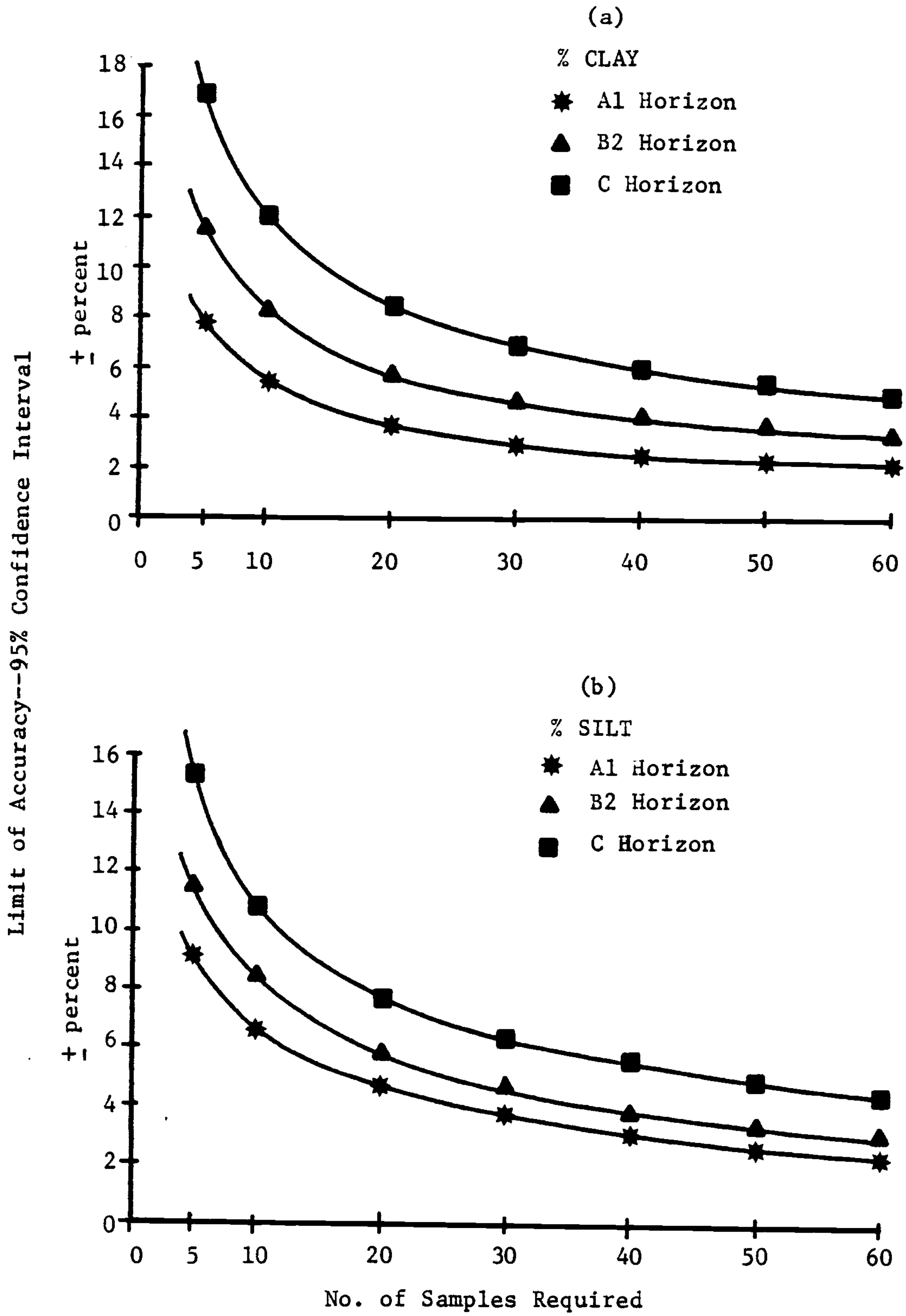

Figure 15: Limit of accuracy curves for (a) clay content and (b) silt content in the A1, B2, and C horizons

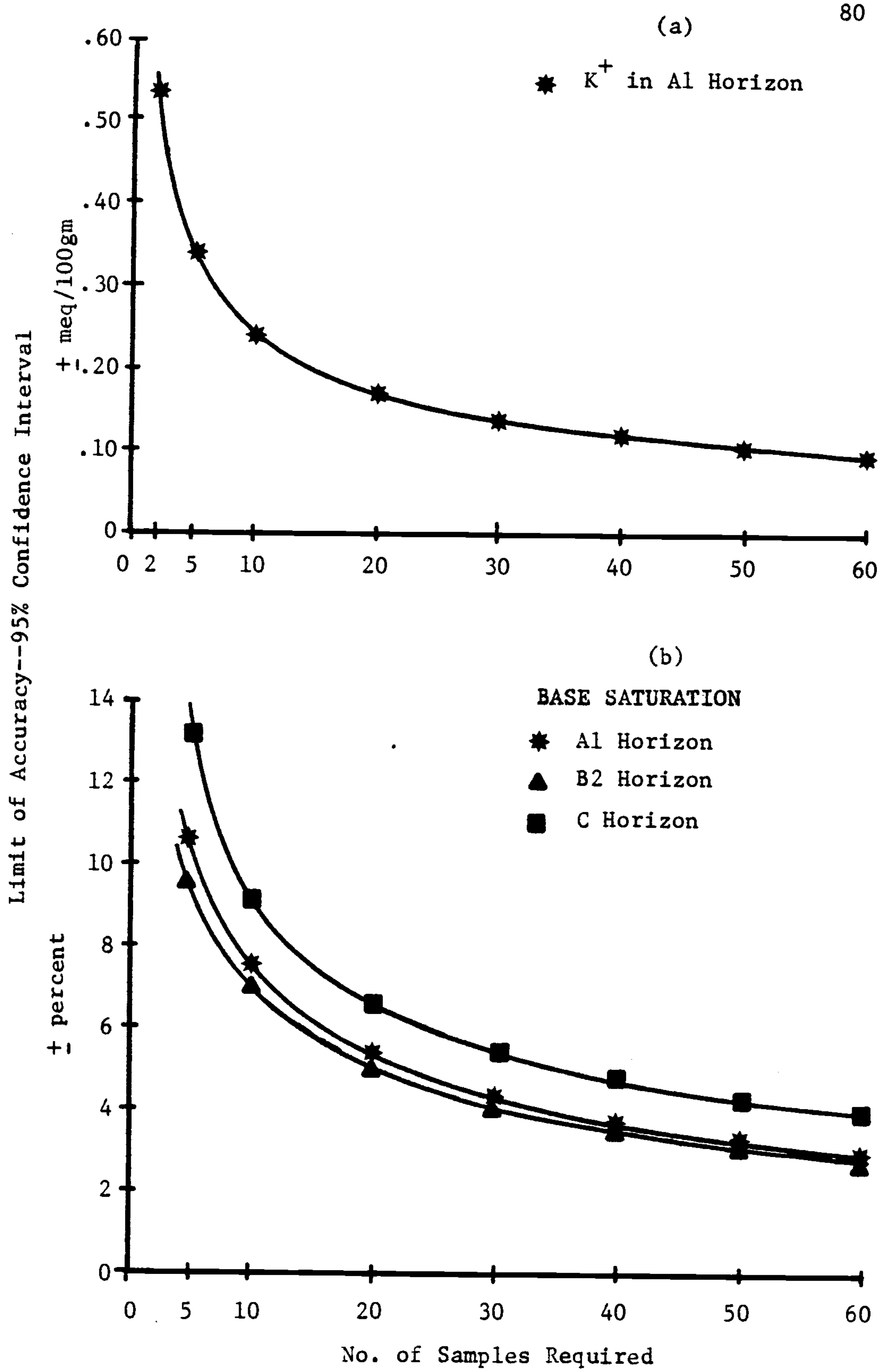

Figure 16: Limit of accuracy curves for (a) K^+ in the Al horizon and (b) base saturation in the Al, B2, and C horizons

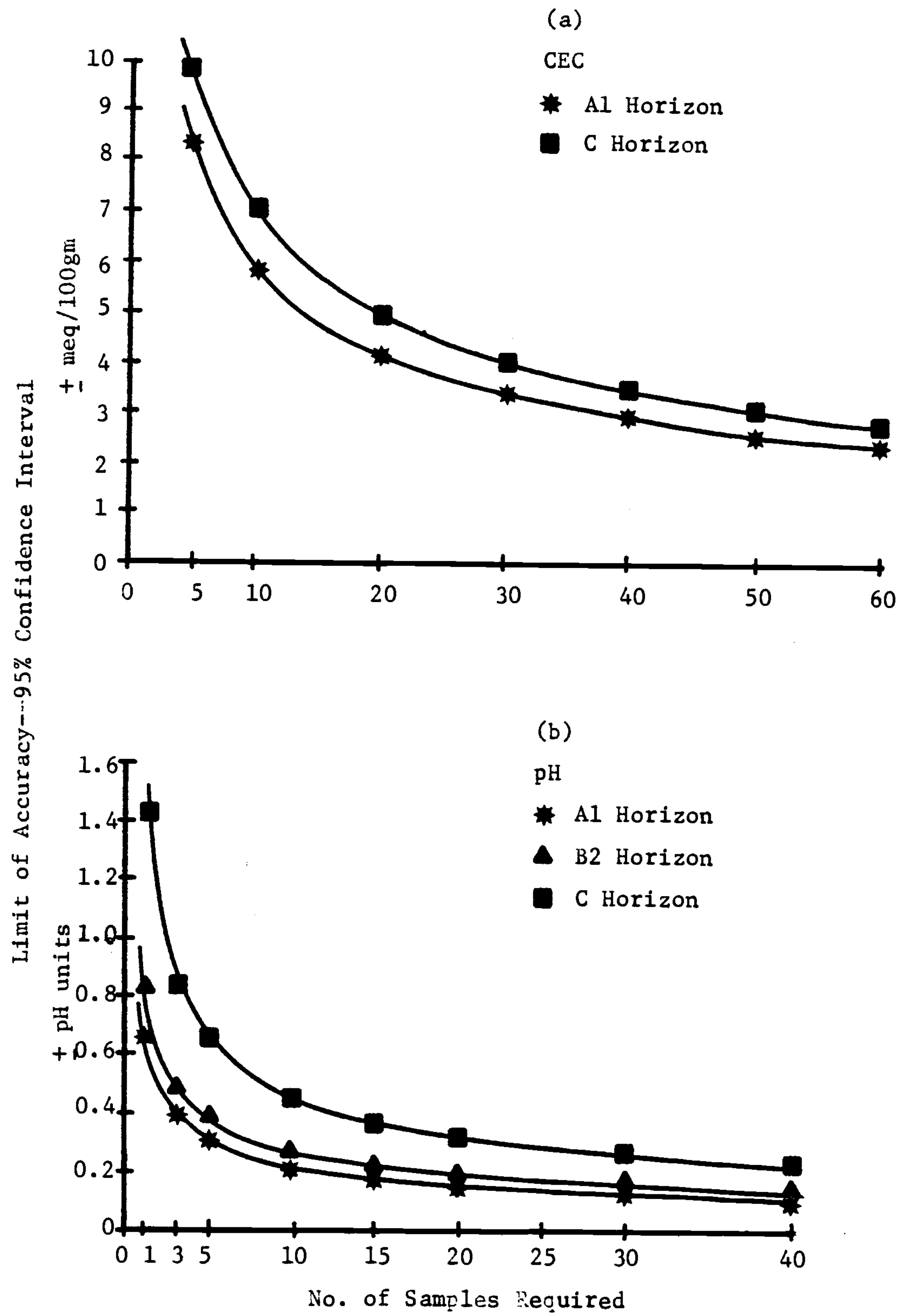

Figure 17: Limit of accuracy curves for (a) CEC in the A1 and C horizons and (b) pH in the A1, B2, and C horizons

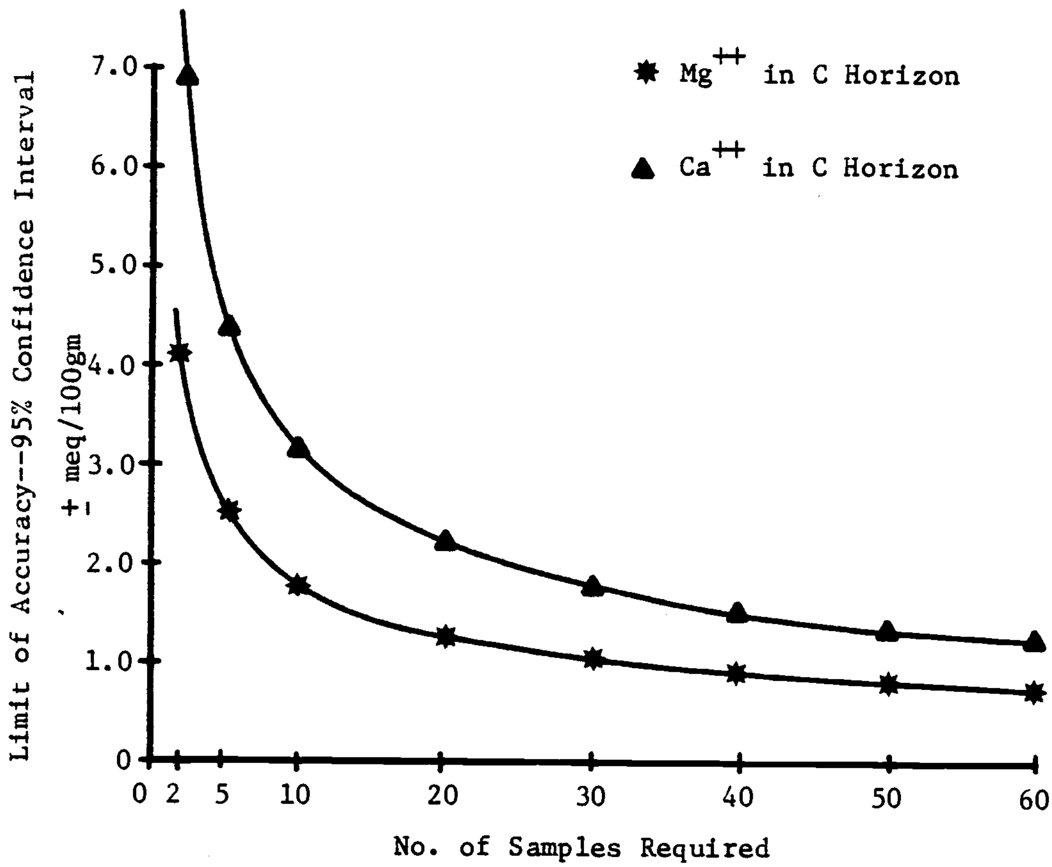

Figure 18: Limit of accuracy curves for Mg^{++} and Ca^{++} in the C horizon

general, 30 to 40 samples are needed before the curves approach a line parallel to the x-axis asymptotically. Little gain in the precision of estimating the mean is acquired with sampling more than 40 sites.

The limit of accuracy calculation can be a useful tool for planning sampling intensities within a study area. An initial random sampling of 6 to 10 sites throughout the area of interest would often be an adequate number of samples with which to perform the calculation (Adams and Wilde, 1976a). From the calculation results, the number of samples required for the remainder of the area can be estimated, depending on the accuracy level the researcher wishes to achieve for estimating the mean of the various soil properties. Properties having high CVs will generally need to be sampled more intensely than properties having low CVs, to establish their respective population means with similar degrees of precision.

The kind of frequency distribution exhibited by an individual soil property affects the ease with which that property can be characterized and compared statistically. Means, standard deviations, and CVs are meaningful descriptors of normally distributed properties, but these statistics may all be inappropriate for skewed data. The median and/or mode, for example, seemed to describe the central tendency of two-thirds of the skewed properties more accurately than the mean. Statistics such as the CV were also misleading for skewed data. All the CVs for the skewed distributions were high ($>.47$) except for one property, percent base saturation, which was the least skewed of the skewed data. Consequently, the variability of the skewed properties could not be compared to the variability of the normally distributed data. Within the group of normally distributed properties, depth to mottling was the most variable property because of its high CV, and soil color and pH were the least variable properties; their low CV values, however, were partially due to their discrete and logarithmic measurement scales.

Relationships To Classification And Mapping

One reason for the measurement of soil properties is to provide values with which soil individuals can be grouped and placed into taxonomic classes. Classification helps to organize ideas or concepts into categories that seem useful (Soil Survey Staff, 1960), and it permits the transfer of soil information from person to person in a coherent, recognizable manner (Cline, 1962). Both soil mappers and map users learn to associate a group of soil characteristics with a specific name on the soil map, which they can then associate with land use capabilities and management needs. Consequently, it is important for soil properties in the field to be similar to the soil properties described for the soil type of the area under question. This portion of the study investigates the reliability of the Willakenzie map unit for identifying areas of soil which possess properties similar to those described for the Willakenzie series.

Range of Characteristics

For each soil series listed in a Survey Report, a representative profile is described along with the series' range of characteristics.

The ranges in quantifiable soil property values and qualitative characteristics are developed by the soil mappers from profile descriptions of pedons from throughout the survey area. The ranges provide sets of limits by which soil pedons in future investigations can be classified and distinguished from each other.

George Otte,[11] who was the party leader for the Yamhill County area soil survey, played a major role in developing the range of characteristics for Yamhill County soils. He was the source of the information that follows concerning the history and development of the Willakenzie series concept.

The Willakenzie series was established as an offshoot of the Melby (then the Melbourne) series after the 1938 Classification system was modified in the 1950's (Thorp and Smith, 1949). It was then classified as a Reddish-brown lateritic soil. The mapper's concept of the series included characteristics such as: good drainage, reddish-brown colors throughout the horizons, base depletion due to a leaching environment, and a convex-convex position on low hills and foothills. At that time there was no concern about the presence or absence of such features as "mollic epipedons" or "argillic horizons." Two depth phases of the series were mapped, one including soil profiles with siltstone, sandstone, or shale at 20-36 inches and the other including those with bedrock at greater than 36 inches. This concept of the series remained nearly the same through the several modifications in taxonomic systems, even though new criteria specifying percent base saturation, surface horizon colors, and amount of clay increase in the Bt horizon became

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[11] G. Otte. McMinnville, Oregon. Personal Communication.

associated with the Willakenzie after its classification as a fine-silty, mixed, mesic Ultic Haploxeralf (Soil Survey Staff, 1960, 1975). The new taxonomic criteria assigned specific characteristics and property value limits to the series, including:

(1) the presence of an argillic horizon,

(2) an epipedon that is not mollic,

(3) less than 75 percent base saturation (by sum of cations) within the upper 75 cm of the argillic horizon, and

(4) less than 15 percent sand and between 18 and 34 percent clay in the upper 50 cm of the argillic horizon.

Depth to bedrock limits also were changed in the early 1960's, from 20-36 and >36 inches to 20-40 and 40-60 inches. After this modification, the Willakenzie was defined either as a moderately deep (30-40 inches to bedrock) or moderately shallow (20-30 inches to bedrock) soil.

