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Soil Survey Laboratory Information Manual

National Soil Survey Center
Soil Survey Laboratory
Lincoln, Nebraska

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FOREWORD

Laboratory data are critical to the understanding of the properties and genesis of a single pedon, as well as to the understanding of fundamental soil relationships based on many observations of a large number of soils. Development of both an analytical database and the soil relationships based on those data are the cumulative effort of a generation of soil scientists at the Soil Survey Laboratory (SSL).

Noteworthy were the efforts of Mr. Benny Brasher, retired SSL Research Soil Scientist, who was responsible for the design of the laboratory database and the Primary and Supplemental Characterization Data Sheets. His work has made possible the accumulation of analytical data for over 10,000 soil pedons.

Many project reports and scientific journal articles have been written that explain the use and significance of the data produced at the SSL. The need for a single comprehensive volume that compiles the accumulated knowledge of these laboratory data has been recognized for many years. Upon completion of the SSL Methods Manual (Soil Survey Investigations Report No. 42, 1992), Mr. Laurence E. Brown, former Analytical Staff Leader at the SSL, recommended that such a document be given high priority.

Dr. Rebecca Burt, editor of the SSL Methods Manual, is the author of this document. She has compiled the knowledge of laboratory data from reports and papers written by scientists both within and outside the SSL. She included numerous citations to help the user find greater detail in the analytical data of interest.

Many soil scientists from the National Soil Survey Center (NSSC) served as reviewers for the various sections of the manual related to their areas of expertise. Noteworthy were the efforts of Dr. Ellis G. Knox, National Leader for Soil Survey Research, whose suggestions and comments have added value to the technical merit of this manual.

PREFACE

The Soil Survey Laboratory (SSL), National Soil Survey Center (NSSC) is responsible for providing accurate and reliable soil characterization data for the National Resource Conservation Service (NRCS) National Cooperative Soil Survey (NCSS) Program. The SSL data are provided in reports, e.g., Primary and Supplementary Characterization Data Sheets and in various electronic forms, including tapes, disks, and CD-ROMs. These reports are the end product of the analytical system and are a means to transmit information to the users of these data. It follows that these data reports must be complete, accurate, and understandable. In addition, these reports provide historical documentation for future reference.

Pedon characterization data, or any soil survey data, are more appropriately used when the operations for collection, analysis, and reporting these data are thoroughly understood. The purpose of this document is to describe the SSL characterization data reports to maximize user understanding of these data. This document *is not intended as an interpretive guide* for soil characterization data.

Included in this document is a brief discussion of sampling methodology and its role in soil analysis. While the definitions, protocols, and applications of the various types of samples and sampling plans are beyond the scope of this document, the importance of sampling as a critical step to successful soil analysis is described. After the discussion on sampling is the description of the SSL Data Sheets, which includes information about sample origin and identification, method documentation, general conventions in reporting data, and finally, a column-by-column explanation of the Primary and Supplementary Characterization Data Sheets. This document contains an extensive appendix, which includes example SSL data reports and pedon descriptions (Appendixes I - II); laboratory preparation codes (Appendix III); soil textural triangle (Appendix IV); example particle-size distribution and water retention curves (Appendix V - VI); basic chemistry terminology (Appendix VII); mineralogy codes and methods (Appendix VIII - X); quality assurance terminology (Appendix XI); data unit conversions (Appendix XII); and example NRCS-SOIL-8 (Appendix XIII).

The example pedon descriptions in the appendix are those made at the time of sampling and therefore may not be uniform in quality or terminology, as soil description techniques have changed over time. Field estimates at the time of sampling are in themselves considered important and have been retained, even though these estimates sometimes vary with SSL data. The record of what was perceived at the time of sampling is deemed to be more important than the achievement of complete editorial uniformity.

The NRCS-SOIL-8 form is a soil data index from which laboratory data are made available to NCSS cooperators. This index includes pedon classification, location data (latitude and longitude, county, soil survey area, and state), data source, and kinds of analyses available.

Trade names are used in the manual solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee of the product by the U.S. Department of Agriculture, nor does it imply an endorsement by the U.S. Department of Agriculture.

Cover: Profile and laboratory data of Marquez soil (clayey, mixed, thermic Typic Haplustult) from Leon County, Texas.

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1. INTRODUCTION

Critical to any measurement program that collects analytical data over a long period of time for comparative purposes is the quality and credibility of those data (Taylor, 1988). Equally critical is that these data are easily understood by the user. Many uses of these data include, but are not limited to, routine soil characterization, special analyses, soil classification, interpretations, and soil genesis and geomorphology studies. Because of the diverse uses of these data, it follows that pedon characterization data, or any soil survey data, are more appropriately used when the operations for collection, analysis, and reporting of these data are well understood. Results differ when different methods are used, even though these methods may carry the same name or concept. Comparison of one bit of data with another is difficult without knowing how both bits were gathered. As a result, operational definitions have been developed and are linked to specific methods. *Soil Taxonomy* (Soil Survey Staff, 1975) is based almost entirely on criteria that are defined operationally, e.g., standard particle-size analysis. When *Soil Taxonomy* (Soil Survey Staff, 1975) was written, the authors knew that no conceptual definition of clay could be approximated in all soils by any feasible combination of laboratory analyses. Hence, instead of defining clay, the authors defined the operations to test the validity of a clay measurement and a default type of operation for those situations in which the clay measurement was not valid. The operational definition helps to describe a soil property in terms of the operations used to measure it. In this document, operational and conceptual definitions are discussed.

2. SAMPLING METHODOLOGY

Several requisites to successful soil analysis occur long before the sample is analyzed. In the field, these requisites include site selection, descriptions of site and soil, and careful sample collection (Soil Conservation Service, 1984). In the laboratory, careful sample collection and preparation are also requirements to successful soil analysis.

Information about the soil sampling site serves as a link between the soil sampling point and the soil horizon and landscape (Canadian Soil Science Society, 1993). The purpose of any soil sample is to obtain information about a particular soil and its characteristics on the landscape on which it occurs. Sampling provides a means to estimate the parameters of these soil characteristics with an acceptable accuracy at the lowest possible cost. Subsampling may also be used because it permits the estimation of some characteristics of the larger sampling unit without measuring the entire unit. Subsampling reduces the cost of the investigation but generally decreases the precision with which the soil characteristics are estimated. Efficient use of subsampling depends on a balance between cost and precision (Petersen and Calvin, 1986).

The project objectives form the basis for designing the sampling strategy. A carefully designed sampling plan is required to provide reliable samples for the purpose of sampling. The plan needs to address the type and number of samples, the details of collection, and the sampling and subsampling procedures to be followed. There are various kinds of sampling plans, e.g., intuitive and statistical, and many types of samples, e.g., representative, systematic, random, and composite. Refer to Appendix XI for quality assurance terminology. In the field, the SSL has more routinely used intuitive sampling plans to obtain representative samples. The intuitive sampling plan is one based on the judgment of the sampler, wherein general knowledge of similar materials, past experience, and present information about the universe of concern, ranging from knowledge to guesses, are used (Taylor, 1988). A representative sample is one that is considered to be typical of the universe of concern and whose composition can be used to characterize the universe with respect to the parameter measured (Taylor, 1988). In the laboratory, the primary objectives of sample collection and preparation are to homogenize and obtain a representative soil sample to be used in chemical, physical, and mineralogical analyses (Soil Survey Laboratory Staff, 1992).

The analyst and the reviewer of data assume that the sample is representative of the soil horizon being characterized. Concerted effort is made to keep analytical variability small. Precise laboratory work means that the principal variability in characterization data resides in sample variability, i.e., sampling is the precision-limiting variable. As a result, site-selection and sample collection and preparation are critical to successful soil analysis.

The SSL field sampling, laboratory sampling and subsampling, and laboratory preparation procedures are documented in the Soil Survey Investigations Report (SSIR) No. 42 (Soil Survey Laboratory Staff, 1992). Refer to Appendix III for SSL laboratory preparation codes. These codes are also noted on the SSL data reports.

3. SOIL SURVEY LABORATORY DATA REPORTS

3.1 General Information

In 1976-1977, the SSL created, and has subsequently maintained on a computer, an analytical laboratory database, pedon description database, and NRCS-SOIL-8 Index of laboratory data for soils sampled by the previous three regional SCS laboratories (Beltsville, Riverside, and Lincoln) and the SSL. These databases are used to generate various other special databases, reports (SSIR's), and data evaluation studies.

The SSL reports are in a standard format that provides uniformity in reporting and enhances communication. This standard format has changed with time as new code sets have been developed reflecting the changes in established methods as well as the adoption of new methods. Subsequently, all the SSL data sheets are not the same.

The runner head at the top of the Primary and Supplementary Data Sheets provides pertinent non-analytical information about the soil pedon. Example SSL Data Sheets are presented in Appendixes I and II. The example pedon in Appendix I (Caribou soil) is used to explain the general information that is provided on all SSL Primary and Supplementary Characterization Data Sheets.

a. Soil Sample Origin: *County, State*
or
Country (if other than USA)

Example: Aroostook County, Maine

b. Laboratory Name and Location:

U.S. Department of Agriculture
Natural Resource Conservation Service
Soil Survey Laboratory
National Soil Survey Center
Lincoln, Nebraska 68508-3866

c. Date: *Print Date*

Example: Print Date 08/01/94

This date is when the SSL characterization Data Sheets are printed and does not reference the dates of sampling or completion of analytical results.

d. Client-Assigned Laboratory Number: *Soil Survey Number*

Example: S88ME-003-001

S = Special sample
88 = Calendar year sampled
ME = Two character (alphabetic) Federal Information Processing Standards (FIPS) code for state where sampled
003 = Three digit (numeric) FIPS code for county where sampled
001 = Consecutive pedon number for calender year for county

e. Pedon Name and Classification: *Sampled as and Revised to*

Example:

Sampled as: Caribou; Fine-loamy, mixed, frigid Typic Haplorthod
Revised to: Caribou; Loamy-skeletal, mixed, frigid Typic Dystrochrept

f. Project File Numbers: *SSL - Project*

Example: SSL - Project 88P 127, (CP88ME188) WEPP Maine

The Soil Survey Laboratory (SSL) is the identification notation for computer records. The project number (88P 127) is a sequential number used in an algorithm to derive a computer record number for the specified fiscal year, e.g., October 1987 to September 1988. Sequential numbers are assigned in order of project receipt. An additional project code (CP88ME188) is provided in parentheses. This alphanumeric project code is referenced in all project data correspondence. Notations in this project code identify whether the project is considered a characterization project (C); the type of SSL database storage (P = permanent vs R = reference or "grab" samples); fiscal year (1988), alphabetic FIPS code for state (ME = Maine), and a sequential project number assigned (188) in order of project receipt. Project code is followed by a project name (WEPP Maine).

g. Laboratory-Assigned Numbers: *Pedon and Sample Numbers*

Example: Pedon 88P 722, Samples 88P 3855 - 3860

Immediately upon receipt, soil samples are logged into the SSL system. The assignment of unique laboratory numbers is an important step in the "chain of custody" sequence as they help to ensure the integrity of results, i.e., there has been no "mix-up" of samples.

The pedon (88P 722) and sample numbers (88P 3855 - 3860) are unique laboratory-assigned numbers for the specified fiscal year (1988). The pedon number is used to derive a random access record number in the SSL data base (hierarchical) for direct access to the file for retrieval of analytical data. The sample number is a sequential number that serves a similar purpose and also appears on the first tiers of the Primary and Supplementary Data Sheets.

h. General Laboratory Methods: *General Methods*

Example: General Methods 1B1a, 2A1, 2B

Some SSL methods are general or applicable to all the samples listed on a particular data sheet. These procedures are referenced by SSL method codes, e.g., laboratory preparation method 1B1a and conventions for reporting laboratory data, 2A1, 2B.

3.2 Soil Survey Laboratory Methods

The SSL ensures continuity in its analytical measurement process with the use of standard operating procedures (SOP's). A standard method is defined herein as a method or procedure developed by an organization, based on consensus opinion or other criteria and often evaluated for its reliability by a collaborative testing procedure (Taylor, 1988). A SOP is a procedure written in a standard format and adopted for repetitive use when performing a specific measurement or sampling operation, i.e., a SOP may be a standard method or one developed by a user (Taylor, 1988).

The use of SOP's provides consistency and reproducibility in soil preparations and analyses and helps to ensure that these preparations and analyses provide results of known quality. The standard SSL methods are described in the SSIR No. 42 (Soil Survey Laboratory Staff, 1992) which replaces *Procedures for Collecting Soil Samples and Methods of Analysis for Soil Survey*, SSIR No. 1 (Soil Conservation Service, 1984) as a methods reference. All SSL procedures are performed with methodologies appropriate for the specific purposes. The SSL SOP's are standard methods, peer-recognized methods, SSL-developed methods, and/or specified methods in *Keys to Soil Taxonomy* (Soil Survey Staff, 1994). Refer to SSIR No. 42 (Soil Survey Laboratory Staff, 1992) for detailed descriptions of these methods.

Included in SSIR No. 42 are descriptions of current as well as obsolete methods, both of which are documented by method codes and linked with analytical results that are stored in the SSL data base. This linkage between laboratory method codes and the respective analytical results is reported on the Primary Data Sheets. Reporting the method by which the analytical result is determined helps to ensure user understanding of SSL data. In addition, this linkage provides a means of technical criticism and traceability if data are questioned in the future. The SSL method codes are alphanumerical and may carry up to four characters, e.g., 6A1c, which refer to a four-level outline.

3.3 General Conventions in Reporting Data

a. Convention: Data Types

The column headings on the Primary and Supplementary Characterization Data Sheets identify the specific type of analytical or calculated data. The Primary Data Sheets are mainly analytical results, i.e., quantitative or semiquantitative measurements. Analytical data include physical, chemical and mineralogical analyses. The Primary Data Sheets also provide some derived values, e.g., coefficient of linear extensibility (COLE) and water-retention difference (WRD).

Except for some primary analytical data included for user convenience, data on the Supplementary Data Sheets are all calculated using primary analytical data as a basis for the calculations. These calculated data include engineering particle-size distribution analyses (PSDA) for user convenience calculated from USDA PSDA; various recalculations of the USDA PSDA; calculated engineering soil densities; volume and weight percentages of certain soil components; ratios of selected soil properties to clay; linear extensibility, and the USDA PSDA on clay-free base.

b. Convention: Particle-Size Fraction Base

The column headings on the Primary and Supplementary Data Sheets designate the particle-size fraction for which the data are reported. On the Primary Data Sheets, most of the analytical or derived data are reported on the <2-mm particle-size fraction. Other data are reported for the <0.4, <20, or <75 mm size-fractions, or for the whole-soil base. On the Supplementary Data Sheets, data are reported on the <2 or <75 mm or whole-soil base.

c. Convention: Sample-Weight Base

Unless otherwise specified, analytical and calculated data are reported on an oven-dry weight or volume base for the designated particle-size fraction in the column heading. The calculation of the air-dry/oven-dry (AD/OD) ratio is used to adjust all results to an oven-dry weight base and, if required in a procedure, to calculate the sample weight that is equivalent to the required oven-dry soil weight.

The AD/OD ratio is calculated by procedure 4B5. The AD/OD ratio is converted to a crystal water basis by procedure 6F3 for gysiferous soils (Nelson et al., 1978; Soil Survey Laboratory Staff, 1992).

Air-dry and oven-dry weights are defined herein as constant sample weights obtained after drying at 30±5°C (≈ 3 to 7 days) and 105±5°C (≈ 12 to 16 h), respectively. As a rule of thumb, air-dry soils contain about 1 to 2 percent moisture and are drier than soils at 15-bar water content.

d. Convention: Significant Figures and Rounding

Unless otherwise specified, the SSL uses the procedure of significant figures to report analytical data. Historically, significant figures are said to be all digits that are certain plus one, which contains some uncertainty. If a value is reported as 19.4 units, the 0.4 is not certain, i.e., repeated analyses of the same sample would vary more than one-tenth but generally less than a whole unit. Most of the data on the SSL Supplementary Data Sheets are not measured values but are calculated from the analytical data. The interpretive weight and volume quantities on the Supplementary Data Sheets may or may not be the exact same values as the analytical data from which they are calculated because of the procedure of rounding and significant digits in calculating the data. Refer to Appendix XII for unit conversions of analytical data, i.e., SI and non-SI units.

e. Convention: Data Sheet Symbols

The analytical result of "zero" is not reported by the SSL. The following symbols are used or have been used for trace or quantities not detected or for samples not tested by the SSL. Refer to the SSIR No. 42 (Soil Survey Laboratory Staff, 1992) for a description of procedure 2B.

tr, Tr, TR	Trace - either is not measurable by quantitative procedure used or is less than reported amount.
tr(s)	Trace - detected only by qualitative procedure more sensitive than quantitative procedure used.
-	Analysis run but none detected.
--	Analysis run but none detected.
-(s)	None detected by sensitive qualitative test.
blank	Analysis not run.

nd	Not determined, analysis not run.
<	Either none is present or amount is less than reported amount, e.g., <0.1 is in fact <0.05 since 0.05 to 0.1 is reported as 0.1.

f. Convention: Data Sheet Format

On the first tier of the Primary and Supplementary Data Sheets, the SSL sample numbers, sample preparation codes, horizon designations, and depth limits are listed. Refer to Appendix III for a more detailed explanation of laboratory preparation codes. The reporting units for horizon depth limits are centimeters (cm) for the Primary Data Sheets and inches (in) for the Supplementary Data Sheets. Inches were chosen to better conform with the conventions of engineers and soil mechanics. Refer to Appendixes I and II for example formats.

The kinds of laboratory analyses may differ depending on whether the soil is acidic or salty. Refer to Appendixes I and II for example Acid and Salt Chemistry Sheet formats, respectively. Some laboratory analyses, e.g., tests for soil organic materials, are not reported on the SSL Data Sheets but are provided in another format on additional data sheets. Description and application of some of these laboratory analyses have been incorporated into specific data elements on the Primary and Supplementary Characterization Data Sheets.

4. PRIMARY CHARACTERIZATION DATA

This part of the manual is a description of the data columns on the Primary Characterization Data Sheets. Operational and conceptual definitions of SSL procedures are discussed. Included are the SSL method codes, the size fractions for which data are reported, and the analytical reporting units. Refer to SSIR No. 42 (SSL Staff, 1992) for laboratory method descriptions. Refer to Appendix XII for unit conversions of analytical data. The Primary Characterization Data Sheets consist of the Particle-Size Distribution Analysis (PSDA), Acid and Salt Chemistries, Ammonium Oxalate, and Mineralogy Data Sheet. Examples of the Acid and Salt Chemistry Data Sheets, herein referenced as Acid and Salt Sheets, are provided in Appendix I (Caribou pedon) and Appendix II (Wildmesa pedon), respectively. Refer to Appendix VII for basic chemistry terminology. The Acid and Salt Data Sheets have many data elements in common, but they also have some elements specific to each, e.g., extractable Al on the Acid Sheet and water soluble cations and anions on the Salt Sheet. Examples of the PSDA, Ammonium Oxalate (herein referenced as Acid Oxalate), and Mineralogy Data Sheets (Tiers 1 and 2 only) are provided in both Appendixes I and II. The names given to specific analysis sheets, e.g., Acid and Salt Sheets, facilitate referencing in this manual and are not routinely printed on the data sheets.

A general discussion usually precedes a broad grouping of similar elements on the data sheet, e.g., cation exchange capacity and pH. Incorporated into these discussions are descriptions of additional SSL data elements that are not reported on the Primary Characterization Data Sheets, e.g., tests for soil organic materials.

On the first sheet of the Primary Data Sheets, the laboratory sample numbers are listed followed by the sample preparation code. Refer to Appendix III for the laboratory preparation codes. The samples for the Caribou pedon (Appendix I) were all moist (M) sieved on a <2-mm basis, whereas the samples for the Wildmesa pedon (Appendix II) were all prepared by the standard (S) SSL method, i.e., air-dry sieved on a <2-mm basis. Averages and other data may be listed as footnotes on the data sheets, e.g., clay percent for the particle-size control section and weight percentage of the 0.1 to 75-mm fraction.

4.1 PSDA SHEET, TIER 1: COLUMNS 1 - 20:

Sample Numbers and Sample Preparation Codes:

Sample numbers and laboratory preparation codes are listed.

Column 1: Depth (cm).

Depth limits in centimeters (cm) are reported for each soil horizon or layer.

Columns 2 - 3: Horizon.

Soil horizon or layer designation including lithological designation are reported in Columns 2 -3. Eleven spaces are currently provided on the data sheet for these designations. The pedon description is made at the time of sampling by the sampling party. This consensus record is deemed important and is rarely changed in the SSL Database. Over time, the horizon nomenclature and other descriptive morphological features may become archaic, but the record as to what was determined at the time of sampling is deemed more important than the achievement of complete editorial uniformity.

Columns 4 - 20: PARTICLE-SIZE DISTRIBUTION ANALYSIS (PSDA).

Particle-size distribution: Perhaps the single most important physical property of a soil is its distribution of particle sizes. Precise meaning is given to the term soil texture only through the concept of particle-size distribution (Skopp, 1992). The behavior of most soil physical properties and many chemical properties are sharply influenced by the particle size classes present and their relative abundance. Particle-size distribution analysis (PSDA) is a measurement of the size distribution of individual particles in a soil sample. These data may be presented on a cumulative PSDA curve. Particle-size distribution curves are used in many kinds of investigations and evaluations, e.g., geologic, hydrologic, geomorphic, engineering, and soil science (Gee and Bauder, 1986). Cumulative curves have the advantage that they allow comparison of particle-size analyses that use different particle-size classes. Most commonly, the cumulative percentage of particles finer than a given particle size is plotted against the logarithm of "effective" particle diameter (Gee and Bauder, 1986). Refer to Appendix V for an example cumulative particle-size (grain-size) distribution curves plotted on forms used by the NRCS Soil Mechanics Laboratories (SML) in Lincoln, Nebraska and Fort Worth, Texas.

USDA classification system: In soil science, particle-size analysis is used to evaluate soil texture. In the USDA classification system (Soil Survey Staff, 1951 and 1993), soil texture refers to the relative proportions of clay, silt, and sand on a <2-mm base. It also recognizes proportions of five subclasses of sand. For the size limits of these seven particle-size classes (separates), refer to Columns 4 - 6 and Columns 11 - 15 on this data tier. The USDA classification scheme uses a textural triangle to show the percentages of clay, silt, and sand in the textural triangle. Refer to Appendix IV for the texture triangle (shown in black). Also refer to the Supplemental Data Sheet, Columns 90 - 91 for additional discussion of textural classes.

Other classification systems: In addition to the USDA classification scheme, there are many other soil classification systems, e.g., the particle-size classes for differentiation of families in the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994). Refer to Appendix IV for the USDA textural classification of families in *Soil Taxonomy* (shown in red) (Soil Survey Staff, 1967). Other soil classification systems include the International Soil Science Society (ISSS); the Canadian Soil Survey Committee (CSSC); and the American Society for Testing and Materials (ASTM). In reporting and interpreting data, it is important to recognize that these other classification systems are frequently cited in the literature, especially engineering systems, e.g., American Association of State Highway and Transportation Officials (AASHTO) and the ASTM Unified Soil Classification System (USCS) (Gee and Bauder, 1986).

Particle-size classes: In general, the term *particle size* is used to characterize the grain-size composition of the mineral portion of a whole soil, while the term *texture* is used in describing its fine-earth fraction (Soil Survey Staff, 1994). As used herein, the fine-earth fraction refers to particles with <2-mm diameters, and the whole soil is all particle-size fractions, including boulders with maximum horizontal dimensions less than those of the pedon. The term *rock fragments* means particles of the whole soil that are ≥2 mm in diameter and includes all particles with horizontal dimensions smaller than the size of the pedon (Soil Survey Division Staff, 1993; Soil Survey Staff, 1994). At one time, the term *rock fragments* was differentiated from the term *coarse fragments* which excluded stones and boulders with diameters ≥250 mm (Soil Survey Staff, 1951, 1975). The rationale for this distinction was that particles <250 mm were generally regarded as part of the "soil mass", i.e., they affect moisture storage, infiltration, runoff, root growth, and tillage (Soil Survey Staff, 1951). In the descriptions of soil horizons, particles ≥250 mm were excluded from the soil textural class name, but phase names for stoniness and rockiness, although not a part of the textural class names, were used to modify the soil-class part of the soil-type name, e.g., Gloucester *very stony* loam (Soil Survey Staff, 1951). Refer to Soil Survey Staff (1951) for additional discussion of the rationale for this particle-size distinction. Refer to Soil Survey Division Staff (1993) for additional discussion on rock fragments. Also refer to the discussion on particle-size distribution on the Supplementary Data Sheets. Particle-size distribution data are reported for the <2-mm fraction in Columns 4 - 15 and for the >2-mm fraction in Columns 16 - 20.

Columns 4 - 15: PARTICLE-SIZE DISTRIBUTION ANALYSIS, PARTICLES <2 mm, PIPET, AIR-DRY SAMPLES.

Clay, historical concepts and class limits: The definition of clay has been debated for many years. Early concepts of clay attempted to characterize clay on the basis of its chemical nature and its effects upon the soil (Baver, 1956). Osborne (1887), who developed the beaker method of soil mechanical analysis in 1886, defined clay as follows: "*True clay* is here meant that material derived from the decomposition of feldspars and similar silicates, which is capable of uniting with a considerable amount of water, and thus assuming a gelatinous condition in which it exerts a powerful binding action upon the particles of sand in the soil. To some extent, probably, this action is also exerted by iron and alumina hydroxides, as well as by colloid organic bodies."

The purely chemical definition of clay by Osborne (1887) was eventually replaced by one that was in colloidal in meaning (Baver, 1956). The colloidal concept of clay was developed when the ideas of disperse systems were applied to the study of soils by Oden (1921-22) and other investigators. Oden (1921-22) defined clay as "disperse formations of mineral fragments in which particles of smaller dimensions than 2 µm (0.002 mm) predominate", i.e., clay consists of primary mineral fragments together with the secondary products of weathering as long as the individual particle sizes are small enough (Baver, 1956). The definition of clay with an upper size-limit of 2 µm was first introduced by Atterberg in 1912. Refer to the discussion on clay vs colloidal clay under the data element Fine Clay (PSDA Sheet, Tier 1, Column 7).

Atterberg classification system, scientific rationale: The Atterberg definition of clay as well as the classification of other soil particles according to size was accepted by the International Society of Soil Science in 1913. This classification of soil particles according to size is as follows: Gravel, 20 to 2.0 mm; Coarse sand, 2.0 to 0.2 mm; Fine sand, 0.2 to 0.02 mm; Silt 0.02 to 0.002 mm; Clay <0.002 mm. Atterberg's scientific rationale for setting up the various size limits and for characterizing clay as <2 µm are described by Baver (1956) as follows: "The 20- to 2-mm limit is between the points where no water is held in pore spaces between particles and where water is weakly held in the pores. The lower limit of the 2- to 0.2-mm is the point where water is held in the pores by the forces of capillary attraction. The lower limit of the 0.2- to 0.02-mm fraction is given the theoretical significance that smaller particles cannot be seen by the naked eye; do not have the usual properties of sand; and can be coagulated to form the *crumbs* that are so significant in the mechanical handling of soils, i.e., there are the limits between dry sand which gives poor soils, and adequately moist sand, which forms productive sandy soils. The lower limit of the 0.02- to 0.002-mm fraction is established on the basis that particles smaller than 2 µm (clay) exhibited Brownian movement in aqueous suspension. Capillary movement of water is very slow for <2-µm particles, and the properties of *stiff* clays are strongly manifested. Thus, silt is visualized as a range of particle-sizes from the point where sand begins to assume some clay-like properties to the upper limit of clay."

Atterberg definition of clay, scientific justification: The Atterberg definition of clay as a soil separate with an upper size-limit of 2 µm has scientific justification in mineralogical studies of soils (Marshall, 1935; Robinson, 1936; Truog, 1936). Robinson (1936) determined that the <2 µm fraction is primarily composed of colloidal products of weathering and is truly the chemically active portion of the soil. Marshall (1935) and Truog (1936) found that very few unweathered primary minerals exist in the <2 μm fraction. Baver (1956) later modified the definition of clay by Oden (1921-22) as follows: "Clays are disperse systems of the colloidal products of weathering in which secondary particles of smaller dimensions than 2 μm predominate".

USDA classification system, historical: In 1896, investigators in the USDA Bureau of Soils modified the beaker method of Osborne. They extended the separation of the smallest particles from 0.1 to 0.005 mm (5 μm) and gave the latter limit the designation of clay. The choices of the different limits were arbitrarily made apparently based on the convenience of calibration with the particular eyepiece micrometer that was used (Baver, 1956) as illustrated by the following statements: "With the microscope used in this Division the 1-in eyepiece and 3/4-in objective, three of the 0.1 mm spaces of the eyepiece micrometer measure 0.05 mm on the stage. With the same eyepiece and 1/5-in objective, two spaces of the micrometer are equal to 0.01 mm, and one space to 0.005 mm. These three values are sufficient for the beaker separation" (Whitney, 1896). This classification of soil separates was used in the United States until 1937.

USDA classification system, revisions, clay: In 1937, the USDA Bureau of Chemistry and Soils changed the size limits for clay from <5 to <2 μm. It was hoped that this change to 2 μm as the upper limit for clay would make the data from mechanical analysis more useful by effecting a better correlation between field textural classification and classification from the data of mechanical analysis (Soil Science Society of America, 1937). The reduction in size limits tended to reduce the percentage of clay, thus offsetting, in part, the higher percentage obtained by modern dispersion methods (Soil Science Society of America, 1937). Additionally, this change made the definition for the clay separate the same for the USDA and International classification systems.

USDA classification system, revisions, silt: In 1937, the Bureau of Chemistry and Soils also changed the size limits for silt as that fraction between 0.002 to 0.05 mm (2 and 50 μm). In addition, an extra pipetting at 0.02 mm (20 μm) was added, making it possible to compare data with those reported under either the former American or the International system (Soil Science Society of America, 1937). The split at 20 μm is a class limit between the sand and silt fractions in the International system proposed by Atterberg (1912). The split at 20 μm is the class limit between fine silt and coarse silt in the USDA classification system.

USDA classification system, particle-size analysis: The USDA classification system classifies soil particles (soil separates) according to size as follows: Very coarse sand, 2.0 - 1.0 mm; Coarse sand, 1.0 - 0.5 mm; Medium sand, 0.5 - 0.25 mm; Fine sand, 0.25 - 0.10 mm; Very fine sand, 0.10 - 0.05 mm; Silt, 0.05 - 0.002 mm; Clay, <0.002 mm. In soil science, the terms *clay, silt, very fine sand, fine sand,* and *coarse sand* are used to define not only soil separates but also specific soil classes (Appendix IV, textural triangle, shown in black). In addition, the term *clay* is used to define a class of soil minerals (Table 1). The PSDA data in Columns 4 - 20 are soil separates reported as weight percentages on a specified base.

Particle-size analysis, objectives: Particle-size analysis (mechanical analysis) consists of isolating various particle sizes or size increments and then measuring the amount of each size-fraction. The major features of PSDA include the destruction or dispersion of soil aggregates into discrete units by chemical, mechanical, or ultrasonic means followed by the separation or fractionation of particles according to size limits by sieving and sedimentation (Gee and Bauder, 1986). The primary objectives of dispersion are the removal of cementing agents; rehydration of clays; and the physical separation of individual soil particles (Skopp, 1992). Chemical dispersion usually involves the use of hydrogen peroxide and sodium hexametaphosphate. The hydrogen peroxide oxidizes the organic matter. The sodium hexametaphosphate complexes any calcium in solution and replaces it with sodium on the ion exchange complex which results in the repulsion of individual particles (Skopp, 1992). Upon completion of the chemical treatments, mechanical agitation is used to enhance separation of particles and facilitate fractionation. Fractionation data provide the size or range of sizes that a measurement represents and the frequency or cumulative frequency with which the size occurs. The most common methods of fractionation are sieving and sedimentation by the hydrometer or pipet method.

Sedimentation theory and Stokes' Law: The sedimentation equation is derived from Stokes' Law and relates the time of settling to the particle-size sampled. This sedimentation equation is as follows:

Equation 1:

$$\nu = 2r^2g(\rho_s-\rho_l)/(9\eta)$$

where:
ν = velocity of fall
r = particle radius
g = acceleration due to gravity
ρ_s = particle density
ρ_l = liquid density
η = fluid viscosity

Assumptions used in applying Stokes' Law to soil sedimentation measurements (Gee and Bauder, 1986) are as follows:

1. Terminal velocity is attained as soon as settling begins.
2. Settling and resistance are entirely due to the viscosity of the fluid.
3. Particles are smooth and spherical.
4. There is no interaction between individual particles in the solution.

Since soil particles are not smooth and spherical, the radius of the particle is considered an equivalent rather than an actual radius. Effective or equivalent diameters are used to represent either an average value or the replacement of the actual value by a value representative of simplified geometry (Skopp, 1992). The use of effective diameters also emphasizes that determinations of particle-sizes are biased by the measurement technique (Skopp, 1992). Identical particles measured by different techniques commonly appear to have different diameters. The USDA-SCS selected the Kilmer and Alexander (1949) pipet method to determine the PSDA for the <2-mm fraction because this method is reproducible in a wide range of soils.

Air-dry and moist samples: The standard SSL PSDA procedure for particles with <2-mm diameter is the air-dry method (procedure 3A1). For soils that irreversibly harden when dried, moist PSDA (procedure 3A2) can be determined. Procedures with either a 3A1 or 3A2 in code refer to air-dry or moist PSDA samples, respectively. The phenomenon of aggregation through oven or air drying is an important example of irreversibility of colloidal behavior in the soil-water system (Kubota, 1972; Espinoza et al., 1975). Drying such soils decreases the measured clay content. This can be attributed to the cementation upon drying (Maeda et al., 1977). The magnitude of the effect varies with the particular soil (Maeda et al., 1977). Both the air-dry and moist PSDA data are determined as percent on oven-dry base. Moist PSDA data by procedure 3A2 are not reported on the SSL Primary Characterization Data Sheets but, if determined, are reported on additional SSL data sheets.

Pretreatments: In the SSL PSDA (procedure 3A1), a 10-g sample of <2-mm air-dry soil is pretreated to remove organic matter and soluble salts. There are additional non-routine chemical pretreatments for the removal of cementing agents that often prevent complete dispersion. These pretreatments include the removal of carbonates with 1 *N* NaOAc buffered at pH 5 (procedure 3A1e and 3A2e); the removal of Fe_2O_3 with sodium dithionite-citrate solution (procedures 3A1f and 3A2f); and the removal of SiO_2 with 0.1 *N* NaOH (procedures 3A1g and 3A2g). Dispersion using an ultrasonic probe (procedure 3A1h and 3A2h) may be used with soils that do not completely disperse with standard particle-size analysis. Refer to SSIR No. 42 (SSL Staff, 1992) for a discussion of these pretreatment procedures.

Dispersion and fractionation: Upon completion of chemical pretreatments, the sample is dried in the oven to obtain the initial weight, dispersed with sodium hexametaphosphate solution, and mechanically shaken. The sand fraction is separated from the suspension by wet sieving and then fractionated by dry sieving. The clay and fine silt fractions are determined using the suspension remaining from the wet sieving process. This suspension is diluted to 1 L in a sedimentation cylinder, stirred, and 25-mL aliquots removed with a pipet at calculated, predetermined intervals based on Stokes' Law (Kilmer and Alexander, 1949). Particle density is assumed to be 2.65 g cc^{-1}.

The aliquots are dried at 105°C and weighed. Coarse silt is the difference between 100% and the sum of the sand, clay, and fine silt percentages.

Other particle-size analyses: The SSL determines fine clay (procedures 3A1b and 3A2b), carbonate clay (procedures 3A1d and 3A2d), and water dispersible PSDA (procedures 3A1c and 3A2c). Fine clay and carbonate clay are reported on this data tier in Columns 7 and 8, respectively. Water dispersible PSDA data by procedure 3A1c are not reported on this data tier but are reported on the Acid Oxalate Sheet, Tier 1, Column 13 - 18. All sand and silt fractions determined by procedure 3A1c are stored in the database, but only the total sand, silt, and clay are printed on the Acid Oxalate Sheet. Particle-size analysis data by the standard SSL procedure are reported as a weight percentage on a <2-mm *mineral* soil base, i.e., free of organic matter and salts, in Columns 4 - 15. These PSDA data can be converted to a volume base. An example calculation of this volume conversion is provided under the data element Total Sand (PSDA Sheet, Tier 1, Column 6).

Column 4: Total Clay (<0.002 mm).

Clay, definition: Clay is a soil separate with a <0.002-mm (<2 μm) particle diameter. The SSL determines the clay separate by pipet analysis in procedure 3A1. The total clay value reported by the SSL includes the clay-size carbonate. Total clay is reported as a percent on a <2-mm base.

Clay percentage, weighted average, calculation: Clay percentages or any data may be averaged and weighted according to horizon thickness. Refer to Appendix II (Wildmesa Pedon), PSDA Sheet, below Tier 2 for AVERAGES, DEPTH 15-65, PCT CLAY 36. The weighted average for clay percentage (upper 50 cm of argillic) is calculated for the Wildmesa Pedon as follows:

Equation 2:

$$\text{Product A} = (\text{Hcm} \times \text{Db}_{1/3} \times \text{Cm})$$

Equation 3:

$$\text{Product B} = (\text{Product A} \times \text{Clay})$$

where:

Hcm = Horizon thickness, cm. Data are reported on the first tier of Primary Data Sheets.

$\text{Db}_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.

Clay = Weight percentage of clay on a <2-mm base. Data are reported on the PSDA Sheet, Tier 1, Column 4.

Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm as follows:

Equation 4:

$$\text{Cm} = \frac{\text{Vol moist <2-mm fabric (cm}^3\text{)}}{\text{Vol moist whole soil (cm}_3\text{)}}$$

OR (alternatively)

Equation 5:

$$\text{Cm} = \frac{100 - \text{Vol>2mm}}{100}$$

where:

Vol>2mm = Volume percentage of the >2-mm fraction. Data are reported on the Supplementary Data Sheet, Column 51.

Equation 6:

$$\text{Weighted Average} = \frac{\text{Sum of Products B}}{\text{Sum of Products A}}$$

where:

Sum of Products A = Sum of (Hcm x $\text{Db}_{1/3}$ x Cm) for all soil horizons.

Sum of Products B = Sum of (Product A x Clay) for all soil horizons.

Example: Refer to Appendix II (Wildmesa Pedon)

Hrz	Depth	Hcm	$\text{Db}_{1/3}$	Cm	Product A	Clay	Product B
	cm	cm	g cc^{-1}			%	
2Bt	15-46	31	1.45	.99	44.50	34.9	1553.07
2Btk	46-74	19	1.38	1.00	26.22	38.1	998.98
SUM OF PRODUCTS		50			70.72		2552.05

$$\text{Weighted Average} = \frac{2552.05}{70.72} = 36 \text{ percent Clay}$$

If no bulk density data, calculate Product A, Product B, and weighted average using Equations 2, 3, and 6 without the $\text{Db}_{1/3}$ values.

Clay minerals: particle dimensions, thickness, and surface area: Refer to Table 1 for particle dimensions, thickness, and surface area of some clay minerals (Sumner, 1992). Refer to additional discussion on surface area under the data element EGME Retention (Mineralogy Sheet, Tier 1, Column 19).

Table 1. Comparison of clay particle dimensions, thickness, and surface area.[1]

Mineral	Particle Dimensions	Particle Thickness	Surface Area
	µm	µm	$m^2\ g^{-1}$
Montmorillonite	0.03*	0.001	600-800
Micas	0.3 - 1	0.02 - 0.07	60-200
Vermiculite	0.03*	0.001	400-800
Hydroxy-interlayered vermiculite	0.2 - 1*	0.02 - 0.07	80-150
Kaolinite	0.3 - 2*	1-4	5-40
Halloysite, tubular	0.07*	0.04 - 1**	21-43
Halloysite, spheroidal	0.02 - 1		
Goethite	0.02*	0.05 - 0.1**	30-200
Hematite	0.02 - 0.05	0.01-0.02	50-120
Gibbsite	0.1	0.005	10-30
Allophane hollow spheres	0.003 - 0.005*		1000
Imogolite hollow filiform	0.002 - 0.003	1-3	1000

[1] Sumner, 1992.

* Diameter

** Length

Column 5: Total Silt (0.002 to 0.05 mm).

Total silt, definition: Total silt is a soil separate with 0.002- to 0.05-mm particle diameter. The SSL determines the fine silt separate by pipet analysis and the coarse silt separate by difference in procedure 3A1. Total silt is reported as a weight percentage on a <2-mm base.

Column 6: Total Sand (0.05 to 2.0 mm).

Total sand, definition: Total sand is a soil separate with 0.05- to 2.0-mm particle diameter. The SSL determines the sand fraction by sieve analysis in procedure 3A1. Total sand is the sum of the very fine sand (VFS), fine sand (FS), medium sand (MS), coarse sand (CS), and very coarse sand fractions VCS). The rationale for five subclasses of sand and the expansion of the texture classes of sand, e.g., sandy loam and loamy sand, is that the sand separates are the most visible to the naked eye and the most detectable by "feel" by the field soil scientist. Total sand is reported as a weight percentage on a <2-mm base.

Total sand, weight to volume conversion: Particle-size analysis data by the standard SSL procedure are reported as a weight percentage on a <2-mm *mineral* soil base, i.e., free of organic matter and salts. Using total sand as an example, PSDA data can be converted from a weight to volume base as follows:

Equation 7:

$$V_{sand} = \frac{Wt_{Sand} \times Db_{1/3} \times (1 - (V_{om}/100))}{2.65\ g\ cc^{-1}}$$

where:

V_{sand} = Volume percentage of sand (0.05- to 2.0-mm diameter) on a <2-mm base.
Wt_{sand} = Weight percentage of sand (0.05- to 2.0-mm diameter) on a <2-mm base. Data are reported on the PSDA Sheet, Tier 1, Column 6.
$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
2.65 = Assumed particle density for sand (g cc^{-1}).
V_{om} = Volume percentage of organic matter on a <2mm-base. Calculate V_{om} as follows:

Equation 8:

$$V_{om} = \frac{Wt_{oc} \times 1.72 \times Db_{1/3}}{1.1\ g\ cc^{-1}}$$

where:

Wt_{oc} = Weight percentage of organic C on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 1.
1.72 = "Van Bemmelen factor". Refer to the discussion on this factor under the data element organic C (PSDA Sheet, Tier 2, Column 1).
$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
1.1 = Assumed particle density of organic matter (g cc^{-1}).

Column 7: Fine Clay (<0.0002 mm).

Fine clay, definition: Fine clay is a soil separate with <0.0002-mm (0.2 µm) particle diameter. Fine clay amounts are never greater than total clay. The SSL determines the fine-clay fraction by centrifuging followed by pipet analysis in procedures

3A1 and 3A1b. Fine clay is reported as a weight percentage on a <2-mm base.

Colloidal clay, definition: Colloids are small particles which, due to their size, tend to remain suspended in solution and exhibit unique physical and chemical properties compared to other soil particle-size classes (Bohn et al., 1979). They have a large surface area per unit of mass and are chemically active with an electrical field that extends into the soil solution. Many of the properties that a soil exhibits are related to the types (both inorganic and organic) and amounts of colloidal materials that are present in the soil.

Colloidal clay vs clay: The distinction between clay and colloidal clay has been debated for many years. Some early separations set the upper limit of the colloidal range at 0.5 µm (Freundlich, 1926); at 1 µm (Brown and Byers, 1932; Bray, 1934); and at 0.2 µm by many many colloidal chemists at this time. Prior to 1937, the U.S. Bureau of Soils and Chemistry termed particles <0.002 mm (<2 µm) as colloids (Soil Survey Staff, 1951). Other investigators (DeYoung, 1925; Joseph, 1925) stated that clay and colloidal contents were identical, if the sample was completely dispersed. Baver (1956) considered the 0.1 to 0.2 µm a more reliable estimate of the upper limit of the colloidal range. Such colloidal material not only conformed more closely to the accepted standards of colloidal chemistry but also possessed a much greater chemical and physical activity per unit weight than coarser fractions (Baver, 1956). The 0.0002-mm (<0.2 µm) separate reported as fine clay (PSDA Sheet, Tier 1, Column 7) most closely corresponds to those estimates of the upper colloidal range proposed by Baver (1956) and others. More recently, the 0.001-µm (1 nm) to 1-µm range has been used to define colloidal particles (van Olphen, 1977; Singer and Munns, 1987). It is difficult to establish exact size limits for colloidal soil particles since activity of a colloid is determined not only by the composition, size, and shape of the colloid but also by the concentration and composition of the soil solution.

Fine clay, taxonomic significance: Fine clay may be used to determine the presence of illuviated clay or argillic horizons or as a tool to help explain soil genesis. As soil genesis occurs, an argillic horizon may form through clay translocation or neoformation of minerals. The fine to total clay ratio is used as an index of argillic development, i.e., this ratio is normally one third higher than in the overlying eluvial or in the underlying horizon (Soil Survey Staff, 1975, 1994). The fine to total clay ratio is reported on the Supplementary Data Sheet, Column 65.

Column 8: Carbonate (CO_3) Clay (<0.002 mm).

Carbonate clay, definition: Carbonate clay is a soil separate with <0.002-mm particle diameter. The SSL determines the carbonate-clay fraction by pipet analysis (procedure 3A1) and by gas pressure evolved after treatment with acid (procedure 3A1d). This determination of carbonate clay is semiquantitative as it is assumed that all of the carbonates in a soil sample are converted to CO_2, i.e., not only the carbonates of Ca but also the carbonates of Mg, Na, and K react with the acid. Carbonate clay is reported as a weight percentage on a <2-mm base.

Carbonate clay, soil-related factors: Carbonate clay is considered important in PSDA because clay-size carbonate particles have properties that are different from noncarbonate clay. The cation exchange capacity of carbonate clay is very low compared to noncarbonate clay. Saturation percentage, Atterberg limits, and 15-bar water retention for carbonate clay are ≈ 2/3 the corresponding values for the noncarbonate clays (Nettleton et al., 1991). Since carbonate clay is a diluent, it is often subtracted from the total clay in order to make inferences about soil genesis and clay activities. Total clay is routinely estimated and carbonates measured by soil scientists in the field. Generally, the amounts of carbonate clay, as estimated by hand texture, are underestimated ≈ 1/2 (Nettleton et al., 1991). In *Soil Taxonomy* (Soil Survey Staff, 1975), carbonates of clay size are not considered to be clay for soil texture but are treated as silt in all particle-size classes.

Column 9: Fine Silt (0.002 - 0.02 mm).

Fine silt, definition: Fine silt is a soil separate with 0.002- to 0.02-mm particle diameter. The SSL determines the fine-silt fraction by pipet analysis in procedure 3A1. Fine silt is reported as a weight percentage on a <2-mm base.

Column 10: Coarse Silt (0.02 - 0.05 mm).

Coarse silt, definition: Coarse silt is a soil separate with 0.02- to 0.05-mm particle diameter. The 0.02 mm (20 µm) is the break between sand and silt in the International classification system. The particle-size separation at 20 µm also has significance in optical microscopy, as this class limit represents the optical limits of the polarizing light microscope. The SSL determines the coarse-silt by difference in procedure 3A1. Coarse silt = (100 - (% total clay + % fine silt + % total sand)). Coarse silt is reported as a weight percentage on a <2-mm base.

Column 11: Very Fine Sand (0.05 to 0.10 mm).

Very fine sand, definition: Very fine sand (VFS) is a soil separate with 0.05- to 0.10-mm particle diameter. The SSL determines the VFS fraction by sieve analysis in procedure 3A1. Very fine sand is reported as a weight percentage on a <2-mm base.

Very fine sand, taxonomic significance: Particle-size classes are a compromise between engineering and pedologic classes (Soil Survey Staff, 1975, 1994). In engineering classifications, the limit between sand and silt is a 0.074-mm diameter. The break between sand and silt is 0.05 and 0.02 mm in the USDA and International classification systems, respectively. In engineering classes, the VFS separate is split. In particle-size classes of soil taxonomy (Soil Survey Staff, 1975, 1994), the VFS is allowed to *float*, i.e., VFS is treated as sand if the texture is fine sand, loamy fine sand, or a coarser class and is treated as silt if the texture is very fine sand, loamy very fine sand, sandy loam, silt loam, or a finer class (Soil Survey Staff, 1975, 1994). Refer to additional discussion on particle-size classes by the Soil Survey Staff (1975, 1994).

Column 12: Fine Sand (0.10 - 0.25 mm).

Fine sand, definition: Fine sand is a soil separate with 0.10- to 0.25-mm particle diameter. The SSL determines the fine sand fraction by sieve analysis in procedure 3A1. Fine sand is reported as a weight percentage on a <2-mm base.

Column 13: Medium Sand (0.25 - 0.50 mm).

Medium sand, definition: Medium sand is a soil separate with 0.25- to 0.50-mm particle diameter. The SSL determines the medium sand fraction by sieve analysis in procedure 3A1. Medium sand is reported as a weight percentage on a <2-mm base.

Column 14: Coarse Sand (0.5 - 1.0 mm).

Coarse sand, definition: Coarse sand is a soil separate with 0.5- to 1.0-mm particle diameter. The SSL determines the coarse sand fraction by sieve analysis in procedure 3A1. Coarse sand is reported as a weight percentage on a <2-mm base.

Column 15: Very Coarse Sand (1.0 - 2.0 mm).

Very coarse sand, definition: Very coarse sand is a soil separate with 1.0- to 2.0-mm particle diameter. In 1947, the class name for the 1.0- to 2.0-mm fraction in the USDA classification system was changed from fine gravel to very coarse sand. The SSL determines the very coarse sand fraction by sieve analysis in procedure 3A1. Very coarse sand is reported as a weight percentage on a <2-mm base.

Columns 16 - 20: PARTICLE-SIZE DISTRIBUTION ANALYSIS, PARTICLES >2 mm.

Particle-size classes: The term *rock fragments* is defined as particles ≥2 mm in diameter and includes all particles with horizontal dimensions smaller than the size of a pedon (Soil Survey Staff, 1975, 1994). Rock fragments are generally sieved and excluded from most chemical, physical, and mineralogical analyses. Exceptions are described by SSL procedures in Section 1B (SSL Staff, 1992). Some gravel codes may also be listed in these data columns, e.g., V = volume estimate or P = porous >2-mm fraction. Refer to SSIR No. 42 (SSL Staff, 1992) for descriptions of laboratory preparation procedures.

Weight percentages of >2-mm fractions, field and laboratory weighings, procedure 3B1a: The SSL determines weight percentages of the >2-mm fractions by field and laboratory weighings by procedure 3B1a. In the field or in the laboratory, the sieving and weighing of the >2-mm fraction are limited to the <75-mm fractions. In the field, fraction weights are usually recorded in pounds, whereas in the laboratory, fraction weights are recorded in grams. The 20- to 75-mm fraction is generally sieved, weighed, and discarded in the field. This is the preferred and usually the most accurate method. Less accurately, the 20- to 75-mm fraction is estimated as a volume percentage of the whole soil. If it is sieved and weighed in the laboratory, the results are usually not reliable because of small sample size. Refer to the discussion on interferences to field and laboratory weighings in this data column.

Weight percentages of >2-mm fractions from volume estimates and weight determinations, procedures 3B1b and 3B2: The SSL estimates weight percentages of the >2-mm fractions from volume estimates of the >20-mm fractions and weight determinations of the <20-mm fractions by procedure 3B1b. The volume estimates are visual field estimates. Weight percentages of the >20-mm fractions are calculated from field volume estimates of the 20- to 75-mm, 75- to 250-mm, and >250-mm fractions. The >250-mm fraction includes stones and boulders that have horizontal dimensions that are smaller than the size of the pedon. Weight measurements for the 2- to 20-mm fraction are laboratory measurements. Weight measurements of the 20- to 75-mm fractions in the field are more accurate than visual volume estimates. Weight measurements of this fraction in the laboratory are not reliable. Refer to the discussion on interferences to field and laboratory weighings in the next section. The volume estimates that are determined in the field are converted to dry weight percentages. For any >2-mm fractions estimated by volume in the field, the SSL calculates weight percentages by procedure 3B2. The visual volume estimates of the >20-mm fraction are subjective. The conversion of a volume estimate to a weight estimate assumes a particle density of 2.65 g cc^{-1} and a bulk density for the fine-earth fraction of 1.45 g cc^{-1}. Refer to a more detailed discussion on particle density and bulk density on the PSDA Sheet, Tier 2, Columns 12 - 14.