As the definition of the Willakenzie series became more precise, the allowable range of characteristics became more narrow. Mapping of the series in Yamhill County was done at a time when wide ranges in the values of some properties were permitted. The new taxonomic criteria allow much narrower ranges in the current definition of the Willakenzie series, and some of the limits (e.g. depth to bedrock) have been changed. As a result, many of the areas originally mapped as Willakenzie are now classified as other series such as the Steiwer (Fine-loamy, mixed, mesic Ultic Haploxeroll). This evolution of the concept with its concomitant narrowing of property ranges is one of the reasons for the high degree of variability observed within the map unit.

The description of the representative profile of the Willakenzie series, together with the prescribed range in characteristics are reproduced below from the Yamhill County soil survey (Otte _et al._, 1974).

Willakenzie silty clay loam, 2 to 12 percent slopes

A1--0 to 4 inches, dark-brown (7.5YR 3/2) silty clay loam, fine, subangular blocky structure; friable, hard, slightly sticky, slightly plastic; many very fine pores; many fine roots; very few fine concretions; medium acid (pH 6.0); clear, smooth boundary. (3 to 9 inches thick)
B1--4 to 12 inches, dark-brown (7.5YR 3/4) silty clay loam, strong brown (7.5YR 5/6) when dry; moderate, medium and fine, subangular blocky structure; friable, hard, sticky, plastic; many very fine pores; many fine roots; medium acid (pH 6.0); clear, wavy boundary. (7 to 10 inches thick)
B21t--12 to 18 inches, dark-brown (7.5YR 4/4) silty clay loam, strong brown (7.5 YR 5/6) when dry; moderate, fine and very fine, subangular blocky structure; friable, hard, sticky, plastic; many very fine pores; many fine roots; few thin clay films in pores and on some ped surfaces; medium acid (pH 6.0); clear, smooth boundary. (5 to 8 inches thick)
B22t--18 to 26 inches, dark-brown (7.5YR 4/4) silty clay loam, strong brown (7.5YR 5/6) when dry; weak, medium, subangular blocky structure; firm, hard, very sticky, very plastic; many very fine pores; common fine roots; few very thin clay films on ped surfaces; medium acid (pH 5.6); gradual, wavy boundary. (6 to 12 inches thick)
B23t--26 to 32 inches, dark-brown (7.5YR 4/4) silty clay loam, strong brown (7.5YR 5/6) when dry; weak, medium and fine that breaks to moderate, very fine, subangular blocky structure; firm, hard, very sticky, very plastic; many very fine pores; common fine roots; many thin clay films; strongly acid (pH 5.4); abrupt, wavy boundary. (5 to 7 inches thick)
IIC--32 to 36 inches, yellowish-red (5YR 4/6) loam; weak, fine, angular blocky structure; friable, sticky, plastic; few fine pores; few fine roots; common thick clay films on the coarse fragments; 80 percent strongly weathered siltstone fragments; very strongly acid (pH 4.7); abrupt, smooth boundary. (3 to 4 inches thick)
IIR--36 inches, hard, fractured siltstone bedrock.

The solum generally has hue of 7.5, but hue grades from 10YR in the A horizon to 5YR in the lower part of the B horizon. Soils that formed from siltstone have redder hues than soils that formed from sandstone. The A horizon has moist values of 2 and 3 and chromas of 2 or 3. Dry values are 5 or 6. Texture is loam to silty clay loam. The B horizon generally has chromas of 4 when moist, but in places chromas are 6 in the lower part. The B horizon ranges from clay loam to silty clay loam. The lower part of the Bt horizon is heavy silty clay loam or silty clay in some areas. The upper 20 inches of the Bt horizon is 27 to 35 percent clay. Strongly weathered rock fragments are commonly abundant below depths of 24 to 30 inches, and a few are embedded throughout the solum where the rock is softer and more weathered.

The range in characteristics for the Willakenzie map unit is the same as that for the series, with the exception of slope steepness and surface horizon texture, which are phase criteria. Data collected from the 35 pedons sampled in this study are compared with the property values given for the map unit, which includes the values listed in the official range of characteristics (above) in addition to slope values of 2 to 12 percent and surface horizon textures of silty clay loam. These comparisons are illustrated in Figures 19-21. The hatched areas on the graphs illustrate the proportion of the 35 pedons which falls within the range described for the map unit.

Surface horizon color was mapped correctly more often than any other soil property. All 35 pedons had hues of 7.5 YR or 10 YR, which are within the map unit limits (Figure 19a). Most (91 percent) had acceptable moist values of 2 or 3, and 77 percent had acceptable dry values between 5 and 6 (Figures 19c,d). Acceptable moist chromas of 2 or 3 were observed in 91 percent of the pedons (Figure 19b). Seven of the eleven pedons that contained color values and chromas outside the prescribed range were Mollisols. This suggests that the deviations from the described range were due to the narrowing of taxonomic limits during the changeover into the 1960 system.

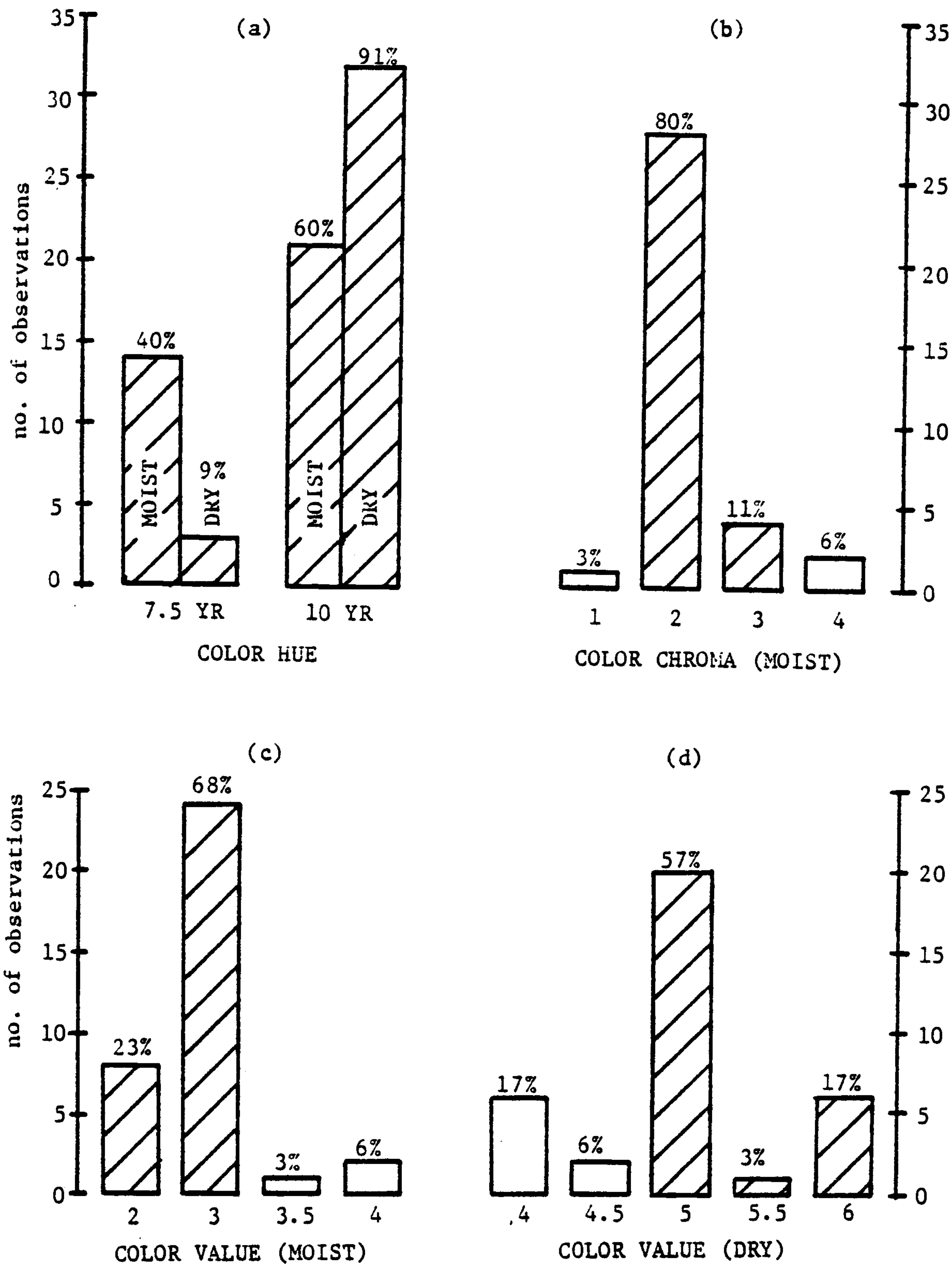

Figure 19: Frequency distributions of surface horizon color (a)hue, (b) chroma, (c) moist value, and (d) dry value

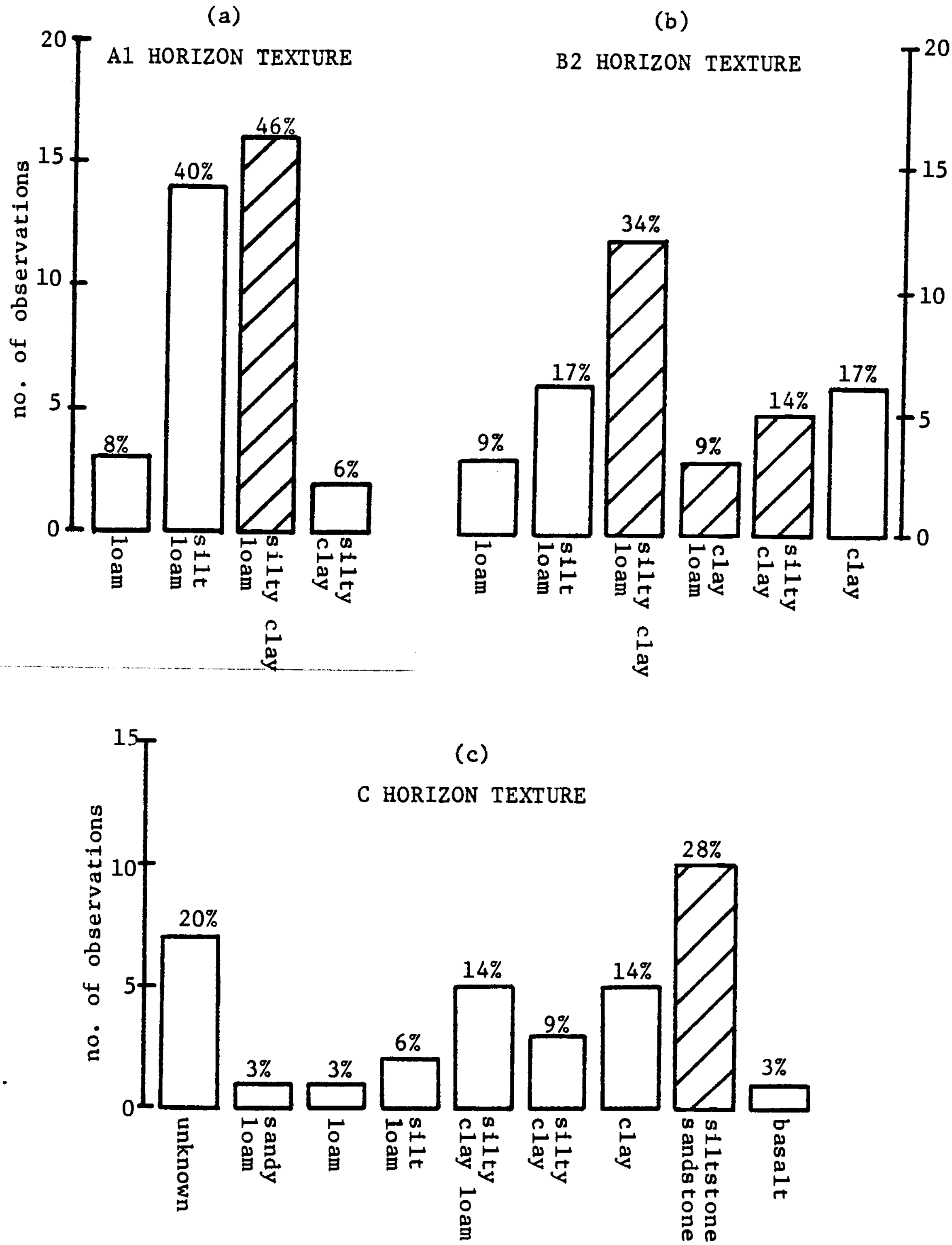

Figure 20: Frequency distributions of (a) A1 horizon texture, (b) B2 horizon texture, and (c) C horizon texture

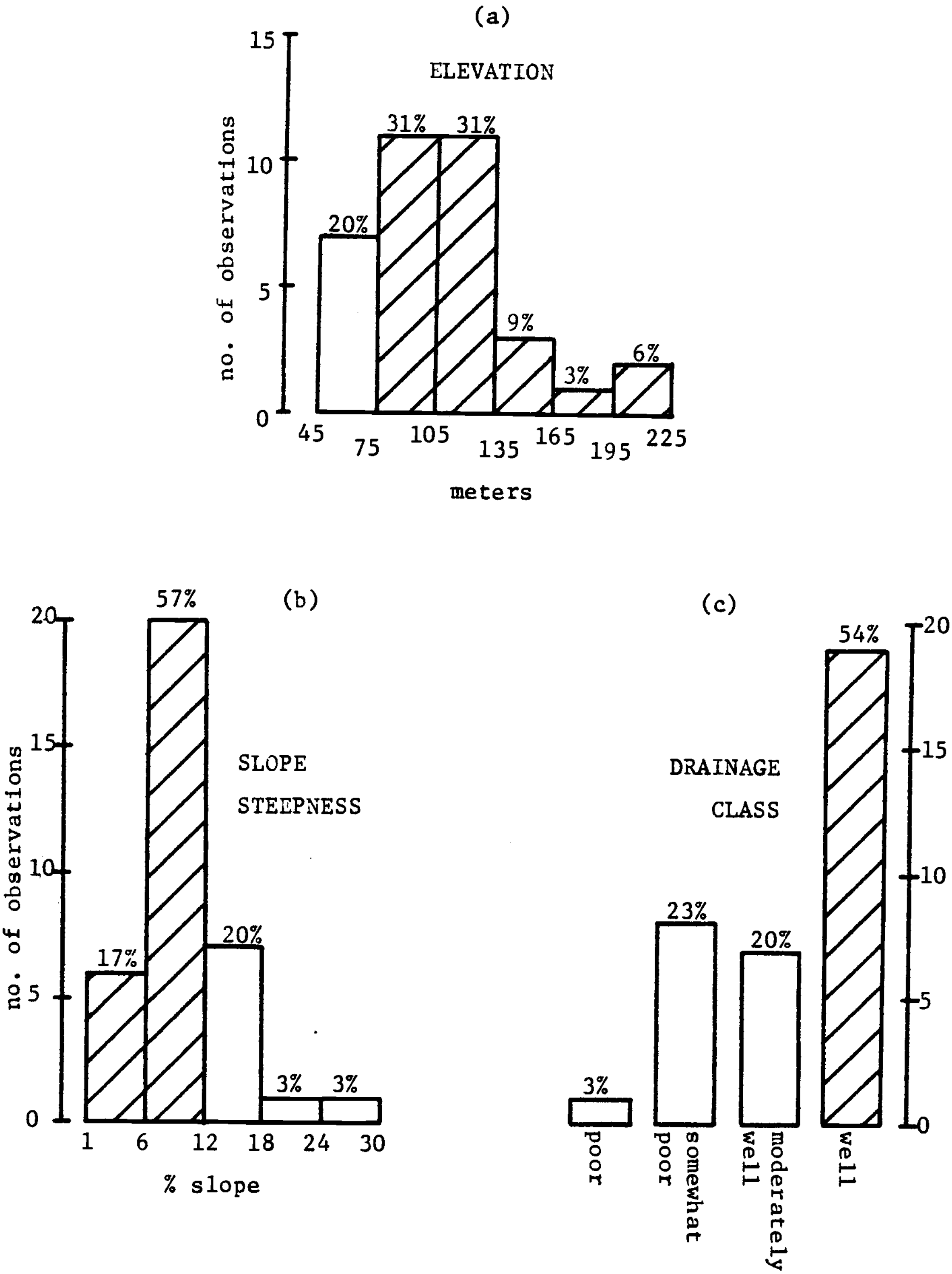

Figure 21: Frequency distributions of (a) elevation of the pedons, (b) slope steepness, and (c) drainage class

Observed A1 horizon textures ranged from loam to silty clay. About half (46 percent) of the pedons fell in the silty clay loam textural class described for the map unit (Figure 20a). Only two profiles (delineation no.'s 43 and 318), containing silty clay textures, fell outside the range defined for the Willakenzie series. These two were both underlain by clayey subhorizons at shallow depths (20 and 26 cm).

A wider range of textural classes was observed in the B2 horizon. Fifty-six percent of the profiles had textures falling within the range described for the Willakenzie map unit and/or series (Figure 20b). Geomorphic processes probably are responsible for some of the variability present in the A1 and B2 horizon textures. It is commonly believed that lake water filled the Willamette valley to a 122 m level during the late Pleistocene epoch (Allison, 1935; Baldwin, 1964) and deposited what is now known as the Greenback member of the Willamette Formation (Balster and Parsons, 1969). Glasmann (1979) found areas between the elevations of 65 and 122 m in Polk County, Oregon to be mantled by the Greenback member. The thickness of the member decreased with elevation, ranging from 90 m at the lower elevations to less than 30 cm at the 122 m elevation. The samples he analyzed from this stratigraphic unit were almost uniformly silt loam textures. Above 122 m, he found 30-40 cm of eolian silts mantling a paleosol, which was formed in the underlying Spencer formation. The paleosol, usually comprised of only B2t and B3 horizons, had textures ranging from silty clay loam to clay.

The occurrence of silts above and below the 122 m elevation may explain the high percentage (40 percent) of observed silt loam textures in the A1 horizons of the 35 pedons. The thinning of the Greenback member with elevation may explain some of the variability in B2 horizon texture. Pedons at low elevations might be expected to have silty sub-horizons as a result of thick lacustrine silt deposits, and pedons located at the higher elevations might be expected to have higher B2 horizon clay contents as a result of paleosol formation. The relationship between A1 and B2 horizon textures and elevation was statistically tested by linear regression analysis. Table 9 lists the 35 pedons, along with their silt and clay contents, in order of increasing elevation. A visual inspection of the silt and clay data indicates no obvious trends in either property with elevation. The regression analysis produces similar results--the r^2 values for both silt and clay in both horizons are nonsignificant. When percent silt is regressed on elevation, the r^2 values are .17 and .25 for the A1 and B2 horizons, respectively. The r^2 values are .07 and .14 when percent clay in the A1 and B2 horizons are regressed on elevation. An example of these nonsignificant relationships is shown in Figure 22 for B2 horizon clay versus elevation.

The absence of a trend between A1 horizon texture and elevation is consistent with Glasmann's geomorphic evidence, which indicated no changes in surface horizon texture between the Greenback silts below

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[12] R. Glasmann. Dept. of Soil Science. Oregon State University, Corvallis, Oregon. Personal Communication.

Table 9. Silt and Clay Content of the Al and B2 Horizons of the 35 Pedons in Relation to Elevation.

Del. No.	Elevation	Silt		Clay	
		Al	B2	Al	B2
	----m----	------------%------------			
220	50	65	69	30	25
107	59	68	61	29	31
108	61	73	72	23	26
234	62	65	48	24	38
161	65	71	66	17	22
68	72	61	49	25	41
199	73	57	65	22	17
35	76	62	67	33	28
319	76	57	44	37	48
69	84	68	71	18	16
43	85	47	33	48	64
120	88	52	35	23	40
191	90	58	--	29	--
145	90	75	68	18	24
41	91	56	53	26	30
322	91	54	46	31	37
135	100	65	51	18	32
261	102	41	38	40	39
142	107	40	36	21	23
26	110	69	52	24	42
34	110	55	43	28	20
128	116	32	37	25	20
143	117	40	28	23	42
223	119	52	55	30	29
311	119	56	35	39	63
314	120	59	59	36	36
32	122	58	51	36	45
98	123	60	54	22	38
242	134	51	46	35	39
328	145	45	40	40	47
31	150	57	58	36	35
292	160	53	55	32	30
84	186	53	31	18	47
93	207	61	41	24	38
318	207	43	32	50	57

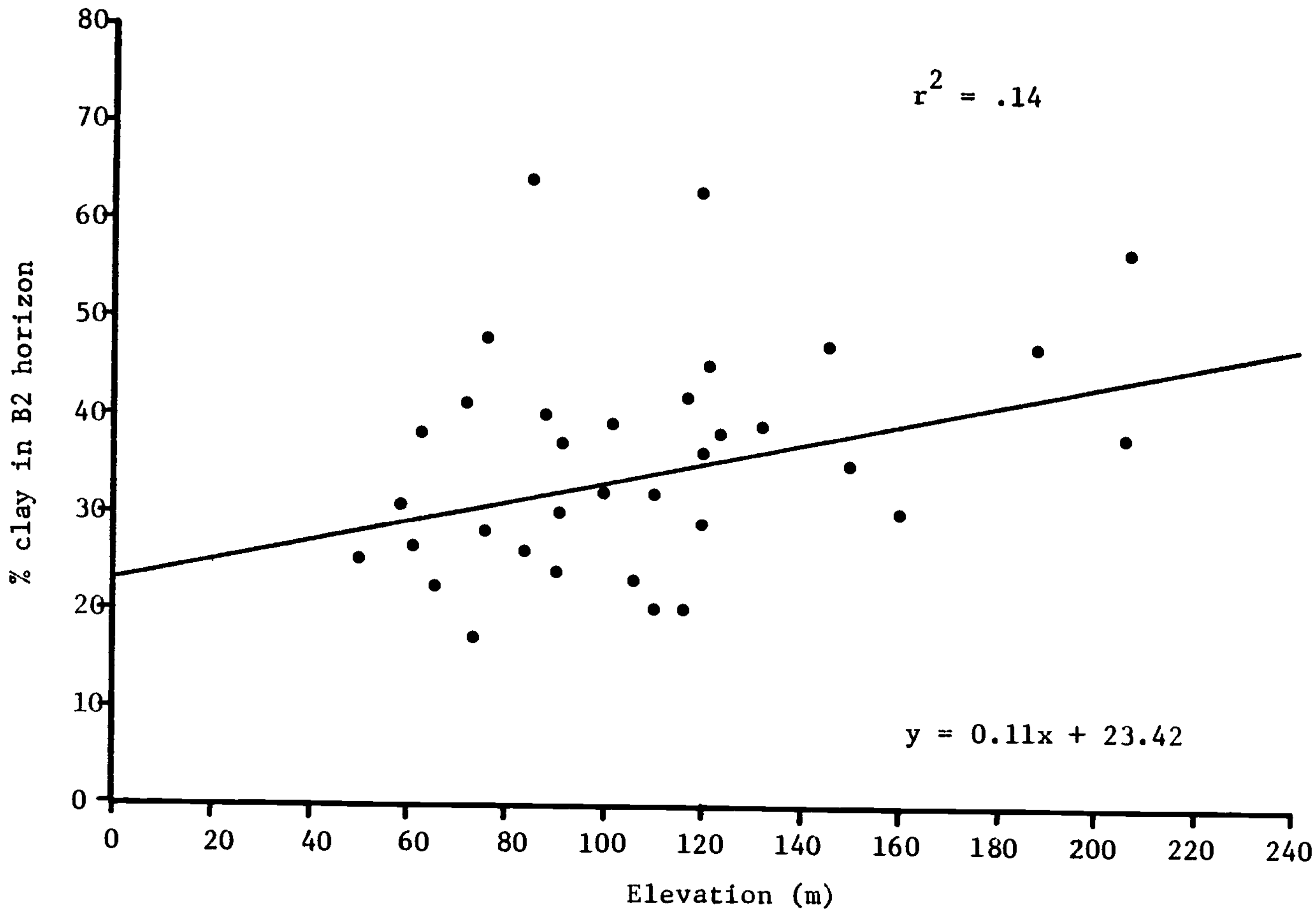

Figure 22: Relationship between elevation and B2 horizon clay content

122 m and the eolian silts above 122 m. In addition, the regression analysis failed to show a relationship between B2 horizon texture and elevation, which might not have been as expected. The B2 horizon textures of the 35 pedons are simply too variable and the pedons themselves too irregularly located about the county to detect a relationship between elevation and B2 horizon texture, if indeed, one really does exist.

The B2 horizon texture in the 35 pedons was more related to the particle size of the underlying C horizon, rather than to the elevation. In profiles underlain by a fine-textured bedrock such as mudstone or siltstone, B2 horizon textures were silty clay loams, silty clays, and clays. In profiles underlain by sandstones or by sandy loam or loam C horizons, B2 horizon textures were loams and clay loams. This relation implies that the B2 horizons were formed in situ by weathering of the bedrock. Seven of the pedons (delineation no.'s 69, 108, 145, 161, 199, 220, and 223) had fairly uniform, silt loam and light silty clay loam textures throughout the A, B, and C horizons. All extended to depths greater than 110 cm, had mollic epipedons (some pachic), and none showed signs of clay translocation. The pedons' elevations ranged from 50-119 m. The morphologic and physical evidence suggest that these particular profiles developed partially or entirely from silty lacustrine sediments of late Pleistocene age, rather than from the weathering of sedimentary rocks in place.

The C and Cr horizons displayed a wide variety of particle sizes and rock types. Textures ranged from sandy loams to clays, and bedrock types ranged from fine-grained mudstones to coarse-grained sandstones.

Twenty-eight percent of the sampled pedons had C horizons similar to the type and within the depth range described for the Willakenzie series (Figure 20c). The other known C horizons were sufficiently unconsolidated to texture and were usually light-colored (2.5Y 5/2 and 6/2, 10YR 5/1, 6/3, and 7/3). Several of the unconsolidated layers also contained "pockets" of reddish-colored (2.5YR 4/6, 7.5YR 4/6, 5/6, and 5/8) material that were difficult to distinguish from drainage mottles.

Thirty-eight percent of the profiles contained silty clay loam, silty clay, or clay C horizon textures. Most of these horizons extended to depths greater than 140 cm. Comparisons of these kinds of profiles with written descriptions of similar soils in a Polk County study area (Glasmann et al., 1980) led to the conclusion that the clayey layers represented a weathered, fine-textured geologic stratum. Glasmann et al. (1980) noted that fine-textured taxadjuncts of the Willakenzie series mapped in their area exhibited high variability due to differences in bedrock texture. Within the underlying Spencer formation, textures ranged from clays to siltstones to weathered gravels to loams[13] (Glasmann et al., 1980). The Nestucca and Oligocene sedimentary rock formations, which underlie most parts of Yamhill County in which the Willakenzie is mapped, both contain members that are fine-textured (Baldwin et al., 1955; Warren et al., 1945). Weathering of these beds is the most probable reason for the presence of clayey horizons in some of the pedons sampled, and this is a fact of which early surveyors were unaware. A careful sampling of the subhorizons during field mapping might

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[13] R. Brown. Unpublished soils map of Elkins Road Watershed. Oregon State University, Corvallis, Oregon.

have eliminated some of these areas from the map unit or would have allowed their mention as inclusions. Mapping the clayey areas precisely, however, could be an arduous task. In Polk County, Oregon, difficulty was encountered while mapping taxadjuncts of the Willakenzie series over the highly variable Spencer formation (Glasmann et al., 1980). The varying bedrock textures did no occur in predictable patterns, and the clayey portions could not be detected solely from surficial observations.

The elevations at which the 35 delineations were mapped ranged from 50 to 207 m (Figure 21a). By comparison, the Willakenzie series in the Yamhill Area Soil Survey (Otte et al., 1974) is said to range from 75 to 245 m. It was questionable as to whether pedons located at the lower elevations would contain soil characterisitics similar to the "typical" Willakenzie profile, which was formed over sedimentary bedrock. Seven of the pedons (delineation no.'s 68, 107, 108, 161, 199, 220, 234) were located below 75 m. Four of these (no.'s 108, 161, 199, and 220) have already been identified as most likely being formed in deep lacustrine silts, which does not fit the concept of the Willakenzie. The pedon in delineation no. 68 had a mollic epipedon with a silt loam texture, but it also contained an argillic horizon with a silty clay texture. Bedrock was not present within 100 cm. Pedon no. 107 contained a mollic epipedon, and it was underlain by siltstone bedrock at 89 cm. Pedon no. 234 was similar to a typical Willakenzie; i.e., it contained an argillic horizon and reddish colors and did not have a mollic epipedon. However, depth to bedrock or to the C horizon was greater than 110 cm.

The inclusion of these soils below 75 m within the Willakenzie map unit is a result, in part, of the broader range of characteristics previously permitted in the Willakenzie. The old classification system did not specify "mollic epipedon" criteria and thus, many of the pedons now are classified as Mollisols. The lack of knowledge concerning soil-geomorphic relationships was another factor contributing to the observed deviations. Soil survey depends heavily on the prediction of soil type by landscape position. Had the early surveyors known more about geomorphic surfaces, landscapes underlain by deep lacustrine silts could have been more precisely identified and separated from the Willakenzie map unit. The fact that the Willakenzie contained a number of deep, silty profiles reemphasizes the need for soil-geomorphic information. Both mapping accuracy and efficiency can be improved with such knowledge.

Slopes at the soil sites ranged from 3 to 40 percent, which is within the range described for the Willakenzie series. Of these, a total of nine pedons (26 percent) were located on slopes outside the range defined for the 2-12 percent slope phase of the Willakenzie map unit (Figure 21b). Mismapping of the delineations or the small scale of occurrence of the steeper areas are the most probable causes for the inclusion of these nine pedons within the Willakenzie map unit.

Soil drainage classes were assessed primarily on the basis of depth to mottling and landscape position. The typical Willakenzie profile is well drained and is located on convex-convex positions. Almost half (46 percent) of the pedons were not well drained and included moderately well, somewhat poorly, or poorly drained soils (Figure 21c). Drainage was somewhat poor or poor in the pedons containing clayey subhorizons and in those pedons situated on slightly concave landscape positions. The one poorly drained soil (delineation no. 314) was located on a convex-concave position, had a heavy silty clay loam texture in the upper 60 cm and a silty clay texture below 60 cm, and exhibited distinct, strong-brown (7.5YR 5/8) mottles in a dark gray (10YR 4/1) matrix within the surface horizon. In the somewhat poorly drained pedons, red and gray mottles appeared at 20-30 cm, and textures were usually heavy silty clay loams and silty clays. Mottling began at 50-60 cm in the moderately well drained profiles. Many of the somewhat poor or moderately well drained pedons were probably included within the map unit due to mismapping; others may have been purposefully included due to their small scale of occurrence.

Classification of Pedons

The classifications of the 35 pedons are given in Table 10. The table is divided into two sections, the first listing soils which are "similar" to the Willakenzie, and the second listing soils which are "dissimilar" to the Willakenzie. The order in which the subgroup and families are listed attempts to rank the soils according to the amount of contrast they represent in relation to the subgroup in which the Willakenzie is placed. Thus, those soils at the top of the list are least-contrasting, and those at the bottom are most-contrasting. The reason(s) for deviation from the Ultic Haploxeralfs are listed in the right-hand column.

The identification of"similar" and "dissimilar" soils is often quite subjective, due to the vagueness of their definitions in the

Table 10. Classification of the 35 Pedons.

I. Similar Soils

Classification	Del. No.	Differentiating Characteristics
Ultic Haploxeralf		----
Fine-silty, mixed, mesic	135	
Fine, mixed, mesic	26, 84, 93 98, 120, 143 234	
Typic Xerochrept		no argillic
Fine-silty, mixed, mesic	41	
Fine-loamy, mixed, mesic	128, 142	
Ultic Argixeroll		mollic epipedon
Fine, mixed, mesic	32	
Ultic Haploxeroll		mollic epipedon, no argillic
Fine-silty, mixed, mesic	145, 161, 292 31, 242, 261 328	
Pachic Ultic Argixeroll		mollic epipedon, pachic
Fine, mixed, mesic	322	
Typic Haploxeroll		mollic epipedon, no argillic, no ultic
Fine-silty, mixed, mesic	108	
Pachic Ultic Haploxeroll		mollic epipedon, pachic, no argillic
Fine-silty, mixed, mesic	223	
Cumulic Ultic Haploxeroll		mollic epipedon, cumulic, no argillic
Fine-silty, mixed, mesic	69, 220	

Table 10. Continued.

II. Dissimilar Soils		
Classification	Del. No.	Differentiating Characteristics
Ultic Haploxeralf		
Very-fine, mixed, mesic	43	B2 texture, SWP drainage
Typic Haploxerult		
Clayey, mixed, mesic	311	B2, C texture, SWP drainage
Typic Xerumbrept		
Fine-silty, mixed, mesic	35	no argillic, SWP drainage
Ultic Argixeroll		
Fine, mixed, mesic	68	SWP drainage, mollic
Ultic Haploxeroll		
Coarse-loamy, mixed, mesic	34	A1, B2 texture, no argillic, mollic
Very-fine, montmorillonitic, mesic	191	AC texture, no argillic, mollic
Pachic Ultic Haploxeroll		
Fine-silty, mixed, mesic	107	30% slopes, no argillic, mollic, pachic
	199	no argillic, SWP drainage, mollic
Typic Haplaquept		
Fine-silty, mixed, mesic	314	no argillic, poor drainage
Aquultic Argixeroll		
Fine, mixed, mesic	319	SWP drainage, mollic
Aquultic Haploxeroll		
Very-fine, mixed, mesic	318	A1, B2 texture, SWP drainage, mollic

National Soils Handbook (Soil Survey Staff, 1977). The Soil Survey Staff (1977, 1980) defines dissimilar soils as those which differ in enough properties or in enough degree to merit different predictions about their potentials or about their behavior under various uses. Similar soils are defined as soils that "share limits of those diagnostic properties in which they differ" (Soil Survey Staff, 1980), which suggests that soils <u>not</u> sharing class limits or boundaries are dissimilar. As an example, the guidelines indicate that a pair of subgroups, such as a Typic Argiudoll and a Typic Hapludalf, are dissimilar, because they are separated taxonomically by a third subgroup, the Mollic Hapludalfs. This kind of difference between soils, based primarily on the presence of a mollic epipedon, can be insignificant for many management purposes. Therefore, criteria that might affect major interpretations about the map unit should be the criteria used to distinguish dissimilar inclusions. This idea is in agreement with the definition stated in the National Soils Handbook (Soil Survey Staff, 1977).

Soil properties commonly used as criteria (Amos and Whiteside, 1975; Soil Survey Staff, 1980) for identifying dissimilar inclusions are soil drainage class, surface horizon texture, depth to bedrock or impermeable layer, and slope steepness. Determinations of dissimilar soils in this study were based on the amount of contrast in these properties relative to the defined property values of the Willakenzie series. Differences of more than one property class were considered contrasting, or dissimilar. For example, the pedon in delineation no. 68 is somewhat poorly drained, which differs from the defined property class of "well drained" by the class, "moderately well drained" (Table 10, Part II). The separation by an intermediate class merited the distinction as a dissimilar soil. Likewise, the pedon in delineation no. 191 was defined as dissimilar, because the family textural class, "very-fine," differed from "fine-silty" by an intermediate class, "fine." If properties contrasted in a beneficial manner, as they did in profiles containing pachic mollic epipedons, the soils were not considered dissimilar, because they would have less management restrictions than the Willakenzie itself. The disadvantage to distinguishing these soils as similar is that it infers that the use and behavior of the soils are similar to those of the Willakenzie, whereas, the productivity actually is better. Therefore, some areas of the Willakenzie can be managed more intensively than what is interpreted for the map unit as a whole.

The Willakenzie map unit contained a total of 31 percent dissimilar soils (Table 10, Part II). The majority of the pedons were somewhat poorly or poorly drained because of clay or silty clay subhorizons. Two had silty clay loam subhorizons, but were located on either a concave landscape position or next to a floodplain. Both locations had seasonally high water tables. In one delineation (no. 107), the pedon was located in an area of 30 percent slopes, and in delineation no. 34, the pedon contained coarse textures throughout the profile. Each of the eleven profiles differed appreciably from the Willakenzie series in one or more properties that lowered the potential for use and management.

The taxonomic purity of the Willakenzie map unit was calculated from the classification of the 35 pedons. Only one of the soil profiles, located in delineation no. 135, classified as a fine-silty, mixed, mesic Ultic Haploxeralf. This particular pedon, however, did not meet all the series criteria for the Willakenzie; it was only moderately well drained, and it was underlain by a massive clay horizon at 107 cm. Accordingly, the purity of the map unit was 0 percent at the series level. This is a very low score in comparison to other map purity studies (Table 1). At the family level, map purity was 3 percent (1 profile). Because there was only one subgroup within the Alfisol order represented by the 35 pedons, the map purity was 26 percent (9 profiles) for each categorical level from subgroup through order. Wilding et al. (1965) and McCormack and Wilding (1969) calculated a 42 and 17 percent purity, respectively, at the series level; an 85 and 22 percent purity at the subgroup level, and a 96 and 74 percent purity at the order level. In contrast to these studies, the Willakenzie map unit contained a high proportion of other soils. Over half of the pedons (20 profiles) were Mollisols, 14 percent (5 profiles) were Inceptisols, and 3 percent (1 profile) were Ultisols.

The large number of Mollisols appearing in the map unit may be partially explained by the circumstances present at the time of mapping. In the late 1950's, SCS classified the Willakenzie as a Reddish-brown lateritic soil. The concept of a mollic epipedon, as such, had not yet been introduced. Surface horizon color and thickness criteria for placing profiles into taxonomic classes were nonexistent. Likewise, criteria for argillic horizons, such as percent clay increase within the profile, were not used to distinguish the Willakenzie from other soils, although the presence of clay skins was noted in some pedons.[14] This may explain the high percentage of soils that did not contain argillic horizons. Differences in the concept of the Willakenzie series between soil mappers also may have accounted for some of the variations in classification. This was particularly true before soil correlators began to oversee the naming of soils.[15]

The mapping of the Willakenzie at low elevations is another factor contributing to the large number of Mollisols within the map unit. Gelderman and Parsons (1972) found that soils formed below 80 m on the Bethel surface were primarily Mollisols. The Bethel surface is associated with low rounded hills that are underlain by both the Greenback and Irish Bend members of the Willamette formation. Nine of the 35 randomly sampled pedons (delineation no.'s 35, 68, 107, 108, 161, 199, 220, 234, 319) were located below 80 m, and seven of them were Mollisols.