Field and laboratory weighings, interferences: Soil variability and sample size are interferences to weight determinations of the >2-mm particles. Enough soil material needs to be sieved and weighed to obtain statistically accurate rock fragment content. In order to accurately measure rock fragments with maximum particle diameters of 20 and 75 mm, the minimum specimen sizes ("dry" weights) that need to be sieved and weighed are 1.0 and 60.0 kg, respectively. Refer to ASTM method D 2487 (American Society for Testing and Materials, 1993). Refer to Table 2 (ASTM, 1993)for the minimum specimen size ("dry" weights) for particle-size analysis.

Table 2. Minimum dry weights for particle-size analysis[1].

Maximum Particle Size Sieve Opening	Minimum Specimen Size Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (3/8 in)	200 g (0.5 lb)
19.0 mm (3/4 in)	1.0 kg (2.2 lb)
38.1 mm (1 1/2 in)	8.0 kg (18 lb)
75.0 mm (3 in)	60.0 kg (132 lb)

[1] American Society for Testing and Materials, 1993.

Whenever possible, the field samples or "moist" material should have weights two to four times larger than shown in Table 2 (American Society for Testing and Materials, 1993). Therefore, sieving and weighing the 20- to 75-mm fraction should be done in the field. The <20-mm fractions are sieved and weighed in the laboratory.

Weight percentages, reporting procedure: Procedures for reporting data for a size fraction base are outlined in Section 2A (SSL Staff, 1992). Unless otherwise specified, the particle-size fractions 2 to 5, 5 to 20, 20 to 75, and 0.1 to 75 mm are reported on a <75-mm oven-dry weight percentage basis in Columns 16 - 19, respectively. The total >2-mm fraction is reported on a whole soil oven-dry weight percentage base in Column 20.

Column 16: Coarse Fractions (2 - 5 mm).

The SSL determines coarse fractions with 2- to 5-mm particle diameter by procedures outlined in Section 3B (SSL Staff, 1992). The 2- and 5-mm divisions correspond to the size of openings in the No. 10 and No. 4 screen (4.76 mm), respectively, used in engineering. Coarse fractions with 2- to 5-mm particle diameter correspond to the rock fragment division, *fine pebbles* (Soil Survey Division Staff, 1993). Coarse fractions with 2- to 5-mm particle diameter are reported as a weight percent on a <75-mm base in this data column.

Column 17: Coarse Fractions (5 - 20 mm).

The SSL determines coarse fractions with 5- to 20-mm particle diameter by procedures outlined in Section 3B (SSL Staff, 1992). The 5- and 20-mm divisions correspond to the size of openings in the No. 4 screen (4.76 mm) and the 3/4-in screen (19.05 mm), respectively, used in engineering. Coarse fractions with 5- to 20-mm particle diameter correspond to the rock fragment division, *medium pebbles* (Soil Survey Division Staff, 1993). Coarse fractions with 5- to 20-mm particle diameter are reported as a weight percent on a <75-mm base in this data column.

Column 18: Coarse Fractions (20 - 75 mm).

The SSL determines coarse fractions with 20- to 75-mm particle diameter by procedures outlined in Section 3B (SSL Staff, 1992). The 20- and 75-mm divisions correspond to the size of openings in the 3/4-in screen (19.05 mm) and the 3-in screen (76.1 mm), respectively, used in engineering. Coarse fractions with 20- to 75-mm particle diameter correspond to the rock fragment division, *coarse pebbles* (Soil Survey Division Staff, 1993). Coarse fractions with 20- to 75-mm particle diameter are reported as a weight percent on a <75-mm base in this data column.

Column 19: Coarse Fractions (0.1 - 75 mm).

The SSL determines coarse fractions with 0.1- to 75-mm particle diameter by procedures outlined in Section 3A and 3B (SSL Staff, 1992). The 75-mm division corresponds to the size of opening in the 3-in screen (76.1 mm) used in engineering. This data column is listed for taxonomic placement of particle-size class, i.e., to distinguish loamy and silty family particle-size classes. Refer to the Soil Survey Staff (1975, 1994) for additional discussion on particle-size classes. Coarse fractions with 0.1- to 75-mm particle diameter are reported as a weight percent on a <75-mm base in this data column.

Column 20: Coarse Fractions (>2 mm).

The SSL determines coarse fractions with >2-mm particle diameter by procedures outlined in Section 3B (SSL Staff, 1992). Coarse fractions with >2-mm particle diameter are reported as a weight percent on whole-soil base in this data column.

4.2 PSDA SHEET: TIER 2: COLUMNS 1 - 20:

Column 1: Organic Carbon (C).

Organic matter: A principle feature that separates soil from rock is organic matter. The quantity and properties of organic matter help determine the direction of soil formation processes as well as the biochemical, chemical, physical, and soil fertility properties (Kononova, 1966). Organic matter affects the composition and mobility of adsorbed cations as well as soil color, heat balance, volume weight, consistency, and specific gravity of the solid phase. The overall influence of accumulating organic matter usually leads to higher soil fertility, with the resultant higher humus content often serving as the first indication of a fertile soil (Orlov, 1985). In addition to changes in soil properties, components of humus and the level of productivity can have a direct physiological influence on plants as well as on the biological activity of the soil (Orlov, 1985).

Soil organic matter, also referred to as soil humus, has been defined as the organic fraction of soil exclusive of undecayed plant and animal residues (Soil Science Society of America, 1987). However, as soil organic matter estimates generally include only those organic materials that pass through a 2-mm sieve, it is difficult to quantitatively estimate the organic matter content of a soil (Nelson and Sommers, 1982). Soil organic matter may be partitioned into humic and nonhumic substances, with the major portion in most soils and waters consisting of humic substances (Schnitzer and Kahn, 1978). Humic materials include humic acid (HA), fulvic acid (FA), and humin. Humic substances are partitioned into these three main fractions based on their solubility in alkali and acid. The HA fraction is soluble in dilute alkali but is precipitated by acidification of the alkaline extract; FA is the fraction that remains in solution when the alkaline extract is acidified, i.e., soluble in both dilute alkali and dilute acid; and the humin is the fraction that cannot be extracted from the soil or sediment by dilute base and acid (Schnitzer and Kahn, 1978). Nonhumic substances include those substances with still recognizable physical and chemical characteristics, e.g., carbohydrates, proteins, peptides, amino acids, fats, waxes, alkanes, and low molecular weight organic acids (Schnitzer, 1982). Most of these substances have a short survival period in the soil as they are readily attacked by microorganisms.

Organic C, component of organic matter: Carbon is a major component of soil organic matter. Studies of organic matter and nutrient cycling (N, P, and S) emphasize the central role of C (Stevenson, 1982). Carbon is important as a major source of CO_2, and humus is a C reservoir sensitive to changes in climate and atmospheric CO_2 concentrations (Schnitzer and Khan, 1978; Schnitzer, 1982). Organic C consists of the cells of microorganisms; plant and animal residues at various stages of decomposition; stable "humus" synthesized from residues; and nearly inert and highly carbonized compounds, e.g., charcoal, graphite, and coal (Nelson and Sommers, 1982).

Organic matter, "Van Bemmelen factor": As a major component of soil organic matter, a measurement of organic C can serve as an indirect determination of organic matter through the use of an approximate correction factor. The "Van Bemmelen factor" of 1.724 has been used for many years and is based on the assumption that organic matter contains 58% organic C. The literature indicates that the proportion of organic C in soil organic matter for a range of soils is highly variable. Any constant factor that is selected is only an approximation. Studies have indicated that subsoils have a higher factor than surface soils (Broadbent, 1953). Surface soils rarely have a factor <1.8 and usually range from 1.8 to 2.0. The subsoil factor may average ~ 2.5 (Broadbent, 1953). The preference of the SSL is to determine and report organic C concentration in a soil rather than to convert the analytically determined organic C value to organic matter content through the use of an approximate correction factor.

Organic C, rules of thumb: Some general rules of thumb about the properties of organic C (NSSL Staff, 1975) are as follows:

Equation 9:

$$1 \text{ g organic C} \approx 3 \text{ to } 4 \text{ meq CEC } (NH_4OAc, \text{ pH } 7.0).$$

Equation 10:

$$1 \text{ g organic C} \approx 1.5 \text{ g } H_2O \text{ (15 bar)}.$$

Equation 11:

$$1 \text{ g organic C} \approx 3.5 \text{ g } H_2O \text{ (1/3 bar)}.$$

Organic C, laboratory measurement, Walkley-Black: The Walkley-Black method is a wet combustion technique to measure organic C. This organic C determination represents decomposed soil organic matter and normally excludes relatively fresh plant residues, roots, charcoal, and C of carbonates. Even though the

Walkley-Black method converts the most active forms of organic C in soils, it does not yield complete oxidation of these compounds. Walkley and Black (1934) determined that ≈ 76% of organic C was recovered by their method and therefore proposed a correction factor of 1.32 to account for unrecovered organic C. Allison (1960) found that the percent recovery of organic C by Walkley-Black procedure varied from 63 to 86% in a wide variety of soils and that the correction factor varied from 1.16 to 1.59. The SSL uses the Walkley-Black correction factor. The Walkley-Black method and similar procedures provide approximate or semiquantitative estimates of organic C in soils because of the lack of an appropriate correction factor for each soil analyzed (Nelson and Sommers, 1982). Organic C data by Walkley-Black are generally considered invalid if organic C is >8 percent. In these cases, the SSL uses a more direct determination of soil organic matter. The organic matter is destroyed on ignition (400°C), and the soil weight loss is used as a measure of the organic matter content. Refer to the discussion on percent mineral content on the Acid Oxalate Sheet, Tier 1, Column 19. The SSL determines organic C by procedure 6A1c (Walkley-Black). Organic C is reported as percent on a <2-mm base.

Organic C, accumulation index, calculation: An accumulation index may be calculated for organic C or other data. An example accumulation index for organic C to a depth of one meter (kg/m^{2-m}) is calculated as follows:

Equation 12:

$$\text{Product } (kg/m^{2-H}) = Wt_{oc} \times 0.1 \times Db_{1/3} \times Hcm \times Cm$$

Equation 13:

$$\text{Accumulation Index} = \text{Sum of Products to 1 m } (kg/m^{2-m})$$

where:

Wt_{oc} = Weight percentage of organic C on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 1.

0.1 = Conversion factor, constant.

$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base ($g\ cc^{-1}$). Data are reported on the PSDA Sheet, Tier 2, Column 13.

Hcm = Horizon thickness (cm). Data are reported on the PSDA Sheet, Tier 1, Column 1.

Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

Example: Refer to Appendix II (Wildmesa Pedon)

Hrz	Depth	OC	Factor	$Db_{1/3}$	Hcm	Cm	Product
	cm	%		g cc^{-1}	cm		
A	0-8	0.45	0.1	1.47	8	.84	0.44
AB	8-15	0.15	0.1	1.60	7	.94	0.16
2Bt	15-46	0.19	0.1	1.45	31	.99	0.85
2Btk	46-74	0.15	0.1	1.38	28	1.00	0.58
2Btk	74-109	0.12	0.1	1.26	26	.99	0.39
ACCUMULATION INDEX					100 cm		2.42 kg/m^{2-m}

Organic matter, weight to volume base, calculation:

Organic carbon can serve as an indirect determination of organic matter through the use of an approximate correction factor termed the "Van Bemmelen factor" of 1.724. Organic carbon is routinely reported as a weight percent. Convert organic carbon on a weight base to a volume base as follows:

Equation 14:

$$V_{om} = \frac{Wt_{oc} \times 1.72 \times Db_{1/3}}{1.1}$$

where:

V_{om} = Volume percentage of organic matter on a <2-mm base.
Wt_{oc} = Weight percentage of organic C on a <2-mm base.
1.72 = "Van Bemmelen factor".
$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
1.1 = Assumed particle density of organic matter (g cc^{-1}).

Column 2: Total Nitrogen (N).

Total N, organic and inorganic: Nitrogen is ubiquitous in the environment as it is continually cycled among plants, soil organisms, soil organic matter, water, and the atmosphere (National Research Council, 1993). Nitrogen is one of the most important plant nutrients and forms some of the most mobile compounds in the soil-crop system, and as such, is commonly related to water quality problems. Total soil N includes both the organic and inorganic forms and may range from 0.06 to 0.5% in surface layers of many cultivated soils, <0.02% in subsoils, and 2.5% in peats (Bremner and Mulvaney, 1982). Organically complexed N comprises over 90% of the total N in surface layers of most soils and is an important factor in soil fertility (Stevenson, 1982). Inorganic N forms were once considered to constitute only a few percent of the total soil N pool (Young and Aldag, 1982). However, more recently, many soils have been found to contain appreciable amounts of N in the form of fixed NH_4^+, particularly in lower horizons. Soils with large amounts of illites or vermiculites can "fix" significant amounts of N compared to those soils dominated by smectite or kaolinite (Nommik and Vahtras, 1982; Young and Aldag, 1982). The uses of total N data include, but are not limited to, the determination of the N distribution in the soil profile; the soil C:N ratio; and the soil potential to supply N for plant growth.

Nitrogen cycle: Nitrogen undergoes a wide variety of transformations in the soil, most of which involve the organic fraction. An internal "N cycle" exists in the soil distinct from the overall cycle of N in nature. Even if gains and losses in N are equal, as may occur in some mature ecosystems, the N cycle is not static. Continuous turnover of N occurs through mineralization-immobilization with transfer of biological decay products into stable humus forms (Stevenson, 1982). This N cycle is critical to crop growth. The balance between the inputs and outputs and the various interactive transformations (mineralization, nitrification, immobilization, and denitrification) in the N cycle determines how much N is available for plant growth and how much may be lost to the atmosphere, surface water, or groundwater (National Research Council, 1993). Nitrogen inputs to a particular agricultural field include rainfall; fertilizers; mineralization from soil organic-N, crop residues, manure; N-fixation by microorganisms; and even delivery of N from irrigation waters (National Research Council, 1993). The primary desired output is N uptake in harvested crops and crop residues (National Research Council, 1993). Nitrogen is applied to soils as NH_4^+ (ammonium) or NO_3^- (nitrate) ions. Generally, NH_4^+ ions rapidly undergo nitrification forming NO_3^- in warm, aerobic soils. Ammonium can be adsorbed by soil particles and lost by fixation or erosion, while NO_3^- remains in soil solution and is subject to leaching or denitrification. Denitrification is the chemical reduction of NO_3^- to gaseous nitric oxide (NO), nitrous oxide (N_2O), or dinitrogen (N_2) forms. Volatilization of these forms of N represents atmospheric N loses (Bremner et al., 1981; Nelson, 1982; Meisinger and Randall, 1991). Some nutrients may be removed by weeds or immobilized by microbes thus entering the organic-N storage pool. These minor outputs are secondary factors and typically have been implicitly included in nutrient-crop yield response models (National Research Council, 1993).

C:N ratio: The C:N ratio relates to fertility and organic matter decomposition. In many soils, the level of "fixed" N usually remains constant or increases with depth while organic C usually diminishes with depth resulting in a C:N ratio which narrows with depth (Young and Aldag, 1982). The potential to "fix" N has important fertility implications as the "fixed" N is slowly available for plant growth. In cultivated, agriculturally important soils of the temperate regions, the C:N ratio of surface soil horizons, e.g., mollic epipedons, usually falls within the narrow limits of about 10 to 12, and in forest soils, often a few units higher (Young and Aldag, 1982). Higher ratios in soils may suggest low decomposition levels or low N levels in plant residues and soils. In many cases, the C:N ratio narrows in the subsoil, partly because of the higher content of NH_4^+-N and the generally lower amounts of C. Variations in the C:N ratio may serve as an indicator of the amount of inorganic soil N. Uncultivated soils usually have higher C:N ratios than do cultivated soils. When C or N values are very low, ratios may appear unrealistic, and care is required in interpreting the data.

Essential plant elements, general discussion: The presence of an element in a plant is not, of and by itself, a valid basis upon which to assess its essentiality to plant life (Noggle and Fritz, 1976). Of the many elements that have been detected in plant tissues, only 20 are essential to the growth of some plant or plants. Symptoms develop, in the absence of each of the essential elements, that are characteristic of the elements, resulting in reduced plant growth and yield (Arnon and Stout, 1939; Noggle and Fritz, 1976). It was proposed that if elements were metabolically active but are not essential, then these elements are better termed functional or metabolic elements rather than essential elements (Bollard and Butler, 1966; Nicholas, 1969). An example would be if one element could be substituted by another, e.g., Br for Cl.

Macroelements (C, H, O, N, P, K, Ca, Mg, and S) are those elements required in relatively large amounts by plants, whereas microelements (B, Fe, Mn, Cu, Zn, Mo, Cl, Co, V, Na, and Si) are those required in relatively small or trace amounts. The above-named elements, with the exception of C, H, O, and N, are known as mineral elements. These mineral elements usually constitute what is known as the plant ash or the mineral remaining after "burning off" C, H, O, and N. Carbon, hydrogen, and oxygen in plants are obtained from carbon dioxide and water and are converted to simple carbohydrates by photosynthesis and, when combined with N, are converted to amino acids, proteins, and protoplasm.

There exists in nature a soil-plant continuum, i.e., the soil with its properties and reactions that affect plant available elements; the root with its growth, distribution, and response to environmental factors; and the plant with its requirements, absorption, and utilization of elements. The interactions of all these components is the continuum which is more critical than any one single component. This continuum can be extended to include the microbial component, as the physical and chemical soil characteristics determine the nature of the environment in which microorganisms are found (Alexander, 1977).

Nitrogen, essential plant element: Nitrogen is an essential plant nutrient that is used in protein formation and serves as an integral part of the chlorophyll molecule, the primary light energy absorber for photosynthesis. Nitrogen has been related to carbohydrate utilization and associated with vigorous vegetative growth and dark green color. Many proteins are enzymes, and the role of N in plant growth is considered as both structural and metabolic. An imbalance of N or an excess of N in relation to other nutrients, e.g., P, K , and S, can prolong the growing period and delay crop maturity (Bidwell, 1979). Plants absorb N in the form of ammonium, urea, and nitrate. The NO_3^- is usually the dominant form in moist, warm, well-aerated soils (Tisdale et al., 1985).

Total N, laboratory measurement: The SSL no longer determines total N by digestion using the Kjeldahl technique (procedure 6B3a). Since 1993, the SSL uses the combustion technique (LECO nitrogen analyzer) (procedure 6B4a). Total N is reported in this data column on a <2-mm base.

Column 3: Extractable Phosphorus (P).

Total P, organic and inorganic: Phosphorus added to the soil-crop system goes through a series of transformations as it cycles through plants, animals, microbes, soil organic matter, and the soil mineral fraction (National Research Council, 1993). Phosphorus is also an essential plant nutrient and often related to water quality problems. However, unlike N, most P is tightly bound in the soil, and only a small fraction of the total P found in the soil is available to crop plants. Total P includes both organic and inorganic P forms. Apatite is a common P-bearing mineral.

Organic P levels may vary from virtually zero to 0.2%, with the inorganic P frequently higher than that of organic P (Tisdale et al., 1985). The organic P fraction is found in humus and other organic materials. The inorganic P fraction occurs in numerous combinations with Fe, Al, Ca, Fl, and other elements. The solubility of these various combinations varies from soluble to very insoluble (Chang and Jackson, 1957; Lindsay and Vlek, 1977). Phosphates may also react with clays to form generally insoluble clay phosphate complexes (adsorbed P). Refer to the discussion on P retention on the Acid Oxalate Sheet, Tier 1, Column 5. Also refer to Sharpley et al. (1985) for detailed P characterization of 78 soils representing 7 major soil orders from all regions of the United States. Sharpley et al. (1985) discusses the various soil P forms, e.g., labile, organic, and sorbed; the various pathways of P transformation; the significance of selected soil P test values; and the relationships between soil P and soil test P values.

C:P:N ratio: Studies of the mineralization of organic P in relation to the C:N:P ratio have indicated that there is no set ratio for all soils. Some studies have indicated that if the C:inorganic P ratio is 200:1 or less, mineralization of P may occur, and if this ratio is 300:1, immobilization would occur (Tisdale et al., 1985). Other studies have indicated that the N:P ratio to be related to the mineralization and immobilization of P and that the decreased supply of one results in the increased mineralization of the other, i.e., if N were limiting, inorganic P may accumulate in the soil and the formation of soil organic matter would be inhibited (Tisdale et al., 1985).

Phosphorus, essential plant element: Phosphorus is an essential nutrient for plant growth and is a primary fertilizer element. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column

2). Phosphorus is essential in supplying phosphate which acts as a linkage or binding site in plants. The stability of phosphate enables it to participate in many energy capture, transfer, and recovery reactions which are important for plant growth (Tisdale et al., 1985). The energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds (ATP and ADP) for subsequent use in growth and reproductive processes. In addition to its metabolic role, P also acts as an important structural component of a wide variety of biochemicals, including nucleic acids (DNA and RNA), coenzymes, nucleotides, phosphoproteins, phospholipids, and sugar phosphates (Tisdale et al., 1985). Phosphorus has also been linked to increased root growth and early maturity of crops, particularly grain crops. Plants can absorb P as either the primary $H_2PO_4^-$ ion or smaller amounts of the secondary HPO_4^{2-} orthophosphate ion. The $H_2PO_4^-$ is the principal form absorbed as it is most abundant over the range in soil pH prevailing for most crops. The absorption of $H_2PO_4^-$ is usually greater at low soil pH values, whereas the uptake of HPO_4^{2-} is usually greater at higher pH values (Bidwell, 1979). Some studies have shown that there are 10 times more absorption sites on plant roots for $H_2PO_4^-$ than for HPO_4^{2-}.

Phosphorus, fertilizer: Fertilizer-P is the single most important source of P added to croplands in the U.S. Relatively small annual additions of P can cause a soil buildup of P (McCollum, 1991). Phosphorus can be lost from the soil-crop system in soluble form through leaching, subsurface flow, and surface runoff. Particulate P is lost when soil erodes. The fraction of total P lost to erosion and runoff can be substantial. Some of the P added in excess of crop needs remains as residual plant-available P. The amount of extractable P declines with time because of the slow conversion of P to unavailable forms, e.g., Ca, Al, and Fe-P compounds (Yost et al., 1981; Mendoza and Barrow, 1987; Sharpley et al., 1989; McCollum, 1991). The rate of decline in extractable P (discounting plant uptake) varies with the soil P-level and P-sorption capacity. The P level in the soil is the critical factor in determining actual loads of P to surface water and the relative proportions of P lost in solution and attached to soil particles (National Research Council, 1993). Understanding the relative importance of transport pathways and the processes regulating these transport pathways helps to design measures to reduce P losses. When P enters surface waters in substantial amounts it becomes a pollutant, contributing to the excessive growth of algae and other aquatic vegetation and, thus, to the accelerated eutrophication of lakes and reservoirs (National Research Council, 1993).

Phosphorus, soil testing: Soil chemical tests for estimating soil nutrient pools are relatively rapid and have the added advantage over deficiency symptoms and plant analyses that soil requirements are determined before a crop is planted. Soil tests usually only measure a part of the total nutrient supplies in the soil. In general, these test values are of no use in themselves and must be calibrated against nutrient rate experiments, i.e., field and greenhouse experiments, before use in the prediction of the nutrient needs of crops. A complete soil testing program includes both the analytical procedures for estimating soil fertility and the appropriate correlation and calibration data for recommending the correct fertilization practices (Corey, 1987; Sabbe and Marx, 1987). Fertilizer recommendations are then based on the interpretation of these calibration data and fertilizer response curves.

Phosphorus, available: The fraction of soil P utilizable for crop growth has been designated as *available P*. This term is also used to refer to the portion of soil P extracted by various solvents, e.g., water, dilute acids or alkalies, and salt solutions (Tisdale et al., 1985). The quantities of total P are much greater than those of the available P, but the available form is of greater importance to plant growth. The term *labile P* has been defined as the fraction that is isotopically exchanged with ^{32}P or that is readily extracted by some chemical extractant or by plants (Foth and Ellis, 1988). Thus, the labile P may include some or all of the adsorbed P in a particular soil, or it may also include some precipitated P (Foth and Ellis, 1988). *Adsorbed P* is generally considered the portion of soil P that is bonded to the surface of other soil compounds when a discrete mineral-phase is not formed, e.g., if soluble P were added to a soil solution, it may be bound to the surface of amorphous Al hydroxide without forming a discrete Al-P mineral (Foth and Ellis, 1988). Labile P has been an important working concept for the soil scientist in relating soil P to plant available P as it is a measurable fraction, even though it may include P from several of the discrete P fractions held in soils (Foth and Ellis, 1988). Soil tests for P generally try to measure all or part of the labile P (Foth and Ellis, 1988). The SSL determines available P by the extractable Bray P-1 method.

Available P, laboratory measurement, Bray P-1: The Bray P-1 method is widely used as an index of plant-available P in the soil. The selectivity of the Bray extractant is designed to remove the easily acid-soluble P, largely Ca phosphates, and a portion of the phosphates of Al and Fe (Bray and Kurtz, 1945; Olsen and Sommers, 1982). In general, this method has been most successful on acid soils (Bray and Kurtz, 1945; Olsen and Sommers, 1982). Phosphorus interpretations for plant growth and fertilizer applications by Bray P-1 extraction procedures or by any other method require the use of regional soil fertility guides. These guides are generally available through the local agricultural extension services. The appropriate use of these guides requires that the soil test measurements for extractable P, or for any other nutrient upon which fertilizer recommendations are based, be the same. The SSL determines extractable P by procedure 6S3 (Bray P-1). Extractable P by Bray P-1 method is reported in this data column as mg kg^{-1} (formerly ppm) in the soil on a <2-mm base.

Column 4: Total Sulfur (S).

Total S, organic and inorganic: Organic and inorganic S forms are found in soils, with the organic S fraction accounting for >95% of the total S in most soils from humid and semi-humid regions (Tabatabai, 1982). Mineralization of organic S and its conversion to sulfate by chemical and biological activity may serve as a source of plant available S. Total S typically ranges from 0.01 to 0.05% in most mineral soils but can be greater in organic soils. In well-drained soils, most of the inorganic S normally occurs as sulfate. Large amounts of reduced S compounds occur in marine tidal flats, other anaerobic marine sediments, and mine spoils which oxidize to sulfur acid upon exposure to the air. Significant amounts of inorganic S are found as sulfates, e.g., gypsum and barite in arid regions.

C:N:S ratio: There have been many investigations of the soil C:N:S ratios with mixed results. Some studies have indicated that these ratios are very similar for different groups of soils. Other studies (Stewart and Bettany, 1982a, 1982b) have found significant differences in the mean C:N:S ratios among and within types of world soils, with the differences being attributed to variations in parent material and other soil-forming factors, e.g., climate, vegetation, leaching intensity, and drainage. However, a close association usually exists between the N and S constituents of soil organic matter (Tisdale et al., 1985). Total N, which is principally organic, and the organic S are often more closely correlated than organic fractions of C and S. The N:S ratio in many soils falls within the narrow range of 6 to 8:1 (Tisdale et al., 1985).

Sulfur, essential plant element: Sulfur is an essential nutrient for plant growth. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column 2). Sulfur plays an important role in protein formation; the functioning of several enzyme systems; chlorophyll synthesis; and in the activity of nitrate reductase (Tisdale et al., 1985). Sulfur is absorbed by plant roots almost exclusively as the sulfate ion SO_4^{2-}. Low levels may also be absorbed through plant leaves and utilized within plants. High levels of the gaseous form (SO_2) are toxic. Symptoms of S deficiencies are often very similar to N deficiencies in plants.

Sulfur, soil testing: In many parts of the U.S. and agricultural lands of the world, the need to supplement the natural S sources to meet plant requirements has been unnecessary (Johnson, 1987). The chemistry of S favors its conservation in soils either as the sparingly soluble sulfate salts, e.g., gypsum and barite, or as a component of organic matter (Johnson, 1987). The recycling of S, along with the significant additions of S from rainfall and irrigation waters, ensures adequate S for crops in most environments. Crop deficiencies of S in desert and arid regions are extremely rare as soils in these areas usually developed under conditions in which S was not leached from the rooting depth of most crops (Johnson, 1987). In those areas with S deficiencies for specific crops, the proper sampling, testing, and use of appropriate calibration tables are factors in the efficient use of S fertilizers. Total S has been used as an index of the total reserves of this element which can be converted to plant available S. Extractable sulfate S (SO_4^{2}-S), which is not determined at the SSL, is an index of readily plant-available S. Extractable SO_4^{2}-S does not include the labile fraction of soil organic S that is mineralized during the growing season (Tabatabai, 1982).

Total S, laboratory measurement: The SSL determines total S by a combustion technique (LECO sulfur analyzer) (procedure 6R3a). A soil sample is oxidized at high temperatures, and the evolved SO_2 in combustion gases is measured using an infrared detector. Total S is reported in this data column as percent on a <2-mm base.

Columns 5 - 7: DITHIONITE-CITRATE EXTRACTIONS.

Broad groupings, soil components: Over the years, various terms have been used to describe broad groupings of soil components, e.g., *crystalline phyllosilicates, amorphous, poorly crystalline, paracrystalline, noncrystalline, allophane, imogolite,* and *short-range-order minerals (SROMs),* etc. These groupings have been related, in part, to various laboratory analyses, and thereby, have been operationally defined quantitatively and semiquantitatively by these analyses. Some of these analytical procedures include X-ray diffraction analysis and selective chemical dissolutions, e.g., dithionite-citrate, sodium pyrophosphate, and ammonium oxalate extractions. These terms have not been used consistently in the literature. In addition, there is not always a clear delineation between dissolution data, either conceptually or operationally. This discussion on terminology is pertinent not only to the data columns for dithionite-citrate extractable Fe, Al, and Mn but also to sodium pyrophosphate and ammonium oxalate extractions.

Soil aluminosilicates, crystalline phyllosilicates: *Soil aluminosilicates* include a broad spectrum of constituents, ranging from noncrystalline materials (exhibiting local and nonrepetitive short-range order) to paracrystalline materials (intermediate-range order) to crystalline phyllosilicates (layer silicates) characterized by three-dimensional periodicity over appreciable distances (long-range order) (Jackson et al., 1986). *Crystalline phyllosilicates* have been defined by Bailey (1980) as follows: "containing two-dimensional tetrahedral sheets of composition T_2O_5 (T = Si, Al, Be ...) with tetrahedra linked by sharing three corners of each, and with the fourth corner pointing in any direction. The tetrahedral sheets are linked in the unit structure to octrahedral sheets, or to groups of coordinated cations, or individual cations." In soils and sediments, the phyllosilicates of common interest include the 1:1 layer types (kaolinite and halloysite) and the 2:1 layer types (smectite, vermiculite, mica, and kaolinite).

Terms: Amorphous, SROMs, poorly crystalline, noncrystalline, and paracrystalline: The term *amorphous* has been used to refer to an array of materials that are amorphous to X-rays and have no more than short-range order, e.g., allophane and imogolite (Kimble et al., 1984). The term *SROMs* has been used interchangeably with the terms amorphous, poorly crystalline, and noncrystalline. The term SROMs is preferred by some investigators because, as the resolving power of mineralogical instruments improve, the possibility of determining and distinguishing among the various kinds of SROMs also improves (Uehara and Ikawa, 1985). Allophane and imogolite are two SROMs that would have been called amorphous 25 years ago. There are other soil materials with even shorter-range order than allophane and imogolite, e.g., allophane-like constituents (Wada, 1980) and surface coatings of SROMs on crystalline minerals (Jones and Uehara, 1973; Uehara and Jones, 1974). The term *noncrystalline* is used by some investigators (Wada, 1977; Jackson et al., 1986; Wada, 1989) in preference to the more commonly used term *amorphous*. The term *paracrystalline* includes the somewhat ordered (short-range-order) materials, e.g., imogolite. Hence, the term *noncrystalline aluminosilicates* has been cited in the literature to address the whole spectrum of short-range order minerals in weathered parent materials and soils (Jackson et al., 1986).

Allophane and imogolite: Allophanes are associated mainly with weathered volcanic ash (Jackson et al., 1986). A definition of the term *allophane* was proposed by van Olphen (1971), in accordance with Ross and Kerr (1934), as follows: "Allophanes are members of a series of naturally occurring minerals which are hydrous aluminum silicates of widely varying chemical composition, characterized by short-range-order, by the presence of Si-O-Al bonds, and by a differential thermal analysis curve displaying a low temperature endotherm and a high temperature exotherm with no intermediate endotherm". By these criteria, allophane is limited to a small sector of the total spectrum of noncrystalline and paracrystalline aluminosilicates developed by weathering of volcanic ash and pumice and other materials of soils and deposits (Jackson et al., 1986). *Imogolite*, a mineral closely associated with allophane, is a hydrated aluminosilicate with a thread-like morphology that consists of paracrystalline cylindrical assemblies of a one-dimensional structure unit (Cradwick et al., 1972). *Allophane-like* constituents are similar to allophane but are difficult to identify or have more defective structures. Opaline silica occurs as amorphous spheres. There are also amorphous Al hydroxide gels and Fe oxides (ferrihydrite). In some studies, ferrihydrite has been considered the primary factor responsible for the irreversible drying of some soils into hard aggregates (Kubota, 1972; Espinoza et al., 1975; Maeda et al., 1977; Parfitt and Childs, 1988).

Selective chemical dissolutions, significance: Selective dissolution data have been used extensively in the study of the noncrystalline material content of soils and sediments. However, there are limitations in using these data. In general, there exists a continuum of crystalline order, ranging from no long-range order to paracrystalline to poorly crystalline to well crystalline (Follet et al., 1965). Selective dissolution data are necessary for independent determinations of various inorganic constituents of soils because of the difficulty with many physical analytical methods in estimating or even recognizing the presence of noncrystalline and paracrystalline free oxides or aluminosilicates mixed with crystalline soil components (Jackson et al., 1986). In general, the crystalline free oxides and phyllosilicates of soils can be identified qualitatively and estimated semiquantitatively by X-ray diffraction analysis. Refer to additional discussion on X-ray diffraction analysis on the Mineralogy Sheet, Tiers 1 - 3. Those soils containing hydroxyls (-OH groups), e.g., kaolinite, gibbsite, and goethite, can sometimes be determined quantitatively by differential thermal analysis (DTA), differential scanning colorimetry (DCS), and thermogravimetric analysis (TGA). Refer to additional discussion on thermal analysis on the Mineralogy Sheet, Tiers 1 - 3.

Selective chemical dissolutions, limitations: With selective chemical dissolution data, there are difficulties in the adequate assessment of the portion that is extracted by particular reagents, e.g., dithionite-citrate, sodium pyrophosphate, and ammonium oxalate. In principle, it cannot be expected that chemical methods are able to perfectly distinguish the degrees of crystallinity, and some caution is required in the interpretation of these analytical data (van Wambeke, 1992). Refer to Table 3 (Wada, 1989) for the dissolution of Al, Fe, and Si in various clay constituents and organic complexes by treatment with different reagents. Refer to the discussion on ammonium oxalate extractions on the Acid Oxalate Sheet, Tier 1, Columns 1 - 4. Also refer to the discussion on sodium pyrophosphate extractions on the Acid Sheet, Tier 2, Columns 1 - 7.

Dithionite-citrate extractions, laboratory measurement: A soil sample is mixed with sodium dithionite, sodium citrate, and distilled deionized water, and shaken overnight. An aliquot of the extract is obtained, and the dithionite-citrate extractable Fe, Mn, and Al are measured using atomic absorption (AA) spectrometry. Refer to SSIR No. 42 (SSL Staff, 1992) for the method description of dithionite-citrate extractions for Fe, Mn, and Al. Note that the dithionite-citrate extraction cited in Table 3 is not the same method as determined by the SSL. The dithionite-citrate extractable Fe, Mn, and Al are reported on this data tier in Columns 5 - 7, respectively.

Table 3. Dissolution of Al, Fe, and Si in various clay constituents and organic complexes by treatment with different reagents.[1]

Element in Specified component and complex	Treatment with				
	0.1 M $Na_4P_2O_7$[2]	Dithionite-Citrate[3]	20 g L^{-1} Na_2CO_3[4]	0.15-0.2 M oxalate-oxalic acid (pH 3.0-3.5)[5]	0.5 M NaOH[6]
Al and Si in					
Allophane	Poor	Poor	Poor	Good	Good
Imogolite	Poor	Poor	Poor	Good-fair	Good
"Allophane-like"	Poor	Good	Good	Good	Good
Layer Silicates	No	No-poor	No	No-poor	Poor-fair
Al in					
Organic complexes	Good	Good	Good	Good	Good
Hydrous oxides					
Noncrystalline	Poor	Good	Good	Good	Good
Crystalline	No	Poor	Poor	No	Good
Si in					
Opaline silica	No	No	Poor	No	Good
Crystalline silica	No	No	No	No	Poor
Fe in					
Organic complexes	Good	Good	No	Good	No
Hydrous oxides					
Noncrystalline[7]	Poor	Good	No	Good	No
Crystalline	No	Good	No	No-poor	No

[1] Wada, 1989.
[2] McKeague et al. (1971); Higashi and Wada (1977).
[3] Mehra and Jackson (1960); Tokashiki and Wada (1975).
[4] Jackson (1956); Tokashiki and Wada (1975).
[5] Schwertmann (1964); Higashi and Ikeda (1974); Wada and Kakuto (1985).
[6] Hashimoto and Jackson (1960); Tokashiki and Wada (1975).
[7] Includes ferrihydrite.

Column 5: Iron (Fe), Dithionite-Citrate Extractable.

"Free" Fe oxides: The original objectives of the dithionite-citrate extraction were to determine the free Fe oxides and to remove the amorphous coatings and crystals of free Fe oxide, acting as cementing agents, for subsequent physical and chemical analysis of soils, sediments, and clay minerals (Weaver et al., 1968; Jackson, 1969; Jackson et al., 1986). Dithionite-citrate extractable Fe (Fe_d) is considered a measure of "free iron" in soils and, as such, is pedogenically significant. Dithionite-citrate extractable Fe data are of interest in soil genesis-classification studies because of its increasing concentration with increasing weathering, and its effect on soil colors (Schwertmann, 1992). "Free iron" is also considered an important factor in P-fixation and soil aggregate stability.

Dithionite-citrate extractable Fe, total pedogenic Fe: In a general way, the Fe_d is considered to be a measure of the total pedogenic Fe, e.g., goethite, hematite, lepidocrocite, and ferrihydrite, while the ammonium oxalate extractable Fe (Fe_o) (probably ferrihydrite) is a measure of the paracrystalline Fe (Birkeland et al., 1989). The Fe_o/Fe_d ratio is often calculated because it is considered an approximation of the relative proportion of ferrihydrite in soils (Schwertmann, 1985). Refer to the discussion on Fe_o on the Acid Oxalate Sheet, Tier 1, Columns 1 - 4.

Dithionite-citrate extractable Fe is used as a criterion in the ferritic and oxidic mineralogy classes (Soil Survey Staff, 1975, 1994). Refer to the Soil Survey Staff (1975, 1994) for additional discussion of these mineralogy classes. Refer to the discussion on the agronomic and engineering significance of ferritic and oxidic mineralogies on the Mineralogy Sheet, Tiers 1 - 3. The SSL determines Fe_d by procedure 6C2b. The Fe_d is reported as percent on a <2-mm base.

Column 6: Manganese (Mn), Dithionite-Citrate Extractable.

The dithionite-citrate extractable Mn (Mn_d) is considered the "easily reducible Mn". The SSL determines Mn_d by procedure 6D2a. The Mn_d is reported as percent on a <2-mm base.

Column 7: Aluminum (Al), Dithionite-Citrate Extractable.

Dithionite-citrate extractable Al, significance: The dithionite-citrate and ammonium oxalate extracts for Al are pedogenically significant. The dithionite-citrate extractable Al (Al_d) represents the Al substituted in Fe oxides which can have an upper limit of thirty-three mole percent substitution (Schwertmann et al., 1977; Schwertmann and Taylor, 1989). The ammonium oxalate extractable Al (Al_o) is generally an estimate of the total pedogenic Al in soils dominated by allophane, imogolite, and organically-bound Al (Wada, 1977; Childs et al., 1983). Unlike Fe_d, the Al_d extract is commonly less than the Al_o (Childs et al., 1983; Birkeland et al., 1989) and so does not necessarily represent the total pedogenic Al (Wada, 1977). Refer to the discussion on Al_o on the Acid Oxalate Sheet, Tier 1, Columns 1 - 4. The SSL determines Al_d by procedure 6G7a. The Al_d is reported as percent on a <2-mm base.

Column 8: CEC/Clay Ratio.

CEC-7/clay ratio, data assessment: The CEC-7 to clay ratio has been used as auxiliary data to assess clay mineralogy. This ratio is an index for clay activity, i.e., probable contribution of clay to the exchange capacity and soil solution chemistry. Clay activity is closely linked to clay mineralogy. The smectites (montmorillonites) and vermiculites are considered high activity clays; kaolinites and hydroxy-interlayered vermiculites are low-activity clays; and micas (illites) and chlorites are intermediate-activity clays (NSSL Staff, 1983). Guidelines for determining taxonomic soil mineralogy placements (Soil Survey Staff, 1975, 1994) have been developed for the suite of montmorillonitic-mixed-kaolinitic materials. The following guidelines were developed primarily from experience with soil samples from the central United States and Puerto Rico (NSSL Staff, 1983).

CEC-7/Clay	**Family Mineralogy as Assessed by XRD and DTA Evidence**
>0.7	Montmorillonite
0.5-0.7	Montmorillonite or Mixed
0.3-0.5	Mixed
0.2-0.3	Kaolinite or Mixed
<0.2	Kaolinite

Soils with illitic family mineralogy usually have CEC-7/clay ratios in the range of mixed (lower end of mixed range). Vermiculitic soils usually have CEC-7/clay ratios similar to smectitic soils. However, some soil minerals determined as vermiculite by X-ray diffraction analysis (termed hydroxy-interlayered vermiculites) appear more similar in nature to inactive soil chlorites which have CEC-7/clay ratios in the range of kaolinite (NSSL Staff, 1983). The CEC-7/clay ratio is useful both as an internal check of the data and as an estimator of mineralogy when mineralogy data are not available.

CEC-7/clay ratio, high and low values: A soil with a silt or sand fraction with a significant CEC can have a higher CEC-7/clay ratio than expected. Soils with organic or glassy materials or with a clay fraction that is incompletely dispersed by PSDA or soils with porous silts and sands too coherent to be disaggregated by PSDA can also have a high CEC-7/clay ratio. In these cases, the 15-bar water to clay ratios are also high. In a study of 34 Borolls (NSSL Staff, 1990), each percent increase in organic C increases the CEC-7 by 3 meq 100 g^{-1} soil ($r^2 = 0.83$) and the CEC-8.2 by 4 meq 100 g^{-1} soil ($r^2 = 0.85$). A soil with clay-size materials with little or no CEC, e.g., calcium carbonate, can have a low CEC-7/clay ratio. In this case, the carbonate clay percentage needs to be checked and the CEC-7/clay ratio recalculated based on the noncarbonate clay (NSSL Staff, 1983).

CEC-7/clay ratio, calculation: Determine the CEC-7/clay ratio by dividing the CEC-7 (NH_4OAc, pH 7.0) by the total clay percentage. The SSL determines the CEC-7/clay ratio by procedure 8D1. The CEC-7 is reported on the Acid or Salt Sheet, Tier 1, Column 9. Total clay percentage is reported on the PSDA Sheet, Tier 1, Column 4. The CEC-7/clay ratio is reported in this data column. In the past, the CEC-7/clay ratio has been reported in meq 100 g^{-1}. The CEC-7/clay ratio is also reported on the Supplementary Data Sheet, Column 67.

Mineralogy, taxonomic, agronomic and engineering significance: The CEC-7 to clay ratio is used as auxiliary data to assess clay mineralogy. These data are especially useful when mineralogy data are not available. Refer to Soil Survey Staff (1975, 1994) for discussion of mineralogy class as a taxonomic criterion of soil families in different particle-size classes. Refer to the discussion of the agronomic and engineering significance of selected mineralogy classes on the Mineralogy Sheet, Tiers 1 - 3.

Column 9: 15 Bar/Clay Ratio.

15-bar water/clay ratio, data assessment: As water retention at 15 bar has been equated with a 0.2-µm pore diameter, a high correlation exists between 15-bar water and clay content, and as such, this ratio is a good tool for data assessment (NSSL Staff, 1983). A good rule of thumb reference point for soils dominated by silicates that disperse well in the standard PSDA is as follows:

Equation 15:

$$W_{15}/\text{Clay} \approx 0.4$$

OR (alternatively)

Equation 16:

$$\text{Clay} \approx 2.5 \times W_{15}$$

where:

W_{15} = Weight percentage of water retained at 15-bar suction on a <2-mm base. Data are reported on the Acid Oxalate Sheet, Tier 1, Column 12 (moist, procedure 4B2b) and on the PSDA Sheet, Tier 2, Column 19 (air-dry, procedure 4B2a).

Clay = Weight percentage of clay on a <2-mm base. Data are reported on the PSDA Sheet, Tier 1, Column 4.

A number of soil-related factors can cause deviation from this 0.4 reference point. Low activity clays, e.g., kaolinites, chlorites, and some micas, tend to lower the ratio to ≤ 0.35. High activity clays, e.g., smectites and some vermiculites, tend to increase this ratio. The relationship between 15-bar water and the amount of clay has been characterized for groups of soils dominated by different kinds of clay minerals (NSSL Staff, 1990) and some average ratios are as follows: 0.45 for smectite (r^2 = 0.88, n = 547); 0.42 for clay mica (r^2 = 0.90, n = 493); and 0.32 for Bt horizons of Paleudults (r^2 = 0.98, n = 18). Whether these differences in the ratios are caused by differences in clay mineralogy or by differences in other properties associated with the different clay mineralogies is not known.

15-bar water/clay ratio, high and low values: Organic matter increases the 15-bar water retention and subsequently increases the ratio. An increased 15 bar to clay ratio can be expected if the organic C percent is >0.1 of the percent clay (NSSL Staff, 1983). In a study of 34 Borolls (NSSL Staff, 1990), each percentage increase in organic C increases the 15-bar percentage approximately 1.5 percent (r^2 = 0.67). In a study of 53 Xerolls (NSSL Staff, 1990), each percentage increase in organic C increases the 15-bar percentage approximately 1.3 percent (r^2 = 0.72).

Poorly crystalline materials also tend to increase this ratio. If this ratio is >0.6, and soil-related factors do not adequately explain the situation, incomplete dispersion in PSDA may be a factor (NSSL Staff, 1983). Soil components which act as cements and cause poor dispersion include carbonates, gypsum, Fe oxides, and poorly crystalline Si. Refer to the discussion of pretreatments to particle-size distribution analysis on the on the PSDA Sheet, Tier 1, Columns 4 - 15.

Clay-size carbonate tends to decrease the ratio in most cases. The 15-bar water retention for carbonate clays is ≈ 2/3 the corresponding value for the noncarbonate clays (Nettleton et al., 1991).

15-bar/clay ratio, dispersion in PSDA: The amount of clay relative to the amount of organic C and the surface area of nonclay constituents affects the 15-bar water content to clay relationship. With decreasing clay content, the organic C and surface area of other nonclay constituents increase the 15-bar retention. For these reasons, ratios above 0.5 for some samples with less than 5 to 10 percent clay may erroneously indicate poor PSDA dispersion (NSSL Staff, 1990).

Poor dispersion by the SSL standard particle-size distribution is typical in Andisols. Yet, poor dispersion in some soils emphasizes one of the fundamental guidelines of the laboratory, i.e., standard methods. Standard operating procedures are necessary in order to compare soil data. These comparisons have been critical factors in developing many relationships used in understanding soils and in the development of *Soil Taxonomy* (Soil Survey Staff, 1975). Not all soils are composed of well-defined particles that can be dispersed into their appropriate fraction if only the "correct method" were used. In addition, there is no exacting measure of poor dispersion. The 15-bar/clay ratio is one measure, as is the comparison of laboratory vs field-determined soil textures and clay contents. Neither measure or indicator is perfect. Alternative and additional pretreatments may extract additional clay from a soil sample, but are these pretreatments freeing or creating clay particles? The fact that a particular soil sample reacts differently to a standard method in itself provides information concerning the soil's properties.

15-bar water/clay ratio, calculation: Determine the 15-bar water/clay ratio by dividing the 15-bar water retention by the total clay percentage. The SSL determines the 15 bar/clay ratio by procedure 8D1. The 15-bar water retention on air-dry samples is reported on the PSDA Sheet, Tier 2, Column 19. Total clay percentage is reported on the PSDA Sheet, Tier 1, Column 4. The 15-bar water/clay ratio is reported in this data column. In the past, the 15-bar/clay ratio has been reported in g g^{-1}. This ratio is also reported on the Supplementary Data Sheet, Column 68. Note that the 15-bar water to noncarbonate clay ratio may also be determined by subtracting the carbonate clay (PSDA Sheet, Tier 1, Column 8) from the total clay.

Columns 10 - 11: ATTERBERG LIMITS.

Atterberg Limits, definition: *Atterberg Limits* is a general term that encompasses liquid limit (LL), plastic limit (PL), and, in some references, shrinkage limit (SL). The test method for these limits by ASTM has the designation of ASTM D 4318 (American Society for Testing and Materials, 1993). This test method is used as an integral part of several engineering classification systems, e.g., American Association of State Highway and Transportation Officials (AASHTO) and the ASTM Unified Soil Classification System (USCS), to characterize the fine-grained fractions of soils (ASTM D 2487 and D 3282) and to specify the fine-grained fraction of construction materials (ASTM D 1241) (American Society for Testing and Materials, 1993). The LL and plastic index (PI) of soils are also used extensively, either individually or together with other soil properties, to correlate with engineering behavior, e.g., compressibility, permeability, compactability, shrink-swell, and shear strength (American Society for Testing and Materials, 1993). The LL and PI are closely related to amount and kind of clay, CEC, 15-bar water, and engineering properties, e.g., load-carrying capacity of the soil.

In general, the AASHTO engineering system is a classification system for soils and soil-aggregate mixtures for highway construction purposes, e.g., earthwork structures, particularly embankments, subgrades, subbases, and bases. The USCS classification is used for general soils engineering work by many organizations including USDA-NRCS.

Column 10: Liquid Limit (LL).

Liquid Limit, definition: The LL is the percent water content of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in) when subjected to 25 shocks from the cup being dropped 10 mm in a standard LL apparatus operated at a rate of 2 shocks s^{-1}. Refer to ASTM method D 4318 (American Society for Testing and

Materials, 1993). The LL is reported as percent water on a <0.4-mm base (40-mesh) (procedure 4F1) in this data column. The LL is also reported on the Supplementary Data Sheet, Column 22. If the LL is not measured, it can be estimated for use in engineering classification through the use of algorithms. Many algorithms have been developed that are applicable to a particular region or area of study. Some equations developed by the National Soil Survey Laboratory (1975) are as follows:

Equation 17:

$$LL = 0.9 \times Clay + 10$$

OR (alternatively)

Equation 18:

$$LL = 2 \times W_{15} + 10$$

where:

LL = Liquid Limit.

$Clay$ = Weight percentage of clay on a <2-mm base. Data are reported on the PSDA Sheet, Tier 1, Column 4.

W_{15} = Weight percentage of water retained at 15-bar suction on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 19.

Column 11: Plasticity Index (PI).