Some of the variability in pedon classification, in general, may be attributed to the precise nature of the taxonomic class limits. The difference between a pedon being classified as an Argixeroll versus a Haploxeralf can be a single color chip in the Munsell Soil Color Chart or as little as 0.1 percent organic carbon content in the surface horizon. In the past, researchers have objected to the rigid, quantitative boundary criteria established for separating soil classes in

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[14] G. Otte. McMinnville, Oregon. Personal Communication.

[15] G. Otte. McMinnville, Oregon. Personal Communication.

the system, because experimental errors can sometimes approach a large percentage of the mean of the property in question (Smith, 1965; Webster, 1968). If a soil property had a measured value near a class boundary, experimental error could justify placing the soil in either class. The subjectivity involved in assigning soil colors to horizons or detecting the presence of clay skins has also been cited as a weakness in the system (Webster, 1968). While some degree of importance has been placed on the dry color value of a mollic epipedon (a value ≤5.5 is required), soil mappers commonly vary in their color designations of the same horizon

color value has been shown to have little relationship with more meaningful soil properties such as organic matter or organic carbon content (McKeague *et al.*, 1971; Shields *et al.*, 1968).

Due to the nature of the classification system, soils placed in different orders can have nearly identical management interpretations (Riecken, 1962) and can have very similar morphologic features. Taxonomic purity of a map unit, therefore, perhaps should not be a major criterion for assessing the reliability (Bascomb and Jarvis, 1976) or "success" (Chittleborough, 1978) of a soil survey. Instead, a more useful criterion might be the "management purity" of a map unit, i.e., the proportion of soils which can be managed similarly. The Willakenzie map unit contained a management purity of 69 percent versus a taxonomic purity of 0 percent. The reporting of a 0 percent taxonomic purity may be misleading to the map user, because the map unit actually contains 69 percent soils that can be managed similarly to or more intensively than the Willakenzie. The map user is more likely to be interested in the management interpretations of a soil rather than in its taxonomic classification.

A percentage stating the reliability of the soil map for predicting specific soil properties such as texture, drainage, or slope could also be beneficial to the map user. Visible or easily measured soil properties like these are mapped correctly more often than a series or soil phase (Adams and Wilde, 1976a; Powell and Springer, 1965; Ragg and Henderson, 1980) which, by definition, includes an entire set of individual property values. Surface horizon texture, drainage, and slope were mapped correctly in 94, 54, and 100 percent of the pedons, respectively, at the series level and in 46, 74, and 54 percent of the pedons, respectively, at the soil phase level. Assessing the composition of map units in terms of individual soil properties may be quite practical considering the increased refinement of soil taxa in the past two decades. The rigid, quantitative class limits imposed by the system have resulted in soil maps that contain delineations encompassing soil complexes rather than taxonomic units with minor inclusions (Amos and Whiteside, 1975).

V. VARIABILITY WITHIN AND BETWEEN MAP UNIT DELINEATIONS

In a soil survey report, behavioral predictions and management interpretations of a soil are made for the map unit as a whole. A well-designed map unit is comprised of delineations having similar characteristics, or having minimum between-delineation variability, so that the published interpretations apply to a maximum percentage of the unit. To evaluate this aspect of map unit composition for the Willakenzie, four, 3-7 acre delineations were sampled along transects at 35 m intervals. This sampling scheme enabled a comparison of individual property variations along each transect at three different separation distances. It also provided a means by which the total variance of a property could be separated into its within and between delineation components through the analysis of variance procedure. The raw data measured in the four delineations are shown in Figures 23-33. In these figures, the transect lines approximate the slope profiles within each delineation, and the values of the property being illustrated are written below the sampling positions on each transect.

Statistical Methods

A technique suggested by Beckett and Bie (1976) was used to measure the variability of soil property values along the transect in each delineation. By inserting observed property values into the

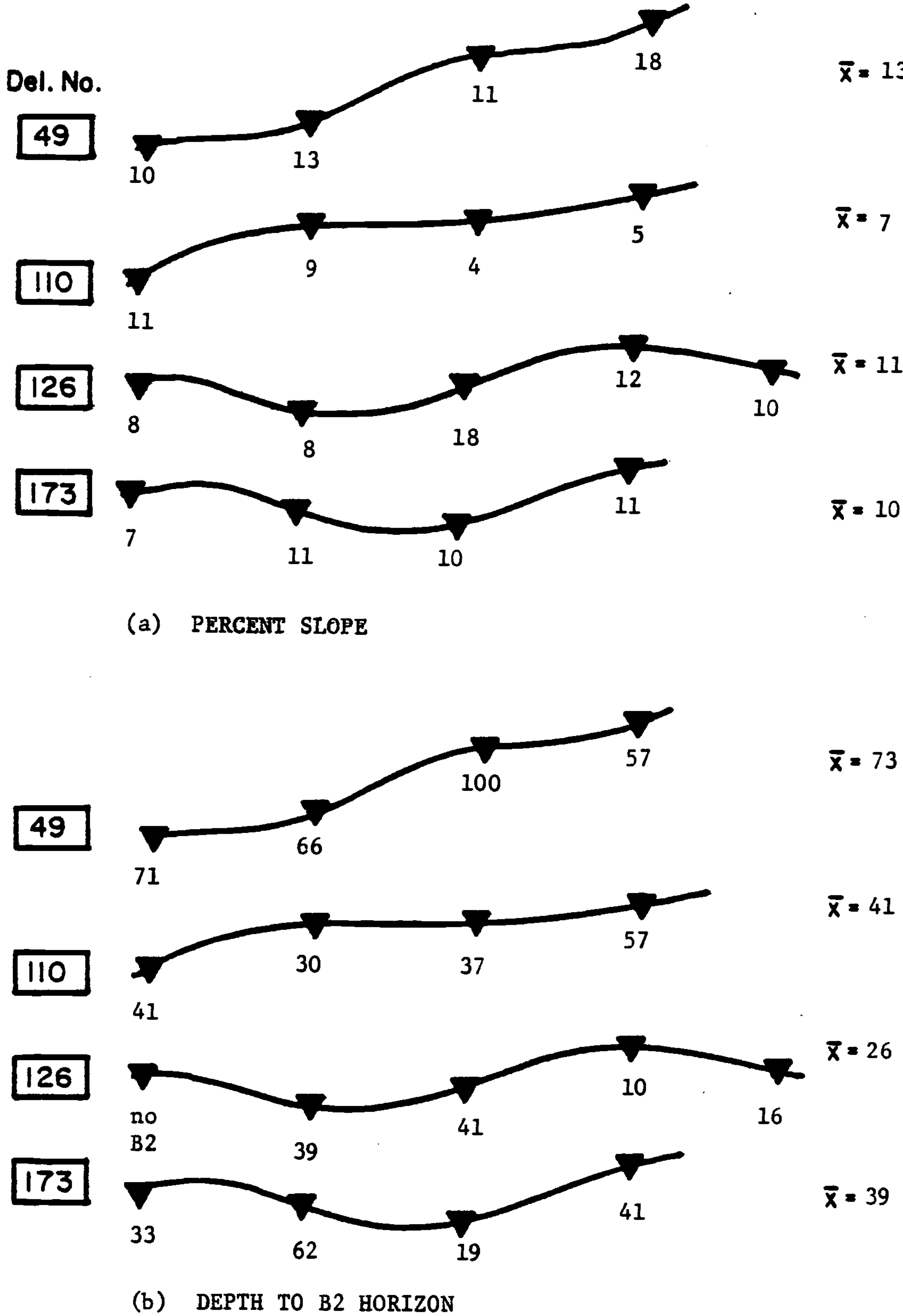
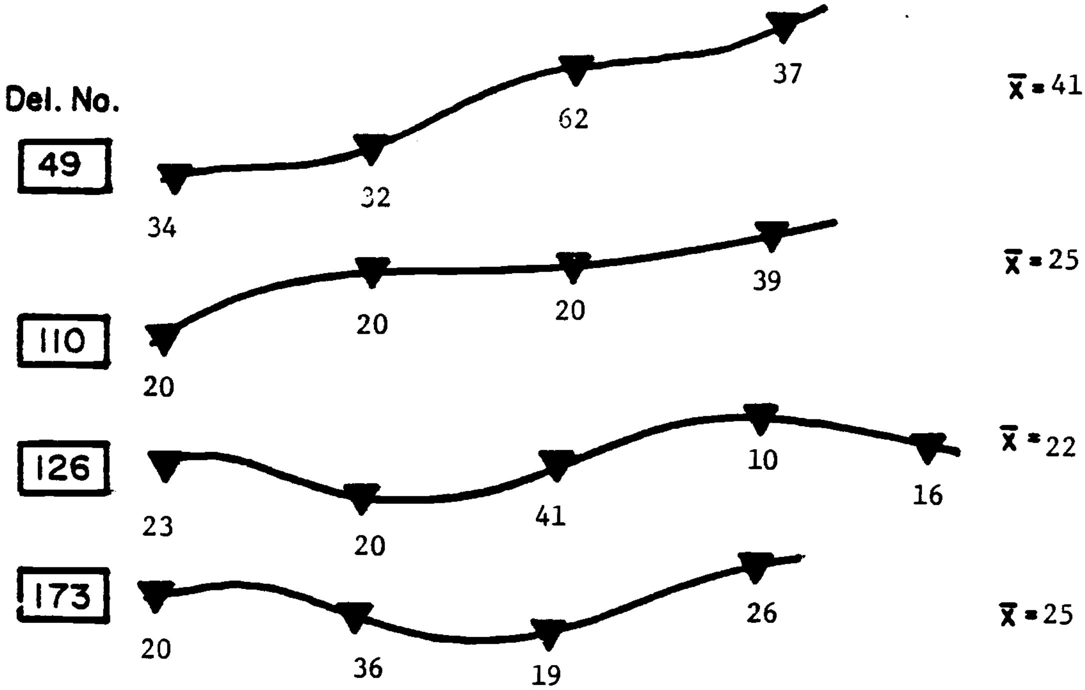
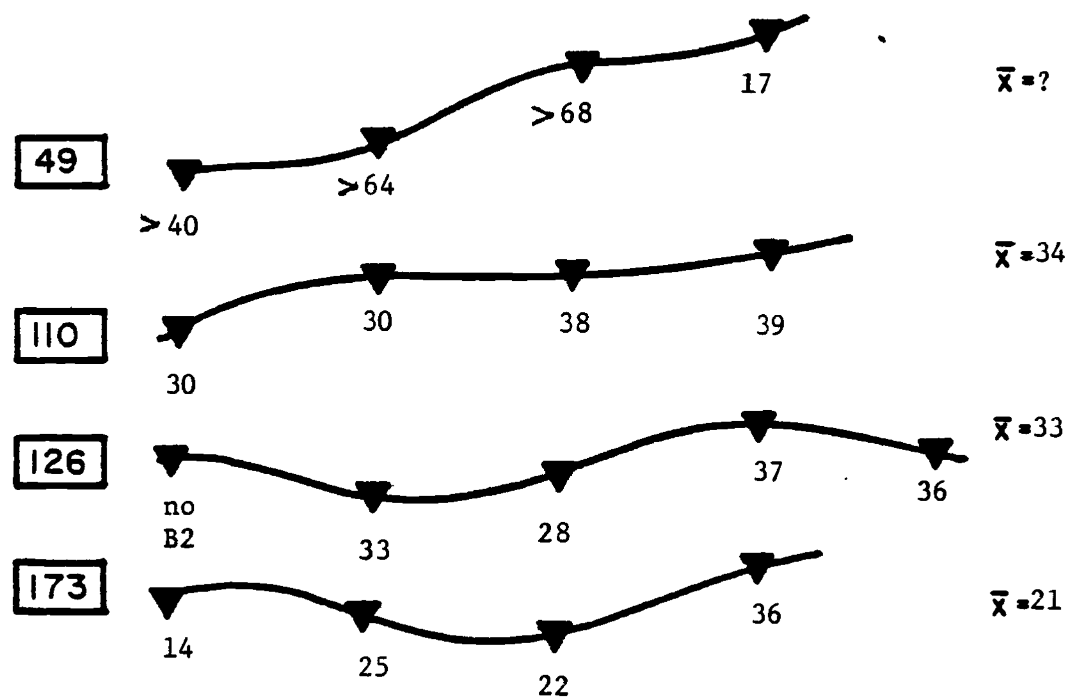


Figure 23: Observed values for (a) slope gradient and (b) depth to the B2 horizon (cm) along the four transects



(a) A1 HORIZON THICKNESS



(b) B2 HORIZON THICKNESS

Figure 24: Observed values for (a) A1 horizon thickness (cm) and (b) B2 horizon thickness (cm) along the four transects

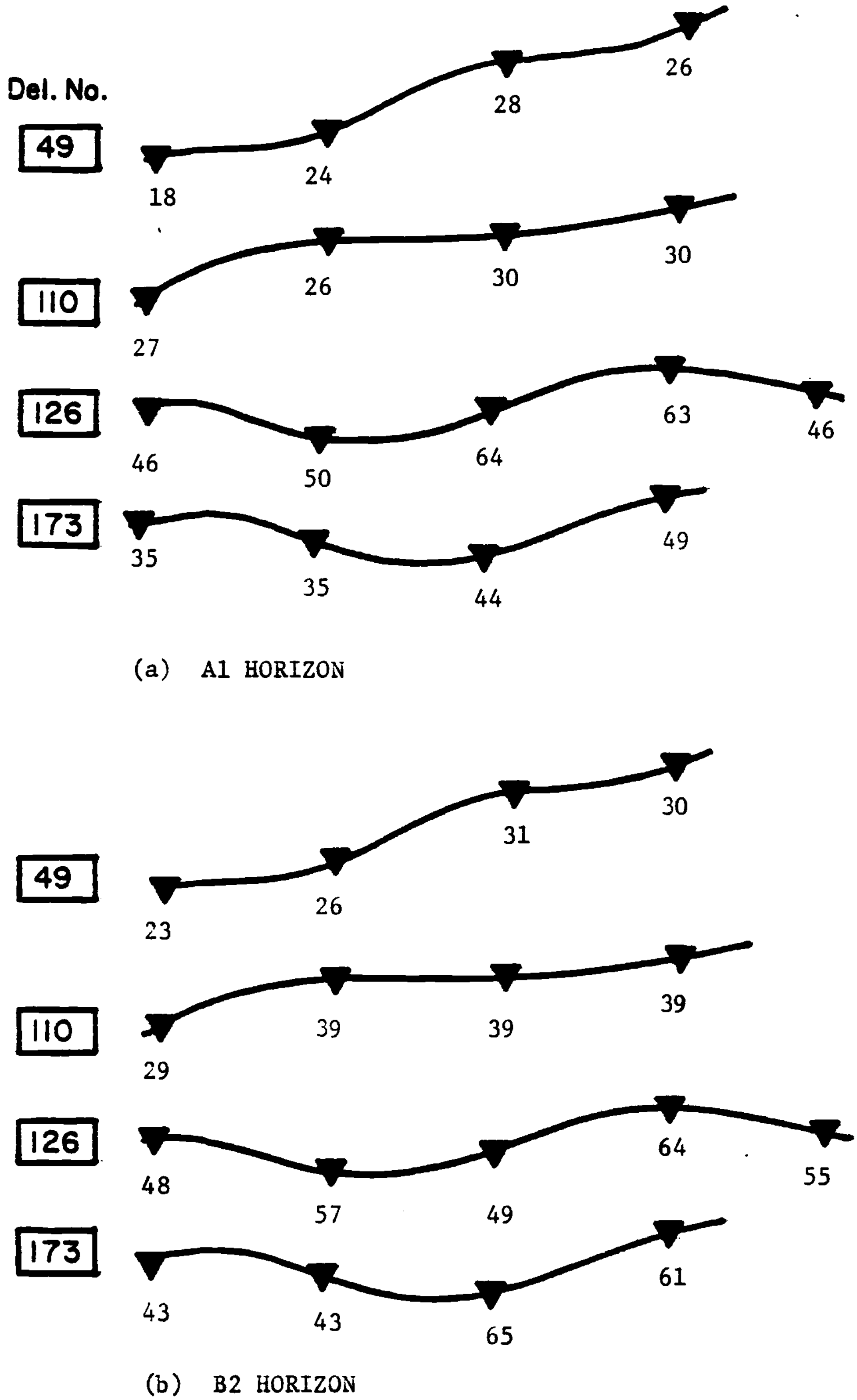


Figure 25: Observed values for percent clay in the (a) A1 horizon and (b) B2 horizon along the four transects

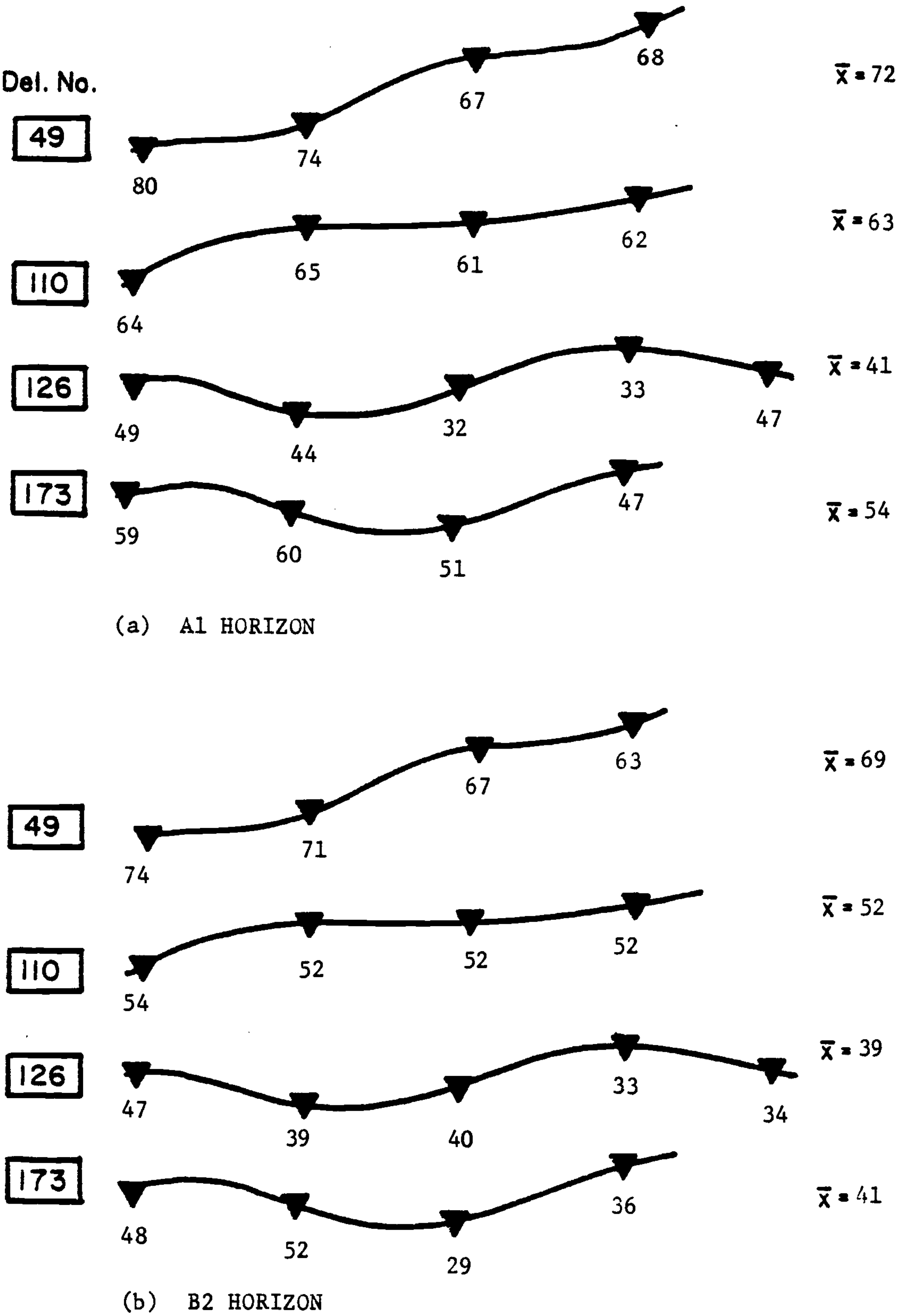


Figure 26: Observed values for percent silt in the (a) A1 horizon and (b) B2 horizon along the four transects