Plasticity Index, definition: The PI is the range of water content over which a soil behaves plastically. Numerically, the PI is the difference in the water content between the LL and the plastic limit (PL). Refer to Column 10 for the definition of LL. The PL is the percent water content of a soil at the boundary between the plastic and brittle states. The boundary is the water content at which a soil can no longer be deformed by rolling into 3.2-mm (1/8-in) threads without crumbling. Refer to ASTM method D 4318 (American Society for Testing and Materials, 1993). If either the LL or PL can not be determined, or if PL is $\geq$ LL, the soil is reported as nonplastic (NP). The PI is reported as percent water on a <0.4-mm base (procedure 4F2) in this data column. The PI is also reported on the Supplementary Data Sheet, Column 23. If the PI is not measured, it can be estimated for use in engineering classification through the use of algorithms. Many algorithms have been developed that are applicable to a particular region or area of study. Some equations developed by the National Soil Survey Laboratory (1975) are as follows:

Equation 19: When <15% clay

$$PI = Clay \times 0.3$$

Equation 20: When 15 to 35% clay

$$PI = Clay \times 0.4$$

Equation 21: When 35 to 55% clay

$$PI = Clay - 21$$

Equation 22: When >55% clay

$$PI = Clay - 15$$

where:

PI = Plasticity Index.

Clay = Weight percentage of clay a <2-mm base. Data are reported on the PSDA Sheet, Tier 1, Column 4.

Columns 12 - 14: BULK DENSITY.

Bulk density, definition: Density is defined as mass per unit volume. Soil bulk density is the ratio of the mass of solids to the total or bulk volume. This total volume includes the volume of both solids and pore space. Bulk density is distinguished from particle density which is mass per unit volume of only the solid phase (Blake and Hartge, 1986a). Particle density excludes pore spaces between particles. Bulk density is usually reported for the <2-mm soil fabric by subtracting the mass and volume of rock fragments from the total mass and volume (Brasher et al., 1966; Blake and Hartge, 1986a; SSL Staff, 1992). This correction for rock fragments with >2-mm diameter requires either knowledge or an assumption of the rock fragment density. Estimate or measurement errors of rock fragment density affect the accuracy of the soil bulk density value. The porosity of the rock fragments is also a factor that must be considered when correcting the values for soil bulk density and water holding capacity.

Bulk density, data assessment: Bulk density is used to convert from a weight to a volume basis; to determine the coefficient of linear extensibility (COLE); as a parameter in estimating saturated hydraulic conductivity; to detect pan layers or other compacted material in soil profiles; to detect the presence of significant amounts of volcanic ash and pumice in soil material; to estimate the degree of weathering of rocks and soils; to follow volume changes with soil genesis; to study gains and losses of soil materials; and to evaluate the possibilities of root impedance (Buol et al., 1980). A bulk density <0.90 g cc^{-1} (g cm^{-3}) at 1/3-bar water retention is a diagnostic criterion for andic soil properties (Soil Survey Staff, 1994). Bulk densities of Histosols range from 0.05 to 0.15 g cc^{-1} for fibric and most of the hemic materials (Lynn et al., 1974). For sapric materials, the range is wider, but densities >0.25 g cc^{-1} are limited to organic soils with <7 percent rubbed fiber, of which most are from cultivated surface soil. Relationships have been established between high bulk density and lack of root penetration (Veihmeyer and Hendrickson, 1948). Bulk densities $\geq$1.8 g cc^{-1} have been related to root growth impedance, and densities of 1.6 to 1.8 g cc^{-1} may indicate that aeration and water movement are too low for optimum growth (NSSL Staff, 1975). Some plow layers approach densities of 1.8 g cc^{-1}, and most duripans, fragipans, and petrocalcic horizons have densities this high or higher (NSSL Staff, 1975). Refer to additional discussion on physical root limitations (Grossman et al., 1994) and on nonlimiting, restriction-initiation, and root-limiting bulk densities for <2-mm family particle-size classes (Pierce et al., 1983).

Bulk density, laboratory measurements: Bulk density is highly dependent on soil conditions at the time of sampling. Changes in soil volume (swelling) due to changes in water content can alter bulk density. Soil mass remains fixed, but the soil volume may change as water content changes (Blake and Hartge, 1986a). Bulk density, as a soil characteristic, is actually a function rather than a single value, e.g., in shrinking-swelling soils, bulk density changes with changes in soil water content Therefore, the SSL adds subscripts to the bulk density notation, Db, to designate the water state of the sample when the volume was measured. The SSL uses the bulk density notations of Db_f, $Db_{1/3}$, Db_d, and Db_r for field state, 1/3-bar equilibration, oven-dry, and rewet, respectively. The Db_f, $Db_{1/3}$, and Db_d are reported in g cc^{-1} on a <2-mm base in Columns 12 - 14, respectively.

Particle density, data assessment: Particle density affects many of the interrelationships of porosity, bulk density, air space, and rates of sedimentation of particles in fluids. Particle-size analyses that use sedimentation rate, as well as calculations involving particle movement by wind and water, require information on particle density (Blake and Hartge, 1986b).

Even though there is a considerable range in the density of individual soil minerals, in most mineral soils that are predominantly quartz, feldspar, and the colloidal silicates, the densities fall within the narrow limits of 2.60 to 2.75 g cc^{-1} (Brady, 1974). The particle density of volcanic glass is approximately 2.55 g cc^{-1} (van Wambeke, 1992). With unusual amounts of heavy minerals, e.g., magnetite, garnet, epidote, zircon, tourmaline, and hornblende present, the particle density may exceed 2.75 g cc^{-1} (Brady, 1974). Organic matter weighs much less than an equal volume of mineral solids. Organic matter has a particle density of 1.2 to 1.5 g cc^{-1}, i.e., the amount of organic matter in a soil markedly affects the particle density of the soil (Brady, 1974).

Particle density, laboratory measurement: The calculation of particle density of a soil sample requires two measurements, the mass and the volume of the sample. The mass is determined by weighing. The volume is determined using a pycnometer, an instrument specifically designed to measure the volume of solid objects. The volume measurement is based on the Archimedes principle of fluid displacement. This fluid is displaced by a gas which can penetrate the finest pores thereby assuming maximum accuracy. Helium is usually the recommended gas as its small atomic dimension assures penetration in spaces approaching one Angstrom (10^{-10} m) in dimension. The SSL either measures particle density or assumes a default value of 2.65 g cc^{-1}. Particle density is not reported on the SSL Primary Characterization Data Sheets but, if determined, is reported on additional SSL data sheets.

Column 12: Bulk Density, Field Moist.

Bulk density, field state, measurements: Field state bulk density (Db_f) at field water content is the density at the time of sampling. The SSL determines the Db_f for moist soil cores of known volume (procedure 4A3a); for natural clods (procedure 4A1a); and for weak or loose material for which the clod or core method is unsuitable (procedure 4A5, compliant cavity method). There are SSL Db_f data by all these methods. At the present time, the code set on the data sheet for Db_f is procedure 4A5 (compliant cavity method, procedure 4A5). The Db_f is reported in g cc^{-1} on a <2-mm base in this data column.

Column 13: Bulk Density, 1/3 bar.

Bulk density, 1/3-bar, laboratory measurement: The SSL determines the bulk density at 1/3-bar equilibration ($Db_{1/3}$) of natural clods that have been saturated with water and desorbed to 1/3 bar (33 kPa) (procedure 4A1d) and the bulk density rewet (Db_r) of natural clods that have been equilibrated at 1/3-bar, air-dried, and reequilibrated at 1/3-bar (procedure 4A1i). The Db_r is used to estimate the irreversible shrinkage of soils and subsidence of organic soils. The $Db_{1/3}$ by procedure 4A1d for natural clods is reported in g cc^{-1} on a <2-mm base in this data column.

Column 14: Bulk Density, Oven-Dry.

Bulk density, oven-dry, laboratory measurement: The SSL determines bulk density (Db_d) of natural clods that have been oven-dried (105°C) by procedure 4A1h. The Db_d and $Db_{1/3}$ may be nearly equal in sandy soils, but the Db_d is greater than $Db_{1/3}$ in smectitic soils. The Db_d exceeds the bulk density of a dry soil in the field. The Db_d is reported in g cc^{-1} on a <2-mm base in this data column.

Column 15: COLE, Whole Soil.

Coefficient of linear extensibility, definition: Coefficient of linear extensibility (COLE) is a derived value that denotes the fractional change in the clod dimension from a dry to a moist state (Franzmeier and Ross, 1968; Grossman et al., 1968; Holmgren, 1968). COLE may be used to make inferences about shrink-swell capacity and clay mineralogy. The COLE concept does not include irreversible shrinkage such as that occurring in organic and some andic soils. Certain soils with relatively high contents of montmorillonite clay have the capacity to swell significantly when moist and to shrink and crack when dry. This shrink-swell potential is important for soil physical qualities (large, deep cracks in dry seasons) as well as for genetic processes and soil classification (Buol et al., 1980).

Linear extensibility percent, definition: COLE can also be expressed as percent, i.e., linear extensibility percent (LEP). LEP = COLE x 100. The LEP is not the same as LE. In the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994), linear extensibility (LE) of a soil layer is the product of the thickness, in centimeters, multiplied by the COLE of the layer in question. The LE of a soil is defined as the sum of these products for all soil horizons (Soil Survey Staff, 1994). Refer to Soil Survey Staff (1994) for additional discussion of LE. Refer to additional discussion of LEP on the Supplementary Data Sheet, Columns 69 - 73.

Coefficient of linear extensibility, calculation, whole-soil base: The SSL calculates the COLE for the whole soil by procedure 4D1 (air-dry or ovendry to 1/3-bar suction). The COLE value is reported in cm cm^{-1}. Calculate COLE when coarse fragments are present as follows:

Equation 23:

$$COLE_{ws} = \{1/[Cm \times (Db_{1/3<2mm}/Db_{d<2mm}) + (1 - Cm)]\}^{1/3} - 1$$

where:

$COLE_{ws}$ = Coefficient of linear extensibility on a whole-soil base.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.

$Db_{d<2mm}$ = Bulk Density, oven-dry or air-dry, on a <2-mm base (g cc^{-1}). Bulk density at ovendryness is reported on the PSDA Sheet, Tier 2, Column 14.

Cm = Coarse fragment (moist) conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

If no coarse fragments, Cm = 1, and the previous equation reduces as follows:

Equation 24:

$$COLE_{ws} = \sqrt[3]{\frac{Db_{d<2mm}}{Db_{d<2mm}}} - 1$$

where:

$COLE_{ws}$ = Coefficient of linear extensibility on a whole-soil base.

$Db_{d<2mm}$ = Bulk Density, oven-dry or air-dry, on a <2-mm base (g cc^{-1}). Bulk density at ovendryness is reported on the PSDA Sheet, Tier 2, Column 14.

$Db_{1/3<2mm}$ = Bulk Density at 1/3 water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.

Columns 16 - 19: WATER CONTENT.

Water content, definition: In soil science, water content has traditionally been expressed as either a dimensionless ratio of two masses or two volumes or as a mass per unit volume (Gardner, 1986). When either of these dimensionless ratios is multiplied by 100, the values become percentages, and the basis (mass or volume) is stated. Conversions from gravimetric to volumetric basis or vice versa require a measure or an estimate of bulk density. In either case (mass or volume base), the amount of water in the sample must be determined by either the removal or measurement of the water or by determination of the sample mass before and after water removal, i.e., dried to a constant weight (Gardner, 1986). In addition, when precision is critical, there must be criteria for determining the point at which the sample is considered "dry". The SSL defines air-dry and oven-dry weights as constant sample weights obtained after drying at 30±5°C (≈ 3 to 7 days) and 105±5°C (≈ 12 to 16 h), respectively.

Water content, data assessment: Direct or indirect (index) determinations of soil water content are generally required in many soil studies. In the field, measurements or estimates of soil water content are required to determine plant available water. In the laboratory, soil water data are necessary to determine and report many physical and chemical properties (Gardner, 1986). In addition, soil water content may be used to help determine the water retention function; water-holding capacity; pore-size distribution; porosity of a soil sample at a specific water content; and to calculate unsaturated hydraulic conductivity.

Water content, related expressions: Calculating the amount of pore space and the amount of water in the pore space is often a complex soil physics problem. Some general definitions and relationships, e.g., bulk density and porosity, are required so that comparisons between soils or soil scientists are appropriate. Some of these definitions and relationships as well as techniques to calculate soil water content (Skopp, 1992) are as follows:

Equation 25:

$$\rho_B = M_s/V_{s+v},$$

where:

ρ_B = Bulk density of soil
M_s = Mass of solids
V_{s+v} = Volume of solids + volume of voids = volume of soil

Bulk density is highly dependent on soil conditions at the time of sampling. Changes in soil swelling due to changes in water content alters the bulk density. Once the bulk density is specified, then the relative amount of pore space is also fixed. The amount of pore space is usually described in terms of volumes (ratio of volumes) as follows:

Equation 26:

$$\varepsilon = V_v/V_{s+v}$$

where:

ε = Total porosity
V_v = Volume of voids
V_{s+v} = Volume of solids + volume of voids = volume of soil

Using the definitions for bulk density and particle density, the derivation of a formula for porosity based on these properties is as follows:

Equation 27:

$$\varepsilon = 1 - (\rho_B/\rho_p)$$

where:

ε = Total porosity
ρ_B = Bulk density of soil
ρ_p = Particle density of soil

This relationship is not empirical but is the result of definitions that confirm that for every value of bulk density for a specified soil there is one possible value of porosity. However, a soil does not have one possible value for bulk density.

Porosity is usually defined as a ratio of volumes which is dimensionless, and as such, can just as easily be defined as a ratio of equivalent depths. In order to make this relationship, a comparison is required based on equal cross-sectional areas (A) which comprise the volumes as follows:

Equation 28:

$$\varepsilon = V_v/V_s = Ad_v/Ad_s = d_v/d_s$$

where:

ε = Total porosity
V_v = Volume of voids
V_s = Volume of soil
A = Cross-sectional area
d_v = Depths of voids
d_s = Depths of soil

Unlike voids, which are usually related in terms of volume, the amount of soil water can be expressed on either a mass (gravimetric) or volumetric basis as follows:

Equation 29:

$$\theta_m = M_w/M_s$$

where:

θ_m = Gravimeteric water content
M_w = Mass of water
M_s = Mass of solids

Equation 30:

$$\theta_v = V_w/V_s$$

where:

θ_v = Volumetric water content
V_w = Volume of water
V_s = Volume of soil

The gravimetric water is based on dry solids, whereas the volumetric water is based on the volume of the soil (solids, water, and gas) at the moisture content at the time of measurement. These water content values can be related as follows:

Equation 31:

$$\theta_v = (\theta_m \times \rho_B)/\rho_w$$

where:

θ_v = Volumetric water
θ_m = Gravimeteric water
ρ_B = Bulk density
ρ_w = Particle density of water

The depth of water can be related to the volumetric water as follows:

Equation 32:

$$d_w = (\theta_v \times d_s)$$

where:

d_w = Depth of water
θ_v = Volumetric water
d_s = Depth of soil

The maximum soil water content (saturation) is the point at which all the voids are filled with water. Saturation may be defined as follows:

Equation 33:

$$\theta_v = E$$

where:

θ_v = Volumetric water
E = Total porosity

In reality, saturated soils are uncommon since a small amount of gas is typically present even after prolonged wetting, i.e., the soil is satiated (Skopp, 1992). The water content of a satiated soil has no fixed value and will change with time (as gas diffuses out of soil) and is strongly dependent on the soil water content prior to wetting as well as the manner of wetting (Skopp, 1992).

A number of other expressions are used to characterize the amount of water or air in the soil. These expressions (Skopp, 1992) are as follows:

Equation 34:

$$\theta_A = V_a/V_{s+v}$$

where:

θ_A = Air-filled porosity
V_a = Volume of air
V_{s+v} = Volume of solids + volume of voids = volume of soil

Equation 35:

$$\theta_R = (\theta_V/E)$$

where:

θ_R = Relative saturation
θ_v = Volumetric water
E = Total porosity

Equations 36 and 37:

$$\lambda = V_v/V_s \quad = \quad \lambda = \varepsilon/(1 - \varepsilon)$$

where:

λ = Void ratio
V_v = Volume of voids
V_s = Volume of solids
ε = Total porosity

Refer to additional discussion on bulk density on the PSDA Sheet, Tier 2, Columns 12 - 14. Refer to additional discussion on the calculation of air-filled porosity on the Acid Oxalate Sheet, Tier 1, Column 9. Also refer to the discussion on pore volume (drained + filled pores) at 1/3-bar water content on the Supplementary Data Sheet, Columns 62 - 63.

Water retention: Water retention is defined as the soil water content at a given soil suction (Gardner, 1986). By varying the soil suction and recording the changes in soil water content, a water retention function is determined. The water retention function is dependent on particle-size distribution, clay mineralogy, organic matter, and structure or physical arrangement of the particles (Gardner, 1986). The water retention function is also dependent upon hysteresis, i.e., whether the water is adsorbing or desorbing from the soil. The relation between the soil water content and the soil water suction is a fundamental part of the characterization of the hydraulic properties of a soil (Klute, 1986). For many purposes, water retention properties of individual soil horizons are more usefully combined to form a complete profile, and the importance of a large or small value for available water or air capacity varies in relation to properties of neighboring horizons (Hall et al., 1977). Agricultural, pedological, and hydrological interpretation depend mainly on the assemblage of properties of the whole profile (Hall et al., 1977). Refer to Appendix VI for example water retention curves.

Water retention, laboratory measurements: Soil water retention data on the SSL Characterization Data sheets are from water desorption procedures. Two desorption procedures are commonly used to measure water retention, a suction method or a pressure method. The SSL uses the pressure method (U.S. Salinity Laboratory Staff, 1954) with either a pressure-plate or pressure-membrane extractor. Soil samples are placed in close contact with the porous plate or membrane in a closed vessel and subjected to air pressure to establish a pressure difference across the plate or membrane corresponding to the tension to be established. Water moves out of the samples through the plate or membrane until equilibrium is established. Water-content at field moist and 1/10-, 1/3- and 15-bars (10, 33, and 1500 kPa, respectively) are reported as percent gravimetric water content on a <2-mm base in Columns 16 - 19, respectively. Refer to Appendix XII for data unit conversions, e.g., bar or kPa to lb in^{-2}.

Column 16: Water Content, Field Moist.

Field water content, measurement: Field water content at the time of sampling is determined for soil cores, natural clods, or for bulk samples by weighing, drying, and reweighing a soil sample (procedure 4B4). Field-determined water-retention data are usually lower than laboratory-determined water-retention data because the confining soil pressure is not present in the laboratory. Field-moist water content is reported as percent gravimetric water content on a <2-mm base. Field moist water content is calculated as follows:

Equation 38:

$$H_2O\ \% = 100 \times \frac{M_{s+w} - M_s}{M_s - M_c}$$

where:

H_2O % = Percent gravimetric water content
M_{s+w} = Weight of solids and H_2O (g) + container (g)
M_s = Oven-dry weight of solids (g) + container (g)
M_c = Weight of container (g)

Columns 17 - 18 Water Retention, 1/10 and 1/3 Bar.

Field capacity, definition: The term *field capacity* was first introduced by Veihmeyer and Hendrickson (1931) and has been used widely to refer to the relatively stable soil water content after which drainage of gravitational water has become very slow, generally, within 1 to 3 days after the soil has been thoroughly wetted by rain or irrigation. The intent of this concept was twofold: (1) to define the upper limit of plant available water retained by the soil; and (2) to provide a concept to encourage farmers in irrigated regions not to irrigate excessively (Cassel and Nielsen, 1986). This water that is slowly draining is assumed to be subject to interception by most plant roots and therefore plant available (Salter and Williams, 1965). There are several unstated assumptions to the field capacity concept, i.e., the soil is deep and permeable; no evaporation occurs from the soil surface; and no water table or slowly permeable barriers occur at shallow depths in the profile (Cassel and Nielsen, 1986).

The term *in situ field water capacity* is defined by Soil Science Society of America (1987) as the content of water, on a mass or volume basis, remaining in a soil 2 or 3 days after having been wetted and after free drainage is negligible. A problem with this definition is the difficulty in defining when the drainage rate is negligible. Many factors affect the field capacity measurement which include the conditions under which it is measured, e.g., initial saturation or presence of wetting front, as well as the characteristics of the soil itself, e.g., degree of nonuniformity.

Field capacity, laboratory measurements: Laboratory determinations of the field capacity of a soil are useful data but are not necessarily reliable indicators of this value in the field because of the effects of soil profile and structure. Laboratory determinations are usually made by simulating the tension that develops during drainage in the field by use of pressure membranes or tension tables. There has been considerable debate as to the appropriate tension to apply. In a study by Richards and Weaver (1944), the average soil moisture content at 1/3-bar pressure for 71 different soils (<2 mm) approximated the moisture equivalent or field capacity of the soils. Water content at field capacity may be overestimated from sieved-sample data (Young and Dixon, 1966). Some studies have indicated that the upper limit of plant available water may be more appropriately represented in some soils by the moisture contents at 0.1 or 0.05-bar water retention. As field capacity has no fixed relationship to soil water potential, it cannot be considered as a soil moisture constant (Kramer, 1969). The amount of water retained at field capacity decreases as the soil temperature increases (Richards and Weaver, 1944). Field capacity is not a true equilibrium measurement but rather a soil condition of slow water movement with no appreciable changes in moisture content between measurements (Kramer, 1969).

Some investigators have attempted to remove the term *field capacity* from technical usage (Richards, 1960; Sykes and Loomis, 1967). However, its usage persists in both technical and practical applications, and to date, no alternative concept or term has been advanced to identify the upper limit of plant available water (Cassel and Nielsen, 1986). It has been argued from a practical standpoint that the concept of field capacity be clarified and maintained until a viable alternative is advanced (Cassel and Nielsen, 1986).

Column 17: Water Retention, 1/10 Bar.

Water retention, 1/10 bar, coarse materials: Water retention at 1/10 bar ($W_{1/10}$) may be used as the upper limit of plant available water for coarse materials. According to the Soil Survey Manual (Soil Survey Division Staff, 1993), coarse materials are defined as follows: if strongly influenced by volcanic ejecta, soil material must be nonmedial and weakly or nonvesicular; and if not strongly influenced by volcanic ejecta, soil material must meet the sandy or sandy-skeletal family particle-size criteria and also be coarser than loamy fine sand with <2 percent organic C and <5 percent water at 1500 kPa suction; and computed total porosity of <2-mm fraction must >35 percent. Refer to Soil Survey Division Staff (1993) and Grossman et al. (1994) for additional discussion on coarse materials and the significance of soil water content at lower suctions, e.g., 0.05 and 0.1 bar, as well as suggestions for the selection of these lower suctions for the determination of water retention difference (WRD).

Water retention, 1/10 bar, laboratory measurements: The SSL determines $W_{1/10}$ for natural clods (procedure 4B1c); for <2-mm air-dry samples (procedure 4B1a); and for soil cores (procedure 4B1d). The $W_{1/10}$ by procedure 4B1c for natural clods is reported as percent gravimetric water content on a <2-mm base in this data column.

Column 18: Water Content, 1/3 bar.

Water retention at 1/3 bar, laboratory determinations: The SSL determines water retention at 1/3 bar ($W_{1/3}$) for natural clods (procedure 4B1c); for <2-mm air-dry samples (procedure 4B1a); for soil cores (procedure 4B1d); and for rewet soils (procedure 4B1e). The $W_{1/3}$ for natural clods is usually measured in conjunction with 1/3-bar bulk density ($Db_{1/3}$) (procedure 4A1d). Refer to discussion on $Db_{1/3}$ on the PSDA Sheet, Tier 2, Column 13. The $W_{1/3}$ for <2-mm samples may be used for nonswelling, loamy sand or coarser soils, and for some sandy loams. The water retention rewet is usually measured in conjunction with bulk density rewet (Db_r) (procedure 4A1i). The rewet water retention (4B1c, 4B1e) and bulk density are used to estimate changes in physical properties of a soil as it undergoes wetting and drying cycles. The $W_{1/3}$ by procedure 4B1c for natural clods is reported as percent gravimetric water content on a <2-mm base in this data column.

Column 19: Water Retention, 15 Bar.

Permanent wilting point, definition: The term *permanent wilting percentage or point* (PWP) has been used widely to refer to the lower limit of soil water storage for plant growth. The establishment of this lower limit of available water retained by the soil reservoir is of considerable practical significance (Cassel and Nielsen, 1986). Briggs and Shantz (1912) defined this lower limit, first termed *wilting coefficient*, as the water content at which plants remain permanently wilted (assuming that leaves exhibit visible wilting), unless water is added to the soil. Briggs and Shantz (1911 and 1912) conducted a large number of measurements on a wide variety of plants and found little variation in the soil water content at which wilting occurred (Kramer, 1969). Other investigators (Richards and Wadleigh, 1952; Gardner and Nieman, 1964) determined that the soil water potential at wilting for indicator plants, e.g., dwarf sunflower, approximated -10 to -20 bars with a mean value of -15 bars. The percentage of water at 15-bar retention has become identified with PWP and is frequently used as an index of PWP (Richards and Weaver, 1943; Kramer, 1969).

The PWP criteria (Briggs and Shantz, 1912) were later modified by Furr and Reeve (1945) to include the incipient wilting point, the water content at which the first (usually lower) leaves wilted, and the permanent wilting point, a much lower soil water potential at which all the leaves wilted. The incipient wilting percentage is related to the lower limit at which soil water is available for plant growth, i.e., water extraction may occur at lower contents. In addition, there is no physical reason why continued water extraction may not occur after growth ceases or even after plant death (although much reduced because of stomatal closure) (Kramer, 1969). The PWP is defined by Soil Science Society of America (1987) as the water content of a soil when indicator plants growing in the soil wilt and fail to recover when placed in a humid chamber (usually estimated by the water content at -15 bar soil matric potential). In general, there is a considerable range in water content between incipient and the permanent wilting percentage (Gardner and Nieman, 1964).

Permanent wilting point, soil-related factors: There are many factors that may affect the onset of and visible wilting of plants in the field. Some of these factors include the soil water conductivity as well as the transient inability of the water supply system in the plant to meet evaporative demand rather than to conditions associated with permanent wilting (Kramer, 1969). Slatyer (1957) criticized the concept of PWP as a soil constant and defined wilting as the loss of turgor (zero point of turgor), which is primarily associated with osmotic characteristics of the leaf tissue sap, i.e., wilting occurs when there is a dynamic balance between the plant and soil water potentials. Soil water potential at wilting can vary as widely as the variation in osmotic potential in plants, ranging from -5 to -200 bars (Kramer, 1969). Furthermore, in the equilibrium measurement (Briggs and Shantz, 1912), the PWP is merely a function of the index plant for any given soil. However, because of the shape of the water potential/water content curve of soils, marked changes in water potential often accompany small changes in water content, so that for practical purposes, the PWP or the percentage at 15-bar retention can still be viewed as an important soil value (Kramer, 1969). This approximation is particularly appropriate for most crop plants, as the osmotic potentials of many species range from -10 to -15 bars (Kramer, 1969).

Water retention at 15-bar, data assessment: The maximum size pore filled with water at 15 bar is 0.2-μm diameter. This diameter is in the clay-size range. For this reason, a high correlation usually exists between this water content and clay percentage (NSSL Staff, 1983). In the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994), clay percentages may be estimated by subtracting the percent organic C from the 15-bar water content and then multiplying by 2.5 or 3. Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for the appropriate use of these estimates, e.g., criteria for oxic and kandic horizons and oxidic mineralogy class. The percent water retained at 15-bar suction (dried and undried samples) is also used as a criterion for modifiers that replace particle-size classes, e.g., ashy and medial classes, and for strongly contrasting particle-size classes, e.g., ashy over medial-skeletal (Soil Survey Staff, 1994). Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for a more detailed discussion of these criteria.

Water content at 15-bar, laboratory determinations: The SSL determines water retention at 15 bar (W_{15}) for <2-mm air-dry samples (procedure 4B2a) and for <2-mm field-moist samples (procedure 4B2b). The W_{15} determination requires <2-mm sieved samples in order to provide adequate capillary contact. The W_{15} for <2-mm field-moist samples is not reported on this data tier but is reported on the Acid Oxalate Sheet, Tier 1, Column 12. The W_{15} for <2-mm air-dry samples is reported as percent gravimetric water content in this data column.

Column 20: Water Retention Difference (WRD), Whole Soil.

Available water capacity, definition: The term *available water capacity (AWC)* refers to the availability of soil water for plant growth and is usually considered the amount of water retained in a soil between an upper limit termed *field capacity* and a lower limit termed *permanent wilting percentage* (PWP). The Soil Science Society of America (1987) defines available water as the portion of water in a soil that can be absorbed by plant roots and is the amount of water released between *in situ field water capacity* and the PWP (usually estimated by water content at soil matric potential of -15 bars). These upper and lower limits represent a range which has been used in determining the agricultural value of soils. The importance of AWC relates to the water balance in the soil during the growing season, i.e., difference between evapotranspiration and precipitation. The calculation of the water retention difference can be used in the approximation of the AWC.

Available water capacity, soil-related factors: Available water capacity varies widely in different soils. In general, finer-textured soils have a wider range of water between field capacity and permanent wilting percentage than do coarser-textured soils. In addition, in finer-textured soils, the slope of the curve for water potential over water content indicates a more gradual water release with decreasing water potential, whereas coarser soil materials, with their large proportion of noncapillary pore space and predominance of larger pores, usually release most of their water within a narrow range of potential (Kramer, 1969). Available water capacity only approximates the soil's ability to retain or store water and does not provide an estimate of the supplying capacity of a soil or even the amount that plants extract. The supplying capacity is affected by many factors, e.g., hydraulic conductivity, stratification, run-off, run-on, irrigation, rainfall, osmotic potential, and the plants themselves. Caution is required when using readily available water data because the availability of water depends on many factors. For example, deep rooting in the whole soil profile can compensate for a narrow range of available water in one or more soil horizons as opposed to restricted root distribution combined with a narrow range of available water.

Available water capacity, plant growth: The range of available water for plant survival is substantially greater than that available for good growth. In addition, within the range of available water, the degree of availability usually tends to decline as soil water content and potential decline (Richards and Wadleigh, 1952; Kramer, 1969). There is no sharp limit between available and unavailable water. The PWP is only a convenient point on a curve of decreasing water potential and decreasing availability (Kramer, 1969). However, the range of soil water between field capacity and PWP constitutes an important field characteristic of soils when interpreted properly (Kramer, 1969).

Water retention difference, definition: The calculation of the water retention difference (WRD) is considered the initial step in the approximation of the AWC. The WRD, as defined by the SSL Staff (1992), is a calculated value that denotes the volume fraction for water in the whole soil that is retained between 15-bar suction and an upper limit of usually 1/3 or 1/10 bar suction. The upper limit (lower suction) is selected so that the volume of water retained approximates the volume of water held at field capacity. The 1/10-, 1/3- and 15-bar gravimetric water contents are then converted to a whole soil volume basis by multiplying by the bulk density ($Db_{1/3}$) and adjusting downward for the volume fraction of rock fragments, if present in the soil. Refer to the discussion on 1/10-, 1/3- and 15-bar water contents on this data tier in Columns 17 - 19, respectively. The lower suctions, e.g., 0.1 or 0.05 bar, are used for coarse materials. Refer to the discussion on 1/10-bar water retention on the PSDA Sheet, Tier 2, Column 17 for the definition of coarse materials as defined in the Soil Survey Manual (Soil Survey Division Staff, 1993). Refer to Soil Survey Staff Division Staff (1993) and Grossman et al. (1994) for additional discussion on coarse materials and the significance of soil water content at lower suctions, e.g., 0.05 and 0.1 bar, as well as suggestions for the selection of these lower suctions for the determination of water retention difference (WRD).

Water retention difference, data assessment: The ratio of 1/3 minus 15-bar water to silt content has been used in estimating available water capacity (National Soil Survey Laboratory, 1983). The water retained between these two suctions has been correlated with 0.2- to 10-µm diameter pores (NSSL Staff, 1983). Hence the amount of silt is important to the concept of plant available water. Ratios of 1/3 minus 15-bar water to silt content range from 0.12 to 0.25 in many soils with silicate clays; quartz and feldspar silts and sands; and modest amounts of organic matter. Higher ratios in soils may be associated with amorphous material and significant amounts of organic matter (NSSL Staff, 1983).

Water retention difference, calculation, 1/3 bar as upper limit and 15 bar as lower limit, whole-soil base: The SSL calculates the WRD between 1/3- and 15-bar suctions in the whole soil by procedure 4C1. The WRD is reported as centimeters of water per centimeter of depth of soil (cm cm^{-1}), but the numbers do not change when other units, e.g., in in^{-1} or ft ft^{-1} are needed. The WRD with $W_{1/3}$ as the upper limit as determined by procedure 4C1 is reported as cm cm^{-1} in this data column. This WRD is calculated on a whole-soil base as follows:

Equation 39:

$$WRD_{ws} = \frac{(W_{1/3<2mm} - W_{15<2mm}) \times (Db_{1/3<2mm}) \times Cm \times P_w}{100}$$

where:

WRD_{ws} = Volume fraction (cm^3 cm^{-3}) of water retained in the whole soil between 1/3-bar and 15-bar suction reported in cm cm^{-1}. This is numerically equivalent to inches of water per inch of soil (in in^{-1}).

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base (g H_2O 100 g^{-1}) soil. Data are reported on the PSDA Sheet, Tier 2, Column 18.

$W_{15<2mm}$ = Weight percentage of water retained at 15-bar suction on a <2-mm base (g H_2O 100 g^{-1}) soil. If available, moist 15-bar (procedure 4B2b) is the first option in the WRD calculation; otherwise, dry 15-bar(procedure 4B2a) is used. The $W_{15<2mm}$ moist and air-dry are reported on the Acid Oxalate Sheet, Tier 1, Column 12 and on the PSDA Sheet, Tier 2, Column 19, respectively.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.

Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

P_w = Density of water (1 cm^3 H_2O 1 g^{-1} H_2O).

Water retention difference, calculations, 1/10 or 1/3 bar rewet as upper limits and 15 bar as lower limit, whole-soil base: The SSL also calculates the WRD between 1/10-bar ($W_{1/10}$) and 15-bar suctions (W_{15}) by procedure 4C2 and between 1/3-bar rewet (W_r) and W_{15} by procedure 4C3. These WRD values can be calculated by substituting the $W_{1/10}$ or W_r in place of $W_{1/3}$ in the previous equation. The $W_{1/10}$ may be used as the upper limit of plant available water for coarse soil materials. The W_r is used for organic materials.

Available water capacity and water retention difference, estimates (when no data in Column 20): In interpretations, the interest is usually not the WRD but the AWC (Grossman et al., 1994). The first step in the estimation of AWC is the selection of the suction to approximate the water retention at field capacity. Usually this is 1/3 bar (0.10 or 0.05 bar for coarse soil materials). The second step in the AWC estimate is the selection of the WRD for the fine earth fraction (WRD_f). The third step is to adjust the WRD_f for salts (WRD_{fs}) (Baumer, 1992). The fourth step is to adjust downward for the volume percentage of >2-mm fraction. The fifth and final step in the AWC estimate is to adjust for root restriction (Grossman et al., 1994). Refer to Baumer (1992) and Grossman et al. (1994) for additional discussion of AWC estimates that are either calculated using measured water retention data or estimated using other soil properties, e.g., family particle-size classes (>2-mm fraction excluded), bulk density, clay mineralogy, etc.

FOOTNOTES: Averages, Depth (cm), Percent Clay, Percent 0.1 - 75 mm: The depth limits (cm) designate the family control section. The averages are calculated weighted averages of percent clay and percent 0.1- to 75-mm fraction (loamy vs silty) for use in determining family particle-size class. Refer to the data element Total Clay (PSDA Sheet, Tier 1, Column 4) for an example weighted average calculation.

4.3 ACID CHEMISTRY SHEET (ACID SHEET): TIER 1: COLUMNS 1 - 20:

Columns 1 - 4: NH_4OAc EXTRACTABLE BASES

Extractable bases, definition: Exchangeable cations have been loosely defined as those removed by neutral salt solutions. The SSL uses the term *extractable* rather than *exchangeable* to report bases measured after NH_4OAc leaching of the soil at pH 7.0 because NH_4OAc extracts not only exchangeable cations adsorbed by the exchange complex but also any water-soluble salts (common in arid regions). In productive agricultural soils, the exchangeable ions are usually $Ca^{2+} > Mg^{2+} > K^+ = Na^+$ (Bohn et al., 1979). The exchangeable K^+ usually exceeds Na^+ in humid regions, but in arid regions, this sequence is usually reversed (Bohn et al., 1969). Deviation from this usual order of dominance signals that some special factor or factors, e.g., free $CaCO_3$ or gypsum, serpentine (high Mg^{2+}), or natric material (high Na^+), control the soil chemistry. Questionable results from cation extractions with this method are Ca^{2+} in the presence of free $CaCO_3$ or gypsum and K^+ in soils that are dominated by mica or vermiculite (Thomas, 1982).

Extractable bases, laboratory measurement: Upon extraction with NH_4OAc at pH 7.0, the bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+) are determined by procedures 6N2e, 6O2d, 6P2b, and 6Q2b, respectively. Due to recent changes in laboratory equipment, the NH_4OAc extraction (presently, procedure 5A8b) will have a new method code (as yet assigned, tentatively 5A8c). The extractable bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+) are reported in meq 100 g^{-1} on a <2-mm base in Columns 1 - 4, respectively.

Column 1: NH_4OAc Extractable Bases, Ca^{2+}.

Calcium, soil-related factors: The Ca present in soils, exclusive of added lime or fertilizer, originates from rocks and minerals from which the soils have developed, e.g., plagioclase minerals (anorthite and impure albite); pyroxenes (augite), amphiboles (hornblende); biotite; epidote; apatite; and certain borosilicates. In semiarid and arid regions, calcite is usually the dominant source of Ca. Other sources of Ca include calcium sulfate as gypsum and dolomite, often found in association with calcite. Regardless of soil texture, the Ca content of soils in arid regions is usually high because of low rainfall and soil leaching (Tisdale et al., 1985). In addition, many of these soils have secondary deposits of calcium carbonate and calcium sulfate in their profiles. In acid, humid regions, Ca occurs largely in the exchangeable form and as undecomposed primary minerals (Tisdale et al., 1985). Typically, very sandy acid soils with low cation exchange capacity have inadequate supplies of available Ca for crops.

Calcium is usually the most abundant exchangeable cation in soils. Most agricultural crops yield best when the soil exchange complex is dominated by Ca^{2+}. A Ca-dominated exchange complex usually indicates a near-neutral pH which is considered optimum for most plants and soil microorganisms (Bohn et al., 1979). This composition also indicates that the concentrations of other potentially troublesome exchangeable cations are probably low, primarily Al^{3+} in acid soils and Na^+ in sodic soils. Despite the importance of Ca^{2+} as an exchangeable cation, soils derived from limestone can be unproductive, i.e., as the limestone weathers, the Ca^{2+} and HCO_3^- ions are released but are leached out of the system because the soils lack the cation exchange capacity to retain the Ca^{2+} (Bohn et al., 1979).

Calcium usually occurs in the soil in the same mineral forms as Mg, as the chemistry of these elements is very similar. The available forms of Ca and Mg in the soil are present in a Ca:Mg ratio of about 10:1 (Cook and Ellis, 1987). These two elements differ widely in their functions within the plant and in the way their deficiencies affect the plant. Refer to the discussion on extractable Mg^{2+} on this data tier in Column 2.

Calcium, deficiencies in soils: Calcium deficiencies have been reported in soils derived from Mg-rich serpentine rocks and in soils that are highly leached, acidic, and Al-saturated. The actual Ca^{2+} content in some soils may be sufficient for plant requirements, but the high concentrations of other cations, e.g., Mg^{2+} or Al^{3+}, may suppress the uptake of Ca^{2+} (Bohn et al., 1979). On the other hand, large quantities of Ca can also induce Mg and K deficiencies. Plant nutrition requires maintenance of a balance between the cations, Ca^{2+}, Mg^{2+}, and K^{+}. The symptoms of Ca and Fe deficiencies in plants are almost identical. However, Fe deficiencies are more common in arid and semiarid regions with soils high in soluble salts, e.g., saline and saline-sodic soils.

Calcium deficiency, serpentine factor: Because of the confusing and often contradictory nature of studies on the serpentine factor as it relates to soil infertility, it is very difficult to assess the evidence and conclusions in a logical, orderly manner (Brooks, 1987). This infertility has been associated with toxic effects of Ni, Cr, and Co; toxicity of excess Mg; infertility due to low Ca content of serpentine soils; problems arising from an adverse Ca/Mg ratio in the substrate; and infertility arising from low levels of plant nutrients in the soils (Brooks, 1987). In general, it is considered that the content of Cr and Co have little or no influence on vegetation because of the very low abundance of plant-available Cr and the lower toxicity of Co. Nickel, however, continues to be a probable source of some or much of the toxicity in serpentine soils. Calcium appears to play a primary role in the reduction or elimination of the toxic effects of Mg and/or Ni. Simplistically, infertility on serpentinitic soils has been related primarily to the absolute or relative abundance of Mg, Ni, and Ca. The deficiency of plant nutrients are due not so much from absolute concentrations of these elements but rather from the antagonism to their uptake by other constituents, primarily Ni and Mg, whose effects may or may not be improved by the pH and Ca status of the soil (Brooks, 1987). Refer to additional discussion serpentinitic soils and their physical properties on the Mineralogy Sheet, Tiers 1 - 3.

Calcium, essential plant element: Calcium is an essential nutrient for plant growth and is absorbed by plants as the ion Ca^{2+}. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column 2). Calcium has an essential role in cell elongation and division; in cell membrane structure and permeability; in chromosome structure and stability; and in carbohydrate translocation (Tisdale et al., 1985).

Calcium, soil test: The NH_4OAc extractable Ca^{2+} is a common soil test for Ca. Convert Ca^{2+} (meq 100 g^{-1}) to kg ha^{-1} for a soil horizon as follows:

Equation 40:

$$Ca = Ca^{2+} \times 0.02 \times 1000 \times Hcm \times Db_{1/3} \times Cm$$

where:

Ca = Calcium for soil horizon (kg ha^{-1})
Ca^{2+} = NH_4OAc extractable Ca^{2+} (meq 100 g^{-1})
0.02 = Milliequivalent weight of Ca^{2+} (g meq^{-1})

1000 = Conversion factor to hectares
Hcm = Soil horizon thickness (cm)
$Db_{1/3}$ = Bulk density at 1/3-bar water content of <2-mm fraction (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

To convert Ca^{2+} (meq 100 g^{-1}) to lb A^{-1} or kg m^{-3}, replace the conversion factor for hectares (1000) in Equation 40 with the factor 2300 or 0.10, respectively. To convert Ca (meq 100 g^{-1}) to $CaC0_3$ (kg ha^{-1}, lb A^{-1}, or kg m^{-3}), replace the milliequivalent weight for Ca (0.02) in Equation 40 with the milliequivalent weight for $CaCO_3$ (0.050). The SSL determines NH_4OAc extractable Ca^{2+} by procedure 6N2e. The extractable Ca^{2+} is reported in meq 100 g^{-1} on a <2-mm base in this data column. Extractable Ca^{2+} is not reported for soils which contain carbonates or soluble salts ($CaCO_3$ >1.0%).

Column 2: NH_4OAc Extractable Bases, Mg^{2+}.

Magnesium, soil-related factors: Magnesium in soils originates from rocks containing primary minerals, e.g., biotite, dolomite, hornblende, olivene, and serpentine, and from secondary clay minerals, e.g., chlorite, illite, montmorillonite, and vermiculite. In arid and semiarid regions, significant amounts of epsomite, hexahydrite, bloedite may also occur (Tisdale et al., 1985). In humid regions, Mg deficiency is most often seen in coarse-textured soils.

Magnesium is the second most abundant exchangeable cation in most soils and is absorbed by plants as Mg^{2+}. Exchangeable Mg^{2+} and other basic cations decrease as soils become leached. An exchange complex with high Mg^{2+} has sometimes been associated with poor physical soil conditions and high pH, e.g., sodic soil conditions. During the processes of soil formation under marine conditions with a predominance of Mg and Na, the poor soil structure may be produced by the Na, which eventually leaches away, leaving the Mg-enriched soil with the inherited structure (Bohn et al., 1979).

Magnesium, deficiencies in soils: Excessive or deficient amounts of Mg are usually uncommon. Refer to the discussion of excess Mg in serpentinitic soils on the Acid Sheet, Tier 1, Column 1. Soils associated with Mg deficiencies are acid sandy soils; soils with large amounts of applied calcitic lime; and soils heavily treated with K- or Na-bearing fertilizers (Cook and Ellis, 1987). Liming can usually correct the acidity and the Mg deficiencies on acid soils. Dolomitic limestone and other agricultural limestones usually contain appreciable Mg impurities. On the other hand, excessive amounts of calcium lime can induce Mg deficiencies.

Magnesium, essential plant element: Magnesium is an essential nutrient for plant growth and is absorbed by plants as the ion Mg^{2+}. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column 2). Magnesium is the mineral constituent of the chlorophyll molecule which is essential for all autotrophic plants to carry on photosynthesis. It also serves as a structural component of ribosomes, participates in a variety of physiological and biochemical functions, and is associated with transfer reactions involving phosphate-reactive groups (Tisdale et al., 1985). Magnesium in conjunction with sulfur has been related to oil synthesis in plants.

Magnesium, soil test: The NH_4OAc extractable Mg^{2+} is a common soil test for Mg. Convert to kg ha^{-1} for a soil horizon as follows:

Equation 41:

$$Mg = Mg^{2+} \times 0.012 \times 1000 \times Hcm \times Db_{1/3} \times Cm$$

where:

Mg = Magnesium for soil horizon (kg ha^{-1})
Mg^{2+} = NH_4OAc extractable Mg^{2+} (meq 100 g^{-1})
0.012 = Milliequivalent weight of Mg^{2+} (g meq^{-1})
1000 = Conversion factor to hectares
Hcm = Soil horizon thickness (cm)
$Db_{1/3}$ = Bulk density at 1/3-bar water content of <2-mm fraction (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

To convert Mg^{2+} (meq 100 g^{-1}) to lb A^{-1} or kg m^{-3}, replace the conversion factor for hectares (1000) in Equation 41 with the factor 2300 or 0.10, respectively. The SSL determines the NH_4OAc extractable Mg^{2+} by procedure 6O2d. The extractable Mg^{2+} is reported in meq 100 g^{-1} on a <2-mm base in this data column.

Column 3: NH_4OAc Extractable Bases, Na^+.

Sodium, soil-related factors: Three forms of Na are usually found in the soil: fixed in insoluble silicates; exchangeable in the structures of other minerals; and soluble in the soil solution (Tisdale et al., 1985). In the majority of soils, most of the Na is present in silicates. In highly-leached soils, Na may occur in high-albite plagioclases and in small amounts of perthite, micas, pyroxenes, and amphiboles, which exist mainly in the fine sand and silt fractions (Tisdale et al., 1985). In arid and semiarid soils, Na usually exists in silicates as well as soluble salts, e.g., NaCl, Na_2SO_4, and Na_2CO_3.

Sodium, adverse affects: Sodium is usually a soil chemical concern when it occurs in excess. Sodium has a dispersing action on clay and organic matter resulting in the breakdown of soil aggregates and decreased permeability to air and water. Because of the loss of large pores, soils with excessive amounts of Na become almost impervious to water and air; root penetration is impeded; clods are hard; seedbed preparation is difficult; and surface crusting results in poor germination and uneven stands. These detrimental effects of excess levels of exchangeable Na^+ are conditioned by soil texture and clay mineralogy (Tisdale et al, 1985).

Sodium is also toxic to some plants at high concentrations, but this problem may be relatively insignificant in comparison to the physical restrictions. A poor physical soil condition normally precedes Na toxicity. High pH usually accompanies the accumulation of Na in soils. However, these problems may be insignificant in comparison to the water and micronutrient problems induced by Na-accumulation (Bohn et al., 1979). Refer to additional discussion on Na-affected soils on the Salt Sheet Tier 1, Columns 10 - 11.

Sodium, essential plant element: Sodium is an essential element and is absorbed by plants as Na^+. Halophytic plant species accumulate Na salts in their vacuoles to maintain turgor and growth. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column 2). Sodium can replace part of the K^+ requirement in some plant species. Sodium has been associated with oxalic acid accumulation; K-sparing action; stomatal opening; and regulation of nitrate reductase in plants (Tisdale et al., 1985).

Sodium, soil test: The NH_4OAc extractable Na^+ is a common soil test for Na. Convert to kg ha^{-1} for a soil horizon as follows:

Equation 42:

$$Na = Na^+ \times 0.023 \times 1000 \times Hcm \times Db_{1/3} \times Cm$$

where:

Na = Sodium for soil horizon (kg ha^{-1})
Na^+ = NH_4OAc extractable Na_+ (meq 100 g^{-1})
0.023 = Milliequivalent weight of Na^+ (g meq^{-1})
1000 = Conversion factor to hectares
Hcm = Soil horizon thickness (cm)
$Db_{1/3}$ = Bulk density at 1/3-bar water content of <2-mm fraction (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.
Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

To convert Na^+ (meq 100 g^{-1}) to lb A^{-1} or kg m^{-3}, replace the conversion factor for hectares in Equation 42 with the factor 2300 or 0.10, respectively. The SSL determines the NH_4OAc extractable Na^+ by procedure 6P2b. The extractable Na^+ is reported in meq 100 g^{-1} on a <2-mm base in this data column.

Column 4: NH_4OAc Extractable Bases, K^+.

Potassium, soil-related factors: Potassium in soils, exclusive to added fertilizer, originates from the weathering of rocks containing K-bearing minerals, e.g., potassium feldspars orthoclase and microcline, muscovite, biotite, and phlogopite. The nature and mode of weathering of these K-bearing minerals largely depend on their properties and the environment. As far as the plant response is concerned, the availability (although slight) of K in these minerals is of the order biotite > muscovite > potassium feldspars (Tisdale et al., 1985). Potassium is also found in the form of secondary clay minerals, e.g., illites or hydrous micas, vermiculites, chlorites, and interstratified minerals.

An equilibrium between exchangeable and solution K generally results in some K in soil solution. Therefore, K has the potential to be leached from the system. As small quantities of soluble K exist in soil, many soils of humid and temperate regions may not have sufficient natural reserves to supply sufficient K to agronomic crops. Although potassium (K^+) is monovalent, its concentration in soil solutions is low relative to exchangeable K^+ because of its strong adsorption by many 2:1 layer silicate minerals (Bohn et al., 1979).

Potassium, essential plant element: Potassium is an essential nutrient for plant growth and is the third most important fertilizer element after N and P. Potassium is absorbed by plants as K^+. Refer to the discussion on essential elements for plant growth under the data element total N (PSDA Sheet, Tier 2, Column 2). Plant requirements for this element are usually high. Potassium is necessary to many plant functions which include carbohydrate metabolism; enzyme activation; osmotic regulation and efficient use of water; nitrogen uptake and protein synthesis; and translocation of assimilates (Tisdale et al., 1985). Potassium also plays a role in decreasing certain plant diseases and in improving plant quality. Potassium deficiencies have been primarily associated with sandy soils because of the scarcity of K-bearing minerals and low clay contents; organic materials low in K; and high lime soils in which K^+ uptake is inhibited by high concentrations of Ca^{2+} (Cook and Ellis, 1987).

Potassium, soil test: The NH_4OAc extractable K^+ is a common soil test for K. Convert to kg ha^{-1} for a soil horizon as follows:

Equation 43:

$$K = K^+ \times 0.039 \times 1000 \times Hcm \times Db_{1/3} \times Cm$$

where:

K = Potassium for soil horizon (kg ha^{-1})
K^+ = NH_4OAc extractable K_+ (meq 100 g^{-1})
0.039 = Milliequivalent weight of K^+ (g meq^{-1})
1000 = Conversion factor to hectares
Hcm = Soil horizon thickness (cm)

$Db_{1/3}$ = Bulk density at 1/3-bar water content of <2-mm fraction (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 13.

Cm = Coarse fragment conversion factor. If no coarse fragments, Cm = 1. If coarse fragments are present, calculate Cm using Equations 4 and 5 in Column 4 of the PSDA Sheet.