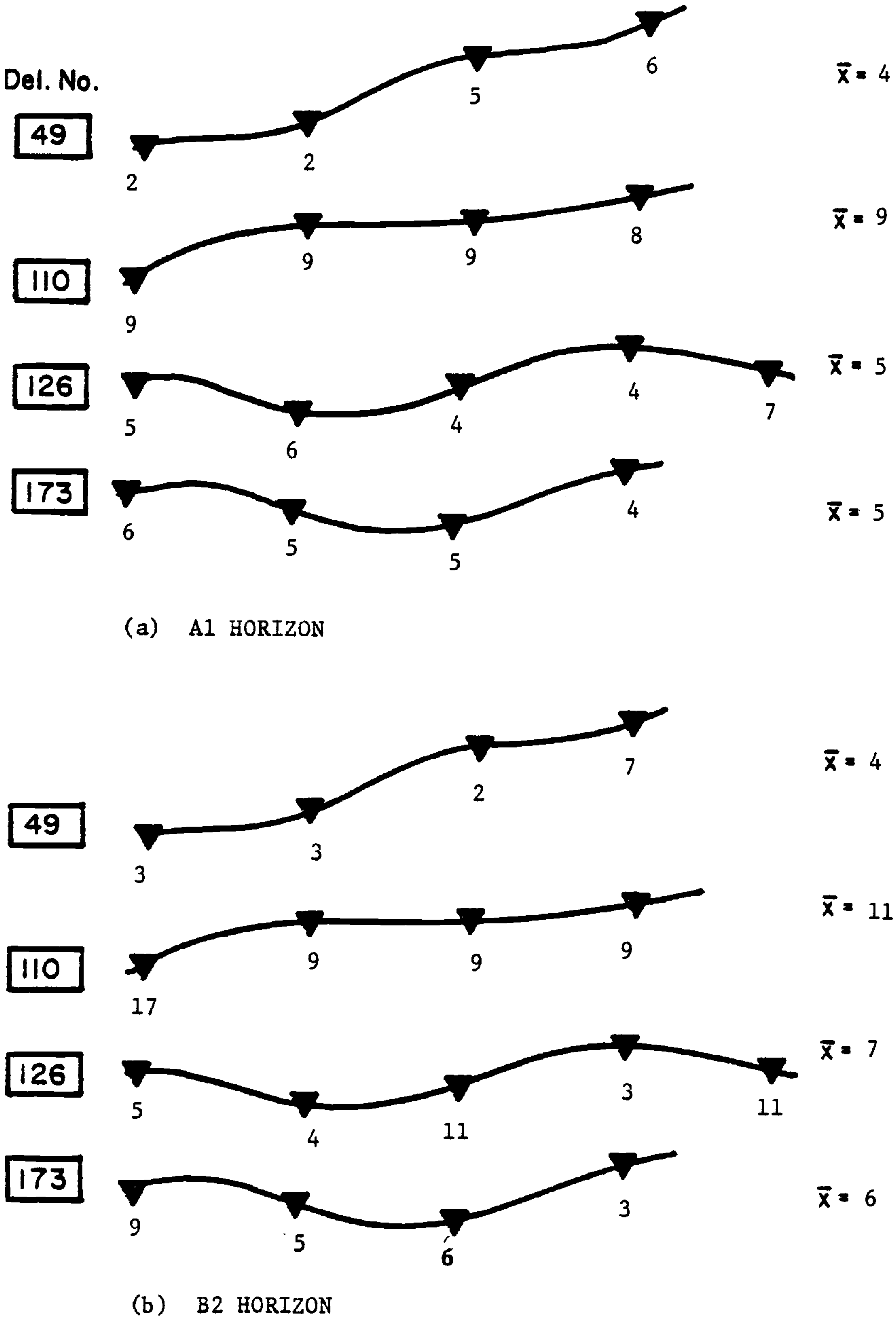
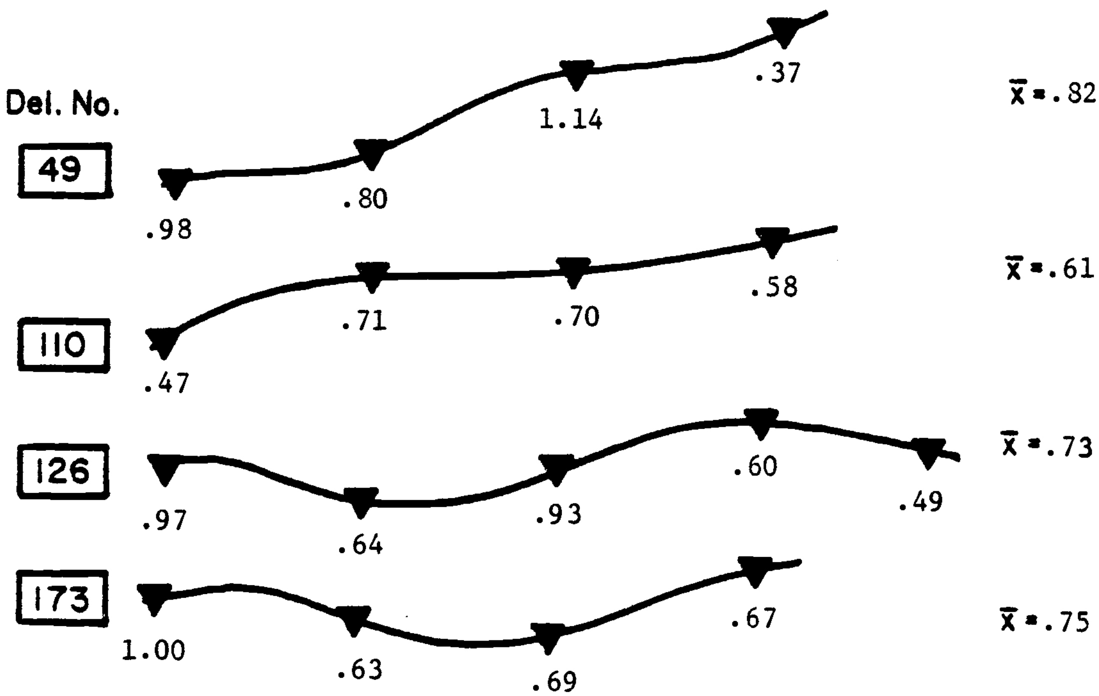
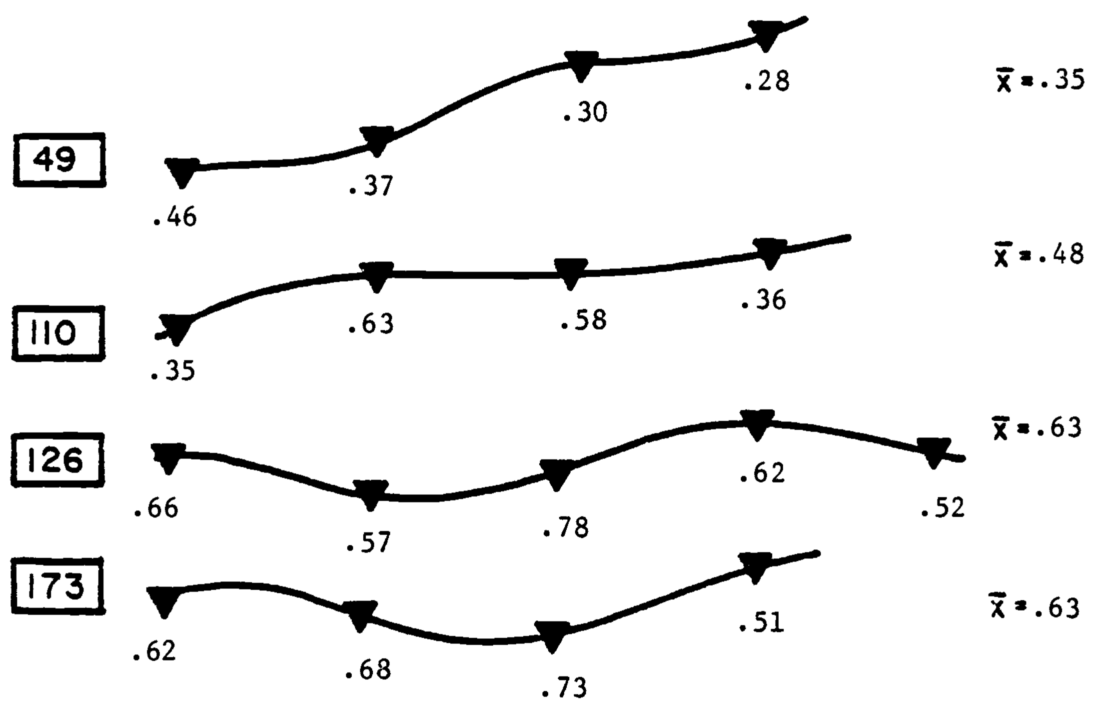


Figure 27: Observed values for percent sand in the (a) A1 horizon and (b) B2 horizon along the four transects



(a) A1 HORIZON



(b) B2 HORIZON

Figure 28: Observed values for meq/100gm of K^+ in the (a) A1 horizon and (b) B2 horizon along the four transects

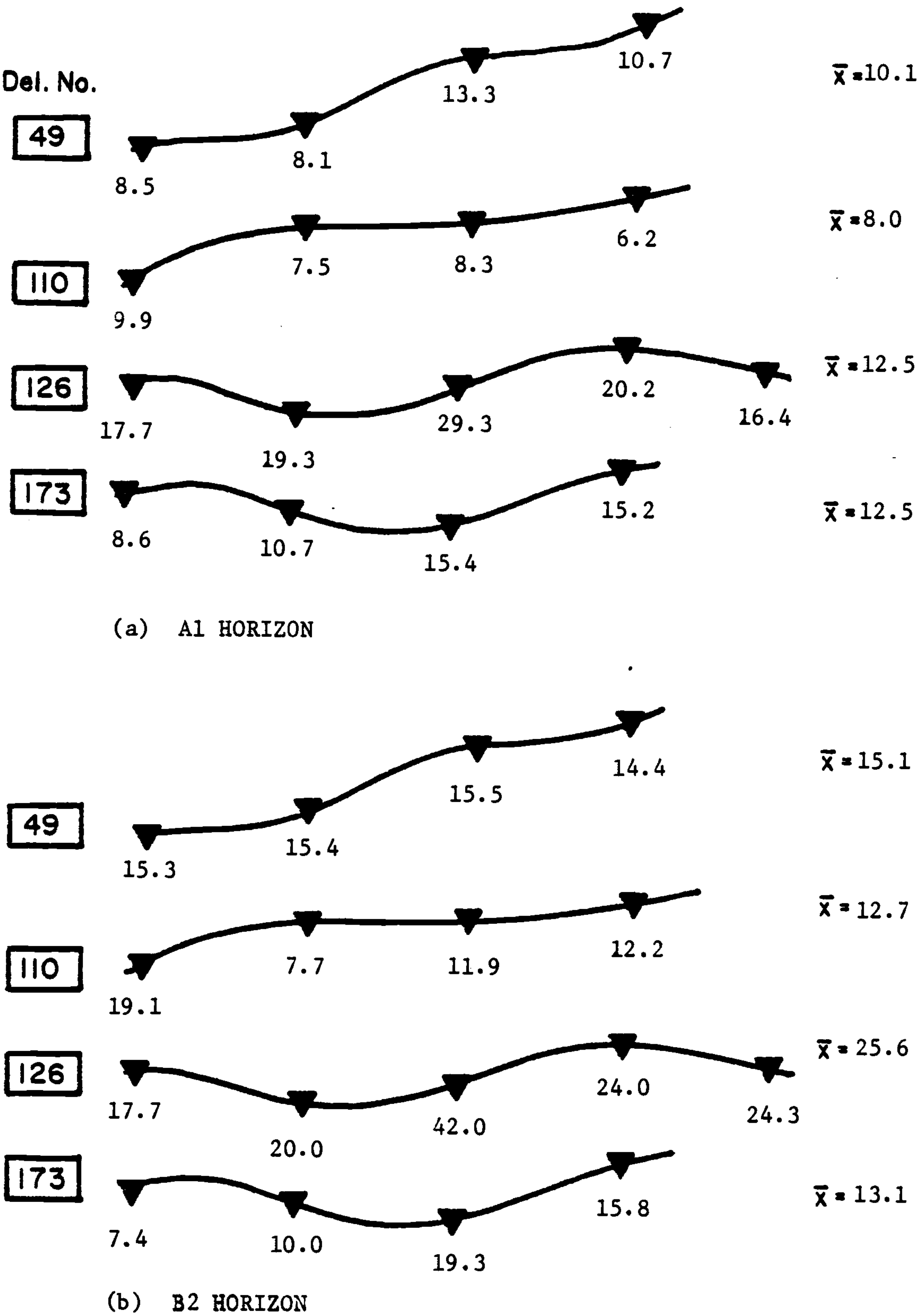
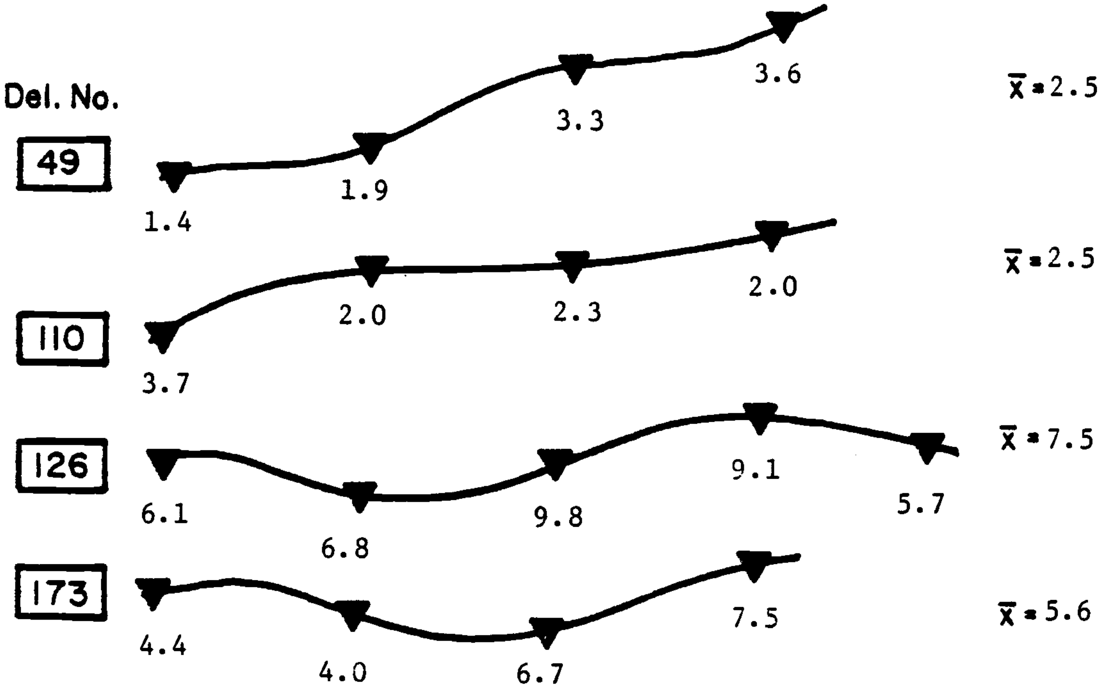
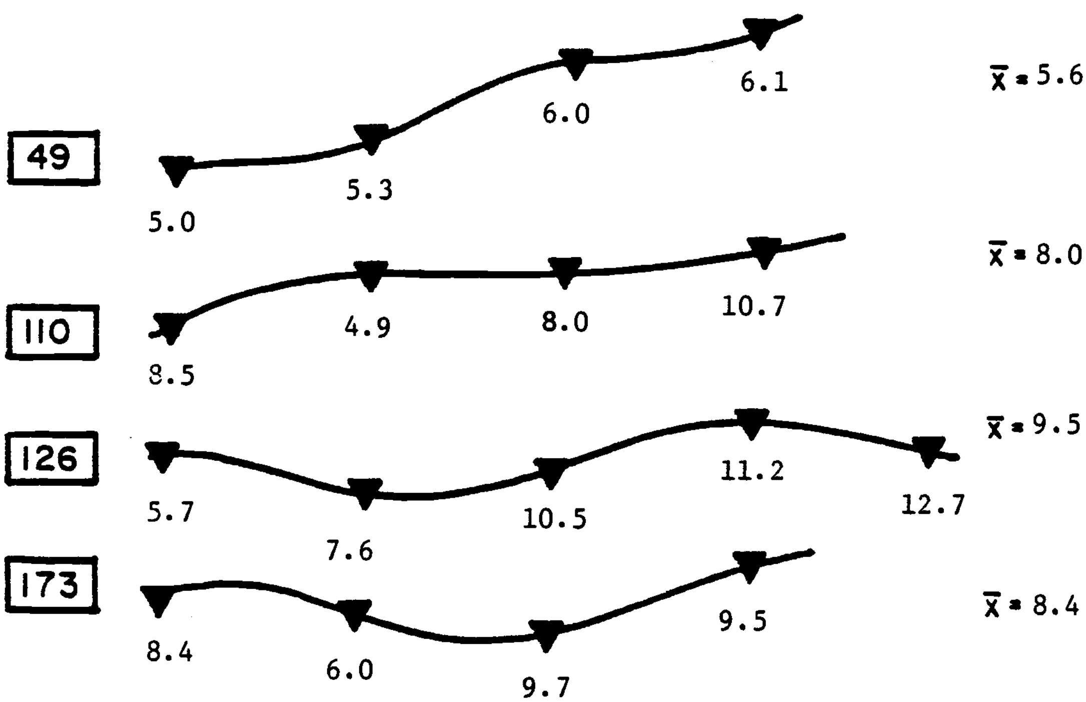


Figure 29: Observed values for meq/100gm of Ca^{++} in the (a) A1 horizon and (b) B2 horizon along the four transects