To convert K^+ (meq 100 g^{-1}) to lb A^{-1} or kg m^{-3}, replace the conversion factor for hectares (1000) in Equation 43 with the factor 2300 or 0.10, respectively. The SSL determines the NH_4OAc extractable K^+ by procedure 6Q2b. The extractable K^+ is reported in meq 100 g^{-1} on a <2-mm base in this data column.

Column 5: Sum of Bases.

Sum of bases, calculation: Determine the sum of bases by summing the NH_4OAc extractable bases in Columns 1 - 4. The sum of bases is reported in meq 100 g^{-1} on a <2-mm base. The sum of bases is calculated as follows:

Equation 44:

$$\text{Sum of Bases} = Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$$

Column 6: Extractable Acidity.

Soil acidity: Soil acidity is determined largely by soil composition and the ion exchange and hydrolysis reactions associated with the various soil components (Thomas and Hargrove, 1984). These soil components include organic as well inorganic substances, e.g., layer silicates, oxide minerals (including allophane), and soluble acids. The development or accumulation of soil acidity usually parallels the mineral-weathering sequence in which Al is released and accumulates in the soil (Foth and Ellis, 1988). Hydroxy-Al accumulates as soils become acid, first as interlayer Al and on clay surfaces and as complexes with organic matter and secondly as exchangeable Al^{3+} when soil pH <5.5 (Foth and Ellis, 1988)

Exchangeable and extractable acidity, definitions: Exchangeable acidity has been defined as the portion of soil acidity that can be replaced with a neutral, unbuffered salt, e.g., 1 *N* KCl or NaCl. Exchangeable acidity is due almost entirely to monomeric Al^{3+} ions and is essentially absent at soil pH values >5.5 (Foth and Ellis, 1988). Titratable or extractable acidity is the amount of acid neutralized at a selected pH, commonly pH 8.2, and does not distinguish between exchangeable and virtually nonexchangeable components. Titratable acidity is only a measure of the total acidity present between the initial and final pH levels (Bohn et al., 1979).

Extractable acidity, laboratory measurement: The titratable or extractable acidity released from a soil by a barium chloride-triethanolamine ($BaCl_2$-TEA) solution buffered at pH 8.2 includes all the acidity generated by replacement of H and Al from permanent and pH dependent exchange sites. A variety of methods have been used to measure extractable acidity as it may be measured at any pH. The USDA-SCS adopted a pH of 8.2 because it approximates the calculated pH of a soil containing free $CaCO_3$ in equilibrium with the normal CO_2 content (0.03%) of the atmosphere. The pH of 8.2 also closely corresponds to the pH of complete neutralization of soil hydroxy-Al compounds and is conveniently maintained by Mehlich's $BaCl_2$-TEA buffered extraction technique (Bohn et al., 1979). The $BaCl_2$-TEA, pH 8.2 method may not always accurately reflect the nature of soils as they occur in the environment, and other pH values are more valid for some types of soils. However, this method has become a standard reference to which other methods are compared.

Extractable acidity at pH 8.2 is a good measure of the "potential" acidity. The KCl-extractable Al is more related to the immediate lime requirement and existing CEC of the soil. The KCl-extractable Al is reported on this data tier in Column 7. The SSL determines the extractable acidity at pH 8.2 by procedure 6H5a. Extractable acidity is reported in meq 100 g^{-1} in this data column.

Column 7: Extractable Aluminum.

KCl extractable Al, significance: The KCl-extractable Al represents a major constituent in strongly acid soils. The Al extracted by 1 *N* KCl approximates exchangeable Al and is a measure of the "active" acidity present in soils with a 1:1 water pH <5.5. Above pH 5.5, polymerization and precipitation of Al occurs rendering it non-exchangeable. Since the KCl extractant is an unbuffered salt and usually affects the soil pH one unit or less, the extraction is determined at or near the soil pH. The KCl-extractable Al is related to the immediate lime requirement and existing CEC of the soil. The "potential" acidity is better measured by the extractable acidity ($BaCl_2$-TEA) at pH 8.2. The extractable acidity at pH 8.2 is reported on this data tier in Column 6.

KCl extractable Al, laboratory measurement: A soil sample is leached with 1 *N* KCl using a mechanical vacuum extractor (Holmgren et al., 1977). The leachate is weighed and diluted, and the KCl extractable Al is measured using inductively coupled plasma spectrometry (ICP). The SSL determines the 1 *N* KCl extractable by procedure 6G9a or 6G9b. The 1 *N* KCl-extractable Al is reported in meq 100 g^{-1} in this data column.

Columns 8 -9: CATION EXCHANGE CAPACITY (CEC).

Ion exchange, definition: Ion exchange is a reversible process by which one cation or anion held on the solid phase is exchanged with another cation or anion in the liquid phase, and if two solid phases are in contact, ion exchange may also take place between two surfaces (Tisdale et al., 1985). In most agricultural soils, the cation exchange is generally considered to be more important than anion exchange the anion molecular retention capacity of these soils is usually much smaller than the cation retention capacity (Tisdale et al., 1985).

Cation exchange capacity, definition: Soil mineral and organic colloidal particles have negative valence charges that hold dissociable cations, and thus are "colloidal electrolytes" (Jackson, 1958). The cation exchange capacity (CEC) is a measure of the quantity of readily exchangeable cations that neutralize negative charges in the soil (Rhoades, 1982). The CEC determination is the measure of the total quantity of negative charges per unit weight of the material.

Cation exchange capacity, components: The CEC may arise from permanently charged or pH-dependent sites on organic and mineral colloid surfaces. The CEC is commonly expressed in units of milliequivalents per 100 g of soil (meq 100 g^{-1}) or centimoles per kg of soil (cmol kg^{-1}). The SSL uses meq 100 g^{-1}. The CEC can range from less than 1.0 to greater than 100 meq 100 g^{-1} soil. The term *equivalent* is defined as "1 gram atomic weight of hydrogen or the amount of any other ion that will combine with or displace this amount of hydrogen". The milliequivalent weight of a substance is one thousandth of its atomic weight. Since the equivalent weight of hydrogen is about 1 gram, the term *milliequivalent* may be defined as "1 milligram of hydrogen or the amount of any other ion that will combine with or displace it". Common CEC values for some soil components (Rhoades, 1982) are as follows:

Soil Component	**meq 100 g^{-1}**
Organic matter	200-400
"Amorphous" Clay	160 (at pH 8.2)
Vermiculite	100-150
Montmorillonite	60-100
Halloysite $4H_2O$	40-50
Illite	20-40
Chlorite	10-40
Kaolinite	2-16
Halloysite $2H_2O$	5-10
Sesquioxides	0

These very broad CEC ranges are intended only as general guidelines. More narrow groupings of CEC values are possible as data are continually collected and correlated, e.g., the CEC of organic matter in Mollisols in the western United States ranges from 100 to 300 meq 100 g^{-1} (average 200), and the CEC of organic matter in Histosols ranges from 125 to 185 meq 100 g^{-1} and increases with decomposition of the organic matter (NSSL Staff, 1975).

The CEC is dependent upon negative charges of soil components. The mechanisms for these charges are isomorphic substitution within layered silicate minerals; broken bonds at mineral edges and external surfaces; dissociation of acidic functional groups in organic compounds; and preferential adsorption of certain ions on particle surfaces (Rhoades, 1982). Isomorphic substitution produces permanent charge. The other charge mechanisms produce variable charge which is dependent on the soil solution phase as affected by soil pH, electrolyte level, valence of counter-ions, dielectric constant, and nature of anions (Rhoades, 1982). As a result of the variable charge in soils, the CEC is a property dependent on the method and conditions of determination. The method of determination is routinely reported with CEC data.

Cation exchange capacity, laboratory measurements: Many procedures have been developed to determine CEC. The more widely adopted methods of CEC determination are classified (Rhoades, 1982) as follows:

(1) Cation summation
(2) Direct displacement
(3) Displacement after washing
(4) Radioactive tracer

Measurements of CEC vary according to the nature of the cation employed, concentration of salt, and the equilibrium pH. The CEC measurement should not be thought of as highly exact but rather as an equilibrium measurement under the conditions selected (Jackson, 1958). Knowledge of the operational definition is necessary before evaluating the CEC measurement. The SSL uses several different reagents and pH levels to measure the CEC. The SSL routinely determines CEC by several methods as follows:

(1) Sum extractable cations (CEC-8.2).
(2) Saturate exchange complex with an index cation, replace it with another cation, and then measure the replaced or index cation (displacement after washing). The SSL uses ammonium in neutral NH_4OAc (CEC-7) as the index cation.
(3) Sum extractable bases plus KCl-extractable Al = effective CEC (ECEC).

Cation exchange capacity (CEC-8.2, CEC-7, and ECEC) is reported in meq 100 g^{-1} on a <2-mm base in Columns 8 - 10, respectively.

Column 8: Cation Exchange Capacity, Sum of Cations (CEC-8.2).

Sum of cations (CEC-8.2), calculation: The CEC-8.2 minus the CEC-7 is considered the pH dependent charge from pH 7.0 to pH 8.2. As a general rule, the CEC-8.2 > CEC-7 > ECEC. The CEC-8.2 is not valid if significant quantities of soluble salts or carbonates are present in the soil. The SSL determines CEC-8.2 by procedure 5A3a. The sum of NH_4OAc extractable bases and extractable acidity at pH 8.2 are reported on this data tier in Columns 5 - 6, respectively. The CEC-8.2 is reported in meq 100 g^{-1} on a <2-mm base in this data column. The CEC-8.2 is calculated as follows:

Equation 45:

$$\text{CEC-8.2} = NH_4OAc \text{ extractable bases} + \text{Extractable acidity}$$

Column 9: Cation Exchange Capacity, NH_4OAc, pH 7.0 (CEC-7).

CEC-7, significance: The CEC-7 is a commonly used method and has become a standard reference to which other methods are compared (Peech et al., 1947). An advantage of using this method is that the extractant is highly buffered so that the extraction is performed at a constant and known pH (pH 7.0). In addition, the NH_4^+ on the exchange complex is easily determined. The CEC-7 is an analytically determined value and is usually used in calculating the CEC-7/clay ratios, although many SSL Primary Characterization Data Sheets predating 1975 show CEC-8.2/clay. The CEC-8.2 minus CEC-7 is considered the pH dependent charge from pH 7.0 to pH 8.2. As a general rule, the CEC-8.2 > CEC-7 > ECEC.

CEC-7, laboratory measurement: Displacement after washing is the basis for this procedure. The CEC is determined by saturating the exchange sites with an index cation (NH_4^+) using a mechanical vacuum extractor (Holmgren et al., 1977); washing the soil free of excess saturated salt; displacing the index cation (NH_4^+) adsorbed by the soil; and measuring the amount of the index cation (NH_4^+). The SSL determines the CEC-7 by procedure 5A8b. Due to recent changes in laboratory equipment, the CEC-7 determinations will have a new method code (as yet assigned, tentatively 5A8c). The CEC-7 is reported in meq 100 g^{-1} on a <2-mm base.

Column 10: Bases + Aluminum (ECEC).

Effective cation exchange (ECEC), definition: Cation exchange capacity can be measured by extraction with an unbuffered salt, which measures the ECEC, i.e., CEC at the normal soil pH (Coleman et al., 1958). Since the unbuffered salt solution, e.g., 1 *N* KCl, only affects the soil pH one unit or less, the extraction is determined at or near the soil pH and extracts only the cations held at active exchange sites at the particular pH of the soil. Neutral NH_4OAc extracts the same amounts of Ca^{2+}, Mg^{2+}, Na^+, K^+ as KCl and therefore extractable bases by NH_4OAc is used at the SSL in place of KCl-extractable bases.

Effective cation exchange, laboratory measurements: Effective cation exchange capacity may be determined by extracting one soil sample with neutral normal NH_4OAc to determine the exchangeable basic cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and by extracting another sample of the same soil with 1.0 *N* KCl to determine the exchangeable Al. The 1 *N* KCl-extractable Al approximates exchangeable Al and is a measure of "active" acidity present in soils with a 1:1 pH <5.5. Aluminum is non-exchangeable at pH >5.5 due to hydrolysis, polymerization, and precipitation. For soils with pH <7.0, the ECEC should be less than the CEC measured with a buffered solution at pH 7.0. As a general rule, the CEC-8.2 > CEC-7 > ECEC.

The SSL also determines ECEC with the neutral unbuffered salt 1 *N* NH_4Cl (procedure 5A9b). For noncalcareous soils, the ECEC by NH_4Cl approximates the ECEC by summing the NH_4OAc

extractable bases plus KCl-extractable Al (Peech et al., 1947). The ECEC by NH_4Cl is not reported on the SSL Primary Characterization Data Sheets.

Effective cation exchange, calculation (extractable bases + Al): Determine the ECEC by summing the NH_4OAc extractable bases plus KCl-extractable Al. The sum of the NH_4OAc extractable bases and the KCl-extractable Al are reported on this data tier in Columns 5 and 7, respectively. The ECEC is not reported for soils with soluble salts. The ECEC is reported in meq 100 g^{-1} on a <2-mm base in this data column. The ECEC is calculated as follows:

Equation 46:

$$\text{ECEC} = \text{NH}_4\text{OAc extractable bases} + \text{KCl-extractable Al}$$

Column 11: Aluminum (Al) Saturation.

Aluminum toxicity: Aluminum is not considered an essential nutrient, even though low concentrations have been shown to sometimes increase plant growth or produce other beneficial effects in selected plants (Foy et al., 1978; Foy and Fleming, 1978). Generally, the primary concern with Al is the possible toxic effects of its high concentrations. Among the soil chemical stresses to roots and to the plants as a whole, Al toxicity in strongly acid subsoils and mine spoils can be one of the most serious. The problem is particularly severe below pH 5.0, but it may occur as high as pH 5.5 in kaolinitic soils (Foy, 1984). Plant sensitivity to Al is usually accentuated in soils low in Ca. Moderate toxicity in the subsoil is usually not readily detectable in the field because the growth of the plant shoots may not be affected in a significant manner while the surface soil is moist and adequate in nutrients (Foy et al., 1978; Alam and Adams, 1979). However, Al toxicity reduces rooting depth and degree of root branching into the subsoil which is usually more apparent during stress periods, e.g., drought (Simpson et al., 1977; Foy, 1984).

Aluminum toxicity, soil-related factors: The critical pH at which Al becomes soluble or exchangeable in toxic concentrations depends on many soil factors, including the predominant clay minerals, organic matter levels, concentrations of other cations, anions, and total salts, and particularly, the plant species or cultivar (Kamprath and Foy, 1972; Foy, 1974). Such complexity makes it difficult to devise a soil Al test that will accurately predict toxicity under all conditions (Foy, 1984).

Aluminum toxicity, plant effects: The effects of excess Al are frequently cited in the literature. Excess Al can restrict plant root penetration and proliferation in acid subsoils by decreasing water uptake in plants when the soil surface becomes dry. Aluminum toxicities can also damage roots to the extent that they cannot absorb adequate water, even in moist soils (Foy, 1984). There is considerable evidence suggesting that Al toxicity limits microbial breakdown of organic matter in strongly acid soils (Alexander, 1980). High concentrations of Al are also linked to adverse interactions with other elements, e.g., Fe and Ca. At a pH <5.5, the Al x Ca antagonism is probably the most important factor affecting Ca uptake by plants (Foy, 1984). Aluminum toxicity is also linked to P deficiency, and conversely, Al tolerance appears to be related to the efficient use of P.

Aluminum toxicity, amelioration: One of the more traditional ways to correct or ameliorate the problem of Al toxicity in field soils is liming. Deep liming of acid subsoils in many instances has been found to be uneconomical or of no significance. In interpreting these data, care is required as percent Al-saturation may or may not indicate a problem of Al-toxicity. There is evidence that the mechanisms of plant tolerance or sensitivity to Al and acidity may be different. In addition, there is evidence that liming may correct the Al-problem less from the raising of the pH or the correcting of the Ca deficiency but rather by the correcting of the relative activities of Ca and Al.

Aluminum saturation, calculation: Determine the Al saturation by dividing the KCl-extractable Al by the sum of NH_4OAc extractable bases plus the KCl-extractable Al and multiplying by 100. The SSL determines the Al saturation by procedure 5G1. The sum of NH_4OAc extractable bases and KCl-extractable Al are reported on this data tier in Column 5 and 7, respectively. Aluminum saturation is reported as percent on a <2-mm base in this data column and calculated as follows:

Equation 47:

$$\text{Al Saturation} = \frac{\text{KCl-extractable Al}}{NH_4OAc\ \text{extractable bases} + \text{KCl-extractable Al}} \times 100$$

Columns 12 - 13: BASE SATURATION.

Base saturation, historical significance: It is important to understand the historical development of base saturation and its significance in soil classification and fertility. In early soil acidity literature, soils were characterized by their percent base saturation values at specified pH levels (Bohn et al., 1979). Soils with low percent base saturation values were considered dominated by kaolinite and hydrous oxide minerals, whereas soils with high percent base saturation were considered dominated by 2:1 type minerals, e.g., montmorillonite, vermiculite, chlorite, and the micas (Bohn et al., 1979).

When work on soil taxonomy began, base saturation criteria were developed when it was commonplace to determine the CEC at pH 7.0 or 8.2 and when the role of Al and the importance and nature of pH-dependent charge were poorly understood (Foth and Ellis, 1988). The CEC in soils dominated by permanent charge varies less with pH change than it does in soils with pH-dependent charge. Base saturation at pH 8.2 was used to differentiate the less-weathered, fertile Alfisols dominated by permanent charge from the more-weathered and less naturally fertile Ultisols dominated by variable charge (Foth and Ellis, 1988). Base saturation at pH 7.0 was used to distinguish between base-rich mollic epipedons and their base-poor umbric equivalents (Foth and Ellis, 1988). Mollisols usually have more permanent-charge clays, less leaching of bases, and are more naturally fertile for the more commonly grown crops than Alfisols (Foth and Ellis, 1988). This base saturation criterion, however, was not intended to imply that Ultisols and Alfisols could not become as productive as Mollisols with proper fertilization and liming (Foth and Ellis, 1988).

Base saturation, index: Percent base saturation is an imprecise index as it is not only a measure of the pH-dependent charge of soils but also of the actual percentage of cation exchange sites occupied by exchangeable bases (Bohn et al., 1979). The denominator includes any additional charge (CEC) generated by soil organic matter and hydrous oxide-mineral complexes between the actual soil pH and the reference pH (pH 7 or 8.2). Since neither exchangeable Al nor exchangeable H is appreciable in soils with pH >5.5, the ECEC of soils with pH >5.5 are usually essentially 100 percent base-saturated (Bohn et al., 1979). However, if base saturation is based on CEC-7 or CEC-8.2, soils in the pH range 5.5 to 7 or 8.2 generally still have measured base saturations significantly <100 percent. These base saturation values are particularly low for minerals such as kaolinite which has a high proportion of pH-dependent charge (Bohn et al., 1979). Below pH 5.5, exchangeable Al saturation increases, and the exchangeable base saturation decreases with decreasing pH. This phenomenon is expressed as Al-saturation (Foth and Ellis, 1988). Refer to the discussion on Al-saturation on this data tier in Column 11.

Although an imprecise index, the percent base saturation is still useful for soil genesis and classification purposes and for empirical liming recommendations (Bohn et al., 1979). However, from the standpoint of soil chemical properties and reactions, base saturation is more correctly an acidity index or liming index, and the degree of nonbase saturation is more meaningful if separated into exchangeable acidity and pH-dependent charge (Bohn et al., 1979). Cation exchange capacity, hence the base saturation, is an arbitrary measurement unless the method by which the data are determined is clearly defined (Tisdale et al., 1985).

Base saturation, calculations: The SSL determines base saturation by sum of cations (CEC-8.2) and by NH_4OAc at pH 7.0 (CEC-7). Base saturation by CEC-8.2 and CEC-7 are reported as percent on a <2-mm base in Columns 12 - 13, respectively.

Column 12: Base Saturation, Sum of Cations (CEC-8.2).

Base saturation, CEC-8.2, calculation: Determine base saturation by CEC-8.2 by dividing the sum of NH_4OAc extractable bases by the CEC-8.2 and multiplying by 100. The SSL determines base saturation (CEC-8.2) by procedure 5C3. The sum of NH_4OAc extractable bases and CEC-8.2 are reported on this data tier in Columns 5 and 8, respectively. The base saturation by CEC-8.2 is not reported if either extractable Ca^{2+} (due to presence of carbonates or soluble salts) or extractable acidity (due to presence of carbonates or high pH) is not reported on this data tier in Columns 1 and 6, respectively. Base saturation by CEC-8.2 is a taxonomic criterion for Alfisols ($\geq$35 percent) vs Ultisols (<35 percent). Refer to Soil Survey Staff (1975, 1994) for additional discussion of this taxonomic criterion. Base saturation by CEC-8.2 is reported as percent on a <2-mm base in this data column and is calculated as follows:

Equation 48:

$$\text{Base saturation} = \frac{\text{Sum of } NH_4OAc \text{ extractable bases}}{\text{CEC-8.2}} \times 100$$

Column 13: Base Saturation, NH_4OAc pH 7.0 (CEC-7).

Base saturation, CEC-7, calculation: Determine base saturation by dividing the sum of NH_4OAc extractable bases by the CEC-7 and multiplying by 100. The SSL determines base saturation by CEC-7 by procedure 5C1. The sum of NH_4OAc extractable bases and CEC-7 are reported on this data tier in Column 5 and 9, respectively. If extractable Ca^{2+} is not reported because of the influence of carbonates or soluble salts, then the base saturation is usually reported as 100 percent. Base saturation by CEC-7 is a taxonomic criterion for mollic epipedons and Mollisols (>50 percent). Refer to Soil Survey Staff (1975, 1994) for additional discussion of this taxonomic criterion. Base saturation by NH_4OAc at pH 7.0 is reported as percent on a <2-mm base in this data column and is calculated as follows:

Equation 49:

$$\text{Base saturation} = \frac{\text{Sum of } NH_4OAc \text{ extractable bases}}{\text{CEC-7}} \times 100$$

Column 14: Carbonate as $CaCO_3$, <2mm.

Carbonates, soil-related factors: The distribution and amount of $CaCO_3$ are important to the fertility, erosion, available water-holding capacity, and genesis of a soil. The $CaCO_3$ content is a diagnostic criterion to define carbonatic, particle-size, and calcareous soil classes and to identify calcic and petrocalcic horizons (Soil Survey Staff, 1975, 1994). The formation of calcic and petrocalcic horizons has been related to a variety of processes, some of which include translocation and net accumulation of pedogenic carbonates from a variety of sources as well as the alteration of lithogenic (inherited) carbonate to pedogenic carbonate (soil-formed carbonate through *in situ* dissolution and reprecipitation of carbonates) (Rabenhorst et al., 1991).

Carbonates, acid-neutralizing capacity: In agriculture, the term *lime* is defined as the addition of any Ca or Ca- and Mg-containing compound that is capable of reducing soil acidity. Lime correctly refers only to calcium oxide (CaO), but the term almost universally includes such materials as calcium hydroxide, calcium carbonate, calcium-magnesium carbonate, and calcium silicate slags (Tisdale et al., 1985). As used in soil fertility, the term *$CaCO_3$ equivalent (CCE)* is defined as the acid-neutralizing capacity of an agricultural liming material expressed as a weight percentage of $CaCO_3$. Pure $CaCO_3$ is the standard against which other liming materials are measured, and its neutralizing value is considered to be 100 percent. The molecular constitution is the determining factor in the neutralizing value of chemically pure liming materials (Tisdale et al., 1985). Consider the following discussion and related equations (Tisdale et al., 1985).

Equation 50:

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

Equation 51:

$$MgCO_3 + 2HCl \longrightarrow MgCl_2 + H_2O + CO_2$$

In both equations, the molecular proportions are the same, i.e., one molecule of either $CaCO_3$ or $MgCO_3$ will neutralize two molecules of acid. However, the molecular weight of $CaCO_3$ is 100, whereas $MgCO_3$ is only 84. Therefore, 84 g of $MgCO_3$ will neutralize the same amount of acid as 100 g of $CaCO_3$. The neutralizing value or CCE of $MgCO_3$ in relation to $CaCO_3$ (CCE = 100) is calculated in the simple proportion as follows:

Equation 52:

$$\frac{84}{100} = \frac{100}{x}$$

$$x = 119 \text{ percent}$$

Therefore, on a weight basis, $MgCO_3$ will neutralize 1.19 times as much acid as the same weight of calcium carbonate. This same procedure is used to calculate the neutralizing value of other liming materials, e.g., CaO (CCE = 170); $Ca(OH)_2$ (CCE = 109); and $CaMg(CO_3)_2$ (CCE = 109).

Carbonates, agronomic and engineering significance: In general, crops grown on carbonatic soils may show signs of chlorosis, reflecting nutrient deficiencies (Fe, Zn, or Cu). Alfalfa grown on these soils may indicate symptoms of B deficiency. Carbonatic soils have also been associated with P fixation; hindrance to root ramification; high base status (near pH 8); and lower available water, especially in soils with calcic horizons. Abundant Ca in the soil has a flocculating effect on soil colloids, i.e., clays tend to be coarser. Carbonate particles have a distribution of sizes from coarse clay to gravel. These carbonates effect the soil regardless of the dominant particle-size, but the clay-size carbonate appears to have a stronger influence. Fine carbonates behave like silt and are less coherent than silicate silts and clays. Carbonatic materials are susceptible to frost disruption and to erosion by piping and jugging. Refer to additional discussion on carbonatic soils on the Mineralogy Sheet, Tiers 1 - 3.

Carbonates, laboratory measurement: The amount of carbonate in the soil is measured by treating the samples with HCl. The evolved CO_2 is measured manometrically. The amount of carbonate is then calculated as $CaCO_3$ even though carbonates of Mg, Na, and K may be present in the sample. The amount of $CaCO_3$ is only a semiquantitative measurement. The SSL determines carbonate as $CaCO_3$ by procedure 6E1g. Carbonate as $CaCO_3$ is reported as percent on a <2-mm base.

Column 15: Soil Resistivity.

Soil resistivity, definition: Resistivity or specific resistance has been defined as the resistance in ohms of a conductor, metallic or electrolytic, which is 1 cm long and has a cross-sectional area of 1 cm^2 (U.S. Salinity Laboratory Staff, 1954). The resistance (ohms) is converted to a 60°F (15.5°C) basis (SSL Staff, 1992). The resistivity of the soil paste (R_s) is used mainly to estimate the salt content in the soil. Soil resistivity, gypsum content, and extractable acidity singly or in combination provide a basis for estimating potential corrosivity of soils (USDA-SCS, 1971).

Soil resistivity and electrical conductivity: The R_s has been related to the electrical conductivity of the saturation extract (EC_s) (U.S. Salinity Laboratory Staff, 1954). There is no simple method to convert electrical conductivity to soil resistivity or vice versa. There is a limited correlation between electrical conductivity and soil resistivity, as the relationship is markedly influenced by variations in saturation percentage (SP), salinity, and soil mineral conductivity. The R_s and EC_s have been related by an equation (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 53:

$$EC_s \approx \frac{0.25}{R_s}$$

where:

EC_s = Electrical conductivity of saturation extract (mhos cm^{-1}).

0.25 = Constant for Bureau of Soils electrode cup.

R_s = Resistivity of saturation extract (ohms cm^{-1}).

Historically, the EC_s is adjusted to 60°F (15.5°C) basis before interpretative use. The EC_s and R_s increase ≈ 2% per °C. The unit EC x 10^3 is called the millimho per centimeter (mmhos cm^{-1}).

The following calculation of resistivity is based on a correlation between measurements of EC_s and R_s of the saturated paste ($r^2 = 0.913$, $n = 191$) (NSSL Staff, 1975).

Equation 54:

$$R_s = \frac{1000}{\dfrac{\text{Log } EC_s - 0.2257}{1.1011}} \times 1.246$$

The EC_s is not reported on the Acid Sheet but is reported on the Salt Sheet, Tier 2, Column 14. The electrical conductivity, reported on the Acid Sheet, Tier 1, Column 17, is a test for the presence of salts. Soil resistivity is reported in ohms cm^{-1} in this data column.

Soil resistivity, laboratory measurement: The soil resistivity apparatus is simple and rugged, the measurements can be made quickly, and the results are reproducible. Many agencies use the Bureau of Soils electrode cup to estimate the soluble salt content in soils (Davis and Bryan, 1910; Soil Survey Staff, 1951). The SSL determines the R_s by procedure 8E1. A saturated paste is placed in an electrode cup, and the resistance is measured.

Column 16: Data column not used.

Column 17: Electrical Conductivity (EC).

Salt prediction test, significance: The salt prediction test is used not only to predict those soils that have measurable amounts of soluble salts but also to predict the quantity and the appropriate dilutions for salt analyses of those soils. If salt predictions or conductances are <0.25 mmhos cm^{-1}, soils are considered nonsalty, and generally, no other salt analyses are determined on these soils by the SSL.

Salt prediction test, laboratory measurement: The SSL tests for the presence of salts (EC) by procedure 8I. A soil sample is mixed with water and allowed to stand overnight. The EC of the 1:2 soil:water mixture is measured using an electronic bridge. This EC is not the same as the electrical conductivity of the saturation extract (EC_s). The EC_s (procedure 8A3a) is not reported on the Acid Sheet but is reported on the Salt Sheet, Tier 2, Column 14. The presence of salts (EC) is reported in mmhos cm^{-1} in this data column.

Columns 18 - 20: REACTION, (pH).

Soil pH, definition: Soil pH is one of the most frequently performed determinations and one of the most indicative measurements of soil chemical properties (McLean, 1982). The pH value is defined as the negative logarithm to the base of 10 (logarithm of reciprocal) of H-ion activity. Activity is the apparent or effective concentration of an ion in solution and is affected by various factors such as the concentration and valence of other ions present in solution. Since pH is logarithmic, H-ion activity in solution increases ten times when the pH is lowered one unit. The activity of H-ion in soil solution is the intensity factor (index) of soil acidity, whereas exchangeable acidity and lime requirement (quick test), performed by soil testing laboratories, are the capacity factors of soil acidity (McLean, 1982).

Soil pH, index: Soil pH may be used as a relative indicator of base saturation, depending on the predominant clay type (Mehlich, 1943). Since the availability of most plant-essential elements depend on soil pH, it is also an indicator of the relative availability of plant nutrients (McLean, 1982), and provides necessary data to help determine liming needs and fertilizer responses. Soil pH can also indicate something about the degree of dissociation of H-ions from cation exchange "sites" or the extent of Al hydrolysis (McLean, 1982), and as such helps to develop inferences about many of the chemical processes that have taken place in the genesis of a soil (Buol et al., 1980).

Soil pH, soil-related factors: The measured soil pH is affected by many factors, e.g., the nature and type of inorganic and organic constituents; amount and type of exchangeable cations and anions; soil:solution ratio; salt or electrolyte content; and CO_2 content (McLean, 1982). The acidity, neutrality, or basicity of a soil influences the solubility of various compounds; the relative ion bonding to exchange sites; and microbial activities. When the pH values of various soils are compared, determination by the same method is important (Foth and Ellis, 1988). An increase in the soil:water ratio or the presence of salts generally results in a decrease in measured soil pH. The influence of the natural soluble salt content of the soil can be overcome by using dilute salt solutions, e.g., $CaCl_2$ or KCl, instead of distilled water (Foth and Ellis, 1988). The use of dilute salt solutions is a popular method for masking seasonal variation in soil pH. The pH readings are usually less with dilute salt solutions than with distilled water but may be equal to or greater in highly weathered soils with high sesquioxide content, i.e., soils with a high anion (OH^-) exchange capacity (AEC).

Soil pH, laboratory measurements: The SSL determines the 1 *N* KCl pH, the 1 *N* NaF pH, the 1:1 water pH, and the 1:2 $CaCl_2$ (0.01 *M*) pH. The SSL also determines the 0.01 *M* $CaCl_2$ pH for organic materials, saturated paste pH, and the oxidized pH,. If determined, the 1 *N* KCl pH, 1 *N* NaF pH, or oxidized pH, is reported in Column 18 on the Acid Sheet. The 1:2 $CaCl_2$ (0.01 *M*) pH and 1:1 water pH are reported on the Acid or Salt Sheet, Tier 1, Columns 19 - 20, respectively. The 0.01 *M* $CaCl_2$ pH for organic materials is not reported on the SSL Primary Characterization Data Sheets but, if determined, is reported on additional SSL data sheets. Refer to the Acid Oxalate Sheet, Mineral Soil Content, Column 19 for a discussion of the 0.01 *M* $CaCl_2$ pH for organic materials. The saturated paste pH is not reported on this data tier but is reported on the Salt Sheet, Tier 1, Column 18.

Column 18: pH, 1 *N* KCl.

The 1 *N* KCl pH is used as an index of soil acidity. This pH is a popular measurement in those regions with extremely acid soils and in which KCl is used as an extractant of exchangeable Al. The KCl pH indicates the pH at which Al is extracted. If the pH is <5.5, significant amounts of Al are expected in the solution. Soils which have pH <4 generally have free acids such as H_2SO_4. The 1 *N* KCl pH readings tend to be uniform regardless of time of year. The SSL determines 1 *N* KCl pH by procedure 8C1g.

Column 18: pH, 1 *N* NaF.

NaF pH, index: The NaF pH test is used as a simple and convenient index of andic materials. As a rule of thumb, a NaF pH $\geq$9.4 is used as a strong indicator that andic materials (allophane) dominate the soil exchange complex (Fieldes and Perrott, 1966). The NaF pH test is based on the ligand exchange between F^- and OH^- which results in a rapid rise in pH when 1.0 g of andic soil materials is suspended in 1 *N* NaF solution. The action of NaF upon andic soil materials releases hydroxide ions (OH^-) to the soil solution and increases the pH of the solution. The amorphous material in the soil controls the release of the OH^- and the subsequent increase in pH (Fieldes and Perrott, 1966). The following reactions illustrate this action and form the basis of this procedure.

Equation 55:

$$Al(OH)_3 + 3F^- \longrightarrow AlF_3 + 3\ OH^-$$

Equation 56:

$$Si(OH)_4 + 4F^- \longrightarrow SiF_4 + 4\ OH^-$$

NaF pH and P-retention tests: The P-retention test is based on a similar ligand exchange, i.e., the exchange between HPO_4^{2-} or $H_2PO_4^-$ and OH^-. In many ways, the P-retention test is a duplication of the information provided by the NaF pH test (Uehara and Ikawa, 1985). Refer to the discussion on P-retention on the Acid Oxalate Sheet, Tier 1, Column 5.

NaF pH test, limitations: Even though the NaF pH test is one of the simplest and most convenient ways of identifying andic materials, the NaF pH of andic and nonandic materials indicates that there is a continuum of materials that range from clearly andic to materials that are marginally andic or nonandic in character (Uehara and Ikawa, 1985). As the glass content of the fine-earth fraction increases and/or the silica/alumina ratio increases, the NaF pH test usually becomes less effective in identifying andic materials (Uehara and Ikawa, 1985). The pH rise with NaF is an intensity rather than a quantity indicator (Bartlett, 1972). A small amount of hydroxy Al produces as much pH increase as a large amount, as demonstrated by the constancy of pH in NaF soil suspensions in spite of several fold increases in solution/soil ratio (Bartlett, 1972). In addition, the NaF pH is not a selective test, e.g., the fluoride in complexing the Al releases OH ions from any form of reactive hydroxy Al, organic or inorganic (Egawa et al., 1960; Birrell, 1961; Bartlett, 1972; Wada, 1977). The NaF pH is not a diagnostic criterion in the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994).

Most soils contain components that react with NaF and release OH^-. Soils with a 1:1 water pH >8.2 do not give a reliable NaF pH. Free carbonates in a soil can also result in a high NaF pH. As high NaF values may be found in soils with large sources of Ca or bases, including carbonates, and in some sesquioxide-rich soils, care is required in the interpretation of these data. The SSL determines 1 *N* NaF (pH 7.2 - 8.1) by procedure 8C1d.

Column 18: pH, Oxidized.

Oxidized pH, significance: The pH of a soil that has been incubated at room temperature and at a moisture content above field capacity is used to assess the potential formation of reducing conditions through the activities of soil microorganisms. If the soil has a ready source of energy for the microorganisms, e.g., fresh organic matter or reduced inorganic compounds such as sulfides, the soil potential is higher. If the soil has no free carbonates and a significant available source of decomposable organic matter for the microorganisms, the oxidized pH is <1:1 water pH.

Oxidized pH, indicator of ochre: The term *ochre* is commonly assigned to oxidized Fe deposits and associated bacterial slimes that can clog drains. Ochre can be so voluminous and gelatinous from water hydration that drains become clogged from masses of these deposits. Drain design, installation, and maintenance can be changed when the ochre forming potentials of drainage sites are known (Ford, 1982). Although the oxidized pH measurement has not been routinely adopted as a standard procedure in determining ochre-forming potentials, this pH may be used as an indicator of these potentials. The SSL determines oxidized pH by procedure 8C1H.

Column 19: pH, 1:2 $CaCl_2$ (0.01 *M*).

1:2 $CaCl_2$ pH, significance: The 1:2 $CaCl_2$ (0.01 *M*) pH is a commonly determined soil pH measurement. This pH measurement estimates the activity of H-ions in a soil suspension in the presence of 0.01 *M* $CaCl_2$ to approximate a constant ionic strength for all soils regardless of past management, mineral composition, and natural fertility level.

1:2 $CaCl_2$ pH, data assessment: A number of general interpretations about soils can be made from pH measurements, but most are made with more confidence if extractable acidity and bases have been measured (NSSL Staff, 1975). Soils with pH 6.5 to 8 usually have a base saturation (CEC-7) in the range of 75 to 100 percent. Soils with pH 8 to 8.5 are fully base saturated; probably contain $CaCO_3$ and some salts; and Ca and Mg usually dominate the exchange sites. Soils with pH >8.5 usually contain significant amounts of exchangeable Na, whereas soils with pH >10 are highly Na-saturated with an EC >4 mmhos cm^{-1}.

The 1:2 $CaCl_2$ soil pH is generally < 1:1 water pH. The combination of Al exchange and hydrolysis in salt solutions (0.1 to 1 *M*) can lower the measured pH from 0.5 to 1.5 units, compared to the pH measured in distilled water (Foth and Ellis, 1988). The 1:2 $CaCl_2$ pH is used as a diagnostic criterion to separate acid and nonacid reaction classes (Soil Survey Staff, 1975, 1994). Refer to the Soil Survey Staff (1975, 1994) for additional discussion of this diagnostic criterion. The SSL determines the 1:2 $CaCl_2$ (0.01 *M*) pH by procedure 8C1f.

Column 20: pH, 1:1 Water.

1:1 water pH, significance:: The 1:1 water pH is a commonly determined soil pH measurement. The 1:1 water pH is generally > 1:2 $CaCl_2$ soil pH. The combination of Al exchange and hydrolysis in salt solutions (0.1 to 1 *M*) can lower the measured pH from 0.5 to 1.5 units, compared to the pH measured in distilled water (Foth and Ellis, 1988).

1:1 water pH, data assessment: A number of general interpretations about soils can be made from pH measurements, but most are made with more confidence if extractable acidity and bases have been measured (NSSL Staff, 1975). Most mineral soils with 1:1 water pH values <3.5, or a pH which drops to <3.5 after drying, usually contain acid sulfates. These type soils can be found in coastal marshes or mine spoil areas and have reduced forms of sulfur which can oxidize forming H_2SO_4. Soils with pH 4.5 to 6.5 have some acidity present as hydroxy-Al and hydronium (H_3O^+). In these soils, base saturation (CEC-8.2) is usually <75 percent and in many cases <35 percent. Soils with pH 6.5 to 8 usually have a base saturation (CEC-7) in the range of 75 to 100 percent. Soils with pH 8 to 8.5 are fully base saturated; probably contain $CaCO_3$ and some salts; and Ca and Mg usually dominate the exchange sites. Soils with pH>10 are highly Na-saturated and have very low resistivities. The pH correlate poorly with corrosion potential, but in general soils with pH <4 and >10 have corrosion potential.

1:1 water pH, laboratory vs field: The pH of an air-dry soil sample in the laboratory will be different from the pH that exists in the same soil in the field during the growing season, i.e., there will be differences in water and salt content, and the roots and microorganisms will produce CO_2 (Foth and Ellis, 1988). The SSL determines the 1:1 water pH by procedure 8C1f.

4.4 ACID CHEMISTRY SHEET (ACID SHEET): TIER 2: COLUMNS 1 - 20:

Columns 1 - 7: SODIUM PYROPHOSPHATE EXTRACTIONS.

Podzol concept: The original concept of the Podzol in Russia emphasized the ashy gray eluvial horizon, and the name was applied to soils having such a horizon regardless of the nature of the underlying illuvial horizon (McKeague et al., 1983). In general, as this term was carried into German and later into English it became associated with soils having, in addition to a bleached layer, an underlying reddish to dark-brownish or black illuvial horizon typical of Podzols (McKeague et al., 1983). These illuvial horizons typically consist largely of humus and sesquioxides.

Spodic Horizon: In the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) those illuvial horizons with "active amorphous" materials composed of organic matter and Al, with or without Fe, are defined as spodic horizons. These materials typically express high pH-dependent CEC, large surface area, and high water retention in relation to their clay content (Soil Survey Staff, 1994). Organic substances are believed to be of the first importance in the development of these horizons because of their dominant role in the processes of mobilization, migration, and accumulation (De Connick, 1980). If enough polyvalent cations, especially Al and Fe, are available, mobile organic substances are immobilized in place, but if there are insufficient amounts of Al and/or Fe to completely immobilize the mobile compounds, these cations are complexed by the mobile compounds and are transported downward (De Connick, 1980).

Spodic horizon, field and laboratory criteria: In the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994), the spodic horizon is defined in terms of both field and laboratory criteria. The original intent of the chemical determinations was to define some of the more weakly defined spodic horizons (McKeague et al., 1983). These requirements were based on the chemical composition and activity of the illuvial material. At one time, sodium pyrophosphate extractable Fe and Al in conjunction with dithionite-citrate data were used to help identify translocated Al and Fe humus complexes in spodic horizons (Soil Survey Staff, 1975). Sodium pyrophosphate extracting solutions tend to selectively extract mainly Fe and Al associated with organic compounds while the dithionite-citrate extractions tend to extract these compounds plus the free oxides (McKeague et al., 1971). To emphasize the organic-sesquioxide complexes, the taxonomic definition for a spodic horizon required the following: (1) the amount of Fe and Al extracted by pryophosphate be high relative to the amount extracted by dithionite-citrate; (2) the pyrophosphate-extractable Al + Fe or Al + C percentages be high relative to the percentage of clay in the horizon in order to eliminate horizons dominated by silicate clay; and (3) a relatively large CEC from non-silicate clay sources so as to eliminate weakly developed soils (McKeague et al., 1983).

Sodium pyrophosphate extractions, significance: Numerous evaluations of pyrophosphate extracts have indicated that the pyrophosphate extraction does not necessarily correlate with organic-bound Fe and Al (Schuppli et al., 1983; Kassim et al., 1984; Parfitt and Childs, 1988; Birkeland et al., 1989) as commonly thought (Schwertmann and Taylor, 1977; Parfitt and Childs, 1988). Pyrophosphate not only extracts organic-bound Fe but also peptizes solid particles of ferrihydrite and in some instances even goethite (Yuan et al., 1993). The use of sodium pyrophosphate extract data in conjunction with dithionite-citrate data as chemical requirements for spodic horizons have been replaced by other criteria (Soil Survey Staff, 1994) and, at one time, were referred to as spodic horizon criteria on the SSL data sheets. Refer to Table 3 for the dissolution of Al, Fe, and Si in various clay constituents and organic complexes by treatment with different reagents. Refer to the discussion on dithionite-citrate extracts on the PSDA Sheet, Tier 2, Columns 5 - 7. Also refer to the discussion on ammonium oxalate extracts on the Acid Oxalate Sheet, Tier 1, Columns 1 - 4.

Sodium pyrophosphate extractions, laboratory measurement: A soil sample is mixed with 0.1 *M* sodium pyrophosphate and shaken overnight (procedures 6A4a). An aliquot of extract is obtained, and sodium pyrophosphate extractable Fe, Mn, and Al are measured using atomic absorption (AA) spectrometry (procedures 6C8a, 6D4a, and 6G10a, respectively). The sodium pyrophosphate extractable C is determined by CO_2 evolution (6A4a).

Column 1: Carbon (C), Sodium Pyrophosphate Extractable.

The SSL determines sodium pyrophosphate extractable C (C_p) by procedure 6A4a. The C_p is reported as percent on a <2-mm base.

Column 2: Iron (Fe), Sodium Pyrophosphate Extractable.

The SSL determines sodium pyrophosphate extractable Fe (Fe_p) by procedure 6C8a. The Fe_p is reported as percent on a <2-mm base.

Column 3: Aluminum (Al), Sodium Pyrophosphate Extractable.

The SSL determines sodium pyrophosphate extractable Al (Al_p) by procedure 6G10. The Al_p is reported as percent on a <2-mm base.

Column 4: Iron (Fe) plus Aluminum (Al), Pyrophosphate Extractable to Dithionite-Citrate Extractable.

Compute the ratio by dividing the sum of Fe_p plus Al_p by the sum of dithionite-citrate extractable Fe plus Al (Fe_d + Al_d). The Fe_p and Al_p are reported on this data tier in Columns 2 - 3, respectively. The Fe_d and Al_d are reported on the PSDA Sheet, Tier 2, Columns 5 - 6, respectively. The SSL computes this ratio by procedure 8D6.

Column 5: Iron (Fe) plus Aluminum (Al), Pyrophosphate Extractable to Total Clay.

Compute the ratio by dividing the sum of Fe_p plus Al_p by the total clay percentage. The Fe_p and Al_p are reported on this data tier in Columns 2 - 3, respectively. The clay percentage is reported on the PSDA Sheet, Tier 1, Column 4.

Column 6: Aluminum (Al) plus Carbon (C), Pyrophosphate Extractable to Total Clay.

Compute the ratio by dividing the sum of C_p plus Al_p by the total clay percentage. The C_p and Al_p are reported in Columns 1 and 3, respectively. The clay percentage is reported on the PSDA Sheet, Tier 1, Column 4.

Column 7: Index of Accumulation.

Compute the accumulation index by subtracting 1/2 the clay percentage of a subhorizon from the CEC-8.2 and multiply the remainder by the thickness of subhorizon (cm). The clay percentage is reported on the PSDA Sheet, Tier 1, Column 4. The CEC-8.2 is reported on the Acid Sheet or Salt Sheet, Tier 1, Column 8. The SSL computes this index by procedure 8D7.

4.5 SALT CHEMISTRY SHEET (SALT SHEET): TIER 1: COLUMNS 1 - 20:

Columns 1 - 5: NH_4OAc EXTRACTABLE BASES.

Refer to the general discussion on NH_4OAc extractable bases on the Acid Sheet, Tier 1, Columns 1 - 4.

Column 1: NH_4OAc Extractable Bases, Ca^{2+}.

Refer to the discussion on NH_4OAc extractable Ca^{2+} on the Acid Sheet, Tier 1, Column 1.

Column 2: NH_4OAc Extractable Bases, Mg^{2+}.

Refer to the discussion on NH_4OAc extractable Mg^{2+} on the Acid Sheet, Tier 1, Column 2.

Column 3: NH_4OAc Extractable Bases, Na^+.

Refer to the discussion on NH_4OAc extractable Na^+ on the Acid Sheet, Tier 1, Column 3.

Column 4: NH_4OAc Extractable Bases, K^+.

Refer to the discussion on NH_4OAc extractable K^+ on the Acid Sheet, Tier 1, Column 4.

Column 5: Sum of Bases.

Refer to the discussion on sum of bases on the Acid Sheet, Tier 1, Column 5.

Column 6: Extractable Acidity.

Refer to the discussion on extractable acidity on the Acid Sheet, Tier 1, Column 6.

Column 7: Data column not used.

Columns 8 - 9: CATION EXCHANGE CAPACITY (CEC).

Refer to the general discussion on cation exchange capacity (CEC) on the Acid Sheet, Tier 1, Columns 8 - 9.

Column 8: CEC, Sum of Cations (CEC-8.2).

Refer to the discussion on CEC by sum of cations (CEC-8.2) on the Acid Sheet, Tier 1, Column 8.

Column 9: CEC, NH_4OAc, pH 7.0 (CEC-7).

Refer to the discussion on CEC by NH_4OAc, pH 7.0 (CEC-7) on the Acid Sheet, Tier 1, Column 9.

Column 10: Exchangeable Sodium (Na).

Exchangeable sodium percentage, historical significance: Historically, the exchangeable sodium percentage (ESP) was used as the main criterion for excessive Na levels in soils. However, in the last several decades, for the classification of Na-affected soils, the emphasis has been on the use of the sodium adsorption ratio (SAR) of the equilibrium soil solution (Bresler et al., 1982). An ESP $\geq$15 percent is a diagnostic criterion for natric soil horizons (Soil Survey Staff, 1975, 1994).

Exchangeable sodium percentage and sodium adsorption ratio: An ESP determination requires (1) measurement of all soluble and exchangeable Na from the soil; (2) subsequent subtraction of any soluble Na in the saturation extract; and (3) a soil CEC determination. The SAR can be readily determined on the saturation extract if that extraction has been made for an EC determination in the soil salinity analysis. The ESP analysis is less precise than the SAR determination.

Exchangeable sodium percentage and cation exchange capacity: The U.S. Salinity Laboratory (1954) gives the following relationship for estimating ESP of saturation extract for soils with CEC < 50 meq 100 g^{-1}.

Equation 57:

$$\text{ESP} = \frac{100\ (-0.0126 + 0.01475\ \text{SAR})}{1 + (-0.0126 + 0.01475\ \text{SAR})}$$

Exchangeable sodium percentage, calculation (when no saturation extract is prepared): Compute the ESP by dividing the exchangeable Na by the CEC-7 and multiplying by 100. The exchangeable Na is calculated by subtracting the water soluble Na^+ from the NH_4OAc extractable Na^+. The CEC-7 is reported on the Salt Sheet, Tier 1, Column 9. The NH_4OAc extractable Na^+ is reported on the Salt Sheet, Tier 1, Column 3. The water soluble

Na^+ is reported on the Salt Sheet, Tier 2, Column 3. When the saturation extract is not prepared, the ESP is calculated as follows:

Equation 58:

$$ESP = \frac{ES}{CEC\text{-}7} \times 100$$

where:

ESP = Exchangeable sodium percentage

ES = Extractable sodium (NH_4OAc extractable Na^+, meq 100 g^{-1}). Data are reported on the Salt Sheet, Tier 1, Column 3.

CEC-7 = CEC by NH_4OAc, pH 7.0 (meq 100 g^{-1}). Data are reported on the Salt Sheet, Tier 1, Column 9.

Exchangeable sodium percentage, calculation (when saturation extract is prepared): When the saturation extract is prepared, the ESP is reported as percent in this data column and calculated by procedure 5D2 as follows:

Equation 59:

$$ESP = 100 \times \frac{[Na_{ex} - (Na_{ex} \times (H_2O_{ws}/1000))]}{CEC\text{-}7}$$

where:

ESP = Exchangeable sodium percentage

Na_{ex} = Extractable Na (NH_4OAc extractable Na^+, meq 100 g^{-1}). Data are reported on the Salt Sheet, Tier 1, Column 3.

Na_{ws} = Water-soluble Na (meq L^{-1}). Data are reported on the Salt Sheet, Tier 2, Column 3.

H_2O_{ws} = Water saturation percentage. Data are reported on the Salt Sheet, Tier 2, Column 12, if all anions are reported; otherwise, the H_2O_{ws} is reported in Column 10.

CEC-7 = CEC by NH_4OAc, pH 7.0 (meq 100 g^{-1}). Data are reported on the Salt Sheet, Tier 1, Column 9.

Column 11: Sodium Adsorption Ratio (SAR).

Sodium adsorption ratio, definition: In addition to the total salinity (osmotic) hazard of irrigation water on plants, the tendency of the solution to produce excessive exchangeable Na must also be considered (Bresler et al., 1982). Significant amounts of Na in soils severely retard the growth of many plants. The SAR was developed as a measurement of the quality of irrigation water, particularly when the irrigation water is salt or Na-affected (U.S. Salinity Laboratory Staff, 1954). The SAR is used as an indirect estimate of the equilibrium relation between soluble Na in the salt solution and exchangeable Na adsorbed by the soil. A SAR $\geq$13 percent is used as a diagnostic criterion for natric soil horizons (Soil Survey Staff, 1975, 1994).

Unlike most theoretical ion "ratios", the SAR is expressed in terms of ion concentration (Gapon-type exchange) rather than ion activity. However, the use of concentration is valid as the activity coefficient decreases more rapidly with increasing salt concentration for divalent cations, e.g., Ca^{2+} and Mg^{2+}, than it does for monovalent cations, e.g., Na^{+} (Sposito, 1989; Cresser et al., 1993). In addition, this ratio is relatively constant over a broad range of concentration.

Sodium adsorption ratio, calculation: Compute the SAR by dividing the molar concentration of the monovalent cation Na^{+} by the square root of the molar concentration of the divalent cations Ca^{2+} and Mg^{2+} divided by two (U.S. Salinity Laboratory Staff, 1954; SSL Staff, 1992). The water soluble Ca^{2+}, Mg^{2+}, and Na^{+} are reported on the Salt Sheet, Tier 2, Columns 1 - 3, respectively. The SSL calculates the SAR by procedure 5E. The SAR is calculated as follows:

Equation 60:

$$\text{SAR} = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{++}]+[Mg^{++}]}{2}}}$$

SAR = Sodium Adsorption Ratio

Na^{+} = Water soluble Na^{+} (meq L^{-1}). Data are reported on the Salt Sheet, Tier 2, Column 3.

Ca^{2+} = Water soluble Ca^{2+} (meq L^{-1}). Data are reported Salt Sheet, Tier 2, Column 1.

Mg^{2+} = water soluble Mg^{2+} (meq L^{-1}). Data are reported on the Salt Sheet, Tier 2, Column 2.

Columns 12 - 13: BASE SATURATION.

Refer to the general discussion on base saturation on the Acid Sheet, Tier 1, Columns 12 - 13.

Column 12: Base Saturation, Sum of Cations (CEC-8.2).

Refer to the discussion on base saturation by sum of cations (CEC-8.2) on the Acid Sheet, Tier 1, Column 12.

Column 13: Base Saturation, NH_4OAc pH 7.0 (CEC-7).

Refer to the discussion on base saturation by NH_4OAc, pH 7.0 (CEC-7) on the Acid Sheet, Tier 1, Column 13.

Column 14: Carbonate as $CaCO_3$, <2mm.

Refer to the discussion on carbonate as $CaCO_3$ on the Acid Sheet, Tier 1, Column 14.

Column 15: Carbonate as $CaCO_3$, <20mm.

The $CaCO_3$ equivalent is most commonly reported on the <2-mm base. However, in some soils with hard carbonate concretions, the carbonates are also determined on the 2- to 20-mm base. The SSL determines carbonate as $CaCO_3$ on a <20-mm base by procedure 6E4. If the SSL determines carbonate as $CaCO_3$ on a <20-mm base, these data are reported as a percent in this data column. However, if the SSL determines soil resistivity, then these data are reported in Column 15.

Column 15: Resistivity

Refer to the discussion on soil resistivity on the Acid Sheet, Tier 1, Column 15. If the SSL determines resistivity, then these data are reported in ohms cm^{-1} in Column 15.

Columns 16 - 17: Calcium Sulfate ($CaSO_4$) as Gypsum.

Gypsum, soil related factors: Gypsum is one of the most commonly occurring sulfate minerals. Gypsum occurs as a soil constituent and is frequently associated with gypsiferous geologic deposits, even if the deposits are deep-seated or are located some distance away from the site of the gypsum-containing soils (Eswaran and Zi-Tong, 1991). Gypsum may be present as traces in the soil or dominate the soil system, as in soils with gypsic or petrogypsic horizons. Gypsum is frequently found in association with halite (NaCl), the dominant soluble salt in Saliorthids, as well as with some soluble sulfate minerals, e.g., assanite, anhydrite, mirabilite, epsomite, konyaite, hexahydrite, and bloedite. All these salts are more soluble than gypsum. Gypsum content of a soil is a diagnostic criterion for gypsic and petrogypsic horizons and for mineralogical class at the family level (Soil Survey Staff, 1975, 1994). Refer to Soil Survey Staff (1975, 1994) for additional discussion of these criteria.

Gypsum, agronomic and engineering significance: Generally, gypsiferous soils have an abundance of Ca. These soils are usually associated with high base status, salinity, and possibly more soluble salts than gypsum. When present in excessive amounts, gypsum controls the properties of the soil and may have adverse effects on the agricultural and engineering properties of the soil (Eswaran and Zi-Tong, 1991). Gypsum can also be a beneficial. Gypsum is added as a plant nutrient (Ca, S) for improved plant growth in leached Oxisols and Ultisols. Gypsum is also used as an amendment to improve soil structure and permeability in sodic soils.

Gysiferous soils may become impervious to roots and water. Available water content and cation exchange capacity are generally inversely proportional to gypsum content. The saturated Ca soil solution may result in the fixation of the micronutrients, Mn, Zn, and Cu. Soil subsidence through solution and removal of gypsum can crack building foundations, break irrigation canals, and make roads uneven. Failure can be a problem in soils with as little as 1.5 percent gypsum (Nelson, 1982). Corrosion of concrete is also associated with soil gypsum. Gypsum content, soil resistivity, and extractable acidity singly or in combination provide a basis for estimating potential corrosivity of soils (USDA-SCS, 1971).

Gypsum, laboratory measurement: Gypsum interferes with PSDA by causing flocculation of particles (SSL Staff, 1992). Gypsum is removed by stirring and washing the soil with distilled water in the PSDA procedure. This procedure is effective if the soil contains <25 percent gypsum. Gysiferous soils are also a special case in determining the air-dry/oven-dry (AD/OD) ratio. Gypsum ($CaSO_4 \cdot 2H_2O$) loses most of its two water molecules at 105°C. Properties of gypsiferous soils that are reported on an oven-dry weight basis are converted to include the weight of crystal water in gypsum (Nelson et al., 1978). The AD/OD ratio is corrected to a crystal water basis when the gypsum content of the soil is ≥ 1 percent. The inclusion of the weight of crystal water in gypsum allows the properties of gysiferous soils to be compared with those properties of nongypsiferous soils. This conversion also avoids the possible calculation error of obtaining >100 percent gypsum when the data are expressed on an oven-dry basis. Normal amounts of organic matter and high AD/OD trigger the SSL to determine gypsum. Calcium sulfate as gypsum is reported as percent for the <2-mm and <20-mm base in Columns 16 and 17, respectively.

Column 16: Calcium Sulfate ($CaSO_4$) as Gypsum, <2mm.

The SSL determines calcium sulfate ($CaSO_4$) as gypsum by procedure 6F1A. Calcium sulfate as gypsum is reported on a <2-mm base.

Column 17: Calcium Sulfate ($CaSO_4$) as Gypsum, <20mm.

The SSL determines calcium sulfate ($CaSO_4$) as gypsum by procedure 6F4. Calcium sulfate as gypsum is reported as percent on a <20-mm base.

Columns 18 - 20: REACTION, pH.

Refer to the general discussion on soil pH on the Acid Sheet, Tier 1, Columns 18 - 20.

Column 18: pH, Saturated Paste.

Saturated paste pH, significance: The saturated paste pH is popular in regions with soils with soluble salts. The water content of the saturated paste varies with soil water storage characteristics. The saturated paste pH may be more indicative of the saturated, irrigated pH than is the soil pH measurement at a constant soil:water ratio (U.S. Salinity Laboratory Staff, 1954). The saturated paste pH is also the pH at which the saturation extract is removed for salt analyses, and hence, is the pH and the dilution at which the SAR is determined. The SSL determines the saturated paste pH by procedure 8C1b.

Saturated paste pH, data assessment: When making interpretations about the soil, the saturated paste pH is usually compared to the 1:1 water pH and the 1:2 $CaCl_2$ pH. The usual pH sequence is as follows: 1:1 water pH > 1:2 $CaCl_2$ pH > saturated paste pH. If saturated paste pH is > 1:2 $CaCl_2$ pH, the soil is considered nonsaline. If the saturated paste pH $\geq$ 1:1 water pH, the soil may be Na-saturated and have no free carbonates.

Saturated paste pH, rules of thumb: Because of the interrelations that exist among the various soil chemical determinations, the saturated paste pH value may be used as a means of cross-checking salinity data for internal consistency and reliability. Some rules of thumb that apply to the saturated paste pH (U.S. Salinity Laboratory Staff, 1954) are as follows:

(1) Soluble carbonates are present only if pH >9.
(2) Soluble bicarbonate seldom >3 or 4 meq L^{-1}, if the pH $\leq$7.
(3) Soluble Ca^{2+} and Mg^{2+} seldom >2 meq L^{-1}, if the pH >9.
(4) Gypsiferous soils seldom have pH >8.2.

Column 19: pH, 1:2 $CaCl_2$ (0.01 *M*).

Refer to the discussion on pH, 1:2 $CaCl_2$ on the Acid Sheet, Tier 1, Column 19.

Column 20: pH, 1:1 Water.

Refer to the discussion on pH, 1:1 water on the Acid Sheet, Tier 1, Column 20.

4.6 SALT CHEMISTRY SHEET (SALT SHEET): TIER 2: COLUMNS 1 - 20

Columns 1 - 13: WATER EXTRACTED FROM SATURATED PASTE.

Salt-affected soils: Salt-affected soils are those soils in which the ionic concentration is in excess of exchange capacity of the soils. These soils are common in, though not restricted to, arid and semi-arid regions. The more pronounced salinity problems in arid and semiarid regions have been attributed to insufficient annual rainfall to flush accumulated salts from the crop root zone (Bresler et al., 1982). The main source of salts in these regions are rainfall, mineral weathering, "fossil" salts, and various surface waters and groundwaters which redistribute accumulated salts, often the result of man's activities (Bresler et al., 1982).

The primary effect of soluble salts on plants is osmotic. High salt levels prevent plants from obtaining water for plant growth. The plant root contains a semi-permeable membrane that preferentially permits water to pass but rejects most of the salt. Under increasingly saline conditions, water becomes osmotically more difficult to extract. Plants growing in saline conditions can modify their internal osmotic concentrations by organic acid production or salt uptake, i.e., osmotic adjustment.

The term *salt tolerance* can be expressed in terms of *saturation-extract EC levels*. The various saturation extract EC levels can be associated with relative plant growth, i.e., 10, 25, and 50 percent decreases in yields (U.S. Salinity Laboratory Staff, 1954; Bernstein, 1964; USDA-SCS and U.S. Salinity Laboratory Staff, 1993). In addition to the general osmotic effects of salts, many plants are sensitive to specific ions in irrigation waters or soil solutions. This sensitivity has been termed *specific ion effects*. Direct sensitivity to exchangeable or soluble Na is more apparent at low salt levels, and therefore is more difficult to differentiate from the effects of Na on soil permeability. Another common specific ion effect is B toxicity. In many cases, B toxicity is more difficult to control than is salinity.

Salt-affected soils, soluble salt concentrations: Salt-affected soils are usually described and characterized in terms of the soluble salt concentrations, i.e., major dissolved inorganic solutes (Rhoades, 1982). Soluble cations and anions have been loosely defined as those removed by water, whereas exchangeable cations are those removed by neutral salt solutions. The aqueous phase outside the electrical double layer of soil colloids is the bulk solution containing the soluble salts. Analyses of water leached in humid regions indicate that the relative cation concentration in the bulk solution are usually $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ (Bohn et al., 1979). There may also be low concentrations of NH_4^+ ions as the result of ammonia fertilization. Sodium may predominate in drainage waters of many irrigated soils. Total salt concentration in the bulk solution of well-drained soils in humid and temperate regions is generally in the range 0.001 to 0.01 *M* (Bohn et al., 1979). In irrigated and arid soils, the soluble salt concentration is usually higher and may be 5 to 10 times higher than in the applied irrigation water because of the salts that remain after the evapotranspiration of water (Bohn et al., 1979). In those areas in which salts (particularly Na salts) accumulate because of improper irrigation, high water table, or seawater intrusion, the salt concentrations may be as high as 0.1 to 0.5 *M* (Bohn et al., 1979).

Salt-affected soils, anion concentrations: In general, the anion concentration in the aqueous phase of nonsaline soils is less than the cation concentration because most of the negative charge in these soils is from soil colloidal particles (Bohn et al., 1979; Sposito, 1989). The difference between the sum of cation and anion charge narrows as soil salinity increases. Some major anions in soils include NO_3^-, SO_4^{2-}, Cl^-, and HCO_3^-. The relative amounts of these anions vary with fertilizer and management practices, mineralogy, microbial and higher plant activity, saltwater encroachment, irrigation water quality, and atmospheric fallout. In humid regions, the sum of anions rarely exceeds 0.01 *M* in soil solution (Bohn et al., 1979). In saline soils, the anion concentrations are generally higher because of precipitation of cations and anions as soluble salt with a typical distribution of ($Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$) or (($HCO_3^-$ +

CO_3^{2-}) > Cl^- > SO_4^{2-} > NO_3) in high pH sodic soils. The major anions are retained weakly and therefore are mobile in soils if solubilized and leached.

Water soluble and NH_4OAc extractable cations: The effect of soluble cations upon the exchangeable cation determination is to increase the cation concentration in the extracting solution, i.e., NH_4OAc, buffered at pH 7.0. Due to recent changes in laboratory equipment, the NH_4OAc extraction (presently, procedure 5A8b) will have a new method code (as yet assigned, tentatively 5A8c). The dissolution of salts by the extractant necessitates an independent determination of soluble cations and a correction to the exchangeable cations. Therefore, in soils with soluble salts or carbonates, the soluble cations (meq L^{-1} solution) must be measured separately and the results subtracted from the extractable bases for determination of exchangeable bases (Exchangeable = Extractable - Soluble). The presence of alkaline-earth carbonates prevents accurate determination of exchangeable Ca and Mg.

Salt-affected soils, electrical conductivity and exchangeable sodium percentage: The salt composition and distribution in the soil profile affect the plant response, i.e., osmotic stress, specific ion effects, and nutritional imbalances. Soil texture and plant species also are factors in plant response to saline soils. Traditionally, the classification of salt-affected soils has been based on the soluble salt concentrations in extracted soil solutions and on the ESP in the associated soil (Bohn et al., 1979). In general, *saline soils* have been defined as having salt contents >0.1 percent, EC >4 mmhos cm^{-1}, ESP <15 percent, and pH <8.5; *sodic soils* usually have an ESP >15 percent, low salt contents, EC <4 mmhos cm^{-1}, and pH 8.5 to 10; and *saline-sodic* soils usually have properties of both saline and sodic soils with appreciable contents of soluble salts, ESP >15 percent, and an EC >4 mmhos cm^{-1} (U.S. Salinity Laboratory Staff, 1954). The ESP and SAR are used as diagnostic criteria for natric horizons (Soil Survey Staff, 1975, 1994). Refer to the Soil Survey Staff (1975, 1994) for additional discussion of these criteria. Refer to the discussion on ESP and SAR on the Salt Sheet, Tier 1, Columns 10 - 11, respectively.

Saturated paste pH and saturation extract, rules of thumb: A means of cross-checking chemical analyses for consistency and reliability is provided by the interrelations that exist among the various soil chemical determinations (U.S. Salinity Laboratory Staff, 1954). The saturated paste pH is the apparent pH of the soil:water mixture and is a key indicator in many of these interrelations. The saturated paste pH is dependent upon the dissolved CO_2 concentration; moisture content of the mixture; exchangeable cation composition; soluble salt composition and concentration; and the presence and amount of gypsum and alkaline-earth carbonates. Some rules of thumb that apply to the saturated paste pH and saturation extract (U.S. Salinity Laboratory Staff, 1954) are as follows:

Relationship: Total Cation and Anion Concentrations.
Rule of Thumb: Total cations ≈ Total anions, expressed on equivalent basis.

Relationship: pH, Ca, and Mg Concentrations.
Rule of Thumb: Concentrations of Ca^{2+} and Mg^{2+} are seldom >2 meq L^{-1} at pH >9.

Relationship: pH, CO_3^{2-}, and HCO_3^- Concentrations.
Rules of Thumb: Carbonate concentration (meq L^{-1}) is measurable only if pH >9.
Bicarbonate concentration is rarely >10 meq L^{-1} in absence of carbonates.
Bicarbonate concentration is seldom >3 or 4 meq L^{-1} if pH <7.

Relationship: pH and Gypsum.
Rules of Thumb: Gypsum is rarely present if pH >8.2.
Gypsum has variable solubility in saline solutions (20 to 50 meq L^{-1}).
Check for the presence of gypsum if Ca^{2+} concentration >20 meq L^{-1} and pH $\leq$8.2.

Relationship: pH, ESP, and Alkaline-Earth Carbonates.
Rules of Thumb: Alkaline-earth CO_3^{2-} and ESP $\geq$15 percent are indicated if pH $\geq$8.5.
ESP $\leq$15 percent may or may not be indicated if pH <8.5.
No alkaline-earth CO_3^{2-} are indicated if pH <7.5.

Relationship: pH and Extractable Acidity.
Rule of Thumb: Significant amounts of extractable acidity are indicated if pH <7.0.

Saturated paste extract, soil:water ratio: The measurable absolute and relative amounts of various solutes are influenced by the soil:water ratio at which the extract is made. Therefore, this ratio is standardized to obtain results that can be applied and interpreted universally. Soil salinity is conventionally defined and measured on aqueous extracts of saturated soil pastes (U.S. Salinity Laboratory Staff, 1954). This soil:water ratio is used because it is the lowest reproducible ratio at which the extract for analysis can be readily removed from the soil with common laboratory equipment, i.e., pressure or vacuum, and because this soil:water ratio is often related in a predictable manner to field soil water contents (Rhoades, 1982). Soil solutions obtained at lower soil moisture conditions are more labor intensive and require special equipment.

Saturated paste extract, laboratory measurements: The SSL measures salinity on aqueous extracts of saturated soil pastes. Upon preparation of the saturation paste, the saturation percentage (SP) is determined and a saturation extract obtained with an automatic extractor. The electrical conductivity (EC_s), water-soluble cations and anions, and total salts are determined on the aqueous extract. The saturated paste pH and soil resistivity (R_s) are determined on the saturated paste. Total salt is a calculated value. The SSL also performs a salt prediction test.

The SSL determines (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and (CO_3^{2}, HCO_3^-, Fl^-, Cl^-, SO_4^{2-}, NO_2^-, NO_3^-). The water soluble cations are measured by atomic absorption. The anions Fl^-, Cl^-, SO_4^{2}, NO_2^-, NO_3^- are determined by anion chromatography and CO_3^{2-} and HCO_3^- by acid/base titration. The water extractable cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) are reported in meq L^{-1} in Columns 1 - 4, respectively. Water extractable anions (CO_3^{2-}, HCO_3^-, Fl^-, Cl^-, SO_4^{2-}, NO_2^-, NO_3^-) are reported in meq L^{-1} in Columns 5 - 11, respectively. Saturation percentage and total salts are reported as percent in Columns 12 - 13, respectively. The EC_s and EC for prediction of salts are reported in mmhos cm^{-1} in Columns 14 and 15, respectively. If any of the listed water extractable anions are not determined by the SSL, then the reporting of these data and other saturated paste extract data are appropriately shifted in the data columns. Some anions that are not routinely reported on the SSL data sheets are Fl^- and NO_2 but are shown in Appendix II (Wildmesa Pedon). The R_s and saturated paste pH are not reported on this data tier but are reported on the Salt Sheet, Tier 1, Columns 15 and 18, respectively.

Column 1: Saturation Extract Calcium (Ca^{2+}).

The SSL determines the saturation extract Ca^{2+} by procedure 6N1b. The saturation extract Ca^{2+} is reported in meq L^{-1}.

Column 2: Saturation Extract Magnesium (Mg^{2+}).

The SSL determines saturation extract Mg^{2+} by procedure 6O1b. Saturation extract Mg^{2+} is reported in meq L^{-1}.

Column 3: Saturation Extract Sodium (Na^+).

Sodium, effects on soils: The exchangeable suite of saline soils is highly variable, depending on the amount and kind of salts (Foth and Ellis, 1988). Being a soluble salt, Na can have a preferential accumulation in the soil over time. Refer to the discussion on exchangeable sodium and SAR on the Salt Sheet, Tier 1, Columns 10 - 11, respectively. The structure of sodic soils tend to disintegrate because Na is weakly adsorbed and is inefficient in neutralizing the negative charge (Foth and Ellis, 1988). The resulting dispersion of clays and humus reduces soil permeability.

Sodium, effects on plants: Significant amounts of Na in soils severely retard the growth of many plants. Sodic soils that are dominated by active Na exert a detrimental effect on plants in the following ways: (1) caustic influence of the high alkalinity induced by the sodium carbonate and bicarbonate; (2) toxicity of the bicarbonate and other anions; and (3) adverse effects of the active sodium ions on plant metabolism and nutrition (Brady, 1974). Direct sensitivity by plants (specific ion effects) to exchangeable or soluble Na is more apparent at low salt levels, and therefore is more difficult to differentiate from the effects of Na on soil permeability. The SSL determines the saturation extract Na^+ by procedure 6P1b. Saturation extract Na^+ is reported in meq L^{-1}.

Column 4: Saturation Extract Potassium (K^+).

The SSL determines the saturation extract K^+ by procedure 6Q1b. Saturation extract K^+ is reported in meq L^{-1}.

Column 5: Saturation Extract Carbonate (CO_3^{2-}).

The SSL determines the saturation extract CO_3^{2} by procedure 6I1b. Saturation extract CO_3^{2-} is reported in meq L^{-1}.

Column 6: Saturation Extract Bicarbonate (HCO_3^-).

Bicarbonate toxicity: An important measurement of water quality is the relative amounts of Na or sodicity of the water. Related to the Na hazard of irrigation waters is the bicarbonate concentration. The precipitation of $CaCO_3$ from these waters generally decreases the concentration of dissolved Ca, increases the SAR, and increases the exchangeable Na level in the soil (Bohn et al., 1979). Potential bicarbonate injury or toxicity to plants in saline environments result more from nutritional deficiencies or micronutrient imbalances rather than from the direct effect of bicarbonate ions or "bicarbonate toxicities", e.g., in high-bicarbonate, high pH soils, there are common occurrences of reduced plant-available Fe (Bohn et al., 1979). The SSL determines saturation extract HCO_3^- by procedure 6J1b. Saturation extract HCO_3^- is reported in meq L^{-1}.

Column 7: Saturation Extract Fluoride (Fl^-).

The SSL determines saturation extract Fl^- by procedure 6U1a. Saturation extract Fl^- is reported in meq L^{-1}.

Column 8: Saturation Extract Chlorine (Cl^-).

Chloride toxicity: Chloride toxicity in saline environments is similar to that of Na toxicity. Direct sensitivity to soluble chlorine is more apparent at low salt levels. Excessive accumulations in plant tissue near the end of the transpiration stream lead to necrosis, leaf tip and margin burn, and eventual death. Some plants are able to screen out such ions through their root membranes, i.e., selective uptake. The SSL determines saturation extract Cl^- by procedure 6K1c. Saturation extract Cl^- is reported in meq L^{-1}.

Column 9: Saturation Extract Sulfate (SO_4^{2-}).

The SSL determines saturation extract SO_4^{2-} by procedure 6L1c. Saturation extract SO_4^{2-} is reported in meq L^{-1}.

Column 10: Saturation Extract Nitrite (NO_2^-).

The SSL determines saturation extract NO_2^- by procedure 6W1a. Saturation extract NO_2^- is reported in meq L^{-1}.

Column 11: Saturation Extract Nitrate (NO_3^-).

The SSL determines saturation extract NO_3^- by procedure 6M1c. Saturation extract NO_3^- is reported in meq L^{-1}.

Column 12: Water Content of Saturated Paste (H_20).

Saturation percentage, significance: The water content at saturation or saturation percentage (SP) is the amount of moisture in the saturated paste. An experienced analyst should be able to repeat the saturated paste preparation to an SP within 5 percent. The SSL determines the water content percentage of the saturated paste by procedure 8A. The water content of the saturated paste is reported in this data column as percent.

Saturation percentage, rules of thumb: The SP can be related directly to the field moisture range. Measurements on soils, over a considerable textural range, indicate some general rules of thumb (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 61:

$$\text{SP} \approx 4 \text{ x 15-bar water content}$$

Equation 62:

$$\text{SP} \approx 2 \text{ x upper end field soil moisture content}$$

Equation 63:

$$\text{AWC} \approx \frac{\text{SP}}{4}$$

Therefore, the soluble-salt concentration in the saturation extract tends to be about one-half of the concentration of the soil solution at the upper end of the field-moisture range and about one-fourth of the concentration of the soil solution at the lower or dry end of the field-moisture range (U.S. Salinity Laboratory Staff, 1954).

If the soil texture is known, and the 15-bar water content has been measured, the preceding SP relationships may be redefined (U.S. Salinity Laboratory Staff, 1954) as follows:

Equations 64, 65, 66, and 67:

15-bar water	*Texture*	*Relationship*
2.0 to 6.5	Coarse	SP ≈ 6 1/3 x 15 bar
6.6 to 15	Medium	SP ≈ 4 x 15 bar
>15	Fine	SP ≈ 3 1/4 x 15 bar
>15	Organic	SP ≈ 3 2/3 x 15 bar

Column 13: Total Estimated Soluble Salts in Soil.

Total salt concentration, definition: Total salt concentration is an important water quality parameter from the standpoint of salinity as it may be used to estimate the osmotic potential of the solution (Bresler et al., 1982). Historically, this parameter was determined as the total dissolved salts (TDS) by evaporating a known volume of water to dryness and then weighing the quantity of dissolved materials contained therein. This measurement has its ambiguities and limitations (Bresler et al., 1982). The various salts exist in different dehydration states depending on the degree of drying employed. The TDS method fails to account for variations in composition of the water under analysis. In addition, the TDS is a more laborious measurement than is EC which is the currently preferred measure of salinity (Bresler et al., 1982).

Total estimated soluble salts in soil, calculation using electrical conductivity: The SSL uses the charts and graphs available from U.S. Salinity Laboratory Staff (1954) to estimate total salt content from the electrical conductivity of the saturation extract (EC_s). The essential relations are summarized in the equations as follows:

Equation 68:

$$\text{Log (Total Salt) (ppm)} = 0.81 + 1.08 \times \text{Log } EC_s + \text{Log SP}$$

Corrigenda:

$$\text{Total Salt in soil (ppm)} = (-4.2333 + (12.2347 \text{ X } Ec_s) + (0.058 \text{ x } Ec_s^2) - (0.0003 \text{ x } Ecs^3)) \text{ x } 0.000064 \text{ x SP}$$

where:
EC_s = Electrical conductivity of saturation extract
SP = Saturation percentage of saturation extract

Equation 69:

$$\text{Total Salt (\%)} = \text{Total salt (ppm)} \times 10^{-4}$$

where:
Total Salt = Total salt in soil in parts per million (ppm) and percent (%) on a <2-mm base.
EC_s = Electrical conductivity of saturation extract (mmhos cm^{-1})
SP = Saturation percentage. Water percentage in saturation extract.

These equations are applicable to saturation extracts with EC_s <20 mmhos cm^{-1}. Deviations occur at higher salt concentrations. The SSL estimates the total salts by procedure 8D5. Total estimated soluble salts are reported as percent.

Total estimated soluble salts, calculation using soluble cations: Total estimated soluble salts may also be calculated using soluble cations. The SSL does not use the following calculation.

Equation 70:

$$\text{Total Salt (\%)} = \frac{\text{Soluble Cations} \times 0.058 \times \text{SP}}{1000}$$

where:

Total salt = Total salt percentage on a <2-mm base

Soluble cations = Sum of soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in the saturation extract, meq L^{-1}

SP = Saturation percentage. Water percentage in saturation extract.

Column 14: Electrical Conductivity (EC).

Electrical conductivity, definition: The electrical conductivity (EC) measurement is based on the principle that the amount of electrical current transmitted by a salt solution under standardized conditions will increase as the salt concentration of the solution in increased. To measure electrical conductivity, a sample solution is placed between two electrodes of standardized or known geometry, and an electrical potential is imposed across the electrodes. The solution resistance is measured and converted to reciprocal resistance or conductance. The basic unit for resistance measurements is the ohm, and the unit of reciprocal resistance is the mho. The SSL determines the EC_s by procedure 8A3a. The SSL reports EC_s in mmhos cm^{-1}.

Electrical conductivity, index: Electrical conductivity is used as a simplified index to the total concentration of dissolved salts in a given irrigation water and as a water quality parameter which can be correlated to plant growth (Scofield, 1942). The electrical conductivity of the saturation extract (EC_s) is used as a criterion for classifying a soil as saline. Other uses of this measurement include the estimation of the total cation concentration in the extract; salt percentage in solution (P_{sw}); salt percentage in soil (P_{ss}); and osmotic pressure (OP).

Electrical conductivity and soil resistivity: The EC_s has been related to soil resistivity (R_s) (U.S. Salinity Laboratory Staff, 1954). The EC_s is the easier measurement from which to make interpretations as the EC_s is more closely related to plant response (U.S. Salinity Laboratory Staff, 1954). There is a limited correlation between electrical conductivity and soil resistivity, as the relationship is markedly influenced by variations in SP, salinity, and soil mineral conductivity. The R_s and EC_s have been related (U.S. Salinity Laboratory Staff, 1954). Refer to Equations 53 and 54 under the discussion of soil resistivity on the Acid Sheet, Tier 1, Column 15 for these relationships.

Electrical conductivity and salt percentage (solution): The EC_s may be used to estimate the salt percentage (P_{sw}) in solution (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 71:

$$P_{sw} \approx 0.064 \times EC_s \text{ (mmhos cm}^{-1}\text{)}$$

where:

P_{sw} = Estimated salt percentage in solution
EC_s = Electrical conductivity of saturation extract

Electrical conductivity and salt percentage (soil): The preceding equation may be used to estimate the salt percentage (P_{ss}) in the soil (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 72:

$$P_{ss} \approx (P_{sw} \times SP)/100$$

where:

P_{ss} = Estimated salt percentage in soil
P_{sw} = Estimated salt percentage in solution
SP = Saturated percentage. Water percentage in saturation extract.

Electrical conductivity and osmotic potential: The EC_s at 25° C may be used to estimate the osmotic potential (OP) in atmospheres of a solution (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 73:

$$OP \approx 0.36 \times EC_s \ (\mathrm{mmhos\ cm^{-1}})$$

where:

OP = Estimated osmotic potential
EC_s = Electrical conductivity of saturation extract

Electrical conductivity and total cation or anion concentration: For solutions with low EC_s, i.e., dilute solutions, the EC_s at 25°C may be used to estimate the total cation or anion concentration (meq L^{-1}) of the solution (U.S. Salinity Laboratory Staff, 1954) as follows:

Equation 74:

$$\text{Total cations} \approx 10 \times EC_s \ (\mathrm{mmhos\ cm^{-1}})$$

Equation 75:

$$\text{Total anions} \approx 10 \times EC_s \ (\mathrm{mmhos\ cm^{-1}})$$

where:

EC_s = Electrical conductivity of saturation extract (mmhos cm^{-1})

Column 15: Electrical Conductivity (EC).

Salt prediction test, significance: The salt prediction test is used not only to predict those soils that have measurable amounts of soluble salts but also to predict the quantity and the appropriate dilutions for salt analyses of those soils. If salt predictions or conductances are <0.25 mmhos cm^{-1}, soils are considered nonsalty, and generally, no other salt analyses are determined on these soils by the SSL. The SSL tests for the presence of salts (EC) by procedure 8I. The predict of EC is not the same as the electrical conductivity of the saturation extract (EC_s). The EC_s (procedure 8A3a) is reported on the Salt Sheet, Tier 2, Column 12. The salt prediction EC is reported in mmhos cm^{-1} in this data column.

4.7 AMMONIUM OXALATE (ACID OXALATE) SHEET: TIER 1: COLUMNS 1 - 20

Columns 1 - 4: AMMONIUM OXALATE EXTRACTIONS.

Noncrystalline soil materials: Although most soils consist primarily of crystalline minerals, many contain appreciable amounts of noncrystalline or short-range-order inorganic materials. Soils derived from volcanic ash and pumice may consist primarily of allophane and imogolite or other noncrystalline Al, Fe, or Si materials (Thorp and Smith, 1949; Mitchell et al., 1964; Wada and Wada, 1976). However, these noncrystalline materials are not limited to soils derived from volcanic materials. Refer to the general discussion on crystalline and noncrystalline soil materials under the data element dithionite-citrate extractions (PSDA Sheet, Tier 2, Columns 5 - 7). Even small amounts of these noncrystalline materials can contribute significantly to the physical and chemical properties of soils (Fey and LeRoux, 1977), and as such, it is helpful to quantify the relative amounts of noncrystalline as well as crystalline components in these soils. In general, some of the more notable properties of these type soils are high variable charge, high surface area, high reactivity with phosphate and organics (high anion retention), high water retention, and low bulk density (Wada, 1985).

Selective chemical dissolutions, significance and limitations: Selective dissolution data have been used extensively in the study of the noncrystalline materials of soils and sediments. However, there are limitations in using these data. In general, there exists a continuum of crystalline order, ranging from nonrepetitive short-range-order (noncrystalline) to paracrystalline to well crystalline (Follet et al., 1965). There are difficulties in the adequate assessment of the portion that is extracted by a particular reagent, e.g., ammonium oxalate.

Ammonium oxalate extractions, significance: In general, ammonium oxalate allowed to react in darkness has been considered to be a selective dissolution for noncrystalline materials (McKeague and Day, 1966; Higashi and Ikeda, 1974; Fey and LeRoux, 1977; Schwertmann and Taylor, 1989; Hodges and Zelazny, 1980).

The ammonium oxalate procedure removes most noncrystalline and paracrystalline materials (allophane and imogolite) from soils (Higashi and Ikeda, 1974; Hodges and Zelazny, 1980) as well as short-range-ordered oxides and hydroxides of Al, Fe, and Mn (Schwertmann, 1959, 1964; McKeague and Day, 1966; McKeague et al., 1971; Fey and LeRoux, 1977). In addition, this method is assumed to extract Al + Fe humus. Opaline Si is not dissolved by this method (Wada, 1977). This procedure has been reported to dissolve very little hematite and goethite and small amounts of magnetite (Baril and Bitton, 1969; McKeague et al., 1971; Walker, 1983). There have been conflicting data on the effect of this procedure on clay minerals, but in general, the ammonium oxalate treatment is considered to have very little effect on phyllosilicates (kaolinite, montmorillonite, illite) or gibbsite. The ammonium oxalate extraction is assumed to dissolve selectively "active" Al and Fe components that are present in noncrystalline materials as well as associated or independent poorly crystalline silica. The method also extracts allophane, imogolite, Al + Fe humus complexes, and amorphous or poorly crystallized oxides and hydroxides.

The intent of the ammonium oxalate procedure is to measure the quantities of poorly crystalline materials in the soil. At the present time, the ammonium oxalate extraction is considered the most precise chemical method for measuring these soil components. However, in principle it cannot be expected that chemical methods are able to perfectly distinguish degrees of crystallinity, and some caution is to be exercised in the interpretation of the analytical data (van Wambeke, 1992). A more reliable and accurate estimation of soil properties and a better understanding of noncrystallinity is provided when ammonium oxalate extraction is used in conjunction with other selective dissolution procedures, thermal techniques, and chemical tests. Refer to Table 3 for the dissolution of Al, Fe, and Si in various clay constituents and organic complexes by treatment with different reagents. Refer to the discussion on dithionite-citrate extractions on the PSDA Sheet, Tier 2, Columns 5 - 7. Also refer to the discussion on sodium pryophosphate extractions on the Acid Sheet, Tier 2, Columns 1 - 7.

Ammonium oxalate extractions, laboratory measurement: A soil sample is extracted in darkness with a mechanical vacuum extractor (Holmgren et al., 1977) in a 0.2 *M* ammonium oxalate solution buffered at pH 3.0. The ammonium oxalate extract is weighed and diluted. The ammonium oxalate extractable Fe, Si, and Al are then measured using inductively coupled plasma spectrometry (ICP). The ODOE is determined using a UV-visible spectrophotometer. The optical density of ammonium oxalate extract (ODOE) and the ammonium oxalate extractable Fe, Si, and Al are reported on this data tier in Columns 1 - 4, respectively.

Column 1: Optical Density, Ammonium oxalate Extract.

Optical density: There is a similarity between optical density and absorbance. In early spectrophotometry, what is now called absorbance was often termed optical density (Skoog, 1985). Optical density or absorbance of a solution or solid is defined as follows:

Equation 76:

$$D = \log_{10} I_o/I = \log_{10} 1/T = -\log_{10} T$$

where:

D = Optical density
I_o = Intensity of incident light
I = Light intensity after passage through solution
T = Transmission

Transmittance of a solution is the fraction of incident radiation transmitted by the solution, i.e., = I/I_o and is often expressed as a percentage, i.e., $\%T = I/I_o \times 100$. These relationships are derived from Beer's Law.

Optical density, Ammonium oxalate extract, significance: The optical density of ammonium oxalate extract (ODOE) of ≥ 0.25 is used as a chemical criterion for spodic materials (Soil Survey Staff, 1994). An increase in ODOE is used as an indicator of the accumulation of translocated organic materials in an illuvial horizon (Soil Survey Staff, 1994). Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for additional discussion of this criterion. The SSL determines the ODOE by procedure 8J.

Column 2: Iron (Fe), Ammonium oxalate Extractable.

Ammonium oxalate extractable Fe, significance: The ammonium oxalate and dithionite-citrate extracts for Fe are pedogenically significant. In a general way, the dithionite-citrate extractable Fe (Fe_d) is considered to be a measure of the total pedogenic Fe and the ammonium oxalate extractable Fe (Fe_o) (probably ferrihydrite) is a measure of the para and noncrystalline Fe (Schwertmann, 1973; Birkeland et al., 1989), but the sodium pyrophosphate extractable Fe (Fe_p) does not necessarily correlate with organic-bound Fe (Birkeland et al., 1989) as commonly thought (Schwertmann and Taylor, 1977; Parfitt and Childs, 1988). Ammonium oxalate analysis appears to release some Fe from magnetite grains (Walker, 1983). The Fe_o/Fe_d ratio is often calculated because it is considered an approximation of the relative proportion of ferrihydrite in soils (Schwertmann, 1985).

Ammonium oxalate extractable Al_o plus 0.5 Fe_o is also used as a taxonomic criterion for andic soil properties (Soil Survey Staff, 1994). The weight of Fe atoms are approximately twice that of Al atoms. In evaluating the relative proportion of Fe and Al atoms solubilized by ammonium oxalate, the weight percent of Fe must be divided by two, i.e., $Al_o + 0.5\ Fe_o$. Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for additional discussion of this criterion. The SSL determines the Fe_o by procedure 6C9a. The Fe_o is reported as a percent on a <2-mm base in this data column.

Column 3: Silica (Si), Ammonium oxalate Extractable.

Ammonium oxalate extractable Si, significance: Ammonium oxalate extractable Si (Si_o) is related to the amount of allophane and imogolite in andic soils (Soil Survey Staff, 1994). Refer to ammonium oxalate extractable Al (Al_o) on this data tier (Table 4) for the use of Si_o in the calculation of allophane and imogolite in andic soils. The SSL determines Si_o by procedure 6V2a. The Si_o is reported as a percent on a <2-mm base.

Column 4: Aluminum (Al), Ammonium oxalate Extractable.

Ammonium oxalate extractable Al, significance: The ammonium oxalate and dithionite-citrate extracts for Al (Al_o, Al_d) are pedogenically significant. The Al_o is generally an estimate of the total pedogenic Al and much of it may be in allophane, imogolite, and complexed with organic matter (Wada, 1977; Childs et al., 1983). Unlike Fe_d, the dithionite-citrate extractable Al (Al_d) is not always greater than that for ammonium oxalate (Childs et al., 1983; Birkeland et al., 1989) and so does not necessarily represent total pedogenic Al (Wada, 1977).

Ammonium oxalate extractable Al, allophane and imogolite, calculation: Allophane is a mineral series that has an Al/Si molar ratio which ranges from 1.0 to 3.0 (Parfitt and Kimble, 1989), but allophanes with Al/Si molar ratio >2.0 have not been isolated (Dahlgren et al., 1993). Allophanes with Al/Si = 2.0 are thought to be the most readily formed and stable in soils (Parfitt and Kimble, 1989).

Allophane in soils can be estimated from the Al_o and Si_o and the pyrophosphate extractable Al (Al_p) (Parfitt and Henmi, 1982; Parfitt and Wilson, 1985). The Al_o represents the Al dissolved from allophane, imogolite, and Al-humus complexes, and the Al_p is the Al from the Al-humus complexes alone (Parfitt and Kimble, 1989). The Al_o minus the Al_p gives an estimate of the Al in allophane and imogolite, whereas the Si_o gives an estimate of the Si in allophane and imogolite. The $(Al_o - Al_p)/Si_o$ times the molar ratio (28/27) is an estimate of the Al/Si ratio of allophane and imogolite in the soil. The values of 28 and 27 represent the atomic weights of Si and Al, respectively.

Parfitt and Henmi (1982) characterized an allophane that had a disordered imogolite structure, an Al/Si ratio of 2.0, and Si_o content of 14.1 percent. Using this allophane and additional samples as references, Parfitt and Henmi (1982) and Parfitt and Wilson (1985) developed an algorithm to estimate the percent allophane in a sample using the calculated Al/Si molar ratio and Si_o content. The amount of allophane is estimated by multiplying the Si_o by the appropriate factor provided in Table 4 (Parfitt, 1990). The Al_p is reported on the Acid Sheet, Tier 2, Column 3. The Si_o is reported on this data tier in Column 3. The SSL determines Al_o by procedure 6G12a. The Al_o is reported as a percent on a <2-mm base in this data column.

Table 4. Al:Si atomic ratios of allophane and factor used to estimate allophane.[1]

Al:Si	Factor[2]	Al:Si	Factor[2]
1.0	5	2.5	10
1.5	6	3.0	12
2.0	7	3.5	16

[1] Parfitt, 1990
[2] Factor to use with Si_o

Column 5: *Phosphorus (P), New Zealand P Retention.*

Phosphorus retention, definition: Sorption is the removal of P from solution and its retention at soil surfaces. When P is held at the surface of a solid, the P is considered adsorbed, but if the retained P penetrates more or less uniformly into solid phase, it is considered to be absorbed or chemisorbed (Tisdale et al., 1985). The less specific term *sorption* is often preferred because of the difficulty in distinguishing between these two reactions (Tisdale et al., 1985). The reverse reaction, desorption, relates to the release of sorbed P into solution. *Fixation* is a term frequently used to collectively describe both sorption and precipitation reactions of P. There is considerable evidence that supports a wide range of sorption and precipitation mechanisms as causes of P retention, with no explicit consensus as to the relative magnitudes of their contributions (Tisdale et al., 1985). Phosphorus retention is viewed by many researchers as a continuous sequence of precipitation, chemisorption, and adsorption. At low P solution concentrations, adsorption may be the dominant mechanism. Refer to additional discussion on the various fractions of soil P on the PSDA Sheet, Tier 2, Column 3.

Phosphorus retention, soil-related factors: Several of the factors that influence soil P-retention are the nature and amount of soil components; pH; cation and anion effects; saturation of sorption complex; organic matter; temperature; and time of reaction. Some of the major soil components that affect P sorption (retention) are hydrous oxides of Fe and Al; type and amount of clay; calcium carbonate; and amorphous colloids. Usually those soils with significant amounts of Fe and Al oxides have greater P-retention capacity than those soils with more crystalline oxides because of the greater relative surface area and sites of adsorption. Phosphorus is usually retained to a greater extent by 1:1 clays, e.g. kaolinite (low SiO_2/R_2O_3 ratio), than by 2:1 clays. Soils with large clay amounts usually retain more P than those with small clay amounts because of greater surface area. In calcareous soils, calcium carbonate and associated hydrous ferric oxide impurities can function as principal P adsorption sites (Hamad et al., 1992). The active Al in noncrystalline colloids, e.g., allophane, imogolite, and Al humus complexes, is highly reactive with anions, e.g., phosphates, sulfates, and silicates (van Wambeke, 1992). The affinity of the noncrystalline minerals for P is the result of very high specific surface of these minerals and the density of active Al on colloidal fractions. In addition, fully hydrated gels can deform, partially liquefy, and trap or encapsulate P (occluded P) in voids that are not connected with the soil solution (Uehara and Gillman, 1981).

Phosphorus retention, selected soils: Andisols and other soils that contain large amounts of allophane and other poorly crystalline minerals have capacities for binding P (Gebhardt and Coleman, 1984). The factors that affect soil P retention in these soils are not well understood. However, allophane and imogolite have been considered as major materials that contribute to P retention in Andisols (Wada, 1985). Phosphate sorption in the surface horizons of 228 acid to neutral Western Australian soils was found to be more closely related ($r^2 = 0.76$) to the content of oxalate extractable Al than to any other constituent (Gilkes and Hughes, 1994). A phosphate retention of $\geq$85 percent is a taxonomic criterion for andic soil properties (Soil Survey Staff, 1994). The intent of the criterion is diagnostic for the dominance of active Al in amorphous clay minerals that generally synthesize in rapidly weathering volcanic glass (van Wambeke, 1992). Refer to the *Keys for Soil Taxonomy* (1994) for a more detailed discussion of this criterion. The P retention test may not necessarily coincide with soil fertility criteria as the concentration of the P solution in this procedure is higher than current P contents in most soil solutions, and in some cases, the method probably overestimates the positive charges on the soil colloids under field conditions (van Wambeke, 1992).

P-retention and NaF pH tests: The P-retention test is based on a ligand exchange between HPO_4^{2-} or $H_2PO_4^-$ and OH^-. The NaF pH test is based on a similar ligand exchange, i.e., the exchange between F^- and OH^-. In many ways, the P-retention test is a duplication of the information provided by the NaF pH test (Uehara and Ikawa, 1985). Soil pH in NaF was found to be related to P-sorbed ($r^2 = 0.48$), particularly when log(P-sorbed) and log(P-sorbed + 10) were related to pH_{NaF} ($r^2 = 0.66$ and 0.74, respectively) (Gilkes and Hughes, 1994). The NaF pH is reported on the Acid Sheet, Tier 1, Column 18.

P-retention, laboratory measurement: A soil sample is shaken in a 1000-ppm P solution for 24-h. The mixture is then centrifuged, an aliquot of supernatant measured colorimetrically, and the percent transmittance read. Refer to procedure 6S4 for additional discussion of the SSL operational definition of P-retention (New Zealand P). Phosphorus retention is reported as percent on a <2-mm base.

Column 6: Phosphorus (P) Citrate Acid Extractable.

Citrate acid extractable P, significance: In fertilizer terminology, the citrate-soluble P fraction is used as a criterion to help define the *available P* in soils. The water solubility of fertilizer P is not always the best criterion for plant available P. Perhaps the most accurate measure of plant availability of any nutrient element is the extent to which it is absorbed by plants under conditions favorable to growth; however, such determinations are not easily made when the availability of fertilizer elements have to be determined quickly on large numbers of samples, as in fertilizer work (Tisdale et al., 1985).

Citric acid soluble P_2O_5 is a diagnostic criterion for distinguishing between mollic (<250 ppm P_2O_5) and anthropic epipedons (>250 ppm P_2O_5) (Soil Survey Staff, 1975, 1994). Additional data on anthropic epipedons from several parts of the world may permit improvements in this definition (Soil Survey Staff, 1975, 1994).

Citrate acid extractable P, laboratory measurement: Chemical methods have been developed which permit a fairly rapid estimate of the water-soluble, available, and total P. In general, available P, is the estimate of the plant available fraction and is the sum of water-soluble and citrate-soluble P in a sequential extraction. Total is the sum of available and citrate-insoluble P. Refer to additional discussion on the various fractions of soil P (PSDA Sheet, Tier 1, Column 3). The SSL determines citrate-acid extractable P by procedure 6S5. Citrate-acid extractable P is reported as mg kg^{-1} (formerly ppm) in the soil on a <2-mm base.

Column 7: KCl Extractable Manganese (Mn).

Manganese, soil-related factors: The KCl extractable Mn is related to exchangeable Mn and is absorbed by the plant as the ion Mn^{2+}. The availability of Mn in the field has been difficult to predict. Since Mn mobility is related to oxidation-reduction reactions in the soil, the availability of Mn is closely related to soil moisture and temperature. Cool temperatures may retard organic Mn mineralization. On the other hand, cool temperatures associated with high rainfall levels in early spring may maintain more available Mn through reduction of Mn oxides (Allen and Hajek, 1989; McKenzie, 1989). In general, the soil chemistries of Fe and Mn are similar, i.e., both can exist in more than one oxidation state; both are affected by drainage conditions; both are precipitated as oxides and hydroxides; both can be complexed with organic matter; but under poorly-drained conditions, the Mn is more easily reduced and mobilized than Fe (Allen and Hajek, 1989; McKenzie, 1989).

Manganese toxicity: Manganese toxicity is probably the second most important growth-limiting factor (after Al toxicity) in acid soils (Foy, 1984). The solubility and, hence, the potential toxicity of Mn to a given crop, depends on many soil properties, including total Mn content, pH, organic matter level, aeration, and microbial activity (Foy, 1973; Stahlberg et al., 1976). Manganese toxicity generally occurs in soils with pH values of $\leq$5.5, if the soil contains sufficient total Mn (Foth and Ellis, 1988), but may also occur at higher soil pH values in poorly drained or compacted soils where reducing conditions favor the production of divalent Mn that plants absorb. Some soils do not contain sufficient Mn to produce toxicity, even at pH 5 or below. Manganese has been reported to interact with Fe, Mo, P, Ca, and Si in affecting toxicity symptoms and growth.

Manganese, essential plant element: Manganese is an essential plant nutrient. Manganese is usually involved in the oxidation-reduction processes, decarboxylation, and hydrolysis reactions in photosynthesis as well as in the evolution of oxygen (Tisdale et al., 1985). Manganese has also been associated with maximal activity of many enzyme reactions in the citric acid cycle and can substitute for Mg in many of the phosphorylating and group-transfer reactions. Manganese influences auxin levels in plants. High concentrations of this element favor the breakdown of indoleacetic acid. The SSL determines the 1 *N* KCl extractable Mn by procedure 6D3. The extractable Mn is reported as mg kg^{-1} (formerly ppm) in the soil on a <2-mm base.

Column 8: Total Carbon (C).

Total C, inorganic and organic: Total C includes both inorganic and organic C. Inorganic C is principally found in carbonate minerals, whereas most organic C is present in the soil organic matter fraction. In humid regions in which there has been extensive leaching of the soil profiles, the organic C is usually the dominant form present. However, in arid and semiarid regions, carbonate minerals, e.g., calcite and dolomite, along with soluble carbonate and bicarbonate salts, usually constitute a significant portion of the total C (Nelson and Sommers, 1982).

Total C, laboratory measurement: There are two basic approaches to quantify total C in soil, i.e., wet and dry combustion. Early carbon analyzers that were used for dry combustion were not very precise, but advances in technology have made these analyzers more reliable in the measurement of total C. The SSL uses a dry combustion technique (LECO carbon analyzer) for the measurement of total C (procedure 6A2d). A soil sample is oxidized at high temperatures; the released gases are scrubbed; and the CO_2 in the combustion gases is measured using an infrared detector.