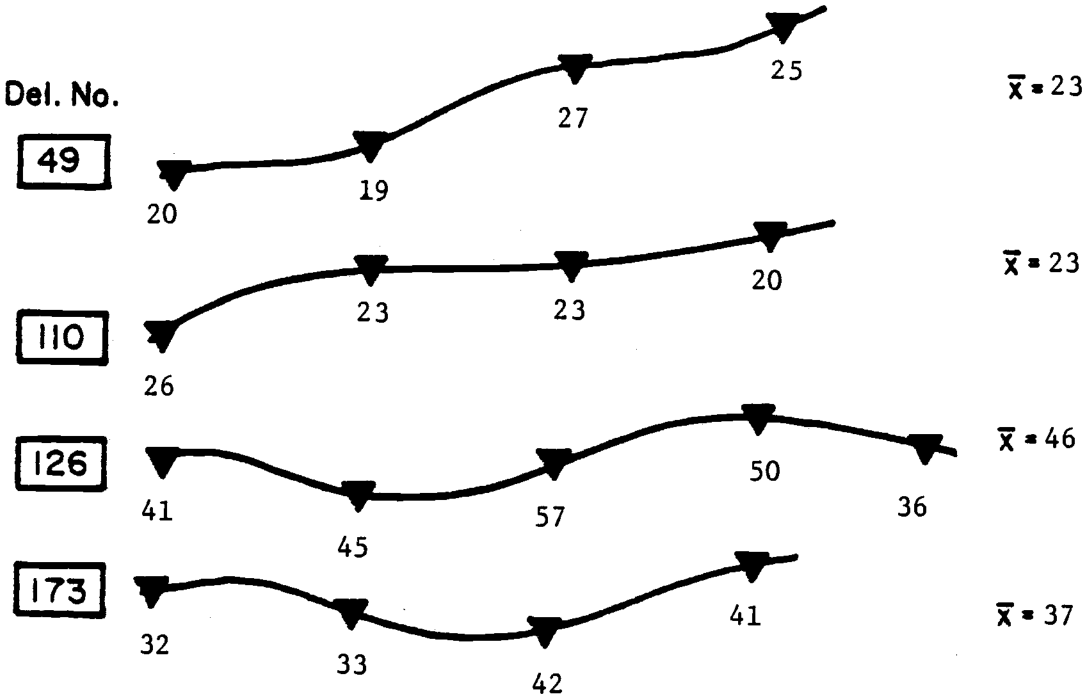


(a) A1 HORIZON

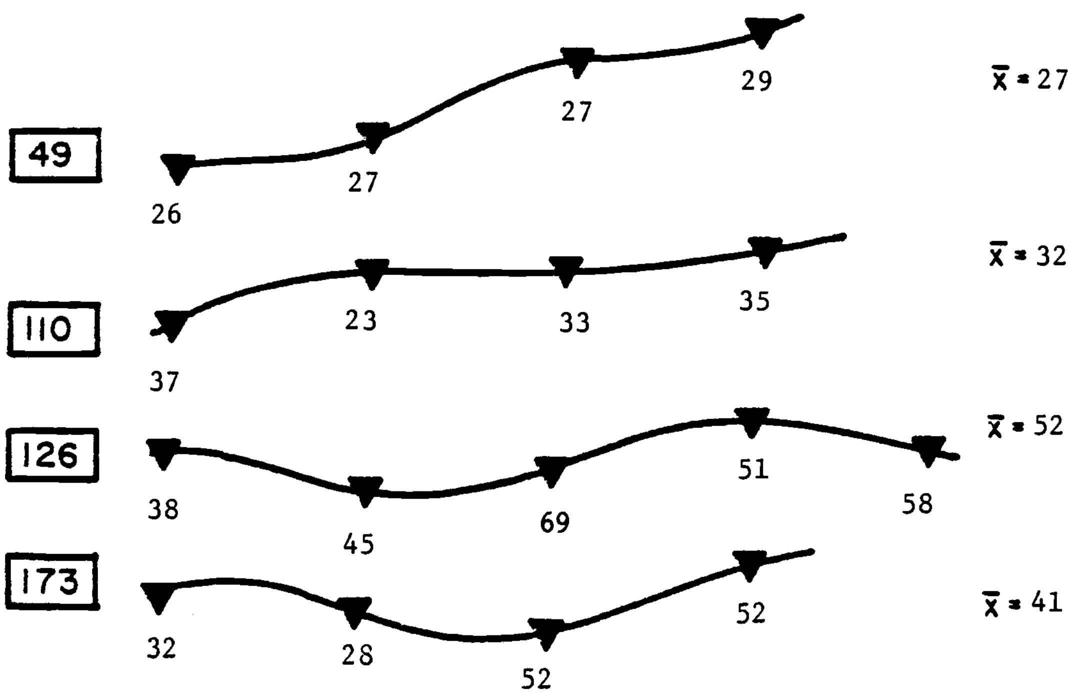


(b) B2 HORIZON

Figure 30: Observed values for meq/100gm of Mg^{++} in the (a) A1 horizon and (b) B2 horizon along the four transects

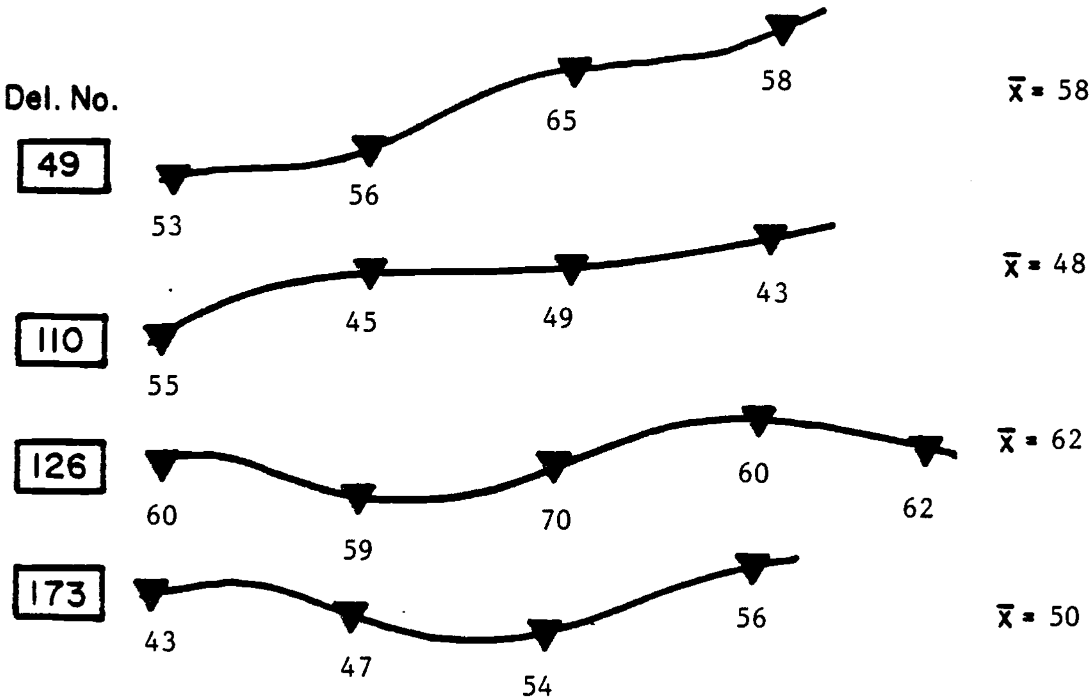


(a) A1 HORIZON

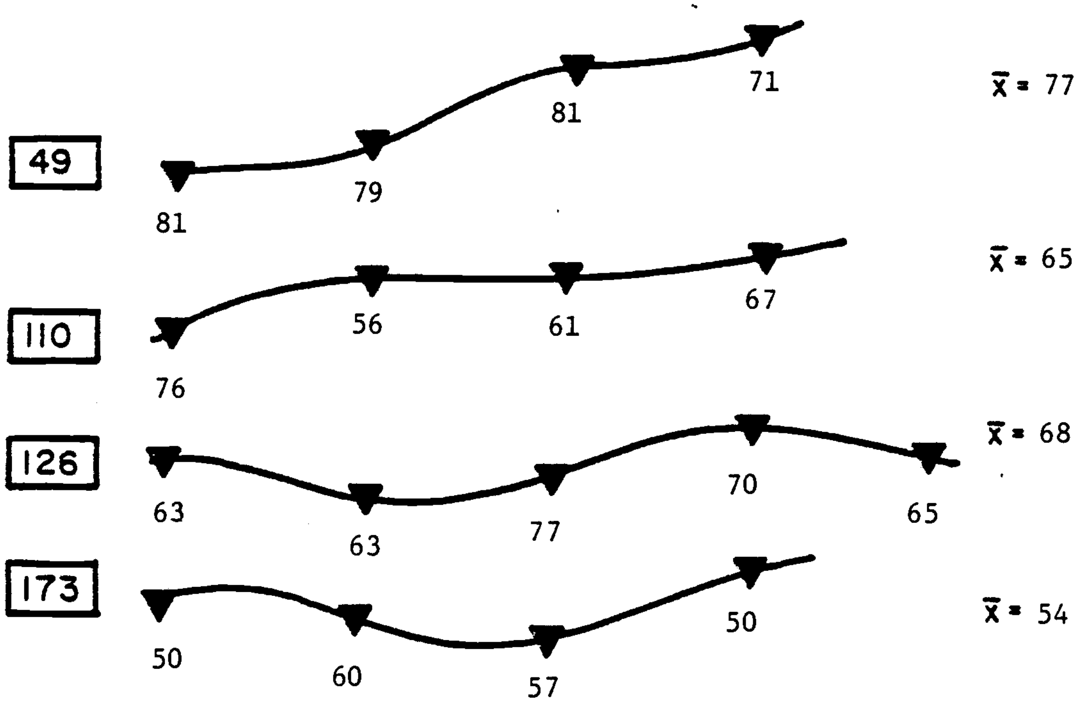


(b) B2 HORIZON

Figure 31: Observed values for meq/100gm of CEC in the (a) A1 horizon and (b) B2 horizon along the four transects



(a) A1 HORIZON



(b) B2 HORIZON

Figure 32: Observed values for percent base saturation (sum) in the (a) A1 horizon and (b) B2 horizon along the four transects

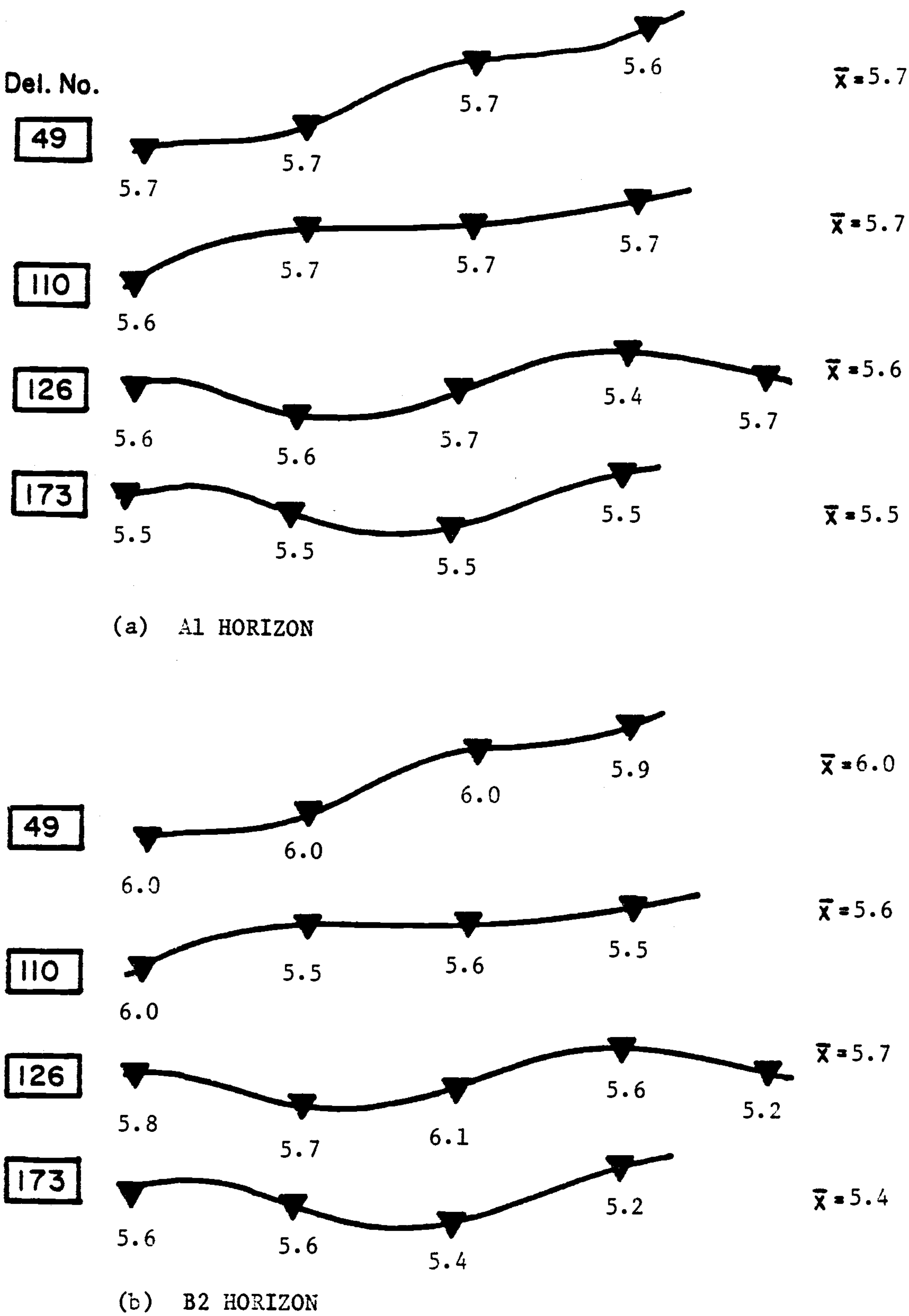


Figure 33: Observed values for pH in the (a) A1 horizon and (b) B2 horizon along the four transects

equation $s_p^2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{p} (\bar{x}_j - x_{ij})^2}{(m - n + 1)(n - 1)}$, a comparison between the pooled variances (s_p^2) of each property at three separation distances was possible. In the equation, m represents the total number of sampling sites along the transect for which the variance is being pooled, and p is the number of sets of sites for which the variance is being pooled. For example, in delineation no.'s 49, 110, and 173, which contain 4 sampling sites each, m=4, n=2, and p=3 when the pooled variance of property values 35 m apart is calculated. When the pooled variance of the three successive values within a 70 m distance is calculated, m=4, n=3, and p=2, because there are 2 overlapping sets of 3 values each which are used to obtain s_p^2. Likewise, m=4, n=4, and p=1 when the pooled variance of values within a 105 m distance is calculated, because values at every site along the transect are used. The transect in delineation no. 126 contains 5 sampling sites and thus, m=5 and n=2, 3, 4, and 5, respectively, and p=4, 3, 2, and 1, respectively, for the 35, 70, 105, and 140 m separation distances. Yates (1948) suggested that calculating variances from overlapping sets in this way is more accurate than calculating from separate halves or quarters of the transect. The disadvantage to this procedure is that the central sites within each transect tend to be over-represented in the pooled variance for distances containing more than m/2 sites (Beckett and Bie, 1976).

A one-way analysis of variance was performed on the transect data to calculate the components of variance associated with the within and between delineation sources of variation and to test for differences in the means of soil properties between the four delineations. The estimation of the expected mean squares for each source (Table 11) was based on a random effects model (Webster, 1977; Snedecor and Cochran, 1967). The model assumes normal property distributions and equal sample variances. Because the latter assumption was particularly important for the calculation of F ratios, Bartlett's test for homogeneity of variance (Snedecor and Cochran, 1967) was applied so that the properties having unequal variances between delineations could be determined. This test showed that the variances of two properties, exchangeable Ca^{++} and CEC in the B2 horizon, differed significantly between delineations. The significant differences in variances were due to the extremely low variances for exchangeable Ca^{++} and CEC in delineation no. 49 in relation to the high variances for the properties in delineation no.'s 110, 126 and 173. The variances for exchangeable Ca^{++} in delineation no.'s 49, 110, 126, and 173, respectively, were 0.26, 25.2, 91.7, and 29.3; the variances for CEC in the four delineations were 2.1, 36.6, 142.9, and 159.6. In the case of the significantly skewed data, the calculation of F ratios presumably would have violated the assumption of normality, on which the analysis of variance is based. However, Sheffe (1959) has indicated that the skewness of the property distribution has little effect on the analysis of variance results, providing the classes being compared have equal sample sizes. Therefore, F ratios were calculated for all properties except exchangeable Ca^{++} and CEC in the B2 horizon. Components of variance were calculated for all properties, regardless of

Table 11. One-Way Analysis of Variance Used for Calculating F Values and Components of Variance.

Source of Variation	df	Sum of Squares	Mean Square	Expected Mean Square
Between Delineations	$(a-1) = 3$	$\Sigma 4(\bar{x}-\bar{\bar{x}})^2 = SS_B$	$SS_B/3 = MS_B$	$\sigma^2 + 4\sigma_B^2$
Within Delineations	$a(n-1) = 12$	$\Sigma\Sigma(x-\bar{x})^2 = SS_W$	$SS_W/12 = MS_W$	σ^2
Total	$(N-1) = 15$	$\Sigma(x-\bar{\bar{x}})^2 = SS_T$		

a: number of delineations
n: number of sites within a delineation
N: total number of sites

σ^2: variance component due to differences within delineations
σ_B^2: variance component due to differences between delineations

$F = MS_B/MS_W$ with null hypothesis, H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4$

$F_{critical\ .95(3,12)} = 3.49$

$F_{critical\ .99(3,12)} = 5.95$

the variance differences or shape of the property distributions, because these deviations from the model assumptions were not critical for the estimation procedure.[16]

Variability Along A Transect Within Delineations

The importance of spatial effects on soil property variability has been recognized by many authors (Ball and Williams, 1968; Cline, 1944; Reed and Rigney, 1947), especially in relation to soil sampling procedures. Beckett and Bie's (1976) pooled variance technique was applied to the transect data to determine the amount of spatial variability within the four delineations. Values of s_p^2 for the 35, 70, 105, and 140 m separation distances in each of the delineations are listed in Table 12 for 22 soil properties. The distance at which maximum and minimum variability occurred for each property can be observed from the graphs of s_p^2 versus distance in Figures 34-39. In Figure 34, for example, the slope gradient varied more over a 70 m distance than over a 35, 105, or 140 m distance within delineation no. 126. In the other three delineations, maximum variability occurred within a 105 m distance. Heterogeneity in the shapes of the four curves was typical for all the soil properties. Maximum variation usually occurred within both a 70 m and a 105 m distance, in different transects, for any given property.

Despite the apparent inconsistencies present in the shapes of the curves for all the properties, some trends can be observed in the

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[16] R. Peterson. Dept. of Statistics. Oregon State University, Corvallis, Oregon. Personal Communication.