Total C and Walkley-Black methods: The SSL method for total C measures all C in soil organic matter, roots, charcoal, carbonaceous shales, coal, wood, plant residues, and carbonates. The Walkley-Black method (procedure 6A2c) is a wet combustion technique to estimate the organic C of decomposed soil organic matter and normally excludes relatively fresh plant residues, roots, charcoal, and C of carbonates. As the Walkley-Black method does not measure these other C fractions, the measurements by Walkley-Black and total C by dry combustion may not necessarily approximate each other. Organic C by the Walkley-Black method is reported on the PSDA Sheet, Tier 2, Column 1. Total C is reported as percent on a <2-mm base in this data column.

Columns 9 - 12: WATER CONTENT.

Water content, laboratory measurements: Refer to the general discussions on soil water content and available water capacity on the available water capacity on the PSDA Sheet, Tier 2, Columns 17 - 19. Water-retention data at 0.06, 1, 2, and 15 bars (6, 100, 200, and 1500 kPa, respectively) are reported as percent gravimetric water content on a <2-mm base in Columns 9 - 12, respectively. Refer to Appendix XII for data unit conversions, e.g., bar or kPa to lb in^{-2}.

Column 9: Water Retention, 0.06 Bar, Air-Dry Samples.

Water retention at lower suctions: The upper limit or lower suctions are selected so that the volume of water retained approximates the volume of water held at field capacity. Usually this limit is 0.33 bar but 0.1 or 0.05 may be used for coarse materials. Refer to the discussion on 1/10-bar water retention on the PSDA Sheet, Tier 2, Column 17 for the definition of coarse materials as defined in the Soil Survey Manual (Soil Survey Division Staff, 1993). Refer to Soil Survey Division Staff (1993) and Grossman et al. (1994) for additional discussion on coarse materials and the significance of soil water content at lower suctions, e.g., 0.05 and 0.1 bar, as well as suggestions for the selection of these lower suctions for the determination of water retention difference (WRD). Also refer to the discussion on available water capacity and the upper and lower limits of plant available water on PSDA Sheet, Columns 17 - 20.

Water retention at 0.05 bar, significance: Some investigators (Hall et al., 1977) have defined the upper limit of plant available water as the percentage of water retained in a core sample when equilibrated at 0.05 bar suction (retained water capacity). This application of 0.05 bar water is supported by some investigations of field moisture regimes under British conditions (Thomasson, 1967; Webster and Beckett, 1972). Even in very permeable, well-drained soils, the suction in surface horizons commonly is in the range of 0.03 to 0.07 bar during winter and spring when the soil moisture deficit is effectively zero (Webster and Beckett, 1972). The air-filled porosity at 0.05 bar has been used as a measure of tilth (McKeague et al., 1982).

Air-filled porosity, calculation: The air-filled porosity at 0.05 bar (Grossman et al., 1994) may be calculated as follows:

Equation 77:

$$AFP = \left[\left(100 - \frac{(100 \times Db_{1/3})}{Dp}\right) - (W_{0.05} \times Db_{1/3})\right] \times \frac{(1 - V_{>2mm})}{100}$$

where:

AFP = Air-filled porosity at 0.05 bar water content. Total porosity minus volume fraction of water at 0.05 bar.

$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2-mm base ($g\ cc^{-1}$). Data are reported on the PSDA Sheet, Tier 2, Column 13.

$W_{0.05}$ = Weight percentage of water at 0.05 bar. Data obtained from soil water retention curve.

$V_{>2mm}$ = Volume percentage of >2-mm fraction. Data are reported on the Supplementary Data Sheet, Column 51.

Dp = Particle density ($g\ cc^{-1}$). Calculate Dp (Soil Survey Division Staff, 1993) as follows:

Equation 78:

$$Dp = \frac{100}{\frac{OC \times 1.7}{Dp1} + \frac{Fe \times 1.6}{Dp2} + \frac{100 - ((Fe \times 1.6) + (OC \times 1.7))}{Dp3}}$$

where:

Dp = Particle density ($g\ cc^{-1}$).

OC = Weight percentage of organic C on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 1.

Fe = Weight percentage of dithionite-citrate extractable Fe on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 5.

$Dp1$ = 1.4 $g\ cc^{-1}$, assumed particle density of organic matter.

$Dp2$ = 4.2 $g\ cc^{-1}$, assumed particle density of the minerals from which dithionite-citrate extractable Fe originates.

$Dp3$ = 2.65 $g\ cc^{-1}$, assumed particle density of material exclusive of organic matter and minerals contributing to the dithionite-citrate extractable Fe.

Equation 78 may be used to calculate air-filled porosity at any suction by substitution of the weight percentage of water at the specified suction for $W_{0.05}$. The water content for any suction can be computed from the calculated soil water characteristic. Refer to Appendix VI for example soil water retention curves. Refer to additional discussion on water content and porosity on the Primary Data Sheet (PSDA Sheet, Tier 2, Columns 16 - 19). Also refer to additional discussion on pore volume (drained + filled pores) at 1/3-bar water content on the Supplementary Data Sheet, Columns 62 - 63.

Water retention at 0.06 bar, laboratory determinations: The SSL determines water retention at 0.06 ($W_{0.06}$) for natural clods (procedure 4B1c); for <2-mm air-dry samples (procedure 4B1a); and for soil cores (procedure 4B1d). The $W_{0.06}$ for <2-mm samples may be used for coarse soil materials. The $W_{0.06}$ by procedure 4B1c for natural clods is reported as percent gravimetric water content on a <2-mm base in this data column.

Column 10: Water Retention, 1 Bar, Air-Dry Samples.

Optimum soil water has been defined as the fraction of available water that is retained between 10- and 1-bar tensions (Cook and Ellis, 1987). Soils with greater amounts of water (<1 bar) may be satisfactory for plant growth but are too moist for tillage (Cook and Ellis, 1987). The SSL determines water retention at 1 bar (W_1) for <2-mm air-dry samples (procedure 4B1a); for natural clods (procedure 4B1c); and for soil cores (procedure 4B1d). The W_1 by procedure 4B1a for <2-mm air-dry samples is reported as percent gravimetric water content in this data column.

Column 11: Water Retention, 2 Bar, Air-Dry Samples.

In practice, the proportion of *easily available water* (<2 bar) in a soil has been considered agronomically significant as total available water in assessing droughtiness (Hall et al., 1977). As a rule of thumb for some soils, the 2-bar water content of a soil has been used as an irrigation index (when water is applied) for some soils. The SSL determines water retention at 2 bar (W_2) for <2-mm air-dry samples by procedure 4B1a. The W_2 for <2-mm air-dry samples is reported as percent gravimetric water content.

Column 12: Water Retention, 15 Bar, Moist Samples.

Water retention at 15-bar, data assessment: Refer to the general discussion on the lower limit of plant available water on the PSDA Sheet, Tier 2, Column 19. As water retention at 15 bar has been equated with a 0.2-µm pore diameter, a high correlation usually exists between this water content and clay percentage (NSSL Staff, 1983). In the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994), clay percentages may be estimated by subtracting the percent organic C from the 15-bar water content and then multiplying by 2.5 or 3. Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for the appropriate use of these estimates, e.g., criteria for oxic and kandic horizons and oxidic mineralogy class. The percent water retained at 15-bar suction (dried and undried samples) is also used as a criterion for modifiers that replace particle-size classes, e.g., ashy and medial classes, and for strongly contrasting particle-size classes, e.g., ashy over medial-skeletal (Soil Survey Staff, 1994). Refer to the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) for a more detailed discussion of these criteria.

Water retention at 15-bar, moist, significance: The phenomenon of aggregation through oven or air drying is an important example of irreversibility of colloidal behavior in the soil-water system (Kubota, 1972; Espinoza et al., 1975). The magnitude of the effect varies with the particular soil (Maeda et al., 1977). In Andisols, water is usually not held on clay surfaces but rather in small voids, the volume of which is a direct function of the allophane content (Warkentin and Maeda, 1980). The drying of allophanic soils drastically changes their water retention at 15-bar, changes which are irreversible and are attributed by some investigators to the shrinking of the specific surface. Upon drying, the field capacity may decrease more than the wilting percentage (Warkentin and Maeda, 1980).

Water retention at 15-bar, laboratory measurements: The SSL determines water retention at 15 bar (W_{15}) for <2-mm field-moist samples (procedure 4B2b) and air-dry samples (procedure 4B2a). The W_{15} on <2-mm air-dry samples is not reported on this data tier but is reported on the PSDA Sheet, Tier 2, Column 19. The W_{15} for <2-mm field-moist samples is reported as percent gravimetric water in this data column.

Columns 13 - 18: PARTICLE-SIZE DISTRIBUTION ANALYSIS, PARTICLES <2 mm, WATER DISPERSIBLE, PIPET AND HYDROMETER, AIR-DRY SAMPLES.

Water dispersible PSDA: The phenomena of flocculation and dispersion (deflocculation) are very important in determining the physical behavior of the colloidal fraction of soils and thus indirectly, have a major bearing on the physical properties which soils exhibit (Sumner, 1992). Particle-size distribution analysis by mechanical means in distilled water without the removal of organic matter, soluble salts, and use of a chemical dispersant is referred to as water dispersible PSDA. The SSL reports water dispersible particle-size analysis by the pipet and hydrometer methods.

Water dispersible PSDA, pipet method: Refer to the discussion of PSDA by the pipet method on the PSDA Sheet, Tier 1, Columns 4 - 15. The standard SSL water-dispersible PSDA for particles with <2-mm diameter is the air-dry method (procedure 3A1c). For soils that irreversibly harden when dried, moist water-dispersible PSDA (procedure 3A2c) is determined. Moist water-dispersible PSDA data are not reported on the SSL Primary Characterization Data Sheets but, if determined, are reported on additional SSL data sheets. Both the air-dry and moist water-dispersible PSDA data are reported as percent on oven-dry base. All sand and silt fractions by procedure 3A1c are stored in the database, but only the total sand, silt, and clay are reported on this data tier (Columns 13 - 15, respectively) as percent on a <2-mm base.

Particle-size analysis, hydrometer method, Bouyoucos: The hydrometer method, like the pipet method, depends fundamentally on Stokes' Law (Gee and Bauder, 1986). The hydrometer method is based on the decrease in density that occurs at a given depth as a dispersed suspension settles. The rate of decrease in density at any given depth is related to the settling velocities of the particles, which in turn are related to their sizes (Kilmer and Alexander, 1949). Since the introduction of the hydrometer by Bouyoucos (1927), this method has been widely adopted for particle-size analysis of soils and other materials (Kilmer and

Alexander, 1949). The primary reasons for the popularity of this method have been the rapidity with which a mechanical analysis can be made and the simplicity of the equipment required (Kilmer and Alexander, 1949). Hydrometer readings at 40 s and 2 h have been used to estimate sand and clay percentages, respectively.

The correlations between sand and clay and the 40-s and 2-h readings are empirical (Gee and Bauder, 1986). Basic sedimentation theory indicates that the 2-h reading is a better estimate of the 5-µm limit than it is of the 2-µm limit (Gee and Bauder, 1986). Errors in clay content using the 2-h reading often exceed 10 percent by weight for clay soils, and differences between sieve and the 40-s hydrometer measurement often exceed 5 percent by weight (Gee and Bauder, 1979; Gee and Bauder, 1986). These errors are primarily attributable to the fact that in 1937 the Bureau of Chemistry and Soils changed the size limits for silt and clay. With the change to 2 µm as the upper limit for clay and the lower limit for silt, a better correlation was determined between field textural classification and laboratory classification by mechanical analysis (Soil Science Society of America, 1937). The reduction in size limits to <2 µm tended to decrease the clay percentage, thus offsetting in part the higher percentage obtained by modern dispersion methods (Soil Science Society of America, 1937).

Particle-size analysis, hydrometer, ASTM method: Over time, modifications to the Bouyoucos hydrometer specifications and procedure have been suggested and adopted (Casagrande, 1934; Bouyoucos, 1951, 1962; American Society for Testing and Materials, 1958, 1963; Day, 1956, 1965; Gee and Bauder, 1986). The NRCS Soil Mechanics Laboratories (SML) in Lincoln, Nebraska and Forth, Texas use ASTM-designated methods for particle-size analysis by hydrometer. Refer to ASTM D 422-63 for the standard test method for particle-size analysis of soils (American Society for Testing and Materials, 1993). This test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes >0.075 mm (retained on No. 200 sieve) is determined by sieving. The distribution of particle sizes <0.075 mm is determined with a hydrometer by a sedimentation process (American Society for Testing and Materials, 1993). Separation may be made on the No. 4 (4.75 mm), No. 40 (0.425 mm), or No. 200 (0.075 mm) sieve instead of the No. 10 (2 mm). The procedure specifies an ASTM hydrometer, graduated to read in specific gravity of the suspension or g L^{-1} suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference (American Society for Testing and Materials, 1993). Refer to the Supplementary Data Sheet, Columns 1 - 10, for complete list of standard sieve dimensions.

Water dispersible PSDA, hydrometer, ASTM method: On the SSL data sheet, water dispersible PSDA by hydrometer is not designated by a specific SSL method but rather by "SML". There is no method documented in the SSIR No. 42 for water dispersible PSDA by hydrometer as PSDA is determined by the pipet method at the SSL. Refer to ASTM D 422-90 for the standard test method for dispersive characteristics of clay soil by double hydrometer (American Society for Testing and Materials, 1993). This test method, when used in conjunction with a test performed by D 422 on a duplicate soil sample, provides an indication of the natural dispersive characteristics of clay soils (American Society for Testing and Materials, 1993). This test method is applicable only to soils with a plasticity index (PI) >4, as determined in accordance with ASTM D 4318, and to soils with >12 percent of soil fraction finer than 0.005 mm, as determined in accordance with Method 422. This test method is similar to Method D 422 except that this method determines the percent soil particles <0.005-mm diameter in a soil-water suspension without mechanical agitation and to which no dispersing agent has been added. The amount of <0.005-mm particles by this method compared with the total amount of <0.005 mm particles as determined by Method D 422 is a measure of the dispersive characteristics of the soil. This method does not identify all dispersive clay soils. Water dispersible PSDA (air-dry) by hydrometer is reported as percent on a <2-mm base in Columns 16 - 18.

Column 13: Total Clay (<0.002 mm), Water Dispersible, Pipet.

Water dispersible clay, definition: Water dispersible clay is a soil separate with <0.002-mm particle diameter. The clay percentage determined by mechanical means without the removal of organic matter and soluble salts and use of a chemical dispersant is referred to as water dispersible clay (WDC). The SSL determines WDC (air-dry) by the pipet method (procedure 3A1c). Water dispersible clay is reported as percent on a <2-mm base.

Water dispersible clay, significance: Middleton (1930) suggested a relationship between the easily dispersed silt and clay (dispersion ratio) and soil erodibility. The WDC measurement was evaluated as a predictor in the USDA-NRCS Water Erosion Prediction Program (WEEP). This measurement has also been suggested as a parameter for evaluating positive charge in tropical soils (Gillman, 1973). Water dispersible clay is a significant factor in the physical condition of a soil in that many of the soil properties that affect soil erodibility, aggregate stability, and crust formation are those properties that affect the propensity of the clay fraction to disperse in water (Brubaker et al., 1992). Some of these properties include organic matter content; relative amounts of various cations on exchange sites; presence of soluble salts such as gypsum; clay mineralogy; nature of charge on colloids; and antecedent soil moisture content (Brubaker et al., 1992). Water dispersible clay values can be useful when relationships can be developed between these data and total clay amounts, as determined by standard PSDA.

Column 14: Total Silt (0.002 to 0.05 mm), Water Dispersible, Pipet.

Water dispersible silt, definition: Water dispersible silt is a soil separate with 0.002- to 0.05-mm particle diameter. The silt percentage determined by mechanical means without the removal of organic matter and soluble salts and use of a chemical dispersant is referred to as water dispersible silt. The SSL determines water dispersible silt (air-dry) by the pipet method (procedure 3A1c). Water dispersible silt is reported as percent on a <2-mm base.

Water dispersible silt, significance: Middleton (1930) cited the ratio of water-dispersible silt plus clay to total silt plus clay (dispersion ratio) as "probably the most valuable single criterion in distinguishing between erosive and non-erosive soils".

Column 15: Total Sand (0.05 to 2.0 mm), Water Dispersible, Pipet.

Water dispersible sand, definition: Water dispersible sand is a soil separate with 0.05- to 2.0-mm particle diameter. The sand percentage determined by mechanical means without the removal of organic matter and soluble salts and use of a chemical dispersant is referred to as water dispersible sand. The SSL determines water dispersible sand (air-dry) by the pipet method (procedure 3A1c). Water dispersible sand is reported as percent on a <2-mm base.

Column 16: Total Clay (<0.002 mm), Water Dispersible, Hydrometer.

Water dispersible clay is reported as percent on a <2-mm base.

Column 17: Total Silt (0.002 to 0.05 mm), Water Dispersible, Hydrometer.

Water dispersible silt is reported as percent on a <2-mm base.

Column 18: Total Sand (0.05 to 2.0 mm), Water Dispersible, Hydrometer.

Water dispersible sand is reported as percent on a <2-mm base.

Column 19: Mineral Soil Content.

Mineral content, laboratory measurement: The mineral content is the plant ash and soil particles that remain after organic matter is lost on ignition. This determination of organic matter is a taxonomic criterion for organic soil materials (Soil Survey Staff, 1994). Organic C data by Walkley-Black are generally considered invalid if organic C is >8 percent. Refer to the discussion on organic C by the Walkley-Black method on the PSDA Sheet, Tier 2, Column 1. Refer to Lucas (1982) for additional discussion of organic soils (Histosols), i.e., their formation, distribution, physical and chemical properties, and management for crop production. The SSL determines mineral soil content by procedure 8F1. Mineral content is reported as percent on a <2-mm base in this data column.

Soil organic materials, other laboratory measurements: The determination of mineral soil content and, by difference, the organic matter content are usually performed in conjunction with other soil organic material tests (1) 0.01 M $CaCl_2$ pH; (2) fiber volume; and (3) sodium pyrophosphate extract color. These tests are used as taxonomic criteria (Soil Survey Staff, 1975, 1994) to help define soil organic materials. Refer to the Soil Survey Staff (1975, 1994) for additional discussion of these criteria. The 0.01 *M* $CaCl_2$ pH, fiber volume, and sodium pyrophosphate extract color data are not reported on the Primary Characterization Data Sheets but, if determined, are reported on additional SSL Data sheets.

These soil organic material tests can be used in the field offices. Since it is not practical in the field to base a determination on a dry sample weight, the moist soil volume is used. The specific volume of moist material depends on how it is packed. Therefore, packing of material must be standardized in order to obtain comparable results by different soil scientists (Soil Survey Staff, 1975). General applications of these additional organic material tests are described as follows:

0.01 *M* $CaCl_2$ pH: The 0.01 *M* $CaCl_2$ pH is used as a taxonomic criterion to distinguish the two reaction classes (Euic and Dysic) of all subgroups of Histosols (Soil Survey Staff, 1975, 1994). Refer to the Soil Survey Staff (1975, 1994) for additional discussion of the taxonomic criteria for these reaction classes. Refer to the general discussion on soil pH on the Acid or Salt Sheet, Tier 1, Columns 18 - 20. The SSL determines 0.01 *M* $CaCl_2$ pH by procedure 8C2a.

Water-dispersed fiber volume, laboratory measurement: The water-dispersed fiber volume is a method to characterize the physical decomposition state of organic materials. The decomposition state of organic matter is used to define sapric, hemic, and fibric organic materials (Soil Survey Staff, 1975, 1994). In general, fibric is the least decomposed; hemic is intermediate; and sapric is the most highly decomposed. Highly decomposed organic matter passes through a 100-mesh sieve (0.15-mm openings). Relatively undecomposed fibers are retained on the sieve. Organic particles that are >2 cm in cross-section and are too firm to be readily crushed between thumb and fingers are excluded from fiber (Soil Survey Staff, 1975, 1994). The SSL determines fiber volume by procedure 8G1. Refer to Soil Survey Staff (1975, 1994) for a more detailed discussion of these three kinds of organic soil materials.

Sodium pyrophosphate extract color, laboratory measurement: Sodium pyrophosphate combined with organic matter forms an extract color which correlates with the physical decomposition state of the organic materials. Light colors are associated with fibric materials and dark colors with sapric materials (Soil Survey Staff, 1975, 1994).

Column 20: Aggregate Stability.

Soil structure: Soil structure and erodibility are some of the most difficult physical properties to determine for quantitative evaluation (Lal, 1981). As used in most soil classification systems, soil structure is more of a qualitative evaluation, e.g., description of soil peds, and does not provide a precise means to predict soil behavior in different management systems (Lal, 1981). Structure and its stability govern soil-water relationships, aeration, crusting, infiltration, permeability, runoff, interflow, root penetration, leaching losses of plant nutrients, and therefore, the productive potential of a soil. Whereas soil texture cannot be changed, at least over a short period of time, by any economical means, successful management of some soils, e.g., tropical soils, depends on the management of soil structure (Lal, 1979). For more detailed discussions on structure and other physical characteristics of soils, refer to Soil Survey Division Staff (1993).

Aggregate stability, definition: The measurement of aggregate stability by wet sieving can serve as a predictor of soil erosion potential but not as an indicator of the soil erosion hazard (Lal, 1981). An aggregate is a group of primary particles that cohere to each other more strongly than to other surrounding soil particles (Kemper and Rosenau, 1986). Disintegration of soil mass into aggregates requires the application of a disrupting force. Aggregate stability is a function of whether the cohesive forces between particles can withstand the applied disruptive forces (Kemper and Rosenau, 1986). Erodibility of soils increases as aggregate stability decreases (Kemper and Rosenau, 1986).

Aggregate stability, laboratory determination: Due to the empirical relationship between laboratory-determined aggregate-size distribution and the distribution as it exists in the field, most investigators use the stability of aggregates rather than aggregate-size distribution as an index of soil structure in the field (Kemper and Rosenau, 1986). A simple procedure for stability analysis involves the use of one size-fraction. The SSL uses the 2- to 1-mm fraction with 2- to 0.5-mm aggregates retained, and the sand weight subtracted. Immediately after cultivation, most soils contain an abundance of large pores which favor high infiltration rates, good tilth, and adequate aeration for plant growth. However, the continued existence of these large pores in the soil depends on the stability of the aggregates. The aggregate stability procedure was developed for use by NRCS Soil Survey field offices. The SSL determines aggregate stability by procedure 4G1. Aggregate stability is reported as percent of aggregates (2- to 0.5 mm) retained after wet sieving. Determinations are not reported if the 2- to 0.5-mm fraction is $\geq$50 percent of the 2- to 2-mm sample.

4.8 - 4.10 MINERALOGY SHEET: TIERS 1 - 3:

Soil mineralogy: taxonomic, agronomic, and engineering significance: Refer to Soil Survey Staff (1975, 1994) for discussion of mineralogy class as a taxonomic criterion of soil families in different particle-size classes. Soil mineralogy has important agronomic and engineering implications for many soils and can be related and described in broad concepts (National Soil Survey Laboratory, 1983). The following descriptions include those mineralogies discussed earlier in relation to the CEC-7 to clay ratio (PSDA Sheet, Tier 2, Column 8), and some mineralogies not previously mentioned are also described. The CEC-7 to clay ratio is used as auxiliary data to assess clay mineralogy and are especially useful when mineralogy data are not available.

Carbonatic: In general, crops grown on carbonatic soils may show signs of chlorosis, reflecting nutrient deficiencies. Carbonatic soils have also been associated with P fixation; hindrance to root ramification; high base status (near pH 8); and lower available water, especially in soils with calcic horizons. Abundant Ca in the soil has a flocculating effect on soil colloids, i.e., clays tend to be coarser. Refer to additional discussion on carbonatic soils on the Acid Sheet, Tier 1, Column 14.

Chloritic: Chloritic clays are low activity clays with low nutrient supply. There may be some nutrient imbalances because of the high Fe and Mg. These soils have been associated with slope instability prone to landslide because of their low shear strength along natural cleavage planes.

Ferritic and Oxidic: In general, ferritic and oxidic soils are low in nutrients from mineral components and recycle them from organic components. Ferritic and oxidic soils have also been associated with fixation of plant nutrients such as P and B. Ferritic soils are considered a good source of roadbed material and a possible source of Fe ore. In ferritic soils, the Fe usually adsorbs on clay surfaces and/or concentrates in nodular forms, and, if the Fe cements, these soils may have low available water. In oxidic soils, the clay contents, Atterberg limits, and other engineering tests are often difficult to measure and interpret. Ferritic and oxidic soils are usually considered stable and permeable, from an engineering standpoint, if not disturbed. Dithionite-citrate extractable Fe (Fe_d) is used as a taxonomic criterion in ferritic and oxidic mineralogies. Refer to the PSDA Sheet, Tier 2, Column 5 for additional discussion on this Fe-extraction.

Gibbsitic: In general, gibbsitic soils have low nutrient supplies from mineral components and recycle nutrients from organic matter. Gibbsitic soils have also been associated with fixation of plant nutrients, e.g., P. Atterberg limit tests and other engineering tests are often difficult to read and interpret in these soils. Gibbsitic mineralogy is incorporated into soil taxonomy because gibbsite is reported in the literature as part of the weathering cycle of soil clays in tropical regions.

Glauconitic: Glauconitic soils are usually high in Fe, P, and Mg. These soils have been associated with unusual 15-bar clay ratios because the clay is held in glauconite pellets (greenish color); favorable structural conditions for root growth; apparently do not have much problem with structural stability; and if clay is high in smectite, soils exhibit shrink-swell properties similar to those of montomorillonitic soils.

Gypsiferous: Gypsiferous soils may become impervious to roots and water. Available water content and cation exchange capacity are generally inversely proportional to gypsum content. The saturated Ca soil solution may result in the fixation of the micronutrients, Mn, Zn, and Cu. Soil subsidence through solution and removal of gypsum can crack building foundations, break irrigation canals, and make roads uneven. Failure can be a problem in soils with as little as 1.5 percent gypsum (Nelson, 1982). Corrosion of concrete is also associated with soil gypsum. Gypsum content, soil resistivity, and extractable acidity singly or in combination provide a basis for estimating potential corrosivity of soils (USDA-SCS, 1971). Refer to additional discussion of gypsiferous soils on the Salt Sheet, Tier 1, Columns 16 - 17.

Halloysitic: Halloysitic soils are commonly found in forested sites in a perudic soil moisture regime. Trees obtain nutrients from underlying saprolite. These soils are usually unstable because of moisture and are prone to slump and solifluction.

Illitic: Illitic soils can be acid or alkaline depending on depositional environment of parent sediments. These soils usually have a moderate to high natural fertility and base status. Illitic soils commonly contain intergrade illite-smectite clays. Illitic materials are usually stable for construction or foundation purposes but tend to be less stable as the clay content increases.

Kaolinitic: Kaolinitic clays are low activity clays with low nutrient supply. Kaolinitic soils may have argillic horizons or clayey B horizons that tend to perch water and cause problems with drain fields for septic tanks. These soils can provide stable construction base and construction material. Ponds tend not to seal well if floored or lined with kaolinitic clays. Small quantities of high activity clays have a large impact on soil properties of these soils.

Micaceous: Micaceous soils are high in K and fertilizer K should not have to be applied to agronomic crops. These soils have been associated with stability problems, especially on slopes. Piping and jugging may occur on embankments. Micaceous soils are susceptible to frost action. Generally, engineering problems occur at levels of 20 to 25 percent mica, and there are more problems with silt-size mica than sand-size mica.

Montmorillonitic: Montmorillonitic clays are high activity clays that are associated with high-base status and natural fertility. These soils can be acidic if associated with weathered acidic volcanic materials. Montmorillonitic soils usually have a high shrink-swell and can cause problems when used in foundations and septic drain fields and when used as construction material.

Noncrystallinity: The colloidal fractions of many Andisols are mixtures that contain predominantly noncrystalline minerals with small amounts of layer lattice clays and also include Al and Fe humus complexes. In general, some of the more notable properties of these type soils are high variable charge, high surface area, high reactivity with phosphate and organics (high anion retention), low nutrient retention (e.g., NH_4^+ and K^+), high water retention, and low bulk density (Wada, 1985). Andisols because of their open structure and large rainwater acceptance have a reputation for being more resistant to water erosion than many other soils; however, demographic pressure and steep slopes very often lead to severe losses of soil, and "thixotropic" properties of some Andisols make them very susceptible to landslides (van Wambeke, 1992).

Serpentinitic (Mafitic): Serpentinitic soils have frequently been associated with infertility related to the toxic effects of Ni, Cr, and Co; toxicity of excess Mg; low Ca content; and adverse Ca/Mg ratio in the substrate. Refer to additional discussion on the serpentine factor as related to soil infertility and toxicity on the Acid Sheet, Tier 1, Column 1. The physical nature of these soils is also a factor in the poor vegetative response, particularly as it relates to the droughty nature of some of these soils. In addition, the physical properties of these soils make them structurally unstable; prone to landslide and highly erodible. It is difficult to control erosion with terraces, diversions, and waterways. These soils may also serve as a ready source of sediment in watersheds.

Siliceous: Soils with siliceous mineralogy usually require fertilizer for agronomic crop growth, and conifers may do better than hardwoods. These soil materials are usually stable for construction, e.g., embankments or as base or subbase for road construction.

Vermiculitic: Vermiculitic clays are P-fixing, necessitating high levels of P fertilization. Vermiculitic soils have a tendency for landslide and solifluction because of strong cleavage. This instability is more pronounced on sloping terrain.

Soil mineralogy, data reporting: Clay mineralogy is reported on a <0.002-mm base (Tier 1, Columns 1 - 20). Sand and silt mineralogy are reported on a 2- to 0.002-mm base (Tier 2, Columns 1 - 20). Fine-earth mineralogy is reported on a <2-mm base (Tier 3, Columns 1 - 20). Examples of the Mineralogy Sheet (Tiers 1 and 2) are shown in Appendixes I and II, but an example of Tier 3 is not shown.

4.8 MINERALOGY SHEET, TIER 1: COLUMNS 1 - 20:

Columns 1 - 20: CLAY MINERALOGY (<0.002 mm).

Mineral identification: The physical and chemical properties of a soil are controlled to a very large degree by the soil minerals, especially by those minerals constituting the clay fraction (Whittig and Allardice, 1986). Clay fractions of soils are commonly composed of mixtures of one or more phyllosilicate minerals together with primary minerals inherited directly from the parent material and Fe oxides formed in the soil (Whittig and Allardice, 1986). Positive identification of mineral species and quantitative estimation of their proportions in these polycomponent systems usually require the application of several complementary qualitative and quantitative analyses (Whittig and Allardice, 1986). Some of the semiquantitative and quantitative procedures performed by the SSL include X-ray diffraction, thermal gravimetric analysis (TGA), differential scanning calorimetry (DSC), and differential thermal analysis (DTA). Refer to Amonette and Zelzany (1994) for more a detailed discussion of quantitative methods in soil mineralogy.

TGA, DSC, and DTA, complementary methods: Thermal analysis defines a group of analyses that determine some physical parameter, e.g., energy, weight, or evolved substances, as a dynamic function of temperature (Tan et al., 1986). The TGA, DSC and DTA are complementary methods available to the analyst. Many of the same clay mineral reactions, e.g., dehydroxylation, loss of surface adsorbed water, decomposition of carbonates, and oxidation, that are studied by DSC or DTA can also be studied by TGA. However, some transformation reactions, e.g., melting or structural reorganization (quartz alpha-beta transition), cannot be measured by TGA because no weight loss is involved. The DSC and DTA procedures provide information about energy relationships in the structures and reactions of the soil solid phase and also quantify minerals if the "nature of the reaction" is assumed constant. The TGA provides quantitative information about quantities of substances gained or lost by the solid phase during certain thermally driven reactions.

Clay mineralogy is reported in Columns 1 - 20 on this data tier. Data include X-ray diffraction, thermal, and total elemental analysis, and amount of ethylene glycol monoethyl ether (EGME) retained by soil (mg g^{-1}).

Column 1: Fraction.

The total clay fraction (<0.002-mm particle diameter) is generally analyzed by X-ray and thermal analysis. The fine clay fraction (<0.0002 mm) is analyzed on occasion.

Columns 2 - 6: X-Ray Diffraction Analysis, Peak Size.

X-ray diffraction analysis, mineral identification: One of the most useful methods to identify and to make semiquantitative estimates of the crystalline mineral components of soil is X-ray diffraction analysis. For phyllosilicates, which are common in <0.002 mm clays, the angles of diffraction, as affected by differentiating sample treatments, are distinctive for a particular mineral and help to identify that mineral. Intensities of diffraction maxima correspond, in part, to the concentrations of the mineral species present (Whittig and Allardice, 1986). Diffraction can be detected whenever Bragg's Law is satisfied. In X-ray analysis of soils or clay samples, there are difficulties in evaluation of and compensation for variations in chemical composition, crystal perfection, amorphous substances, and particle-size (Whittig and Allardice, 1986). A more reliable and accurate estimation of mineral percentages is provided when X-ray diffraction analysis is used in conjunction with other methods, e.g., thermal analysis, specific surface, elemental analysis, and other species-specific chemical methods (Alexiades and Jackson, 1966).

Mineral identification, interatomic distances: The angle of X-ray diffraction depends on the interatomic distances in the crystals in the sample. Generally, no two minerals have exactly the same interatomic distances in three dimensions and the angle at which diffraction occurs is distinctive for a particular mineral (Whittig and Allardice, 1986). These interatomic distances within a mineral crystal result in a unique array of diffraction maxima, which help to identify that mineral. When several minerals are present in a sample, species identification is usually accomplished most easily and positively by determining the interatomic spacings that give rise to the various maxima and by comparing these with known spacings of minerals (Whittig and Allardice, 1986).

Bragg's Law: X-ray diffraction produces peaks on a chart that correspond to angles measured by a goniometer. The angles marked by the peaks (2θ) are two times greater than the angles between the X-ray beam and the planes of atoms in the crystals (θ) that cause the diffraction. A diffraction peak is produced when the angle detected by the goniometer (2θ), the wavelength of the X-ray radiation (λ), and the spacing between planes of atoms (d), have the relationship specified by Bragg's Law as follows:

Equation 79:

$$n\lambda = 2d \sin \theta$$

where:

n = Order of diffraction (integer)
λ = X-radiation wavelength (Angstroms, A)
d = Crystal "d" spacing (A)
θ = Angle of incidence

Standard tables to convert θ or 2θ angles to crystal "d" spacings are published in the U.S. Geological Survey Circular 29 (Switzer et al., 1948) and in other publications. The order of diffraction (n) is the number of wavelengths of phase shift in radiation from adjacent planes of atoms. When n = 1, diffraction is of the first order. The wavelength of radiation from an X-ray tube is constant and characteristic for the target metal in the tube. Copper radiation (CuKa) with a wavelength of 1.54 A (0.154 nm) is used at the SSL. Because of similar structures of layer silicates commonly present in soil clays, several treatments which characteristically affect the "d" spacings are necessary to identify components. At the SSL, four treatments are used, i.e., Mg^{2+} (room temperature); Mg^{2+}-glycerol (room temperature); K^+ (300°C); and K^+ (500°C).

Peak size: Each layer silicate mineral identified in a sample is assigned one of five semiquantitative classes based on X-ray peak height or intensity and, by subjective judgment of the analyst, peak area. These classes are as follows:

5 Very large
4 Large
3 Medium
2 Small
1 Very small

Pretreatments: The SSL does not presently perform any pretreatments, e.g., carbonate, organic matter, or Fe-oxide removal prior to X-ray diffraction analysis. Prior to 1976, the Riverside and Beltsville Soil Survey Laboratories commonly used pretreatments for clay analysis. Refer to SSIR No. 42 (SSL Staff, 1992) for additional discussion of the present SSL method for X-ray diffraction (procedure 7A2i) and previously used pretreatments (procedures 7A1a,b,c).

Columns 7 - 8: Thermal Analysis, DSC.

Differential scanning calorimetry (DSC), laboratory measurement: Differential scanning calorimetry (DSC) is a calorimetric technique that measures the amount of energy required to establish zero temperature difference between a sample and a reference material as the two are heated side by side at a controlled rate (Tan et al., 1986). The DSC is used for the same purposes as differential thermal analysis (DTA). In DTA the endothermic and exothermic reactions are monitored by difference in temperature between sample and reference. The DSC has the advantage of directly measuring the magnitude of an energy change (vH, enthalpy or heat content) in a material undergoing an exothermic or endothermic reaction.

In the DSC technique (procedure 7A6b), the sample and reference, usually an empty pan, are each heated independently from one another by separate heating elements. The two samples are held at the same temperature by increasing or decreasing the power supplied to the sample heater in response to change in temperature caused by a reaction (endothermic or exothermic event) in the sample. In order to maintain sample temperature equal to that of the reference material, thermal energy is added to the sample when an endothermic change occurs or subtracted from the sample when an exothermic transition occurs. The energy input is equivalent in magnitude to the energy absorbed or evolved in the particular transition (Tan et al., 1986). The amount of thermal energy required to balance temperature differences is recorded.

Mineral quantification: Differential scanning colorimetry is commonly used to quantify gibbsite ($Al(OH)_3$) and kaolinite ($Al_2Si_2O_5(OH)_4$) in soils and clays by measuring the magnitude of their dehydroxylation endotherms which are between 250 to 350°C and 450 to 550°C, respectively, and then comparing to endotherms from known quantities of standard gibbsite and kaolinite (Jackson, 1956; Mackenzie, 1970; Mackenzie and Berggen, 1970; Karathanasis and Hajek, 1982). These values are related to the values for the respective known quantities of the two minerals (gibbsite and kaolinite). Goethite (FeOOH) with a dehydroxylation endotherm of 280 to 400°C may also be quantified (Schwertmann and Fanning, 1976). Differential scanning colorimetry is reported in Columns 7 - 8. Alternatively, differential thermal analysis (DTA) may be reported in these data columns. Differential scanning colorimetry data are reported as percent gibbsite and/or kaolinite to the nearest whole number on a <0.002-mm base.

Columns 7 - 8: Thermal Analysis, DTA.

Differential thermal analysis (DTA), laboratory measurement: In the DTA method (procedure 7A3c), the sample and a thermally inert reference material, e.g., Al_2O_3 or ignited kaolinite, are heated at a constant rate by a common furnace or heating element. Thermocouples are in contact with two platinum pans or may reside within sample and inert reference material. One pan contains the sample, and the other pan contains the inert reference material of similar composition. If a reaction occurs, thermocouples measure the temperature differential between the sample and reference, i.e., the samples are not held isothermal to one another as in DSC. The magnitude of the temperature differential depends on the nature of the reaction and the amount of reacting substance in the sample. The temperature at which the reaction occurs identifies the substance, if enough is known about the sample to predict the possibilities. Differential thermal analysis is reported in Columns 7 - 8. Alternatively, differential scanning colorimetry (DSC) may be reported in these data columns. Differential thermal analysis data are reported as percent gibbsite and/or kaolinite to the nearest whole number on a <0.002-mm base.

Columns 9 - 10: Thermal Analysis, TGA.

Thermogravimetric analysis (TGA), laboratory measurement: Many soil constituents undergo several thermal reactions upon heating, which serve as diagnostic properties for the qualitative and quantitative identification of these substances (Tan et al., 1986). Thermogravimetric analysis (TGA) is a technique for determining weight loss of a sample while it is heated at a constant rate. The TGA is an outgrowth of dehydration curves that were used in early studies of various phyllosilicate clay minerals (Jackson, 1956). The TGA differs from these earlier dehydration curves in that sample weight is monitored continuously rather than measured at discrete intervals after periods of heating at a constant temperature (Earnest, 1984; Wendlandt, 1986). The TGA only measures reactions that involve a weight loss of the sample.

Mineral quantification: Thermogravimetric analysis (TGA) (procedure 7A4c) is a technique for determining weight loss of a sample as it is being heated at a controlled rate. The weight changes are recorded as a function of temperature, i.e., a thermogravimetric curve, and provide quantitative information about substances under investigation, e.g., gibbsite ($Al(OH)_3$), kaolinite ($Al_2Si_2O_5(OH)_4$), and 2:1 expandable minerals (smectite and vermiculite) (Jackson, 1956; Mackenzie, 1970; Tan and Hajek, 1977; Karanthasis and Hajek, 1982; Tan et al., 1986). Thermal gravimetric analysis data are reported as percent gibbsite and/or kaolinite to the nearest whole number on a <0.002-mm base.

Columns 11 - 17: Total Elemental Analysis.

Total elemental analysis, data assessment: Historically, elemental analysis was developed for the analysis of rocks and minerals (Washington, 1930). The elemental analysis of soils, sediments, and rocks necessitates their decomposition into soluble forms. Total elemental analysis data may be used to estimate various components of the clay-fraction. The percent Fe_2O_3 and Al_2O_3 in the clay fraction of soils are alone not generally used for mineral calculations. However, these data are useful to compare horizons within or between pedons as indicators of depletion or concentration by weathering or other pedogenic processes. If percent Al_2O_3 is <10 there should be a reason, e.g., calcite may represent a large proportion of the clay fraction. If kaolinite = 5 by X-ray and/or gibbsite is present, percent Al_2O_3 should approach or exceed 30 percent. The percent K_2O may be used to estimate mica (illite) in those soils in which feldspars are absent in the clay-fraction. Some rules of thumb are as follows:

In a clay derived from a soil developed in igneous parent materials, the soil mica is assumed to contain 10 percent K_2O, which is less than found in theoretically ideal micas (11.8 percent) (Alexiades and Jackson, 1966; Fanning et al., 1989).

Equation 80:

$$\% \text{ Mica} = \% \text{ } K_2O \times 10$$

In a clay derived from marine sedimentary materials, the mica is assumed to contain only 8.0 percent K_2O (Berdanier et al., 1978). The 8.0 percent K_2O value, which represents 100 percent mica, is used to help define the illitic family mineralogy class of Soil Taxonomy (Soil Survey Staff, 1975). Illitic mineralogy is defined as more than one half hydrous mica and commonly more than 4 percent K_2O in the <0.002-mm fraction (Soil Survey Staff, 1975, 1994).

Equation 81:

$$\% \text{ Mica (illite)} = \% \text{ } K_2O \times 12.5$$

Some adjustment to these rules may be needed in dryland areas (Nelson and Nettleton, 1975) and in other source materials of illites. In some dryland areas, clays showing only mica X-ray diffraction patterns have K_2O contents of 4 to 6 percent.

Equation 82:

$$\% \text{ Mica (illite)} = \% \; K_2O \times 20$$

The percent K_2O may also be used as a check for internal consistency in laboratory data. The relative amounts of mica by X-ray analysis are adjusted in accordance with the percent K_2O in total clay as follows:

X-ray	**%K_2O**
1 or 2	0 -1
2 or 3	1 -2
3 or 4	2 -4
5	>4

Total elemental analysis, laboratory measurement: The SSL uses hydrofluoric acid (HF) in the acid digestion of silicate minerals for elemental analysis. Elemental concentrations for Fe, Al, and K are determined by atomic absorption (procedures 6C7a, 6G11a, and 6Q3a, respectively) after dissolution using an aliquot of clay suspension with about 100 mg of clay contained in a closed vessel followed by an addition of boric acid (H_3BO_3) to complex fluoride ions so as to enhance dissolution and to prevent volatilization of gaseous SiF_4 (Lim and Jackson, 1982).

Total elemental analysis is routinely determined on the clay fraction (<0.002-mm particle-size fraction) but may also be determined on the <2-mm soil. The SSL converts the total elemental contents of Al, Fe, and K to percent oxide, Al_2O_3, Fe_2O_3, and K_2O, respectively. The SSL performs the HF digestion for total elemental analysis by procedure 7C3. The Al_2O_3, Fe_2O_3, and K_2O are reported as percent on a <0.002-mm base in Columns 12, 13, and 16, respectively.

Total elemental analysis, laboratory measurement, new method. The total analysis method is currently undergoing revision and will have a new method code (as yet unassigned, tentatively 7C3b) with the addition of aqua regia (HNO_3 and HCl) to the HF prior to sample digestion. In addition, the SSL will now routinely analyze and report 12 elements (Si, Al, Mg, K, Ca, Ti, Mn, Fe, Ti, Zr, Cu, and Zn) on the clay (<0.002-mm) fraction. Results from digestion of the fine earth (<2-mm) fraction will include these elements plus Na and P. The same data interpretations can be made as described for the current HF method. Information can also be determined for parent material uniformity, pedon development, and mineral weathering within or between pedons. This information is determined by changes between horizons or pedons in elemental concentrations, or elemental ratios such Si/Al, Si/(Al+Fe) or Ti/Zr. The amount of basic cations (Ca, Mg, Fe, Na, K) relative to Si and Al of a soil parent material is an indicator of the inherent fertility of the parent rock or sediment. Potential water quality problems can be better understood by measurements of total P, especially when compared with other P measurements, such as Bray-extractable P. At the present time, these data are not routinely reported on the SSL data sheets, and there are no assigned SSL method codes for these additional elements. However, the modified HF digestion procedure for total elemental analysis tentatively has a new method code of 7C3b.

Column 18: Data column not used.

Column 19: Ethylene Glycol Monoethyl Ether (EGME) Retention.

Surface-area, soil-related factors: Surface area influences many physical and chemical properties of materials, e.g., physical adsorption of molecules and the heat loss or gain which results from this adsorption; shrink-swell capacity; water retention and movement; cation exchange capacity; and pesticide adsorption (Carter et al., 1986). In addition, many biological processes are closely related to specific surface (Carter et al., 1986). Soils vary widely in their reactive surface area because of differences in mineralogical and organic composition and in their particle-size distribution (Carter et al., 1965).

Ethylene glycol monoethyl ether retention, laboratory measurement: The purpose of surface-area measurements is to determine the accessibility of internal and external surfaces of the clay mineral complex to molecules or ions which can be adsorbed thereon (Carter et al., 1986). Clay-size particles, and particularly expandable layer silicate minerals, contribute most of the inorganic surface area to soils (Carter et al., 1986). Specific surface has been measured for several clays, e.g., smectite (810 m^2 g^{-1}) and kaolinite and mica (20 to 40 m^2 g^{-1}). Ethylene glycol monoethyl ether (EGME) retention is a surface-area determination. A soil sample is saturated with EGME, desorbed until a monomolecular layer of EGME remains. The specific surface by EGME is determined by weighing the sample and weighing the sample plus EGME (Carter et al., 1965). Specific surface is defined as surface area per unit mass of soil and is usually expressed in m^2 g^{-1} or cm^2 g^{-1} soil. The SSL determines EGME retention by procedure 7D2. The SSL reports EGME retention as mg EGME per g of soil to the nearest mg on a <2-mm base.

Ethylene glycol monoethyl ether retention and surface area, calculations: The EGME retention is calculated as follows:

Equation 83:

$$\text{Retention of EGME (mg g}^{-1}\text{)} = (Wt_1 - Wt_2) \times (1000/Wt_1)$$

where:

Wt_1 = Soil weight with monomolecular layer of EGME
Wt_2 = Soil weight after drying with P_2O_5
1000 = Conversion factor (mg g^{-1})

The surface area in units of mg EGME per g of soil is converted to m^2 g^{-1}, the convention commonly used in clay mineralogy. The conversion is as follows:

Equation 84:

$$\text{Surface area } (m^2\ g^{-1}) = (\text{EGME retention } (mg\ g^{-1}))/0.286$$

where:
0.286 = Conversion factor (mg EGME m^{-2}).

The constant, 0.286, is the amount of EGME (mg) that is required to cover a m^2 of clay surface with a monomolecular layer (Carter et al., 1986). This value is calculated from the measured value of 231.7 mg EGME per g of pure montmorillonite assumed to have 810 $m^2\ g^{-1}$ on the basis of other measurements.

Column 20: Interpretation.

Clay mineralogy, interpretation: This column is provided for the project leader to describe mineralogical interpretation of the clay fraction for a particular horizon or sample based on laboratory data, e.g., taxonomic placement in mineralogy families (Soil Survey Staff, 1975, 1994). Horizons within the control section have to be weighted to derive the family mineralogy placement for the pedon.

4.9 MINERALOGY SHEET: TIER 2: COLUMNS 1 - 20:

Columns 1 - 20: SAND AND SILT MINERALOGY (2.0 - 0.002 mm).

Column 1: Fraction.

Specific sand and silt fractions may be analyzed by X-ray and thermal procedures. Optical analysis of specific sand and silt fractions are routine procedures. These fractions include the very fine sand (0.05 to 0.10 mm), fine sand (0.10 to 0.25 mm), or coarse silt (0.02 to 0.05 mm). The entire <2-mm fraction or other fractions of the fine earth also may be examined. Data for the fine-earth fraction (<2 mm) are reported on Tier 3, Columns 1 - 20.

Columns 2 - 5: X-Ray, Peak Size.

The SSL does not routinely perform X-ray diffraction analysis on the sand and silt fractions of a soil. However, these data may be useful in confirming the presence of a particular mineral species as identified by optical microscopy. Data may also be used in identifying phyllosilicate mineral species present in the coarser fractions of the fine-earth. Refer to the discussion on X-ray diffraction analysis on the Mineralogy Sheet, Tier 1, Columns 2 - 6. Minerals are identified on the data sheet by a 2-letter code. Refer to Appendix VIII for the list of mineralogy codes for resistant and weatherable minerals.

Columns 6 - 7: Thermal, DTA.

Refer to the discussion on differential thermal analysis (DTA) (procedure 7A3c) on the Mineralogy Sheet, Tier 1, Columns 7 - 8.

Columns 6 - 7: Thermal, DSC.

Refer to the discussion on differential scanning colorimetry (DSC) (procedure 7A6b) on the Mineralogy Sheet, Tier 1, Columns 7 - 8.

Columns 8 - 9: Thermal, TGA.

Refer to the discussion on thermal gravimetric analysis (TGA) (procedure 7A4c) on the Mineralogy Sheet, Tier 1, Columns 9 - 10.

Column 10: Optical, Total Resistant Minerals.

Resistant vs weatherable minerals: An understanding of the concepts of weatherable and resistant minerals is important in the assessment of the sand mineralogy of soils (National Soil Survey Laboratory, 1983). Resistant minerals include quartz or more resistant minerals that persist under a humid leaching environment (Soil Survey Staff, 1975, 1994). Weatherable minerals are depleted by the soil forming processes in the same environment. Carbonates and more soluble components are excluded from weatherable minerals in the taxonomic definition. For certain taxonomic criteria, weatherable minerals are considered only part of the range of particle size components (Soil Survey Staff, 1975, 1994). The percentage by weight of resistant minerals is estimated from grain counts, i.e., usually, counts from one or two of the dominant grain-size fractions of a conventional mechanical analysis is sufficient for placement of a soil (Soil Survey Staff, 1975, 1994).

Resistant minerals, agronomic and engineering significance: More than 90 percent by weight silica minerals (quartz, chalcedony, or opal) and other extremely durable minerals that are resistant to weathering in the 0.02- to 2.0-mm fraction is a diagnostic criterion for the siliceous mineralogy class (Soil Survey Staff, 1975, 1994). Soils with siliceous mineralogy usually require fertilizer for agronomic crop growth, and conifers may do better than hardwoods. These soil materials are usually stable for construction, e.g., embankments or as base or subbase for road construction. Refer to the Soil Survey Staff (1975, 1994) for additional discussion of this mineralogy class.

Resistant minerals, laboratory measurement: Refer to SSIR No. 42 (SSL Staff, 1992) for a detailed description of the grain counts procedure (method 7B1a). The SSL reports the sum of the grain-count percentages of resistant minerals reported in Columns 11 - 16. Refer to Appendix VIII for lists of resistant and weatherable minerals.

Columns 11 - 16: Optical, Grain Count.

Grain counts, significance: Single grains of sand and silt size may be identified and described by examination under a petrographic microscope. Knowledge of the nature and conditions of the minerals in these fractions provides information on the source of parent material; on the presence of lithological discontinuities or overlays in the solum or between the solum and the underlying material; and on the degree of weathering in the soil as a key to its history, genetic processes, and possible fertility reserve (Cady et al., 1986). These data are also used as taxonomic criteria to classify pedons in soil mineralogy families (Soil Survey Staff, 1975, 1994). Refer to Appendix IX for a description of the analysis and interpretation of grain studies (procedure 7B1).