Table 12. Pooled Variances of Soil Properties at 35, 70, 105, and 140 m distances

Del. No.	Distance	Slope	A1 Thick	B2 Thick	Depth to B2	Clay (A1)	Clay (B2)	Silt (A1)	Silt (B2)	Sand (A1)	Sand (B2)	K^+ (A1)	K^+ (B2)	Ca^{++} (A1)	Ca^{++} (B2)	Mg^{++} (A1)	Mg^{++} (B2)	CEC (A1)	CEC (B2)	B.S. (A1)	B.S. (B2)	pH (A1)	pH (B2)
		Soil Property																					
	---m---	-%-	---------cm---------			------------------%------------------						------------------meq------------------								----%----			
49	35	10.3	254.8	*	505	9.3	5.8	14.3	6.8	1.70	4.3	.123	.002	5.7	0.2	0.38	0.10	11.5	0.8	23.2	18.0	.002	0
	70	7.7	269.8	*	426	15.0	11.7	28.3	14.1	3.70	3.6	.149	.011	7.6	0.2	0.89	0.65	18.2	0.7	20.6	14.6	.002	0
	105	12.7	195.6	*	120	18.7	13.6	36.3	22.9	4.30	4.9	.110	.006	5.7	0.2	1.13	0.29	14.9	1.6	26.0	22.7	.003	0
110	35	5.0	60.2	10.8	95	2.8	16.7	3.0	0.7	0.17	10.8	.012	.021	1.8	22.8	0.51	4.97	2.8	50.0	25.3	76.8	.002	.04
	70	10.0	10.9	17.0	113	4.8	16.6	4.3	0.7	0.17	10.8	.031	.021	1.1	18.2	0.42	6.31	3.0	46.7	64.0	69.3	.002	.03
	105	10.9	89.8	24.2	130	4.2	25.0	3.3	1.0	0.27	17.6	.013	.021	2.4	20.9	0.66	5.72	6.0	38.7	28.0	74.0	.003	.06
126	35	17.5	180.9	152.5	167	59.4	56.4	45.7	14.4	1.75	22.2	.039	.011	25.0	101.5	2.69	1.84	49.5	124.7	28.2	33.7	.025	.07
	70	26.3	216.7	120.3	286	84.3	45.9	63.6	15.9	1.80	18.2	.052	.010	38.0	141.0	3.71	3.58	73.3	167.5	34.0	50.2	.019	.11
	105	20.5	174.1	148.3	250	83.2	47.3	63.8	22.6	1.60	16.0	.036	.010	29.1	108.5	3.43	4.47	62.8	141.3	25.9	41.9	.020	.09
	140	17.2	136.5	**	**	81.2	42.3	63.5	31.3	1.70	15.2	.090	.007	25.9	90.8	3.38	8.04	65.7	142.7	20.1	35.8	.017	.11
173	35	3.0	99.0	23.2	529	17.6	83.3	16.3	99.0	0.33	4.3	.023	.009	4.4	16.5	1.35	3.25	14.5	98.7	11.5	26.3	0	.01
	70	2.3	82.0	17.7	472	38.7	68.7	34.3	145.0	0.35	3.3	.020	.008	9.6	30.0	2.74	3.92	27.3	178.6	26.6	26.3	0	.03
	105	3.6	60.5	27.0	323	25.9	136.0	39.6	112.9	0.67	6.3	.028	.009	11.4	30.0	2.93	2.89	27.3	164.0	36.7	25.6	0	.04

*unknown thickness values

**one pedon contained an AC horizon

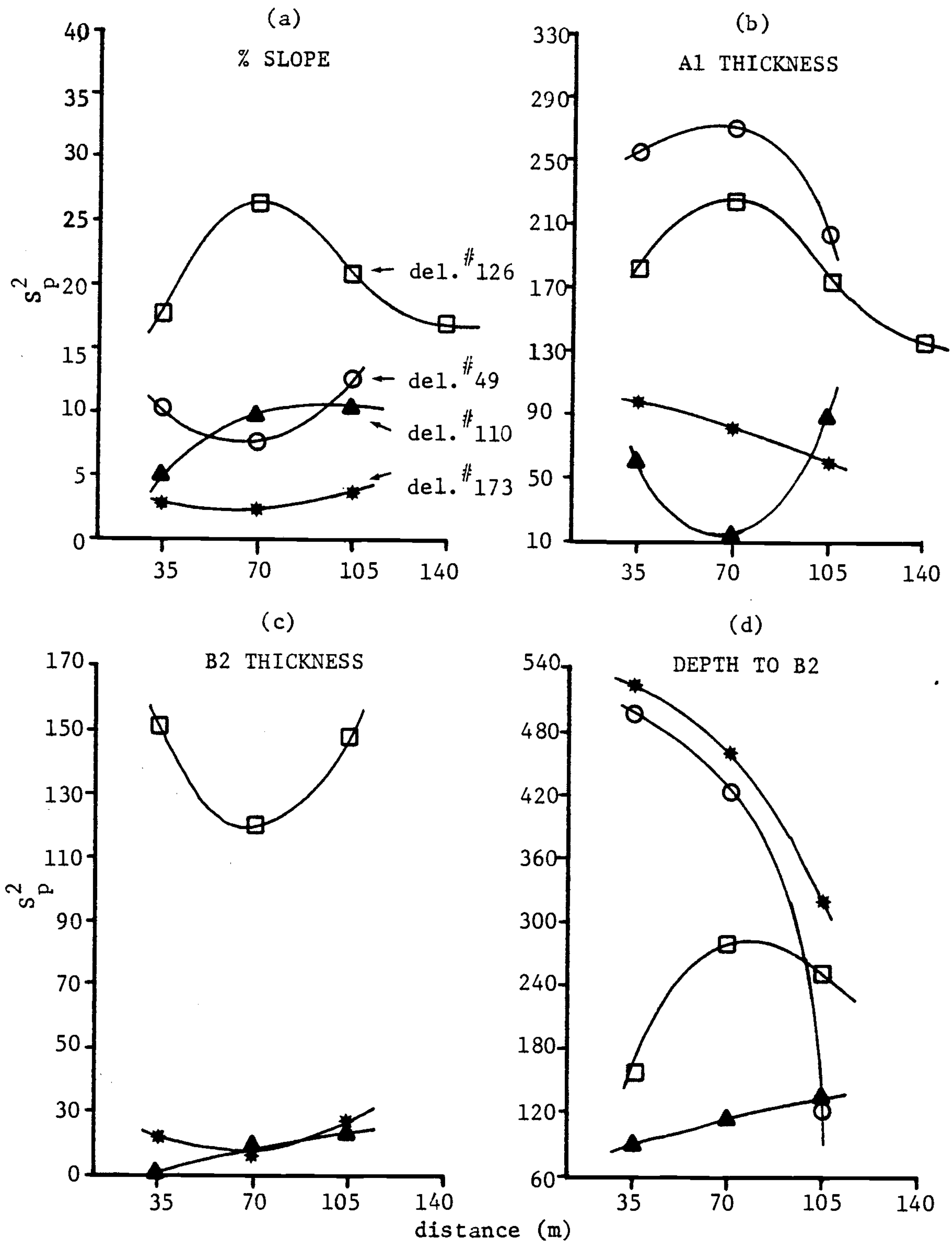


Figure 34: The pooled variances of (a) percent slope, (b) A1 thickness, (c) B2 thickness, and (d) depth to the B2 horizon versus distance for each of the four transects

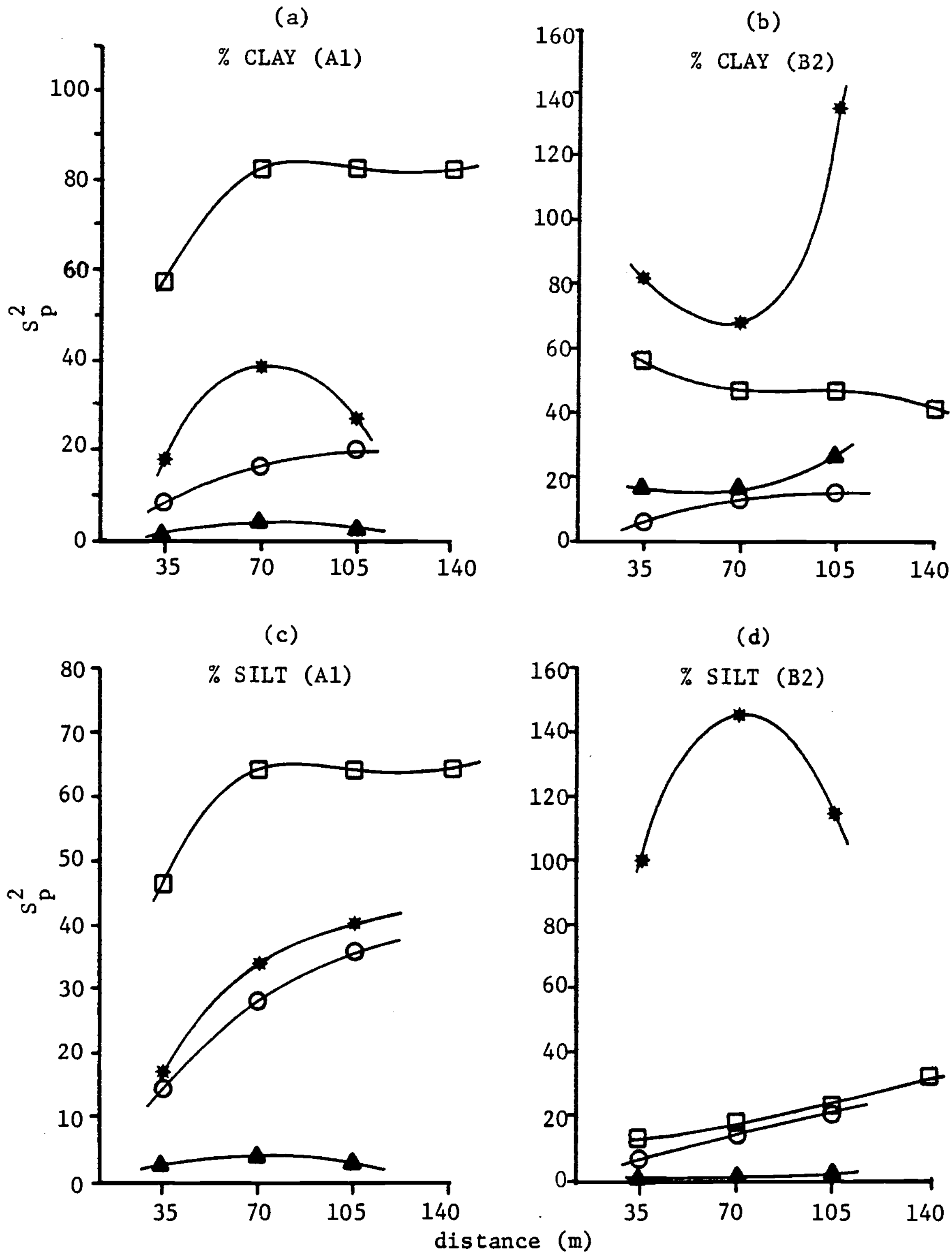
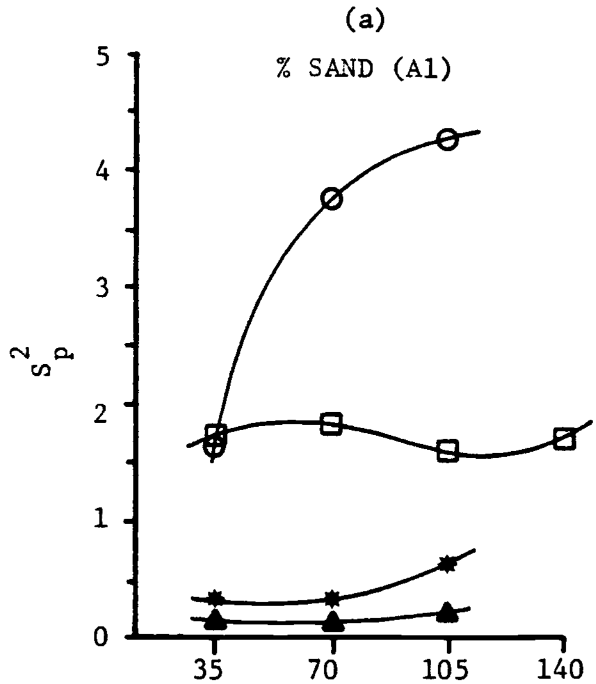


Figure 35: The pooled variances of percent clay in the (a) A1 horizon and (b) B2 horizon and of percent silt in the (c) A1 horizon and (d) B2 horizon versus distance for each of the four transects



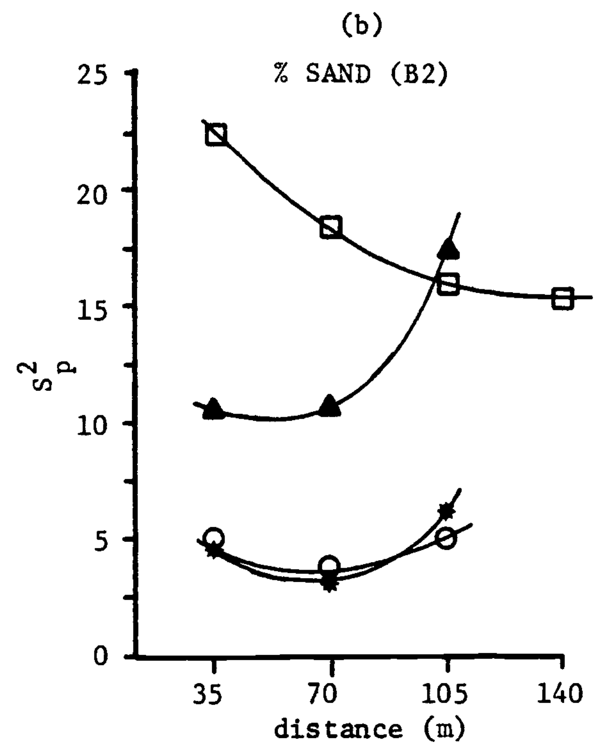


Figure 36: The pooled variances of percent sand in the (a) A1 horizon and (b) B2 horizon versus distance for each of the four transects

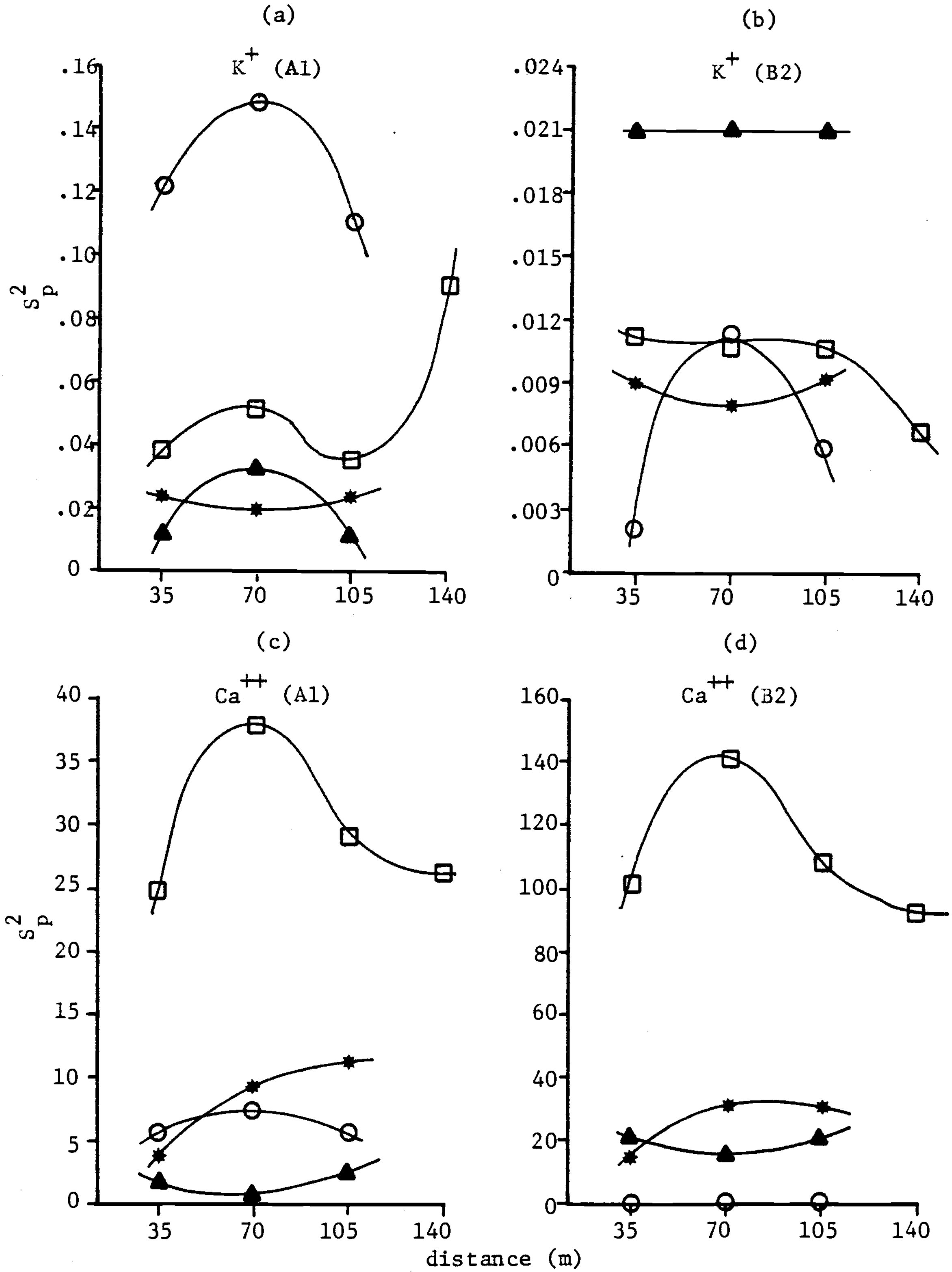


Figure 37: The pooled variances of meq/100gm of K^+ in the (a) A1 horizon and (b) B2 horizon and of meq/100gm of Ca^{++} in the (c) A1 horizon and (d) B2 horizon versus distance for each of the four transects