Grain counts, laboratory measurement: A mineralogical analysis of a sand or silt fraction may be entirely qualitative, or it may be quantitative to different degrees (Cady, 1965). The SSL reports lists of these minerals and an estimated quantity of each mineral as a percentage of the grains counted. Grain counts are reported to the nearest whole percent. These data are accurate for the size-fraction analyzed but may need to be recomputed to convert to weight percentages. For each grain size counted, the mineral type and amount are reported, e.g., quartz 87 percent of fraction analyzed is reported as QZ87.

Minerals are identified on the SSL data sheet by a 2-letter code. Refer to Appendix VIII for the list of mineralogy codes for resistant and weatherable minerals. Refer to SSIR No. 42 (SSL Staff, 1992) for a detailed description of the grain counts procedure (method 7B1a). Identification procedures and reference data on minerals are also described in references on sedimentary petrography (Krumbein and Pettijohn, 1938; Durrell, 1948; Deer et al., 1966; Kerr, 1977; Milner, 1962) and optical crystallography (Bloss, 1961).

Column 17: Data column not used.

Column 18: Data column not used.

Column 19: Data column not used.

Column 20: Optical, Interpretation.

Sand and silt mineralogy, interpretation: This column is provided for the project leader to describe mineralogical interpretation of sand and silt fractions for a particular horizon or sample based on laboratory data, e.g., placement in taxonomic mineralogy families (Soil Survey Staff, 1975, 1994). Horizons within the control section have to be weighted to derive the family mineralogy placement for the pedon.

4.10 MINERALOGY SHEET: TIER 3: COLUMNS 1 - 20:

Columns 1 - 20: FINE-EARTH MINERALOGY (<2 mm).

Column 1: Fraction.

The entire fine-earth fraction (<2 mm) may be analyzed by X-ray and thermal procedures. Total elemental analysis and surface area may also obtained for the fine-earth fraction.

Columns 2 - 6: X-Ray Diffraction Analysis, Peak Size.

The SSL does not routinely perform X-ray diffraction analysis on the fine-earth fraction. However, these data may be useful in confirming the presence of a particular mineral species as identified by optical microscopy. Data may also be used in identifying phyllosilicate mineral species present in the coarser fractions of the fine-earth. Refer to the discussion on X-ray diffraction analysis on the Mineralogy Sheet, Tier 1, Columns 2 - 6. Minerals are identified on the data sheet by a 2-letter code. Refer to Appendix VIII for the list of mineralogy codes for resistant and weatherable minerals.

Columns 7 - 8: Thermal Analysis, DSC.

Refer to the discussion on differential scanning colorimetry (DSC) (procedure 7A6b) on the Mineralogy Sheet, Tier 1, Columns 7 - 8.

Columns 7 - 8: Thermal Analysis, DTA.

Refer to the discussion on differential thermal analysis (DTA) (procedure 7A3c) on the Mineralogy Sheet, Tier 1, Columns 7 - 8.

Columns 9 - 10: Thermal Analysis, TGA.

Refer to the discussion on thermal gravimetric analysis (TGA) (procedure 7A4c) on the Mineralogy Sheet, Tier 1, Columns 9 - 10.

Columns 11 - 17: Total Elemental Analysis.

Column 18: Data column not used.

Column 19: Surface Area.

Refer to the discussion on ethylene glycol monoethyl ether (EGME) retention (procedure 7D2) on the Mineralogy Sheet, Tier 1, Column 19. The EGME data are reported as mg g^{-1} on a <0.002-mm base on Tier 1, Column 19. Surface area data are reported as m^2 g^{-1} on the fine-earth fraction (<2-mm base) in this data column. Refer to the Mineralogy Sheet, Tier 1, Column 19 for the conversion of surface area in units of mg EGME per g of soil to m^2 g^{-1}.

Column 20: Interpretation.

Fine-earth fraction, interpretation: This column is provided for the project leader to describe mineralogical interpretation of the fine-earth fraction for a particular horizon or sample based on laboratory data, e.g., placement in taxonomic mineralogy families (Soil Survey Staff, 1975, 1994). Horizons within the control section have to be weighted to derive the family mineralogy placement for the pedon.

Interpretation, micromorphology: Micromorphology may be defined as the study of microfabrics of soils in their natural undisturbed arrangement (Cady, 1965). Examination of thin sections (natural fabrics of fine-earth fraction) with a polarizing light microscope can be considered an extension of field morphological studies. The results of micromorphological studies are most useful when they are combined with other field and laboratory information (Cady, 1965). Micromorphology is used to identify illuviation of argillans, fabric types, skeleton grains, weathering intensity, and to investigate genesis of soil or pedological features. Micromorphological interpretations are not reported on the SSL data sheets but are provided in technical reports by project coordinators. Refer to Appendix X for a description of the micromorphological interpretation of thin sections (procedure 4E1b).

5. SUPPLEMENTARY CHARACTERIZATION DATA

This part of the manual is a description of the data columns on the Supplementary Characterization Data Sheets. The Supplementary Characterization Data Sheets are considered the interpretive physical data for pedons analyzed by the SSL. These data sheets are primarily composed of derived or calculated data, but they also repeat some analytical information provided on the Primary Data Sheets, e.g., bulk density at 1/3-bar and ovendryness and percent sand, silt, and clay. The interpretive information on the Supplementary Data Sheets may or may not be the exact same value as the analytical information provided on the Primary Data Sheets for a specific datum, e.g., weight percentage for >2-mm fraction on a whole-soil base. The interpretive weight and volume quantities on the Supplementary Data Sheets may or may not be the exact same values as the analytical data from which they are calculated because of the procedure of rounding and significant digits in calculating the data.

On the first sheet of the Supplementary Data Sheets, the laboratory sample numbers are listed followed by the sample preparation code. Refer to Appendix III for the laboratory preparation codes. Averages and other data may also be listed as footnotes on the data sheets.

5.1 SUPPLEMENTAL SHEET 1: TIER 1: COLUMNS 1 - 25:

Sample Numbers and Sample Preparation Codes:

Sample numbers and laboratory preparation codes are listed.

Columns 1 - 10: PARTICLE-SIZE DISTRIBUTION ANALYSIS (PSDA), ENGINEERING.

Engineering PSDA, definition: The engineering PSDA data in Columns 1 - 10 are derived from USDA PSDA data and are reported as cumulative weight percentages less than a given diameter passing a 3-in sieve (76.1 mm). Percent passing expresses the percentage of total sample that is finer than each sieve size and is not the percentage retained on sieve. Square-holed sieves are routinely used to obtain engineering and USDA PSDA data.

Columns 2, 3, 4, 6, and 9: In interpolating between sieve sizes, a logarithmic distribution on the cumulative particle-size curve is usually assumed with a linear relationship between size fractions. Log factors for these relationships in Equations 2, 3, 4, 6, and 9 are calculated as follows:

Steps:

1. (1) Use sieve dimensions in millimeters to obtain logarithms of larger and smaller sieve sizes for which there are measured particle percentages.
2. (2) Determine range of these two logarithmic values by subtraction.
3. (3) Determine logarithm of sieve size for which there is an estimated particle percentage and subtract result from logarithm of larger sieve size determined in step 1.
4. (4) Divide result in step 3 by value determined in step 2. Result is Log Factor.

The sieve dimensions used to obtain Log Factors (Table 1) are from the engineering grain-size distribution graph (form NRCS-ENG-353).

Table 1. Sieve dimensions used to obtain Log Factors.

Sieve Size (in)	Sieve Size (mm)	Sieve Size (No.)	Sieve Size (mm)
3	76.1	4	4.76
2	50.8	10	2.00
3/2	38.1	40	0.420
1	25.4	200	0.074
3/4	19.0		
3/8	9.51		

Example:
Calculate Log Factor 0.2906 (Column 2) as follows:

Steps:

(1) Log of sieve size 76.1 mm (3 in) = 1.881
Log of sieve size 19.0 mm (3/4 in) = 1.279
(2) Determine log range by subtraction = 0.602
(3) Log of sieve size 50.8 mm (2 in) = 1.706
Subtract 1.706 from 1.881 = 0.175
(4) Divide 0.175 (Step 3) by 0.602 (Step 2)
Resulting Log Factor = 0.2906

These sieve dimensions can be related to rock fragments by diameter (Soil Survey Staff, 1993) as follows:

2-75 mm	Pebbles
2-5 mm	Fine
5-20 mm	Medium
20-75 mm	Coarse
75-250 mm	Cobbles
250-600 mm	Stones

Column 1: Particles Passing 3-in Sieve.

Particles passing a 3-in sieve (76.1 mm) are reported as a cumulative weight percentage on a <3-in base. These data should always be 100%.

Equation 1:

$$P_{<3\text{-in}} = 100\%$$

where:

$P_{<3\text{-in}}$ = Cumulative weight percentage of particles passing 3-in sieve on a <3-in base.

Column 2: Particles Passing 2-in Sieve.

Particles passing a 2-in sieve (50.8 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 2:

$$P_{<2in} = 100 - (Wt_{20\text{-}75mm} \times 0.2906)$$

where:

$P_{<2in}$ = Cumulative weight percentage of particles passing 2-in sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

0.2906 = Calculate Log Factor as determined by Steps 1 through 4.

Column 3: Particles Passing 3/2-in Sieve.

Particles passing a 3/2-in sieve (38.1 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 3:

$$P_{<3/2in} = 100 - (Wt_{20\text{-}75mm} \times 0.4981)$$

where:

$P_{<3/2in}$ = Cumulative weight percentage of particles passing 3/2-in sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base is reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

0.4981 = Calculate Log Factor using sieve dimensions as outlined in Steps 1 through 4.

Column 4: Particles Passing 1-in Sieve.

Particles passing a 1-in sieve (25.4 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 4:

$$P_{<1in} = 100 - (Wt_{20\text{-}75mm} \times 0.7906)$$

where:

$P_{<1in}$ = Cumulative weight percentage of particles passing 1-in sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

0.7906 = Calculate Log Factor using sieve dimensions as outlined in Steps 1 through 4.

Column 5: Particles Passing 3/4-in Sieve.

Particles passing a 3/4-in (19.05 mm) sieve are reported as a cumulative weight percentage on a <3-in base.

Equation 5:

$$P_{<3/4in} = 100 - Wt_{20\text{-}75mm}$$

where:

$P_{<3/4in}$ = Cumulative weight percentage of particles passing 3/4-in sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

Column 6: Particles Passing 3/8-in Sieve.

Particles passing a 3/8-in sieve (9.51 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 6:

$$P_{<3/8in} = P_{<3/4in} - (Wt_{5\text{-}20mm} \times 0.4962)$$

where:

$P_{<3/8in}$ = Cumulative weight percentage of particles passing 3/8-in sieve on a <3-in base.

$P_{<3/4in}$ = Cumulative weight percentage of particles passing 3/4-in sieve. Interpretive data for $P_{<3/4in}$ are reported in Column 5 (Supplementary Data Sheet).

$Wt_{5\text{-}20mm}$ = Weight percentage of particles with 5- to 20-mm diameter on a <75-mm base. To obtain $Wt_{5\text{-}20mm}$ fraction in equation, subtract the percent passing the No. 4 sieve reported in Column 7 (Supplementary Data Sheet) from the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet). Analytical data for $Wt_{5\text{-}20mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 17).

0.4962 = Calculate Log Factor using sieve dimensions as outlined in Steps 1 through 4.

Column 7: Particles Passing No. 4 Sieve.

Particles passing a No. 4 (4.76 mm) sieve are reported as a cumulative weight percentage on a <3-in base.

Equation 7:

$$P_{<4} = 100 - (Wt_{20\text{-}75mm} + Wt_{5\text{-}20mm})$$

where:

$P_{<4}$ = Cumulative weight percentage of particles passing No. 4 (4.76 mm) sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

$Wt_{5\text{-}20mm}$ = Weight percentage of particles with 5- to 20-mm diameter on a <75-mm base. To obtain $Wt_{5\text{-}20mm}$ fraction in equation, subtract the percent passing the No. 4 sieve reported in Column 7 (Supplementary Data Sheet) from the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet). Analytical data for $Wt_{5\text{-}20mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 17).

Column 8: Particles Passing No. 10 Sieve.

Particles passing a No. 10 (2.00 mm) sieve are reported as a cumulative weight percentage on a <3-in base.

Equation 8:

$$P_{<10} = 100 - (Wt_{20\text{-}75mm} + Wt_{5\text{-}20mm} + Wt_{2\text{-}5mm})$$

where:

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 sieve on a <3-in base.

$Wt_{20\text{-}75mm}$ = Weight percentage of particles with 20- to 75-mm diameter on a <75-mm base. To obtain $Wt_{20\text{-}75mm}$ fraction in equation, subtract the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet) from the percent passing the 3-in sieve reported in Column 1 (Supplementary Data Sheet). Analytical data for $Wt_{20\text{-}75mm}$ fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

Wt_{5-20mm} = Weight percentage of particles with 5- to 20-mm diameter on a <75-mm base. To obtain Wt_{5-20mm} fraction in equation, subtract the percent passing the No. 4 sieve reported in Column 7 (Supplementary Data Sheet) from the percent passing the 3/4-in sieve reported in Column 5 (Supplementary Data Sheet). Analytical data for Wt_{5-20mm} fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 17).

Wt_{2-5mm} = Weight percentage of particles with 2- to 5-mm diameter on a <75-mm base. To obtain Wt_{2-5mm} fraction on a <75-mm base in equation, subtract the percent passing the No. 10 sieve reported in Column 8 (Supplementary Data Sheet) from the percent passing the No. 4 sieve reported in Column 7 (Supplementary Data Sheet). Analytical data for Wt_{2-5mm} fraction on a <75-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 16).

Column 9: Particles Passing No. 40 Sieve.

Particles passing a No. 40 (0.420 mm) sieve are reported as a cumulative weight percentage on a <3-in base.

Equation 9:

$$P_{<40} = P_{<10} - [(Wt_{1-2mm} + Wt_{0.5-1mm} + (Wt_{0.25-0.5mm} \times 0.2515)) \times (P_{<10}/100)]$$

where:

$P_{<40}$ = Cumulative weight percentage of particles passing No. 40 (0.420 mm) sieve on a <3-in base.

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Wt_{1-2mm} = Weight percentage of particles with 1- to 2-mm diameter (very coarse sand) on a <2-mm base. Analytical data for Wt_{1-2mm} fraction on a <2-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 15).

$Wt_{0.5-1mm}$ = Weight percentage of particles with 0.5- to 1-mm diameter (coarse sand) on a <2-mm base. Analytical data for $Wt_{0.5-1mm}$ fraction on a <2-mm base are re ported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 14).

$Wt_{0.25-0.5mm}$ = Weight percentage of particles with 0.25- to 0.5-mm diameter (medium sand) on a <2-mm base. Analytical data for $Wt_{0.25-0.5mm}$ fraction on a <2-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 13).

0.2515 = Calculate Log Factor using sieve dimensions as outlined in Steps 1 through 4.

Column 10: Particles Passing No. 200 Sieve.

Particles passing a No. 200 (0.074 mm) sieve are reported as a cumulative weight percentage on a <3-in base in this data column.

If very fine sand <15 percent: For the 0.074-mm size fraction, a linear relationship (non-logarithmic distribution) is assumed, if the very fine sand fraction (VFS) (0.05-0.10 mm) is <15 percent. If the VFS fraction is <15 percent, use Equation 10 to calculate the particles passing a No. 200 sieve. To determine equation factor for Equation 10, use sieve dimensions (mm) as outlined in Steps 1 - 4 but do not convert to logarithmic values.

Equation 10:

$$P_{<200} = [\,(0.56559 \text{ x } Wt_{0.05-0.10mm}) + Wt_{0.002-0.05mm} + Wt_{<0.002mm}\,] \text{ x } (P_{<10}/100)$$

where:

$P_{<200}$ = Cumulative weight percentage of particles passing No. 200 sieve (0.074 mm) on a <3-in base.

$Wt_{0.05\text{-}0.10mm}$ = Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base. Analytical data for $Wt_{0.05\text{-}0.10mm}$ fraction on a <2-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 11).

$Wt_{0.002\text{-}0.05mm}$ = Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt). Analytical data for $Wt_{0.002\text{-}0.05mm}$ fraction on a <2-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 5).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction on a <2-mm base are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

0.56559 = Calculate Equation factor as outlined in Steps 1 through 4 but no logarithmic conversion.

If very fine sand ≥15 percent: A relationship between variables may be approximately linear when studied over a limited range but markedly curvilinear when a broader range is considered (Steele and Torrie, 1980). If the VFS is ≥15 percent, a short curve is fitted to three points just above and below 0.074 mm. These points or cumulative points are as follows:

(1) Medium sand (0.50- to 0.25-mm diameter)
(2) Medium sand (0.50- to 0.25-mm diameter) + Fine sand (0.25- to 0.10-mm diameter)
(3) Medium sand (0.5- to 0.25-mm diameter) + Fine sand (0.25- to 0.10-mm diameter) + Very fine sand (0.10- to 0.05-mm diameter)

In those instances in which VFS ≥15 percent, the cumulative particle percentage passing the No. 200 sieve is based on the principle of *least squares* and is determined using the computer subroutine entitled CURVE. Previous studies at the former regional SCS SSL at Riverside, California have shown that this procedure gives a slightly better prediction than the linear assumption.

Columns 11- 18: PARTICLE-SIZE DISTRIBUTION ANALYSIS (PSDA), USDA.

The USDA PSD analyses are recalculated and reported in Columns 11 - 18 as cumulative weight percentages of particles less than a specified diameter on a <3-in base. The particle-size data reported in Columns 11 - 13 add detail in the silt and clay particle-size range. The particle-size data reported in Columns 14 - 18 add detail in the sand particle-size range.

The headings for Columns 11, 12, and 13 (Particles Passing 20, 5, and 2-µm sieves, respectively) are misnomers, as these analytical separations are made by sedimentation based on Stokes' Law. The headings would be more correctly stated as Particles Finer Than 20, 5, and 2 µm.

Column 11: Particles Passing 20-µm Sieve (Particles Finer Than 20 µm).

Particles finer than 20 µm (0.02 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 11:

$$P_{<20\mu m} = (Wt_{<0.002mm} + Wt_{0.002-0.02mm}) \text{ x } (P_{<10}/100)$$

where:

$P_{<20\mu m}$ = Cumulative weight percentage of particles <20 µm on a <3-in base.

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (clay) on a <2-mm base. Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$Wt_{0.002-0.02mm}$ = Weight percentage of particles with 0.002- to 0.02-mm diameter (fine silt) on a <2-mm base. Analytical data for $Wt_{0.002-0.02mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 9).

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 12: Particles Passing 5-µm Sieve (Particles Finer Than 5 µm).

Particles finer than 5 µm (0.005 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 12:

$$P_{<5\mu m} = [\ Wt_{<0.002mm} + (Wt_{0.002\text{-}0.02mm} \times 0.39794)\ ] \times (P_{<10}/100)$$

where:

$P_{<5\mu m}$ = Cumulative weight percentage of particles <5 µm (0.005 mm) on a <3-in base.

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay) on a <2-mm base. Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$Wt_{0.002\text{-}0.02mm}$ = Weight percentage of particles with 0.002- to 0.02-mm diameter (fine silt) on a <2-mm base. Analytical data for $Wt_{0.002\text{-}0.02mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 9).

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

0.39794 = Calculate Log Factor using sieve dimensions as outlined in Steps 1 through 4.

Column 13: Particles Passing 2-µm Sieve (Particles Finer Than 2 µm).

Particles finer than 2 µm (0.002 mm) are reported as a cumulative weight percentage on a <3-in base.

Equation 13:

$$P_{<2\mu m} = Wt_{<2\mu m} \times (P_{<10}/100)$$

where:

$P_{<2\mu m}$ = Cumulative weight percentage of particles <2 µm (<0.002 mm) on a <3-in base.

$Wt_{<2\mu m}$ = Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base. Analytical data for $Wt_{<2\mu m}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 14: Particles <1 mm.

Particles with <1-mm diameter are reported as a cumulative weight percentage on a <3-in base.

Equation 14:

$$P_{<1.0mm} = (\text{Columns } 4 + 5 + 11 + 12 + 13 + 14) \times (P_{<10}/100)$$

where:

Column 4 = Column 4 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base.

Column 5 = Column 5 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt).

Column 11 = Column 11 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base.

Column 12 = Column 12 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.10- to 0.25-mm diameter (fine sand) on a <2-mm base.

Column 13 = Column 13 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.25- to 0.50-mm diameter (medium sand) on a <2-mm base.

Column 14 = Column 14 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.50- to 1.0-mm diameter (coarse sand) on a <2-mm base.

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 15: Particles <0.5 mm.

Particles with <0.5-mm diameter are reported as a cumulative weight percentage on a <3-in base. Data may be determined as follows:

Equation 15:

$$P_{<0.05\text{mm}} = (\text{Columns } 4 + 5 + 11 + 12 + 13) \times (P_{<10}/100)$$

where:

Column 4 = Column 4 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base.

Column 5 = Column 5 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt).

Column 11 = Column 11 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base.

Column 12 = Column 12 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.10- to 0.25-mm diameter (fine sand) on a <2-mm base.

Column 13 = Column 13 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.25- to 0.50-mm diameter (medium sand) on a <2-mm base.

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 16: Particles <0.25 mm.

Particles with <0.25-mm diameter are reported as a cumulative weight percentage on a <3-in base. Data may be determined as follows:

Equation 16:

$$P_{<0.25mm} = (\text{Columns } 4 + 5 + 11 + 12) \times (P_{<10}/100)$$

where:

Column 4 = Column 4 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base.

Column 5 = Column 5 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt).

Column 11 = Column 11 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base.

Column 12 = Column 12 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.10- to 0.25-mm diameter (fine sand) on a <2-mm base.

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 17: Particles <0.10 mm.

Particles with <0.10-mm diameter are reported as a cumulative weight percentage on a <3-in base.

Equation 17:

$$P_{<0.10mm} = (\text{Columns } 4 + 5 + 11) \times (P_{<10}/100)$$

where:

Column 4 = Column 4 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base.

Column 5 = Column 5 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt).

Column 11 = Column 11 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base.

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Column 18: Particles <0.05 mm.

Particles with <0.05 diameter are reported as a cumulative weight percentage on a <3-in base.

Equation 18:

$$P_{<0.05mm} = (\text{Columns } 4 + 5) \times (P_{<10}/100)$$

where:

Column 4 = Column 4 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with <2-µm (<0.002 mm) diameter (total clay) on a <2-mm base.

Column 5 = Column 5 of Primary Data Sheet, PSDA Sheet, Tier 1. Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt).

$P_{<10}$ = Cumulative weight percentage of particles passing No. 10 (2.00 mm) sieve on a <3-in base. Interpretive data for $P_{<10}$ are reported in Column 8 (Supplementary Data Sheet). $P_{<10}/100$ is the decimal fraction passing the No. 10 sieve and is used in converting from 2-mm to 75-mm base percentage.

Columns 19 - 21: PARTICLE DIAMETER, CUMULATIVE FRACTION CURVE.

Particle diameters in millimeters (mm) at specified percentile points on the cumulative particle-size distribution curve are reported on a <3-in base. Particles finer than the reported diameters are 60, 50, and 10 percent of <3-in material (Columns 19, 20, and 21, respectively). Calculation of these diameters are embedded in a computer protocol too complicated to include in this discussion. Refer to ASTM method D2487 (American Society for Testing and Materials, 1993) for a more detailed discussion of these criteria.

Column 19: Particle Diameter, 60 Percentile.

Particle diameter corresponding to 60% finer on the cumulative particle-size distribution curve is reported. Data (D_{60}) are used in the classification of soils for engineering purposes in the Unified Soil Classification System (USCS).

Column 20: Particle Diameter, 50 Percentile.

Particle diameter corresponding to 50% finer on the cumulative particle-size distribution curve is reported. Data (D_{50}) are the particle-size geometric mean for the cumulative distribution curve.

Column 21: Particle Diameter, 10 Percentile.

Particle diameter corresponding to 10% finer on the cumulative particle-size distribution curve is reported. Data (D_{10}) are used in the classification of soils for engineering purposes in the Unified Soil Classification System (USCS).

Columns 23 - 24: ATTERBERG LIMITS.

Atterberg Limits is a general term that encompasses liquid limit (LL), plastic limit (PL), and, in some references, shrinkage limit (SL). The test method for these limits by ASTM has the designation of ASTM D 4318 (American Society for Testing and Materials, 1993). This test method is used as an integral part of several engineering classification systems, e.g., Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO), to characterize the fine-grained fractions of soils (ASTM D 2487 and D 3282) and to specify the fine-grained fraction of construction materials (ASTM D 1241) (American Society for Testing and Materials, 1993). The LL and plastic index (PI) of soils are also used extensively, either individually or together with other soil properties, to correlate with engineering behavior, e.g., compressibility, permeability, compactability, shrink-swell, and shear strength (American Society for Testing and Materials, 1993)). The LL and PI are closely related to amount and kind of clay, CEC, 15-bar water, and engineering properties, e.g., load-carrying capacity of the soil.

In general, the AASHTO engineering system is a classification system for soils and soil-aggregate mixtures for highway construction purposes, e.g., earthwork structures, particularly embankments, subgrades, subbases, and bases. The Unified Soil Classification System (USCS) is used for general soils engineering work by many organizations including USDA-SCS.

Column 22: Liquid Limit (LL).

The LL is the percent water content of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in) when subjected to 25 shocks from the cup being dropped 10 mm in a standard LL apparatus operated at a rate of 2 shocks s^{-1}. Refer to ASTM method D 4318 (American Society for Testing and Materials, 1993). The LL is reported as percent water on a <0.4-mm base in this data column. If the LL is not measured, it can be estimated for use in engineering classification through the use of algorithms. Refer to the Primary Data Sheet (PSDA Sheet, Tier 2, Column 10) for additional discussion of LL and the use of these algorithms.

Column 23: Plasticity Index (PI).

The PI is the range of water content over which a soil behaves plastically. Numerically, the PI is the difference in the water content between the LL and the PL. Refer to Column 22 (Supplementary Data Sheet) for the definition of LL. The PL is the percent water content of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2-mm (1/8-in) threads without crumbling. Refer to ASTM method D 4318 (American Society for Testing and Materials, 1993). If either the LL or PL can not be determined, or if PL is $\geq$ LL, the soil is reported as nonplastic (NP). The PI is reported as percent water on a <0.4-mm base in this data column. If the PI is not measured, it can be estimated for use in engineering classification through the use of algorithms. Refer to the Primary Data Sheet (PSDA Sheet, Tier 2, Column 11) for additional discussion of PI and the use of these algorithms.

Columns 24 - 25: GRADATION CURVE.

Gradation curve is the cumulative grain-size distribution curve described by data on the Supplementary Data Sheet, Columns 1 - 21. The coefficients of uniformity (Cu) and curvature (Cc) help to define the shape and position of the grain-size distribution curve. Characteristics of the gradation curve are used as classification criteria in the Unified Soil Classification System (USCS). Refer to ASTM method D2487 (American Society for Testing and Materials, 1993) for a detailed discussion of these criteria.

Column 24: Uniformity.

The coefficient of uniformity (Cu) is used to evaluate the grading characteristics of coarse-grained soils. The Cu is calculated as follows:

Equation 19:

$$Cu = \frac{D_{60}}{D_{10}}$$

where:

Cu = Coefficient of uniformity

D_{60} = Particle diameter corresponding to 60 percent finer on gradation curve. Data are reported on the Supplementary Data Sheet, Column 21.

D_{10} = Particle diameter corresponding to 10 percent finer on gradation curve. Data are reported on the Supplementary Data Sheet, Column 19.

Column 25: Curvature.

The coefficient of curvature (Cc) is used to evaluate the grading characteristics of coarse-grained soils. The Cc is calculated as follows:

Equation 20:

$$Cc = \frac{(D_{30})^2}{(D_{10} \times D_{60})}$$

where:

Cc = Coefficient of curvature

D_{30} = Particle diameter corresponding to 30 percent finer on gradation curve. Value calculated but not reported on data sheet.

D_{10} = Particle diameter corresponding to 10 percent finer on gradation curve. Data are reported in Column 21 on the Supplementary Data Sheet.

D_{60} = Particle diameter corresponding to 60 percent finer on gradation curve. Data are reported in Column 19 on the Supplementary Data Sheet.

5.2 SUPPLEMENTAL SHEET 1: TIER 2: COLUMNS 26 - 50:

Columns 26 - 38: WEIGHT FRACTIONS.

Weight fractions are reported as percentages on a whole-soil base in Columns 26 - 33 and on a <75-mm base in Columns 34 - 38. These data add detail to the distribution of the >2-mm particle-sizes. Weight percentages reported in these columns are derived from field and laboratory weights of coarse fragments, if available. If these data are not available, estimated field volume percentages and an estimated particle density are used for calculations. Refer to the discussion on weight percentages of the >2-mm fractions on the Primary Data Sheet (PSDA Sheet, Tier 1, Columns 16 - 20).

Some of these interpretive weight fractions reported in Columns 26 - 38 are also reported as analytical data on the Primary Data Sheet. Analytical and interpretive data may or may not be the exact same values because of the procedure of rounding and significant digits in calculating the data.

Column 26: Particles >2 mm, Whole-Soil Base.

Particles with >2-mm diameter are reported as a weight percentage on a whole-soil base. As used herein, the fine-earth fraction refers to particles with <2-mm diameter, and the whole soil is all particle-size fractions, including boulders with maximum horizontal dimensions less than those of the pedon. In addition, the term *rock fragments* means particles ≥2 mm in diameter and includes all particles with horizontal dimensions smaller than the size of the pedon and is not the same as the term *coarse fragments* which excludes stones and boulders with diameter ≥250 mm (Soil Survey Staff, 1975). The >250-mm division corresponds to the size opening in the 10-in screen (254 mm) used in engineering. Refer to Soil Survey Staff (1993) for additional discussion of rock fragments. Refer to additional discussion on particle-size distribution of the >2-mm fraction on a <75-mm base on the Primary Data Sheet (PSDA Sheet, Tier 1, Columns 16 - 20).

Column 27: Particles 250 mm - UP, Whole-Soil Base.
Particles with ≥250-mm diameter are reported as a weight percentage on a whole-soil base. Fragments with >250-mm particle diameter correspond to the rock fragment division, *stones* (Soil Survey Staff, 1993).

Column 28: Particles 75 - 250 mm, Whole-Soil Base.
Particles with 75- to 250-mm diameter are reported as a weight percentage on a whole-soil base. Coarse fractions with 75- to 250-mm particle diameter correspond to the rock fragment division, *cobbles* (Soil Survey Staff, 1993).

Column 29: Particles 2 - 75 mm, Whole-Soil Base.
Particles with 2- to 75-mm diameter ares reported as a weight percentage on a whole-soil base.

Column 30: Particles 20 - 75 mm, Whole-Soil Base.
Particles with 20- to 75-mm diameter are reported as a weight percentage on a whole-soil base.

Column 31: Particles 5 - 20 mm, Whole-Soil Base.
Particles with 5- to 20-mm diameter are reported as a weight percentage on a whole-soil base.

Column 32: Particles 2 - 5 mm, Whole-Soil Base.
Particles with 2- to 5-mm diameter are reported as a weight percentage on a whole-soil base.

Column 33: Particles <2 mm, Whole-Soil Base.
Particles with <2-mm diameter are reported as a weight percentage on a whole-soil base.

Column 34: Particles 2 - 75 mm, <75-mm Base.
Particles with 2- to 75-mm diameter are reported as a weight percentage on a <75-mm base. Coarse fractions with 2- to 75-mm particle diameter correspond to the rock fragment division, *pebbles* (Soil Survey Staff, 1993).

Column 35: Particles 20 - 75 mm, <75-mm Base.
Particles with 20- to 75-mm diameter are reported as a weight percentage on a <75-mm base. Coarse fractions with 20- to 75-mm particle diameter correspond to the rock fragment division, *coarse pebbles* (Soil Survey Staff, 1993). Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 18).

Column 36: Particles 5 - 20 mm, <75-mm Base.

Particles with 5- to 20-mm diameter are reported as a weight percentage on a <75-mm base. Coarse fractions with 2- to 5-mm particle diameter correspond to the rock fragment division, *medium pebbles* (Soil Survey Staff, 1993). Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 17).

Column 37: Particles 2 - 5 mm, <75-mm Base.

Particles with 2- to 5-mm diameter are reported as a weight percentage on a <75-mm base. Coarse fractions with 2- to 5-mm particle diameter correspond to the rock fragment division, *fine pebbles* (Soil Survey Staff, 1993). Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 16).

Column 38: Particles <2 mm, <75-mm Base.

Particles with <2-mm diameter are reported as a weight percentage on <75-mm base.

Column 39: Data column not used.

Columns 40 - 48: WEIGHT PER UNIT VOLUME.

Refer to the general discussion on bulk density on the Primary Data Sheet (PSDA Sheet, Tier 2, Columns 12 - 14). The SSL reports weight per unit volume on a whole-soil base in Columns 40 - 43 and <2-mm base in Columns 44 - 48. These data are calculated for soil survey and engineering purposes.

Column 40: Weight per Unit Volume (1/3 Bar), Whole-Soil Base, Soil Survey.

Weight per unit volume at 1/3-bar water content ($Db_{1/3}$) is reported in g cc^{-1} on a whole-soil base.

Equation 21:

$$Db_{1/3ws} = \frac{100}{\dfrac{Wt_{>2mm}}{SG_{>2mm}} + \dfrac{100 - Wt_{>2mm}}{Db_{1/3<2mm}}}$$

where:

$Db_{1/3ws}$ = Bulk density at 1/3-bar water content on a whole-soil base, (g cm^{-3}).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use analytical data for $Wt_{>2mm}$ fraction reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20). Interpretive data for $Wt>_{2mm}$ fraction are reported on the Supplementary Data Sheet (Column 26).

$SG_{>2mm}$ = Specific gravity of the whole soil, default value of 2.65 g cc^{-1}. For most >2-mm fractions, the specific gravity is ~ 2.65 g cc^{-1} (NSSL Staff, 1975). If these fractions are weathered, the specific gravity may be less, or if the fractions contain heavy minerals, the specific gravity may be greater than 2.65 g cc^{-1} (NSSL Staff, 1975). Specific gravity or particle density is herein defined as the density of solid particles collectively and is expressed as the ratio of the total mass of solid particles to their total volume excluding pore spaces between particles (Blake and Hartge, 1986).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 41: Weight per Unit Volume (Oven-dry), Whole-Soil Base, Soil Survey.

Weight per unit volume at ovendryness (Db_d) is reported in g cc^{-1} on a whole-soil base.

Equation 22:

$$Db_{dws} = \frac{100}{\dfrac{Wt_{>2mm}}{SG_{>2mm}} + \dfrac{100 - Wt_{>2mm}}{Db_{d<2mm}}}$$

where:

Db_{dws} = Bulk density at ovendryness on a whole-soil base (g cc^{-1}).

$Wt_{>2mm}$ = Weight percentage of the >2-mm fraction. Use analytical data for $Wt_{>2mm}$ fraction reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20). Interpretive data for $Wt>_{2mm}$ fraction are reported on the Supplementary Data Sheet (Column 26).

$SG_{>2mm}$ = Specific gravity of the whole soil, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{d<2mm}$ = Bulk density at ovendryness on a <2-mm base (g cc^{-1}). Analytical data for $Db_{d<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 14) and Supplementary Data Sheet (Column 45).

Column 42: Moist Weight per Unit Volume, Whole-Soil Base, Engineering.

Moist weight per unit volume is reported in g cc^{-1} on a whole-soil base. These data are calculated from the bulk density and 1/3-bar water content of the whole soil. For example, if the calculated density of moist soil is 1.85 g cm^{-3}, then 1 m^3 weighs 1.85 x 10^6 g or 1,850 kg. Since 1 yd^3 = 0.765 m^3 and 1 lb = 0.4536 kg, then the soil weighs ≈ 1.6T yd^{-3} or ≈ 116 lb ft^{-3}.

Equation 23:

$$MW/V_{ws} = Db_{1/3ws} + \frac{(Wt_{<2mm} \times (W_{1/3<2mm}/100)) \times Db_{1/3ws}}{100}$$

where:

MW/V_{ws} = Moist weight per unit volume on a whole-soil base (g cc^{-1}).

$Db_{1/3ws}$ = Refer to Equation 21 for Column 40 on the Supplementary Data Sheet.

$Wt_{<2mm}$ = Weight percentage of the <2-mm fraction on a whole-soil base. To obtain $Wt_{<2mm}$ fraction in equation, subtract analytical data for $Wt_{>2mm}$ fraction reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20) from 100%. Interpretive data for $Wt_{<2mm}$ fraction are reported on the Supplementary Data Sheet (Column 33).

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

Column 43: Saturated Weight per Unit Volume, Whole-Soil Base, Engineering.

Saturated weight per unit volume is reported in g cc^{-1} on a whole-soil base. These data are calculated from the bulk density and 1/3-bar water content of the whole soil plus the amount of water necessary to saturate the whole soil.

This calculation ignores the possibility for swelling with change in water content between 1/3 bar and saturation. For example, if the calculated wet density of a soil is 1.95 g cm^{-3}, then 1 m^3 weighs 1,950 kg. Since 1 yd^3 = 0.765 m^3 and 1 1b = 0.4536 kg, then the soil weighs ≈ 1.6T yd^{-3} or ≈ 122 lb ft^{-3}.

Equation 24:

$$SW/V_{ws} = Db_{1/3ws} + \left[1 - \frac{Db_{1/3ws}}{SG_{ws}}\right]$$

where:

SW/V_{ws} = Saturated weight per unit volume on a whole-soil base (g cc^{-1}).

$Db_{1/3ws}$ = Refer to Equation 21 in Column 40 on the Supplementary Data Sheet.

SG_{ws} = Specific gravity of the whole soil, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

Column 44: Weight per Unit Volume (1/3-Bar), <2-mm Base, Soil Survey.

Weight per unit volume at 1/3-bar water content ($Db_{1/3}$) is reported in g cc^{-1} on a <2-mm base. Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13).

Column 45: Weight per Unit Volume (15-Bar), <2-mm Base, Soil Survey.

Weight per unit volume at 15-bar water content (Db_{15}) is reported in g cc^{-1} on a <2-mm base. This calculation assumes that the change in bulk density with change in water content is a straight line but in actuality is more sigmoidal in nature.

Equation 25:

$$Db_{15<2mm} = Db_{1/3<2mm} + \left[(Db_d - Db_{1/3})_{<2mm} \, x \, \frac{W_{1/3<2mm} / W_{15<2mm}}{W_{1/3<2mm} - (AD/OD - 1)} \right]$$

where:

$Db_{15<2mm}$ = Weight per unit volume at 15-bar water content on a <2-mm base (g cc^{-1}).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

$Db_{d<2mm}$ = Bulk density at ovendryness on a <2-mm base (g cc^{-1}). Analytical data for $Db_{d<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 14).

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

$W_{15<2mm}$ = Weight percentage of water retained at 15-bar suction on a <2-mm base. Analytical data for $W_{15<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 19).

AD/OD = Air-dry/Oven-dry ratio. Ratio is not reported on either the Primary or Supplementary Data Sheet.

Bulk density, intermediate and weight per unit volume, 15-bar, <2-mm: The bulk density of clods at water contents intermediate between 1/3- or 1/10-bar water retention and ovendryness is termed *bulk density intermediate* (Db_i). The calculation for $Db_{15<2mm}$ (Equation 25) is essentially equivalent to the calculation for Db_i (Equation 26) when $Db_i = Db_{15<2mm}$. When $Db_i = Db_{15<2mm}$, the difference in the equations is that Equation 25 uses the laboratory data for AD/OD, whereas in Equation 26, the decimal fraction for 15-water content (Factor x W_{15}) is used to allow an approximation in the field. The Db_i is calculated (Grossman et al., 1990) as follows:

Equation 26:

$$Db_i = Db_f + \frac{(Db_d - Db_f) \times (W_f - W_i)}{W_f - (\text{Factor} \times W_{15})}$$

where:

Db_i = Bulk density intermediate between 1/3- or 1/10-bar water content and ovendryness on a <2-mm base (g cc^{-1}).

Db_f = Bulk density at 1/3- or 1/10-bar water content on a <2-mm base (g cc^{-1}). Bulk density at 1/3-bar water content is reported on the PSDA Sheet, Tier 2, Column 13.

Db_d = Bulk density at ovendryness on a <2-mm base (g cc^{-1}). Data are reported on the PSDA Sheet, Tier 2, Column 14.

W_f = Weight percentage of water retained at 1/3- or 1/10-bar suction on a <2-mm base. Water retention at 1/10 and 1/3-bar suctions are reported on the PSDA Sheet, Tier 2, Columns 17 and 18, respectively.

W_i = Weight percentage at intermediate water content. The W_i is not reported on the SSL data sheets.

Factor = Factors (F) related to linear extensibility (LE) are as follows:
F = 0.6 when LE = <0.06
F = 0.5 when LE = 0.06 - 0.09
F = 0.4 when LE = 0.09 - 0.12
F = 0.3 when LE = $\geq$0.12
W_{15} = Weight percentage of water retained at 15-bar suction on a <2-mm base. Data are reported on the PSDA Sheet, Tier 2, Column 19.

From Db_i an intermediate coefficient of linear extensibility ($COLE_i$) may be calculated (assume no >2-mm fraction) as follows:

Equation 27:

$$COLE_i = \sqrt[3]{\frac{Db_i}{Db_f}} - 1$$

where:
$COLE_i$ = Coefficient of linear extensibility intermediate.
Db_i = Bulk density intermediate between 1/3- or 1/10-bar water content and ovendryness on a <2-mm base (g cc^{-1}). The Db_i is not reported on the SSL data sheets.
Db_f = Bulk density at 1/3- or 1/10-bar water content on a <2-mm base (g cc^{-1}). Bulk density at 1/3-bar water content is reported on the PSDA Sheet, Tier 2, Column 13.

If field water content is estimated or measured, the associated Db_i may be computed and used for prediction of root restriction. The related intermediate extensibility may be helpful in the prediction of surface-connected cracks (Grossman et al., 1990). The Db_i and $COLE_i$ are not reported on the SSL data sheets.

Column 46: Weight per Unit Volume (Oven-dry), <2-mm Base, Soil Survey.

Weight per unit volume at ovendryness (Db_d) is reported in g cc^{-1} on a <2-mm base. Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 14).

Column 47: Moist Weight per Unit Volume, <2-mm Base, Engineering.

Moist weight per unit volume is reported in g cc^{-1} on a <2-mm base.

Equation 28:

$$MW/V_{<2mm} = Db_{1/3<2mm} + \left[Db_{1/3<2mm} x \left[W_{1/3<2mm} \Big/ 100\right]\right]$$

where:

$MW/V_{<2mm}$ = Moist weight per unit volume on a <2-mm base (g cm^{-3}).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

Column 48: Saturated Weight per Unit Volume, <2-mm Base, Engineering.

Saturated weight per unit volume is reported in g cc^{-1} on a <2-mm base.

Equation 29:

$$SW/V_{<2mm} = Db_{1/3<2mm} + \left[1 - \frac{Db_{1/3<2mm}}{SG_{<2mm}}\right]$$

where:

$SW/V_{<2mm}$ = Saturated weight per unit volume on a <2-mm base (g cc^{-1}).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet in Column 44. If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

$SG_{<2mm}$ = Specific gravity of the <2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

Column 49 - 50: VOID RATIOS.

Void ratio is defined as the ratio of volume of void space (space occupied by air and water) to volume of solids. This ratio is reported at 1/3-bar water content on a whole-soil base and on a <2-mm base in Columns 49 and 50, respectively.

Column 49: Void Ratio, 1/3-Bar, Whole-Soil.

Void ratio at 1/3- bar water content is reported on a whole-soil base.

Equation 30:

$$Void_{1/3ws} = \left[\frac{SG_{ws}}{Db_{1/3ws}}\right] - 1$$

where:

$Void_{1/3ws}$ = Void ratio at 1/3-bar water content on a whole-soil base.

SG_{ws} = Specific gravity of the whole soil, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3ws}$ = Refer to Equation 21 in Column 40 of the Supplementary Data Sheet.

Column 50: Void Ratio, 1/3-Bar, <2-mm base.

Void ratio at 1/3-bar water content is reported on a <2-mm base.

Equation 31:

$$\text{Void}_{1/3<2\text{mm}} = \left[\frac{SG_{<2mm}}{Db_{1/3<2mm}} \right] - 1$$

where:

$\text{Void}_{1/3<2\text{mm}}$ = Void ratio at 1/3-bar water content of <2-mm fraction.

$SG_{<2\text{mm}}$ = Specific gravity of the <2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2\text{mm}}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2\text{mm}}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

5.3 SUPPLEMENTAL SHEET 2: TIER 1: COLUMNS 51 - 75:

Columns 51 - 61: VOLUME FRACTIONS.

Volume fractions, as used in Columns 51 - 75, refer to the volume (percent) of components of a soil horizon at 1/3-bar water content on a whole-soil base. The 1/3-bar bulk density is used to convert mass (weight) to volume percents.

Column 51: Particles >2 mm.

Particles with >2-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 32:

$$P_{>2mm} = \left[\frac{Wt_{>2mm} / SG_{>2mm}}{Wt_{>2mm} / SG_{>2mm} + \left[(100 - Wt_{>2mm}) / Db_{1/3<2mm} \right]} \right] \text{ X } 100$$

where:

$P_{>2mm}$ = Volume percentage of particles with >2-mm diameter on a whole-soil base.

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for Wt$>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 52: Particles 250 mm - UP.
Particles with ≥250-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 33:

$$P_{\geq 250mm} = \left[\frac{Wt_{\geq 250mm} / SG_{>2mm}}{Wt_{>2mm} / SG_{>2mm} + \left[(100 - Wt_{>2mm}) / Db_{1/3<2mm} \right]} \right] \text{X } 100$$

where:

$P_{\geq 250mm}$ = Volume percentage of particles with ≥250-mm diameter on a whole-soil base.

$Wt_{\geq 250mm}$ = Weight percentage of ≥250-mm fraction on a whole-soil base. Interpretive data for $Wt_{>250mm}$ fraction are reported on the Supplementary Data Sheet (Column 27).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20) from 100%.

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of ≥250 mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 53: Particles 75 - 250 mm.

Particles with 75- to 250-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 34:

$$P_{75\text{-}250mm} = \left[\frac{Wt_{75-250mm} / SG_{>2mm}}{Wt_{>2mm} / SG_{>2mm} + \left[(100 - Wt_{>2mm}) / Db_{1/3<2mm} \right]} \right] X\ 100$$

where:

$P_{75\text{-}250mm}$ = Volume percentage of particles with 75- to 250-mm diameter on a whole-soil base.

$Wt_{75\text{-}250mm}$ = Weight percentage of 75- to 250-mm fraction on a whole-soil base. Use interpretive data for $Wt_{75\text{-}250mm}$ fraction reported on the Supplementary Data Sheet (Column 28).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 75- to 250-mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 54: Particles 2 - 75 mm.

Particles with 2- to 75-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 35:

$$P_{>2\text{-}75mm} = \left[\frac{Wt_{2-75mm} \big/ SG_{>2mm}}{Wt_{>2mm} \big/ SG_{>2mm} + \left[(100 - Wt_{>2mm}) \big/ Db_{1/3<2mm} \right]} \right] \text{ X } 100$$

where:

$P_{2\text{-}75mm}$ = Volume percentage of particles with 2- to 75-mm diameter on a whole-soil base.

$Wt_{2\text{-}75mm}$ = Weight percentage of 2- to 75-mm fraction on a whole-soil base. Use interpretive data for $Wt_{2\text{-}75mm}$ fraction reported on the Supplementary Data Sheet (Column 29).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 2- to 75-mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 55: Particles 20 - 75 mm.

Particles with 20- to 75-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 36:

$$P_{20\text{-}75mm} = \left[\frac{Wt_{20-75mm} \big/ SG_{>2mm}}{Wt_{>2mm} \big/ SG_{>2mm} + \left[(100 - Wt_{>2mm}) \big/ Db_{1/3<2mm} \right]} \right] \text{X } 100$$

where:

$P_{20\text{-}75mm}$ = Volume percentage of particles with 20- to 75-mm diameter on a whole-soil base.

$Wt_{20\text{-}75mm}$ = Weight percentage of 20- to 75-mm fraction on a whole-soil base. Use interpretive data for $Wt_{20\text{-}75mm}$ fraction reported on the Supplementary Data Sheet (Column 30).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 20- to 75-mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 56: Particles 5 - 20 mm.

Particles with 5- to 20-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 37:

$$P_{5\text{-}20mm} = \left[\frac{Wt_{5-20mm} / SG_{>2mm}}{Wt_{>2mm} / SG_{>2mm} + \left[(100 - Wt_{>2mm}) / Db_{1/3<2mm} \right]} \right] \text{X } 100$$

where:

$P_{5\text{-}20mm}$ = Volume percentage of particles with 5- to 20-mm diameter on a whole-soil base.

Wt_{5-20mm} = Weight percentage of 5- to 20-mm fraction on a whole-soil base. Use interpretive data for Wt_{5-20mm} fraction reported on the Supplementary Data Sheet (Column 31).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 5- to 20-mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 57: Particles 2 - 5 mm.

Particles with 2- to 5-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 38:

$$P_{2-5mm} = \left[\frac{Wt_{2-5mm} \Big/ SG_{>2mm}}{Wt_{>2mm} \Big/ SG_{>2mm} + \left[(100 - Wt_{>2mm}) \Big/ Db_{1/3<2mm} \right]} \right] \text{X } 100$$

where:

P_{2-5mm} = Volume percentage of particles with 2- to 5-mm diameter on a whole-soil base.

Wt_{2-5mm} = Weight percentage of 2- to 5-mm fraction on a whole-soil base. Use interpretive data for Wt_{2-5mm} fraction reported on the Supplementary Data Sheet (Column 32).

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt>_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 2- to 5-mm assumed to equal $SG_{>2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 58: Particles <2 mm.

Particles with <2-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 39:

$$P_{<2mm} = \left[\frac{Wt_{<2mm} / Db_{1/3<2mm}}{Wt_{<2mm} / Db_{1/3<2mm} + \left[(100 - Wt_{<2mm}) / SG_{>2mm} \right]} \right] \text{ X } 100$$

where:

$P_{<2mm}$ = Volume percentage of particles with <2-mm diameter on a whole-soil base.

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a 2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 59: Particles 0.05 - 2.0 mm.

Particles with 0.05- to 2-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 40:

$$P_{0.05\text{-}2.0mm} = \left[\frac{(100-Wt_{>2mm})x(Wt_{0.05-2.0mm}/100)\Big/SG_{<2mm}}{Wt_{>2mm}\Big/SG_{>2mm} + (100-Wt_{>2mm})\Big/Db_{1/3<2mm}}\right] x\ 100$$

where:

$P_{0.05\text{-}2.0mm}$ = Volume percentage of particles with 0.05- to 2-mm diameter (total sand) on a whole-soil base.

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{>2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$Wt_{0.05\text{-}2.0mm}$ = Weight percentage of 0.05- to 2-mm fraction on a <2-mm base. Analytical data for $Wt_{0.05\text{-}2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 6).

$SG_{<2mm}$ = Specific gravity of <2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 0.05- to 2.0-mm assumed to equal $SG_{<2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 60: Particles 0.002 - 0.05 mm.

Particles with 0.002- to 0.05-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 41:

$$P_{0.002-0.05mm} = \left[\frac{(100-Wt_{>2mm})x(Wt_{0.002-0.05mm.}/100)\Big/SG_{<2mm}}{Wt_{>2mm}\Big/SG_{>2mm} + (100-Wt_{>2mm})\Big/Db_{1/3<2mm}}\right] \text{ x } 100$$

where:

$P_{0.002-0.05mm}$ = Volume percentage of particles with 0.002- to 0.05-mm particle diameter (total silt) on a whole-soil base.

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{>2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$Wt_{0.002-0.05mm}$ = Weight percentage of 0.002- to 0.05-mm fraction on a <2-mm base. Analytical data for $Wt_{0.02-0.05mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 5).