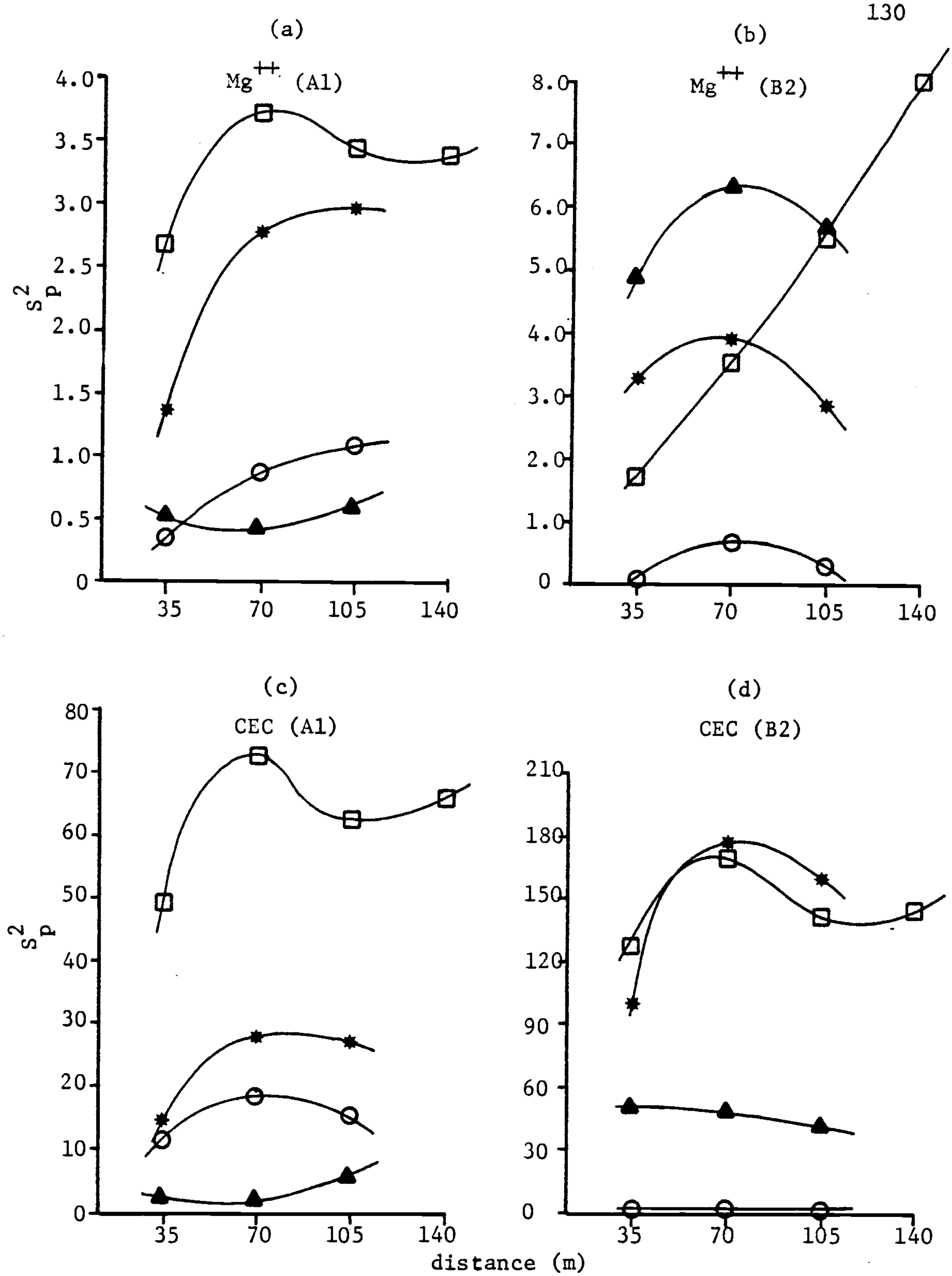


Figure 38: The pooled variances of meq/100gm of Mg^{++} in the (a) A1 horizon and (b) B2 horizon and of CEC in the (c) A1 horizon and (d) B2 horizon versus distance for each of the four transects

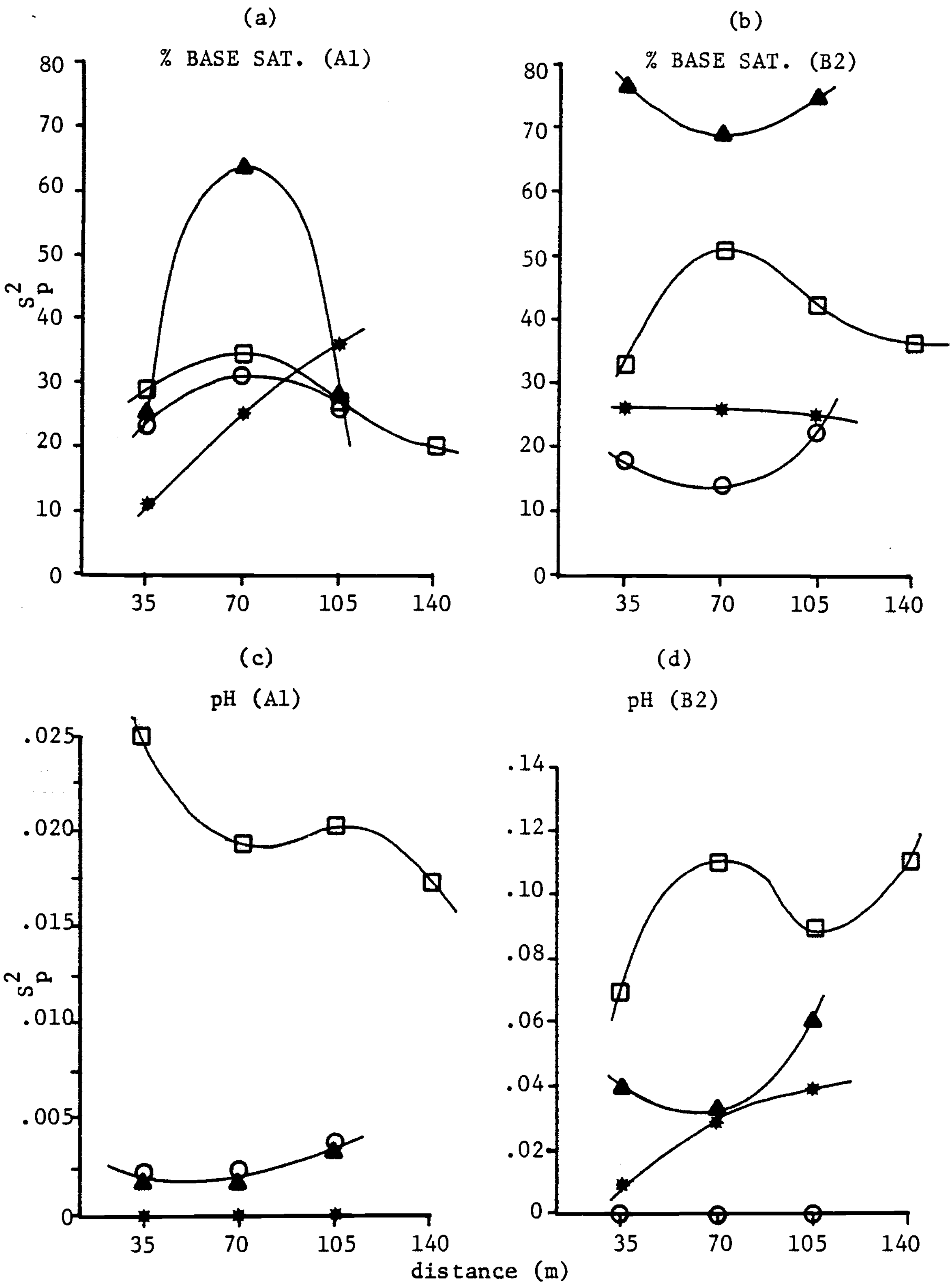


Figure 39: The pooled variances of percent base saturation (sum) in the (a) A1 horizon and (b) B2 horizon and of pH in the (c) A1 horizon and (d) B2 horizon versus distance for each of the four transects

relationships between pooled variance and distance. (These observed trends do not take into account the 140 m distance within delineation no. 126--it is discussed separately). The chemical properties, as a group, tended to have maximum pooled variances within the 70 m distance, whereas the physical properties, as a group, tended to have maximum pooled variances within the 105 m distance. Approximately 35 percent of the chemical properties in all the transects (Figures 37-39) achieved maximum variability within the 105 m distance, 53 percent had maximum variances within the 70 m distance, and 12 percent had maximum variances within the 35 m distance. In contrast, approximately 61 percent of the physical properties in all the transects (Figures 35 and 36) achieved maximum variability within the 105 m distance, 30 percent had maximum variances within the 70 m distance, and 9 percent had maximum variances within the 35 m distance. Trends were not as distinct for morphologic properties (Figure 34). Forty-two percent had maximum variances within 105 m, 33 percent within 70 m, and 25 percent within 35 m.

Minimum variability was achieved within 35 m for 55 percent of the chemical and 70 percent of the physical properties. Twenty-four and 19 percent of the chemical and physical properties, respectively, obtained minimum variances within the 70 m distance, and 21 and 11 percent of the chemical and physical properties, respectively, obtained minimum variances within the 105 m distance. The morphologic properties did not exhibit distinct trends. Thirty-three percent had minimum variances within 35 m, 25 percent within 70 m, and 42 percent within 105 m.

No consistent trends were observed between the pooled variances of soil properties and the 140 m distance within delineation no. 126. The pooled variance for the 140 m distance was actually the minimum s_p^2 value for 38 percent of the soil properties, and it was the maximum s_p^2 value in 14 percent.

It is unclear why the variances of some of the properties increase with distance and why some decrease with distance. It is even more difficult to understand why some properties first increase and then decrease (or vice-versa) with distance. The skewness or the CV of the soil property distribution does not explain the shapes of the graph, because no relationship was found when these statistics were compared to the various shapes. Beckett and Bie (1976) found similarly shaped graphs in their transect studies, although they concluded that variance generally increased with distance when the individual transects were plotted on one graph. Their transects varied in length from 180 m to 1450 km.

High variances within the 35 m distance suggest that the property is highly variable within relatively short distances along the transect, whereas increasing variances with distance suggest that the property changes more gradually across the landscape. The tendency for chemical properties to have high variances within the 70 m distance substantiates the results of many other researchers (Ball and Williams, 1968; Cameron _et al_., 1971; Downes and Beckwith, 1951; Reed and Rigney, 1947), who found chemical properties to display large differences over distances of centimeters and meters.

The pooled variance analysis is a useful procedure in that it gives the researcher an idea of the distances over which different property variabilities occur. Beckett and Bie (1976) calculated the maximum spacing between soil boundaries by this method during soil survey reconnaissance procedures. The distance that corresponded to the desired level of property variance (or s_p^2) was the maximum spacing between boundaries. The interpretations of the transects within the four Willakenzie delineations are limited by their relatively short lengths and by the distances between sampling sites. They do not traverse enough of the landscape to provide information on the optimum spacing of delineation boundaries, and the sampling intervals are spaced too far apart to be of practical use for designing intensive sampling schemes within a delineation.

Within Delineation Versus Between Delineation Variability

The uniformity of soil properties within and between map unit delineations was assessed by the analysis of variance technique. Table 13 lists the components of variance for each soil property along with F ratios, which test for significant differences between the delineation means. Sixty-one percent of the 23 properties measured had higher between delineation variance components than within delineation components (Table 13, Part I). The properties that varied most highly between delineations (based on F ratios > 10.00) were sand, silt, and clay content in the A1 horizon, silt and clay content in the B2 horizon, exchangeable Ca^{++} and Mg^{++} in the A1 horizon, and CEC in the A1 horizon.

Table 13. Within and Between Delineation Variance Components and ANOVA F Ratios for Selected Soil Properties.

I. Soil Properties Exhibiting High Between Delineation Variance Components

Soil Property	Within Del. Component	Betw. Del. Component	F Ratio
	--------%	--------	
Morphologic Properties			
Depth to B2 Horizon	44	56	6.14**
B2 Horizon Thickness	33	67	9.09**
Physical Properties			
% Sand (A1)	26	74	12.65**
% Silt (A1)	17	83	20.86**
% Clay (A1)	17	83	21.15**
% Silt (A1)	20	80	16.91**
% Clay (B2)	27	73	11.88**
Chemical Properties			
meq/100 g Ca^{++} (A1)	26	74	12.32**
meq/100 g Mg^{++} (A1)	23	77	14.16**
% Base Sat. (A1)	44	56	6.11**
CEC (A1)	14	86	25.41**
meq/100 g K^{+} (B2)	39	61	7.29**
% Base Sat. (B2)	32	68	9.59**
pH (B2)	47	53	5.59*

*F ratio is significant at 5% level.

**F ratio is significant at 1% level.

Table 13. Continued.

II. Soil Properties Exhibiting High Within Delineation Variance Components

Soil Property	Within Del. Component	Betw. Del. Component	F Ratio
	----------%----------		
Morphologic Properties			
% Slope	80	20	1.97
A1 Horizon Thickness	77	23	2.20
Mollic Ep. Thickness*	55	45	3.42
Physical Properties			
% Sand (B2)	62	38	3.42
Chemical Properties			
pH (A1)	54	46	4.43‡
meq/100 g K^{+} (A1)	100	0	0.69
meq/100 g Ca^{++} (B2)†	61	39	--
meq/100 g Mg^{++} (B2)	78	22	2.11
CEC (B2)†	52	48	--

*Three sites within each of the 4 delineations contained mollic epipedons

†F ratios were not calculated due to significant differences in the variances between the 4 delineations (by Bartlett's Test for Homogeneity of Variances).

‡F ratio is significant at 5% level.

The opposite situation occurred for properties such as slope gradient, A1 horizon thickness, mollic thickness, exchangeable K^+ in the A1 horizon, and exchangeable Mg^{++} in the B2 horizon, whose delineation means differed insignificantly (Table 13, Part II). The majority of the variation in these can be attributed to differences within each of the delineations. In the case of K^+ in the A1 horizon, virtually all the variability occurs within delineations.

No relationships between the variance components and the soil property statistics, such as the skewness, CV, variance, or pooled variance over distance, could be detected in the data. Physical properties tended to have greater between delineation components. Morphologic and chemical properties were just as likely to have high between delineation components as high within delineation components. Both Wicherski (1980) and McCormack and Wilding (1969) found morphologic properties to uniformly exhibit high within delineation proportions of variance, whereas other work (Wilding _et al_., 1965) showed that morphologic variability could be greater between delineations than within.

The low within delineation variance components associated with the properties in Table 13-I indicate that the property values are fairly uniform within a single delineation, whereas the high within delineation variance components calculated for the properties in Table 13-II suggest that these vary to a greater degree along the transect. Slope steepness varied considerably within delineations, because the transect was purposely placed over the most topographically variable portion of the landscape. The contrasts in slope probably accounted for much of the differences in A1 horizon and mollic epipedon thicknesses, considering that landscape position and slope steepness have often been cited as influencing factors on horizon thicknesses (McCormack and Wilding, 1969; Norton and Smith, 1930; Walker et al., 1968b). Factors such as fertilizer placement and cultivation may have caused place to place variations in K^+ content, especially within delineation no. 49, which supported an intensely managed walnut orchard. In delineation no. 126, the highly variable K^+ values may be due partly to the effects of grazing animals, which was the case in a study by During and Mountier (1967).

The amount of within delineation variability versus between delineation variability has implications for map unit design. The purpose of map unit design is to achieve groupings of soils that share similar behavior and which, when compared among each other, reflect differences in morphology and genesis (Soil Survey Staff, 1980). Through the analysis of variance procedure, it was found that the major portion of map unit variability occurred between the delineations rather than within them. This situation implies inaccurate mapping or a poor map unit design, because specific behavioral interpretations for the map unit as a whole may not be applicable to many of the individual delineations. An example is provided by Figure 25a. Within each of the delineations the values for clay content are fairly similar along the transects. The means for the delineations, however, are significantly different at a .99 confidence level. A clay content of 24 percent versus 54 percent could conceivably cause major differences in soil permeabiltiy and soil drainage. These differences would then merit different behavioral and land use predictions about the two delineations with low clay content relative to the two delineations with high clay content. When map units are being designed, and also when soils are being mapped in the field, attempts should be made to minimize the between delineation variability of important physical and morphologic properties. By minimizing these differences, management practices could be applicable to a greater proportion of delineations. Management purity of the map unit could also be maximized. Achieving inter-delineational uniformity in chemical properties would not be as crucial, because major differences could usually be corrected by fertilizer applications, provided an adequate program of soil testing fields in the delineations was instituted.

VI. SUMMARY AND CONCLUSIONS

The Willakenzie silty clay loam, 2 to 12 percent slopes, map unit is highly variable in its morphologic, physical, and chemical characteristics as well as in its taxonomic composition. This assessment is based on individual soil property analyses of samples taken from 35 randomly located sites throughout the map unit and from systematically located sites within single map unit delineations. The major conclusions regarding the study are as follows.

L. Twelve of the 32 properties measured in the randomly sampled pedons had skewed distributions; the remaining 20 properties were approximately normal. The median and/or the mode were a better descriptor of central tendency than the mean in two-thirds of the skewed data. CV values were high for all the skewed properties. Of the normally distributed data, depth to mottling and exchangeable K^+ in the A1 horizon were the most variable, and pH and surface horizon color were the least variable properties. Percent sand in the A1, B2, and C horizons and exchangeable Mg^{++} in the A1 horizon were the most variable of the skewed properties; CEC of the B2 horizon was the least variable.

2. All the soil properties measured, except color hue of the surface horizon, had ranges of values greater than the ranges of values described for the Willakenzie map unit. Slope steepness and surface horizon color (hue, chroma, and value) were the properties mapped correctly most often at the 35 random sites. The C or Cr horizon

texture/character was most variable, exhibiting a mapping accuracy of only 28 percent.

3. None of the 35 pedons sampled classified exactly as the Willakenzie series.

(a) The fine, mixed, mesic family of Ultic Haploxeralfs was the most commonly occurring profile class (7 profiles). The Mollisol order was represented by 57 percent (20 profiles) of the pedons.

(b) Thirty-one percent (11 profiles) of the pedons were dissimilar to the Willakenzie; i.e., they had properties that differed from the Willakenzie sufficiently to lower potential for use and management.

(c) The management purity of the map unit was 69 percent, in contrast to the 0 percent taxonomic purity. The former may be a more useful descriptor of map unit purity for the survey user.

4. Several hypotheses were explored to help explain the sources contributing to taxonomic and soil property variability within the map unit:

(a) The high variability in bedrock geology and/or parent material was a major factor contributing to morphologic differences between the pedons. Clayey subhorizons, which were most likely weathered layers of fine-textured geologic strata, occurred in 23 percent of the pedons (8 profiles). These clayey horizons contributed to the poor and somewhat poor drainage of the pedons.

(b) Lacustrine silts deposited during the late Pleistocene may have accounted for some of the variability in horizon thicknesses and textures. Pedons with uniform silt loam textures throughout the A, B, and C horizons may have formed entirely in the lake-laid silts; other pedons with silt loam surface horizons may be mantled by the silts.

(c) The mapping of the Willakenzie under the 1938 classification system accounts for some of the variability in taxonomic classification of the 35 pedons under the present system, primarily because major class differentiating features such as mollic epipedons and argillic horizons were not defined in the earlier system. Also, the rigid, quantitative class limits imposed by Soil Taxonomy (Soil Survey Staff, 1960) may result in the placement of soil pedons in entirely different classes, when they actually differ only slightly in features such as surface horizon color or in the amount of clay increase occurring in their profiles. The perceived taxonomic variability is thus increased.

5. Relationships between three separation distances and soil property variabiltiy were studied. Chemical properties tended to have higher pooled variances within 70 m distances than within 35 or 105 m distances, whereas physical properties tended to have highest variabilities within 105 m distances. Both chemical and physical properties achieved minimum pooled variances at the 35 m interval. The variances of morphologic properties showed no definite trends with distance.

6. Sixty-one percent of the properties measured within the four delineations varied significantly more between delineations than within

delineations. This situation implies a poor map unit design, because many of the properties, particularly morphologic and physical ones, are sufficiently contrasting to merit different management and behavioral interpretations; hence, map unit delineations cannot be treated uniformly.

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