$SG_{<2mm}$ = Specific gravity of <2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of 0.002 to 0.05-mm assumed to equal $SG_{<2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 61: Particles <0.002 mm.

Particles with <0.002-mm diameter are reported as a volume percentage on a whole-soil base.

Equation 42:

$$P_{<0.002mm} = \left[\frac{(100 - Wt_{>2mm}) x (Wt_{<0.002mm} / 100) \big/ SG_{<2mm}}{Wt_{>2mm} \big/ SG_{>2mm} + (100 - Wt_{>2mm}) \big/ Db_{1/3<2mm}} \right] \quad x\ 100$$

where:

$P_{<0.002mm}$ = Volume percentage of particles with <0.002-mm diameter (total clay) on a whole-soil base.

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{>2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$Wt_{<0.002mm}$ = Weight percentage of <0.002-mm fraction on a <2-mm base. Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$SG_{<2mm}$ = Specific gravity of <2-mm fraction, default value of 2.65 g cc^{-1}. Specific gravity of <0.002 mm assumed to equal $SG_{<2mm}$. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$SG_{>2mm}$ = Specific gravity of >2-mm fraction, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

$\mathrm{Db}_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $\mathrm{Db}_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $\mathrm{Db}_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Columns 62 - 63: PORE VOLUME, 1/3-BAR WATER CONTENT.

Drained and filled pores at 1/3-bar water content are reported as percentages on a whole-soil base. Refer to additional discussion on the calculation of air-filled porosity on the Primary Data Sheet (Acid Oxalate Sheet, Tier 1, Column 9). Also refer to additional discussion on water content and porosity on the Primary Data Sheet (PSDA Sheet, Tier 2, Columns 16 - 19). Total porosity (drained + filled pores) at 1/3-bar water content is calculated as follows:

Equation 43:

$$\mathrm{Pores}_{T} = 100 - \left[{Db_{1/3ws}} \big/ {SG_{ws}} \; x100 \right]$$

where:

Pores_T = Percent total porosity (drained + filled pores) at 1/3-bar water content on a whole-soil base.

$\mathrm{Db}_{1/3ws}$ = Refer to Equation 21 in Column 40 of the Supplementary Data Sheet.

SG_{ws} = Specific gravity of the whole soil, default value of 2.65 g cc^{-1}. Refer to Column 40 (Supplementary Data Sheet) for definition of specific gravity.

Column 62: Pores, Drained (D), 1/3-Bar Water Content.

Pores drained at 1/3-bar water content are reported as percent on a whole-soil base. These have been defined as noncapillary pores.

Equation 44:

$$\mathrm{Pores}_D = \mathrm{Pores}_T - (\mathrm{Db}_{1/3ws} \text{ x } (\mathrm{Wt}_{<2mm}/100) \text{ x } \mathrm{W}_{1/3<2mm})$$

where:

Pores_D = Percent pores drained at 1/3-bar water content on a whole-soil base.

Pores_T = Percent total porosity (drained + filled pores) at 1/3-bar water content on a whole-soil base.

$\text{Db}_{1/3ws}$ = Refer to Equation 21 in Column 40 of the Supplementary Data Sheet.

$\text{Wt}_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $\text{Wt}_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$\text{W}_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base (g H_2O 100 g^{-1} soil). Analytical data for $\text{W}_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18) and Supplementary Data Sheet (Column 44).

Column 63: Pores, Filled (F), 1/3-Bar Water Content.

Pores filled at 1/3-bar water content is reported as percent on a whole-soil base. Capillary pores.

Equation 45:

$$\text{Pores}_F = \text{Pores}_T - \text{Pores}_D$$

where:

Pores_F = Percent filled pores at 1/3-bar water content on a whole-soil base.

Pores_T = Percent total porosity at 1/3-bar water content on a whole-soil base. Refer to Equation 43 in Columns 62-63.

Pores_D = Refer to Equation 44 in Column 62 of the Supplementary Data Sheet.

Column 64: Carbon/Nitrogen (C/N) Ratio.

The C:N ratio provides information on soils relating to fertility and organic matter decomposition. Decomposed humified organic materials as found in a mollic epipedon usually have a C:N ratio of 10 or 12 to 1. Higher ratios in soils may suggest low decomposition levels or low N levels in plant residues and soils. Lower ratios may be a result of the accumulation of inorganic N in the soil horizon. Care is required in interpreting this ratio especially when the data are numerically small. Extremely low N levels can significantly inflate this ratio. Refer to additional discussion on the C:N ratio under the data element total N on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 2). Organic C is a measured value and is reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 1).

Columns 65 - 69: TOTAL CLAY, RATIOS.

Ratios of some properties to clay are provided in Columns 65 - 69. All these ratios are expressed on a <2-mm base.

Column 65: Fine Clay/Total Clay.

An increase in the ratio of fine clay to total clay with depth commonly occurs in soils that have argillic horizons. Refer to Soil Survey Staff (1975, 1992) for a more detailed discussion of this ratio and its use as a diagnostic criterion for argillic horizons. Both total and fine clay are measured values and are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Columns 4 and 7, respectively). The ratio of fine clay to total clay is reported on a <2-mm base in this data column.

Column 66: CEC-8.2/Total Clay.

Total clay is a measured value and is reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4). The CEC by sum of cations (CEC-8.2) is reported on the Acid or Salt Sheet, Tier 1, Column 8. The ratio of CEC-8.2 to total clay is reported on a <2-mm base in this data column.

Column 67: CEC-7/Total Clay.

In general, soils contain negatively charged colloids, and their CEC increases with increasing pH. This increase in CEC is due to pH dependent charge prevalent in oxide minerals and organic matter. As a rule of thumb, the CEC-8.2 > CEC-7 > ECEC. Refer to additional discussion on the CEC-7/clay ratio on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 8). The ratio of CEC-7 to total clay is reported on a <2-mm base in this data column.

Column 68: 15-Bar Water Content/Total Clay.

The 15-bar water retention on air-dry samples is a measured value and is reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 19). Total clay percentage on air-dry samples is also a measured value and is reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4). Refer to additional discussion on this ratio on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 9). The ratio of 15-bar water to total clay is reported on a <2-mm base in this data column.

Columns 69 - 73: LINEAR EXTENSIBILITY PERCENT.

The *coefficient of linear extensibility* (COLE) can be expressed as percent, i.e., *linear extensibility percent* (LEP). LEP = COLE x 100. The LEP is not the same as LE. In *Soil Taxonomy*, the LE of a soil layer is the product of the thickness, in centimeters, multiplied by the COLE of the layer in question, whereas the LE of a soil is the sum of these products for all soil horizons (Soil Survey Staff, 1975). Refer to additional discussion on COLE on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 15). Refer to additional discussion on LEP on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 15).

The SSL reports the ratio of LEP at 1/3-bar water to total clay on a <2-mm base in Column 69. The SSL reports the LEP between 1/3- and 15-bar water content on a whole-soil base in Column 70 and between 1/3-bar and ovendryness on a whole-soil base in Column 71. The SSL also reports the LEP between 1/3- and 15-bar water content on a <2-mm base in Column 72 and between 1/3-bar and ovendryness on a <2-mm base in Column 73.

Column 69: LEP/Total Clay, <2-mm Base.

Linear extensibility percent (LEP) or (COLE x 100) is a function of several factors including the kind and amount of clay. A ratio of LEP to clay takes out the factor of clay content and permits a more direct comparison of LEP and clay mineralogy (National Soil Survey Laboratory Staff, 1983). Cemented aggregates and $CaCO_3$ decrease the linear extensibility, i.e., decrease the potential to swell with increase in water content. Smectites usually have high LEP to clay ratios; kaolinites have low ratios; and micas or mixed layer clays have intermediate ratios. In a study of soils of Western United States (NSSL Staff, 1990), some LEP/clay relationships were determined as follows: smectite 0.18 (r^2 = 0.76, n = 291); clay mica 0.13 (r^2 = 0.77, n = 118); and kaolinite 0.08 (r^2 = 0.44, n = 71). Some general rules of thumb for LEP/clay ratios as related to clay mineralogy (NSSL Staff, 1983) are as follows:

LEP/clay	**Mineralogy**
>0.15	Smectites
0.05 - 0.15	Micas (illites) chlorites
<0.05	Kaolinites

Explanations should be sought if data deviate widely from the ranges indicated. The LEP/clay ratio as well as the CEC/clay ratio are useful as internal checks of the data as well as estimators of mineralogy when mineralogy data are not available (NSSL Staff, 1983). The ratio of linear extensibility to total clay is reported on a <2-mm base in this data column.

Coefficient of linear extensibility and linear extensibility percent, fine-earth fraction: The COLE and LEP values for the fine-earth fraction alone are referred to as $COLE_f$ and LE_f, respectively. The LE_f is a function of clay content, clay mineralogy, organic matter, and carbonate clay. The LE_f correlates with clay content (r = 0.90 to 0.95) and to a lesser extent with 15-bar water and cation exchange capacity (NSSL Staff, 1975).

With each absolute 10 percent increase in clay content, some general rules of thumb for $COLE_f$ increase in soils with 0 to 60 percent clay (NSSL Staff, 1975) are as follows:

Mineralogy	**$COLE_f$ increase**
nonexpanding 1:1 layer clays	0.005
nonexpanding 2:1 layer clays	0.01
nonexpanding 1:1 and 2:1 clays	0.01
mixed expanding and nonexpanding clays	0.06
expanding 2:1 layer clays	0.015 - 0.02

OR (alternatively)

Equations 46, 47, 48, 49, and 50:

LEP_f = 0 to 3% nonexpanding 1:1 layer clays
LEP_f = 0 to 6% nonexpanding 2:1 layer clays
LEP_f = 0 to 6% mixed nonexpanding 1:1 and 2:1 clays
LEP_f = 0 to 10% mixed expanding and nonexpanding clays
LEP_f = 0 to 15 - 20% expanding 2:1 layer clays

The shrink-swell classes based on LEP and COLE values, as defined in the National Soil Survey Handbook (1993), are as follows:

Class	**LEP**	**COLE**
Low	<3	<0.03
Moderate	3-6	0.03-0.06
High	6-9	0.06-0.09
Very High	>9	>0.09

Column 70: LEP, 1/3 to 15 Bar Water Content, Whole-Soil Base.

Linear extensibility between 1/3- and 15-bar water content is reported as percent on a whole-soil base. Refer to the discussion of $Db_{15<2mm}$ and Db_{i} on the Supplementary Data Sheet, Column 45 (Equations 25 and 26). The calculation of bulk density at 15-bar water content on a whole-soil base (Db_{15ws}) is required in order to calculate the LEP between 1/3- and 15-bar water content. The Db_{15ws} is calculated as follows:

Equation 51:

$$Db_{15ws} = \frac{[(A - B) \times (C - D) \times (E/100)]}{[E \times (C/100)] - [((F - 1) \times 100) \times (E/100)]} + B$$

where:

Db_{15ws} = Bulk density at 15-bar water content on a whole-soil base (g cc^{-1}).

A = Bulk density at ovendryness on a whole-soil base (g cc^{-1}). Interpretive data for Db_{dws} are reported on the Supplementary Data Sheet (Column 41).

B = Bulk density at 1/3-bar water content on a whole-soil base (g cc^{-1}). Interpretive data for $Db_{1/3ws}$ are reported on the Supplementary Data Sheet (Column 40).

C = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

D = Weight percentage of water retained at 15-bar suction on a <2-mm base. Analytical data for $W_{15<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 19).

E = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

F = Air-dry/Oven-dry ratio (AD/OD). Ratio is not reported on either the Primary or Supplementary Data Sheet.

Equation 52:

$$\text{LEP}_{1/3\text{ to }15ws} = \left[\left[\sqrt[3]{\frac{Db_{ws}}{Db_{1/3ws}}}\right]-1\right]x100$$

where:

$\text{LEP}_{1/3\text{ to }15ws}$ = Linear extensibility percent between 1/3- and 15-bar water content on a whole-soil base.

Db_{15ws} = Bulk density at 15-bar water content on a whole-soil base (g cc^{-1}). Refer to Equation 51 in Column 70 on the Supplementary Data for calculation of Db_{15ws}.

$\text{Db}_{1/3ws}$ = Bulk density at 1/3-bar water content on a whole-soil base (g cc^{-1}). Interpretive data for $\text{Db}_{1/3ws}$ are reported on the Supplementary Data Sheet (Column 40).

Column 71: LEP, 1/3 bar to Oven-dryness, Whole-Soil Base.

Linear extensibility between 1/3-bar water content and ovendryness is reported as percent on a whole-soil base.

Equation 53:

$$\text{LEP}_{1/3\text{ to }ODws} = \left[\left[\sqrt[3]{\frac{Db_{dws}}{Db_{1/3ws}}}\right]-1\right]x100$$

where:

$\text{LEP}_{1/3\text{ to }ODws}$ = Linear extensibility percent between 1/3-bar and ovendryness on a whole-soil base.

Db_{dws} = Bulk density at ovendryness on a whole-soil base (g cc^{-1}). Interpretive data for Db_{dws} are reported on the Supplementary Data Sheet (Column 41).

$Db_{1/3ws}$ = Bulk density at 1/3-bar water content on a whole-soil base (g cc^{-1}). Interpretive data for $Db_{1/3ws}$ are reported on the Supplementary Data Sheet (Column 40).

Column 72: LEP, 1/3 to 15 Bar, <2-mm Base.

Linear extensibility between 1/3- and 15-bar water content is reported as percent on a <2-mm base.

Equation 54:

$$LEP_{1/3\ to\ 15<2mm} = \left[\left[\sqrt[3]{\frac{Db_{15<2mm}}{Db_{1/3<2mm}}}\right] - 1\right] x100$$

where:

$LEP_{1/3\ to\ 15<2mm}$ = Linear extensibility percent between 1/3- and 15-bar water content on a <2-mm base.

$Db_{15<2mm}$ = Bulk density at 15-bar water content on a <2-mm base (g cc^{-1}). Interpretive data for $Db_{15<2mm}$ are reported on the Supplementary Data Sheet (Column 45).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Column 73: LEP, 1/3 Bar to Ovendryness, <2-mm Base.

Linear extensibility between 1/3-bar water content and ovendryness is reported as percent on a <2-mm base.

Equation 55:

$$\mathrm{LEP}_{1/3\ \mathrm{to\ OD}<2\mathrm{mm}} = \left[\left[\sqrt[3]{\frac{Db_{d<2mm}}{Db_{1/3<2mm}}}\right] - 1\right] x100$$

where:

$\mathrm{LEP}_{1/3\ \mathrm{to\ OD}<2\mathrm{mm}}$ = Linear extensibility percent 1/3- to 15-bar water content on a <2-mm base.

$\mathrm{Db}_{d<2mm}$ = Bulk density at ovendryness on a <2-mm base (g cc^{-1}). Analytical data for $\mathrm{Db}_{d<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 14) and Supplementary Data Sheet (Column 46).

$\mathrm{Db}_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $\mathrm{Db}_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $\mathrm{Db}_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

Columns 74 -75: WATER RETENTION DIFFERENCE (WRD).

Refer to the discussion on WRD on the Primary Data Sheet, Tier 2, Column 20. The WRD between 15 and 1/3-bar suctions is reported on the whole soil and <2-mm base in Columns 74 and 75, respectively. The units are expressed as in in^{-1}, but the numbers do not change when other units, e.g., cm cm^{-1} or ft ft^{-1} are needed.

Column 74: Water Retention Difference (WRD), Whole-Soil Base.

The WRD is reported between 15 and 1/3-bar suctions on a whole-soil base (in in^{-1}). Refer to additional discussion on this value on the Primary Data Sheet, Tier 2, Column 20 where these data are also reported.

Equation 56:

$$WRD_{ws} = \frac{(W_{1/3<2mm} - W_{15<2mm}) \quad x \; (Wt_{<2mm}/100) \quad x \; Db_{1/3ws}}{100}$$

where:

WRD_{ws} = Volume fraction (in^{3} in^{-3}) of water retained in the whole soil between 1/3-bar and 15-bar suction reported in inches of water per inch of soil (in in^{-1}). This is numerically equivalent to cm cm^{-1}.

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

$W_{15<2mm}$ = Weight percentage of water retained at 15-bar suction on a <2-mm base. If available, moist 15-bar (procedure 4B2b) is the first option in the WRD calculation; otherwise, dry 15-bar (procedure 4B2a) is used. Analytical data for $W_{15<2mm}$ moist and air-dry are reported on the Primary Data Sheets (Acid Oxalate Sheet, Tier 1, Column 12 and PSDA Sheet, Tier 2, Column 19, respectively).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$Db_{1/3ws}$ = Refer to Equation 21 in Column 40 of the Supplementary Data Sheet.

Column 75: Water Retention Difference (WRD), <2-mm Base.

The WRD is reported between 1/3 and 15-bar water content on a <2-mm base (in in^{-1}).

Equation 57:

$$WRD_{<2mm} = \frac{(W_{1/3<2mm} - W_{15<2mm}) \; x \; Db_{1/3<2mm}}{100}$$

where:

$WRD_{<2mm}$ = Volume fraction (in^3 in^{-3}) of water retained in the <2-mm fraction between 1/3-bar and 15-bar suction reported in inches of water per inch of soil (in^{-1}). This is numerically equivalent to cm cm^{-1}.

$W_{1/3<2mm}$ = Weight percentage of water retained at 1/3-bar suction on a <2-mm base. Analytical data for $W_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 18).

$W_{15<2mm}$ = Weight percentage of water retained at 15-bar suction on a <2-mm base. If available, moist 15-bar (procedure 4B2b) is the first option in the WRD calculation; otherwise, dry 15-bar (procedure 4B2a) is used. Analytical data for $W_{15<2mm}$ moist and air-dry are reported on the Primary Data Sheets (Acid Oxalate Sheet, Tier 1, Column 12 and PSDA Sheet, Tier 2, Column 19, respectively).

$Db_{1/3<2mm}$ = Bulk density at 1/3-bar water content on a <2-mm base (g cc^{-1}). Analytical data for $Db_{1/3<2mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 2, Column 13) and Supplementary Data Sheet (Column 44). If there is no measured value, then a $Db_{1/3}$ estimate, Db rewet (Db_r), or a default value of 1.45 g cm^{-3} may be used.

5.4 SUPPLEMENTAL SHEET 2: TIER 2: COLUMNS 76 - 100:

Columns 76 - 89: WEIGHT FRACTIONS, CLAY FREE BASE.

Weight fractions, data assessment: Laboratory data may be used to assess if a field designated discontinuity is corroborated; to see if any data show evidence of discontinuity not observed in the field, and if so, to help sort the lithological changes from the pedogenic changes (NSSL Staff, 1983). In some cases, the quantities of sand and coarser fractions are not altered significantly by soil-forming processes. As particle size increases, the change in particle-size by weathering decreases, i.e., an abrupt change in sand content is a clue to lithologic change (NSSL Staff, 1983). The gross soil mineralogy and the resistant mineral suite are other clues.

Weight fractions, sand ratios: Another aid used to assess lithological changes are ratios of one sand separate to another (NSSL Staff, 1983). The ratios can be computed and examined as a numerical array, or they can be plotted in graphical form. The ratios work well if sufficient quantities of the two fractions are present. Low quantities magnify changes in ratios, especially if the denominator is low.

Weight fractions, clay-free base: A common manipulation in assessing lithologic change is to compute sand and silt separates on a clay-free base. Clay distribution is subject to pedogenic change and may mask inherited lithologic differences (NSSL Staff, 1983). The numerical array on a clay-free base can be inspected visually or plotted in graphical form. Particle-size data are reported on a whole-soil clay-free base in Columns 76 - 81 and on a <2-mm clay-free base in Columns 82 - 89.

Column 76: Particles >2 mm.

Particles with >2-mm diameter are reported as a weight percentage on a whole-soil clay-free base. Whole-soil clay-free base = >2-mm fraction + total sand + total silt.

Equation 58:

$$P_{>2mm} = \left[\frac{Wt_{>2mm}}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] \text{x } 100$$

where:

$P_{>2mm}$ = Weight percentage of particles with >2-mm diameter on a whole-soil clay-free base.

$Wt_{>2mm}$ = Weight percentage of >2-mm fraction. Use interpretive data for Wt>$_{2mm}$ fraction reported on the Supplementary Data Sheet (Column 26). Analytical data for $Wt_{>2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 20).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 77: Particles 2 - 75 mm.

Particles with 2- to 75-mm diameter are reported as a weight percentage on a whole-soil clay-free base.

Equation 59:

$$P_{2\text{-}75mm} = \left[\frac{Wt_{2-75mm}}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] \text{ x } 100$$

where:

$P_{2\text{-}75mm}$ = Weight percentage of particles with 2- to 75-mm diameter on a whole-soil clay-free base.

$Wt_{2\text{-}75mm}$ = Weight percentage of particles with 2- to 75-mm diameter on a whole-soil base. Use interpretive data for $Wt_{2\text{-}75mm}$ fraction reported on the Supplementary Data Sheet (Column 29).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 78: Particles 2 - 20 mm.

Particles with 2- to 20-mm diameter are reported as a weight percentage on a whole-soil clay-free base.

Equation 60:

$$P_{>2\text{-}20mm} = \left[\frac{Wt_{2-20mm}}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] \text{ x } 100$$

where:

$P_{2\text{-}20mm}$ = Weight percentage of particles with 2- to 20-mm diameter on a whole-soil clay-free base.

$Wt_{2\text{-}20mm}$ = Weight percentage of particles with 2- to 20-mm diameter on a whole-soil base. Use interpretive data for $Wt_{2\text{-}20mm}$ fraction reported on the Supplementary Data Sheet (Columns 31 and 32).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 79: Particles 0.05 - 2 mm.

Particles with 0.05- to 2-mm diameter are reported as a weight percentage on a whole-soil clay-free base.

Equation 61:

$$P_{0.05\text{-}2mm} = \left[\frac{Wt_{<2mm} x \left[{Wt_{0.05-2mm}}/{100} \right]}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] \text{ x } 100$$

where:

$P_{0.05-2mm}$ = Weight percentage of particles with 0.05- to 2-mm diameter (total sand) on a whole-soil clay-free base.

$Wt_{0.05-2mm}$ = Weight percentage of particles with 0.05- to 2-mm diameter (total sand) on a <2-mm base. Analytical data for $Wt_{0.05-2mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 6).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction reported on the Supplementary Data Sheet (Column 33).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter on a <2-mm base. Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 80: Particles 0.002 - 0.05 mm.

Particles with 0.002- to 0.05-mm diameter are reported as a weight percentage on a whole-soil clay-free base.

Equation 62:

$$P_{0.002-0.05mm} = \left[\frac{Wt_{<2mm} x \left[{Wt_{0.002-0.05mm}}/{100} \right]}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] x\ 100$$

where:

$P_{0.002-0.05mm}$ = Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt) on a whole-soil clay-free base.

$Wt_{0.002\text{-}0.05mm}$ = Weight percentage of particles with 0.002- to 0.05-mm diameter (total silt) on a <2-mm base. Analytical data for $Wt_{0.002\text{-}0.05mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 5).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction are reported on the Supplementary Data Sheet (Column 33).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 81: Particles <0.002 mm.

Particles with <0.002-mm diameter are reported as a weight percentage on a whole-soil clay-free base. These data have application in assessing discontinuities only if all the clay is inherited in the sediment, i.e., there is no pedogenic clay.

Equation 63:

$$P_{<0.002mm} = \left[\frac{Wt_{<2mm} x \left[Wt_{0.002mm} / 100 \right]}{100 - \frac{(Wt_{<2mm} x Wt_{<0.002mm})}{100}} \right] \text{ x } 100$$

where:

$P_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay) on a whole-soil clay-free base.

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter on a <2-mm base. Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

$Wt_{<2mm}$ = Weight percentage of <2-mm fraction on a whole-soil base. Use interpretive data for $Wt_{<2mm}$ fraction are reported on the Supplementary Data Sheet (Column 33).

Column 82: Very Coarse Sand, (1.0 - 2.0 mm).

Very coarse sand (1.0- to 2.0-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base. The <2-mm clay-free base = total sand + total silt.

Equation 64:

$$P_{1.0\text{-}2.0mm} = \left[\frac{Wt_{1.0-2.0mm}}{(100 - Wt_{<0.002mm})}\right] \text{ x } 100$$

where:

$P_{1.0\text{-}2.0mm}$ = Weight percentage of particles with 1.0- to 2.0-mm diameter (very coarse sand) on a <2-mm clay-free base.

$Wt_{1.0\text{-}2.0mm}$ = Weight percentage of particles with 1.0- to 2.0-mm diameter (very coarse sand) on a <2-mm base. Analytical data for $Wt_{1.0\text{-}2.0mm}$ are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 15).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 83: Coarse Sand (0.5 - 1.0 mm).

Coarse sand (0.5- to 1.0-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 65:

$$P_{0.05\text{-}1.0mm} = \left[\frac{Wt_{0.05-1.0mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.50\text{-}1.0mm}$ = Weight percentage of particles with 0.5- to 1.0-mm diameter (coarse sand) on a <2-mm clay-free base.

$Wt_{0.50\text{-}1.0mm}$ = Weight percentage of particles with 0.50- to 1.0-mm diameter (coarse sand) on a <2-mm base. Analytical data for $Wt_{0.50\text{-}1.0mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 14).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 84: Medium Sand (0.25 - 0.50 mm).

Medium Sand (0.25- to 0.50-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 66:

$$P_{0.25\text{-}0.50mm} = \left[\frac{Wt_{0.25-0.50mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.25\text{-}0.50mm}$ = Weight percentage of particles with 0.25- to 0.50-mm diameter (medium sand) on a <2-mm clay-free base.

$Wt_{0.25\text{-}0.50mm}$ = Weight percentage of particles with 0.25- to 0.50-mm diameter (medium sand) on a <2-mm base. Analytical data for $Wt_{0.25\text{-}0.50mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 13).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 85: Fine Sand (0.10 - 0.25 mm).

Fine sand (0.10- to 0.25-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 67:

$$P_{0.10\text{-}0.25mm} = \left[\frac{Wt_{0.10-0.25mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.10\text{-}0.25mm}$ = Weight percentage of particles with 0.10- to 0.25-mm diameter (fine sand) on a <2-mm clay-free base.

$Wt_{0.10\text{-}0.25mm}$ = Weight percentage of particles with 0.10- to 0.25-mm diameter (fine sand) on a <2-mm base. Analytical data for $Wt_{0.10\text{-}0.25mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 12).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 86: Very Fine Sand (0.05 - 0.10 mm).

Very fine sand (0.05- to 0.10-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 68:

$$P_{0.05\text{-}0.10mm} = \left[\frac{Wt_{0.05-0.10mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.05\text{-}0.10mm}$ = Weight percentage of particles with 1.0- to 2.0-mm diameter (very fine sand) on a <2-mm clay-free base.

$Wt_{0.05\text{-}0.10mm}$ = Weight percentage of particles with 0.05- to 0.10-mm diameter (very fine sand) on a <2-mm base. Analytical data for $Wt_{0.05\text{-}0.10mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 11).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 87: Coarse Silt (0.02 - 0.05 mm).

Coarse silt (0.02- to 0.05-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 69:

$$P_{0.02\text{-}0.05mm} = \left[\frac{Wt_{0.02-0.05mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.02-0.05mm}$ = Weight percentage of particles with 0.02- to 0.05-mm diameter (coarse silt) on a <2-mm clay-free base.

$Wt_{0.02-0.05mm}$ = Weight percentage of particles with 0.02- to 0.05-mm diameter (coarse silt) on a <2-mm base. Analytical data for $Wt_{0.02-0.05mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 10).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 88: Fine Silt (0.002 - 0.02 mm).

Fine silt (0.002- to 0.02-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 70:

$$P_{0.002-0.02mm} = \left[\frac{Wt_{0.002-0.02mm}}{(100 - Wt_{<0.002mm})}\right] \times 100$$

where:

$P_{0.002-0.02mm}$ = Weight percentage of particles with 0.002- to 0.02-mm diameter (fine silt) on a <2-mm clay-free base.

$Wt_{0.002-0.02mm}$ = Weight percentage of particles with 0.002- to 0.02-mm diameter (fine silt) on a <2-mm base. Analytical data for $Wt_{0.002-0.02mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 9).

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 89: Total Clay (<0.002 mm).

Total clay (<0.002-mm particle diameter) is reported as a weight percentage on a <2-mm clay-free base.

Equation 71:

$$P_{<0.002mm} = \left[\frac{Wt_{<0.002mm}}{(100 - Wt_{<0.002mm})}\right] \text{ x } 100$$

where:

$P_{<0.002mm}$ = Weight percentage of particles with 1.0- to 2.0-mm diameter (total clay) on a <2-mm clay-free base.

$Wt_{<0.002mm}$ = Weight percentage of particles with <0.002-mm diameter (total clay). Analytical data for $Wt_{<0.002mm}$ fraction are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Columns 90 - 91: TEXTURE.

Texture, definition: The term *texture* is defined in Webster's Dictionary as "something composed of closely interwoven elements; the visual or tactile surface characteristics and appearance of something; a basic scheme or overall structure". Although soil texture is a seemingly simple basic concept in soil science, its consistent application has not been easy (Soil Survey Staff, 1951). Historically, the textural terms were related not only to the qualities of texture but also had some connotations of both consistence and structure, as these soil properties are related in part to texture (Soil Survey Staff, 1951). However, as investigations of all soils continued, scientists realized that structure, consistence, and texture had to be measured or observed separately. In addition, the early laboratory methods for soil dispersion were so inadequate that fine granules of clay were reported as silt or sand. Structure and consistence are related not only to the amount of clay but also on the kind and condition of the clay, as well as other constituents and living tissue in the soil (Soil Survey Staff, 1951). Textural class names are not used to express differences in consistence or structure; else the names lose their fundamental significance (Soil Survey Staff, 1951).

Soil texture, field and laboratory determined: The determination of soil textural class is made in the field mainly by feeling of the soil with the fingers, sometimes supplemented by examination under the hand lens. This requires skill and experience, but good accuracy can be obtained if the field scientist frequently checks against laboratory results, especially for each soil varying widely from other soils of the area in structure, consistence, and organic matter content (Soil Survey Staff, 1951). Refer to Shaw (1928) for the early definitions of the basic soil textural classes as related to field experience and "feel". These definitions were intended to be suggestive only, limited to a group of similar soils and not applicable to all soils (Soil Survey Staff, 1951). Refer to additional discussion on field determination of soil textural class in the Soil Survey Manual (1951, 1993). Definitions of the basic soil classes are presented in graphic form in the USDA textural triangle (Appendix IV, shown in black).

Soil texture, data reporting: The field-determined soil texture is reported in Column 90. Laboratory-determined texture is reported in Column 91. Soil texture class names are reported as codes (abbreviations). Texture class names are based first on the distribution of sand, silt, and clay and then, for some classes, on the distribution of several size fractions of sand. Names are based on PSDA data to the nearest 1 percent applied to definitions of the texture classes (Soil Survey Staff, 1951). The texture class codes are as follows:

COS - coarse sand
S - sand
FS - fine sand
VFS - very fine sand
LCOS - loamy coarse sand
LS - loamy sand
LFS - loamy fine sand
LVFS - loamy very fine sand
COSL - coarse sandy loam
SL - sandy loam
FSL - fine sandy loam
VFSL - very fine sandy loam
L - loam
SIL - silt loam
SI - silt
SCL - sandy clay loam
CL - clay loam
SICL - silty clay loam
SC - sandy clay
SIC - silty clay
C - clay

Column 90: Texture Determined, Field.

Field-determined soil texture is reported. The field texture reported on the SSL request form is the source data for this entry on the Supplementary Data Sheet.

Column 91: Texture Determined, PSDA.

Laboratory-determined soil texture is reported. Data may or may not agree with the field-determined texture reported on the Supplementary Data Sheet in Column 90. Field estimates at the time of sampling are in themselves considered important and are retained, even though these estimates sometimes vary with SSL data. The record as to what was perceived at the time of sampling is deemed to be more important than the achievement of complete editorial uniformity.

Columns 92 - 94: PARTICLE-SIZE DISTRIBUTION ANALYSIS (PSDA), Particles, < 2 mm.

Particle-size distribution analysis summaries are reported for the soil horizons. Refer to the discussion on particles with <2-mm diameter on the Primary Data Sheet, (PSDA Sheet, Tier 1, Columns 4 - 15). These PSDA summaries are expressed on a <2-mm base.

Column 92: Total Sand (0.05 - 2.0 mm).

Total sand (0.05- to 2.0-mm diameter) is reported as a weight percentage on a <2-mm base. Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 6).

Column 93: Total Silt (0.002 - 0.05 mm).

Total silt (0.002- to 0.05-mm diameter) is reported as a weight percentage on a <2-mm base. The silt to clay ratio is an important criterion for classification of soils in the tropics (Van Wambeke, 1962) and for evaluating phenomena such as clay migration, stage of weathering, and age of parent material (Ashaye, 1969). In general, soils with high silt contents are associated with unweathered soils that are fertile. Sandy clay and sandy clay loam textures (low silt contents) are common in highly weathered materials. Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 5).

Column 94: Total Clay (<0.002 mm).

Total clay (<0.002-mm diameter) is reported as a weight percentage on a <2-mm base. Analytical data are reported on the Primary Data Sheet (PSDA Sheet, Tier 1, Column 4).

Column 95: pH, $CaCl_2$ 0.01 *M*.

Refer to the discussion on pH, $CaCl_2$ 0.01 *M* on the Primary Data Sheet (Acid Sheet, Tier 1, Column 19).

Column 96: Electrical Resistivity.

Refer to the discussion on resistivity of the soil paste on the Primary Data Sheet (Acid Sheet, Tier 1, Column 15).

Column 97: Electrical Conductivity.
Refer to the discussion on electrical conductivity of the saturation extract on the Primary Data Sheet (Salt Sheet, Tier 2, Column 12).

Column 98: Data column not used.

Column 99: Data column not used.

Column 100: Data column not used.

APPENDIX I

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APPENDIX I

                                            ***   P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S88ME-003-001                                          (AROOSTOOK COUNTY, MAINE                         )
                                                                                                                        PRINT DATE 08/01/94
SAMPLED AS    : CARIBOU                  ; FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
REVISED TO    : CARIBOU                  ; LOAMY-SKELETAL, MIXED, FRIGID TYPIC DYSTROCHREPT
                                                                                                         U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 88P 127, (CP88ME188) WEPP MAINE                                                            SOIL CONSERVATION SERVICE
    - PEDON   88P 722, SAMPLES 88P 3855- 3860                                                            SOIL SURVEY LABORATORY
    - GENERAL METHODS  1B1A, 2A1, 2B                                                                     NATIONAL SOIL SURVEY CENTER
                                                                                                         LINCOLN, NEBRASKA 68508-3866
                                                                        PSDA SHEET

            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
--------- -------------------------------------------------------------------------------------------------------------------------
                             (- - -TOTAL - - -)(- -CLAY- -)(- -SILT- -)(- - - -  - -SAND- -  - - - -)(-COARSE FRACTIONS(MM)-)(>2MM)
                              CLAY  SILT  SAND  FINE   CO3  FINE COARSE   VF     F     M     C    VC   - - - - WEIGHT - - - -    WT
SAMPLE     DEPTH   HORIZON     LT  .002   .05    LT    LT  .002   .02   .05   .10   .25    .5     1   2     5    20        .1- PCT OF
 NO.       (CM)               .002  -.05    -2 .0002  .002  -.02  -.05  -.10  -.25  -.50    -1    -2  -5   -20   -75       75  WHOLE
                              <- - - - - - - - - - - - - PCT OF <2MM  (3A1) - - - - - - - - - - - - - - ->  <- PCT OF <75MM(3B1)->  SOIL

88P3855M   0- 11   AP1         12.2  40.8  47.0   1.5        25.6  15.2  11.5  11.0   7.8   7.0   9.7   9    18    18      65  45
88P3856M  11- 24   AP2         12.1  42.8  45.1   1.1        26.3  16.5  11.1  12.0   8.6   6.7   6.7  10    19     9      59  38
88P3857M  24- 39   BS          12.3  44.5  43.2   1.4        28.9  15.6  12.1  11.8   7.9   6.5   4.9   5     7    41      68  53
88P3858M  39- 66   C1          13.3  44.9  41.8   3.3        26.2  18.7  13.1  12.1   8.0   5.1   3.5   4     1     4      35  13
88P3859M  66-104   C2          11.3  17.6  71.1   3.4        12.4   5.2   2.8   3.7   9.3  19.6  35.7  15    29    34      93  83
88P3860M 104-143   C3          23.2  45.2  31.6   7.3        26.9  18.3   6.5   7.1   6.3   6.2   5.5   8    10    20      54  46

Tier 2:  Columns 1 - 20
--------- -------------------------------------------------------------------------------------------------------------------------
            ORGN TOTAL  EXTR TOTAL (- - DITH-CIT - -)(RATIO/CLAY)(ATTERBERG )(- BULK DENSITY -) COLE (- - -WATER CONTENT - -)  WRD
             C      N      P     S        EXTRACTABLE           15    - LIMITS -  FIELD   1/3  OVEN WHOLE FIELD  1/10   1/3    15 WHOLE
 DEPTH                                FE    AL     MN    CEC   BAR    LL      PI  MOIST   BAR   DRY  SOIL MOIST   BAR   BAR   BAR  SOIL
  (CM)      6A1c  6B3a   6S3  6R3a  6C2b  6G7a  6D2a   8D1   8D1   4F1      4F  4A3a  4A1d  4A1h   4D1   4B4  4B1c  4B1c  4B2a   4C1
            PCT   <2MM   PPM <- PERCENT  OF  <2MM -->               PCT <0.4MM  <- - G/CC - - -> CM/CM  <- - -PCT OF <2MM - -> CM/CM

   0- 11     2.28 0.193               1.3   0.4          1.05  0.73    32     3                                                8.9
  11- 24     1.80 0.170               1.1   0.3          0.97  0.71                        1.24  1.29 0.010              26.9   8.6  0.18
  24- 39     0.93                     1.4   0.3          0.80  0.63                        1.47  1.50 0.004              20.7   7.8  0.12
  39- 66     0.16                     0.9   0.1          0.44  0.80    28     2            1.81  1.84 0.005              13.8  10.7  0.05
  66-104     0.16                     1.4   0.1          1.04  0.58                                                            6.6
 104-143     0.24                     2.0   0.1          0.44  0.52                        1.63  1.69 0.008              19.3  12.0  0.08

--------- -------------------------------------------------------------------------------------------------------------------------

        AVERAGES,    DEPTH  25-100:  PCT CLAY   12  PCT  .1-75MM    67
```

APPENDIX I (continued)

*** PRIMARY CHARACTERIZATION DATA ***

S88ME-003-001 PRINT DATE 08/01/94
SAMPLED AS : CARIBOU ; FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 88P 722, SAMPLE 88P 3855- 3860

ACID SHEET

Tier 1: Columns 1 - 20

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
	(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - - -CEC - - - -)			AL	-BASE SAT-		CO3 AS	RES.		COND.		(- - - -PH - - -)	
	CA	MG	NA	K	SUM	ITY	AL	SUM	NH4-	BASES	SAT	SUM	NH4	CACO3	OHMS		MMHOS		CACL2	H2O
DEPTH	5B5a	5B5a	5B5a	5B5a	BASES			CATS	OAC	+ AL			OAC	<2MM	/CM		/CM		.01M	
(CM)	6N2e	6O2d	6P2b	6Q2b		6H5a	6G9b	5A3a	5A8b	5A3b	5G1	5C3	5C1	6E1g	8E1		8I		8C1f	8C1f
	<- - - - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->										<- - - - - -PCT - - - - ->								1:2	1:1
0- 11	5.5	1.5	0.1	0.6	7.7	14.0		21.7	12.8			35	60						5.3	5.6
11- 24	3.4	0.9	0.1	0.3	4.7	15.0	0.9	19.7	11.7	5.6	16	24	40						4.8	5.2
24- 39	1.2	0.3	0.1	0.2	1.8	12.7	1.5	14.5	9.8	3.3	45	12	18						4.6	4.9
39- 66	1.5	0.4	0.1	0.2	2.2	6.6	0.5	8.8	5.9	2.7	19	25	37						4.5	4.9
66-104	4.0	0.6	0.1	0.2	4.9	4.5	0.1	9.4	11.7	5.0	2	52	42						4.9	5.4
104-143	9.5	0.6	0.1	0.1	10.3	2.5		12.8	10.2			80	100						6.9	7.4

Tier 2: Columns 1 - 20

	(- - - -SPODIC HORIZON CRITERIA - - - - - -)						
	(- -NA PYROPHOSPHATE EXTRACTABLE- -)						INDEX
	C	FE	AL	FE+AL	FE+AL	AL+C	OF
DEPTH				(- -DIVIDED BY- -)			ACCUM
(CM)	6A4a	6C8a	6G10	DI-CI	PCT	PCT	
	<- PCT OF <2MM->			FE+AL	CLAY	CLAY	
0- 11		0.4	0.4	0.5	0.1		
11- 24		0.5	0.5	0.7	0.1		
24- 39		0.5	0.3	0.5	0.1		
39- 66		0.1	0.1	0.2			
66-104		0.1	0.1	0.1			
104-143		TR	TR				

ANALYSES: M= ALL ON SIEVED <2mm BASIS

APPENDIX I (continued)

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                          ***   P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S88ME-003-001                          (AROOSTOOK COUNTY, MAINE                          )
                                                                                                          PRINT DATE 08/01/94
CLASSIFICATION: CARIBOU             ; LOAMY-SKELETAL, MIXED, FRIGID TYPIC DYSTROCHREPT
                                                                                               U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 88P 127, (CP88ME188) WEPP MAINE                                                  SOIL CONSERVATION SERVICE
    - PEDON   88P 722, SAMPLES 88P 3855- 3860                                                  SOIL SURVEY LABORATORY
    - GENERAL METHODS  1B1A, 2A1, 2B                                                           NATIONAL SOIL SURVEY CENTER
                                                                                               LINCOLN, NEBRASKA 68508-3866
                                                       ACID-OXALATE SHEET

                  -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
----------------------------------------------------------------------------------------------------------------------------------
                ACID OXALATE EXTRACTION  PHOSPHOUS   KCL   TOTAL  (- -WATER  CONTENT- - )(- - - - WATER DISPERSIBLE - - - - ) MIN   AGGRT
                 OPT   FE    SI    AL            CIT-   MN     C    0.06    1-    2-     15  <- - PIPETTE - - >< - HYDROMETER - > SOIL  STABL
                 DEN                      RET   ACID                BAR    BAR   BAR    BAR  CLAY  SILT  SAND  CLAY  SILT  SAND   CONT  <5mm
SAMPLE   HZ      8J   6C9a  6V2   6G12   6S4    6S5   6D3   6A2d   4B1c   4B1a  4B1a  4B2b <- - - 3A1c - - -><- - - SML  - - -> 8F1   4G1
 NO.     NO          <- P C T  o f < 2 m m -><- P P M  -><- - - - - - - - - - - P E R C E N T  o f  < 2 m m - - - - - - - - - - - >< PCT>

88P3855  1  0.16  1.07  0.09  0.58                     1.98                     9.9   7.7  41.9  50.4
88P3856  2  0.15  1.07  0.09  0.55                                              9.9
88P3857  3  0.13  1.39  0.08  0.52                                             11.6
88P3858  4  0.08  0.49  0.06  0.22                                              5.1
88P3859  5  0.06  0.74  0.09  0.20                                              6.9
88P3860  6  0.05  0.77  0.12  0.21                                             16.3

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APPENDIX I (continued)
                                         ***  P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A  ***

S88ME-003-001                                                                                                   PRINT DATE 08/01/94
SAMPLED AS    : CARIBOU                ; FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 88P 722, SAMPLE 88P 3855- 3860

                                                            MINERALOGY SHEET

            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
--------- ------------------------------------------------------------------------------------------------------------------------
            < - - - - - - - - - - - - - - - - - - - - - - - CLAY MINERALOGY (<.002mm) - - - - - - - - - - - - - - - - - - - - - - - - >
            FRACT < - - - - - - X-RAY - - - - - - ->< - - - THERMAL - - - ->< - - - - - - - - - ELEMENTAL - - - - - - - - ->< - -> EGME  INTER
SAMPLE       ION <                        >< - DTA - ->< - TGA - -> SiO2 AL2O3 Fe2O3  MgO   CaO   K2O   Na2O <    > RETN  PRETA
                  < - - - - - - 7A2i - - - - - - ->< - 7A6  - >< - 7A4b - >< - - - - - - - - - - - 7C3 - - - - - - - - - - ->< > 7D2    TION
NUMBER      <- - >< - - - - peak size - - - - - ->< - - - Percent - - - ->< - - - - - - - - - - Percent - - - - - - - - - ->< - -><mg/g>< - ->

88P3855      TCLY  KK 2  VR 2  MI 1                                            5.7               1.4                 15
88P3857      TCLY  VR 3  KK 2  MI 2                                           10.4               1.7

Tier 2:  Columns 1 - 20
--------- ------------------------------------------------------------------------------------------------------------------------
            < - - - - - - - - - - - - - - - - - - - - - - - SAND - SILT MINERALOGY (2.0-0.002mm) - - - - - - - - - - - - - - - - - - - - - - - - >
            FRACT < - - - - - - X-RAY - - ->< - - - THERMAL - - - ->< - - - - - - - - OPTICAL - - - - - - - - - -><                        > INTER
SAMPLE       ION <                   >< - DTA - ->< - TGA - ->TOT RE< - - - - - - GRAIN COUNT - - - - - - -><                        > PRETA
                  < - - - - - 7A2i - - - - - >< - 7A3b - >< - 7A4b - >< - - - - - - - - 7B1a - - - - - - - - - -><                        >  TION
NUMBER      < - -><- - - Peak Size - - - ->< - - - Percent - - - ->< - - - - - - - - - - Percent - - - - - - - - - ->< - - - - - - - - - ->< - ->

88P3857      VFS                                                     93  QZ90  OT 5  OP 3  BT 1  FK 1  FP 1
88P3857      VFS                                                         CL 1  ZRtr  PRtr  GNtr  HNtr

--------- ------------------------------------------------------------------------------------------------------------------------

FRACTION INTERPRETATION:

    TCLY  Total Clay, <0.002mm             VFS   Very Fine Sand, 0.05-0.10mm

MINERAL INTERPRETATION:

    KK  kaolinite        VR  vermiculite      MI  mica             QZ  quartz           OT  other            OP  opaques
    BT  biotite          FK  potas-feld       FP  plag-feld        CL  chlorite         ZR  zircon           PR  pyroxene
    GN  garnet           HN  hornblende

RELATIVE PEAK SIZE:   5 Very Large   4 Large   3 Medium   2 Small   1 Very Small   6 No Peaks

INTERPRETATION (BY HORIZON):


PEDON MINERALOGY
    BASED ON SAND/SILT:
    BASED ON CLAY:
    FAMILY MINERALOGY:
    COMMENTS:
```

NARRATIVE PEDON DESCRIPTION

Pedon: Caribou
NSSL Pedon Number: 88P0722
Soil Survey Number S88-ME-003-001
Print Date: 08/01/94
Location: Aroostook County, Maine
2 mi N of Presque Isle on Rt. 1, 1.1 mi E on Rt. 210, 2300' N on field Rd, 100' E.
Latitude: 46-00-55-N
Longitude: 068-01-11-W
Physiography: in glaciated uplands
Geomorphic Position: backslope sideslope
Microrelief: on middle third of component
Slope: 6% convex north facing
Elevation: 190 m MSL
Precipitation: 102 cm - Udic Moisture Regime.
MLRA: 146 Aroostook Area
Water Table Depth:
Permeability: Moderate
Air Temperature: Ann: 42 Summ: Win:
Soil Temperature: Ann: 44 Summ: Win:
Drainage: Well drained
Land Use: Cropland
Stoniness: Erosion or Deposition: Moderate
Runoff: Moderate
Particle Size Control Section: 25 to 100 cm
Parent Material: glacial till from mixed material
Classification: Coarse-loamy, mixed, frigid Typic Haplorthod
Vegetation: POTATO OATS
Diagnostic Horizons: 0 to 24 cm Ochric, 24 to 39 cm Spodic
Described By: Lytle, Olson and Grossman
Sample Date: 06/88
Complete characterization profile. Water Erosion Prediction Project.

Ap1 -- 0 to 11 cm; dark yellowish brown (10YR 4/4) interior moist gravelly loam and pale brown (10YR 6/3) interior dry gravelly loam; moderate medium subangular blocky structure parting to moderate medium granular; slightly hard, very friable, slightly sticky, slightly plastic; common very fine and fine roots; common very fine and fine interstitial pores; 30 percent pebbles; clear wavy boundary.
88P3855

Ap2 -- 11 to 24 cm; dark yellowish brown (10YR 4/4) interior moist gravelly loam; moderate medium subangular blocky structure; friable, slightly sticky, slightly plastic; common very fine and fine roots; very fine and fine interstitial pores; 30 percent pebbles; abrupt smooth boundary.
88P3856

Bs -- 24 to 39 cm; dark yellowish brown (10YR 4/6) interior moist gravelly fine sandy loam; moderate medium and coarse subangular blocky structure; firm, slightly sticky, nonplastic; few very fine and fine roots; few very fine and fine tubular and few very fine and fine interstitial pores; 20 percent pebbles; abrupt wavy boundary.
Pockets of (10YR 6/2) fine sandy loam E horzion in a few areas.
88P3857

C -- 39 to 66 cm; dark grayish brown (10YR 4/2) interior moist gravelly fine sandy loam; massive; friable, nonsticky, nonplastic; very few very fine roots; very few very fine and fine tubular pores; 30 percent pebbles, 3 percent cobbles; abrupt wavy boundary.
Soil temperature 60 degrees F at 50 cm.
88P3858

2C2 -- 66 to 104 cm; brown to dark brown (10YR 4/3) interior moist extremely gravelly sand; single grain; loose, nonsticky, nonplastic; 50 percent pebbles, 20 percent cobbles; gradual wavy boundary.
88P3859

3C3 --104 to 143 cm; dark yellowish brown (10YR 4/6) interior and brown to dark brown (10YR 4/3) interior moist very gravelly silt loam; massive; firm, sticky, slightly plastic; 30 percent pebbles, 10 percent cobbles.
88P3860

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APPENDIX I (continued)

                        ***  S U P P L E M E N T A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S88ME-003-001                            (AROOSTOOK COUNTY, MAINE                       )
                                                                                                               PRINT DATE 08/01/94
SAMPLED AS    : CARIBOU              ; FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
REVISED TO    : CARIBOU              ; LOAMY-SKELETAL, MIXED, FRIGID TYPIC DYSTROCHREPT
                                                                                                  U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 88P 127, (CP88ME188) WEPP MAINE                                                     SOIL CONSERVATION SERVICE
    - PEDON   88P 722, SAMPLES 88P 3855- 3860                                                     SOIL SURVEY LABORATORY
    - GENERAL METHODS  (ENGINEERING FRACTIONS ARE CALCULATED FROM USDA FRACTION SIZES)            NATIONAL SOIL SURVEY CENTER
                                                                                                  LINCOLN, NEBRASKA 68508-3866

                                                          SUPPLEMENTAL SHEET 1

Tier 1:  Columns 1 - 25
-------- --------------------------------------------------------------------------------------------------------------------------
                             E  N  G  I  N  E  E  R  I  N   G     P  S  D  A    CUMULATIVE CURVE FRACTIONS(<75mm)  ATTER- GRADATION
                           P E R C E N T A G E     P A S S I N G     S I E V E  USDA   LESS  THAN  DIAMETERS(mm) AT  BERG  UNI- CUR-
SAMPLE    DEPTH  HORIZON     3   2 3/2   1 3/4 3/8   4  10  40 200  20   5   2  1. .5  .25 .10 .05   60    50     10  LL PI FMTY VTUR
 No.      (In.)            <-----I N C H E S-----> <-N U M B E R-> <-MICRONS-> <--- MILLIMETER ---><--PERCENTILE--> <-PCT>  CU   CC
                             1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18   19    20     21  22 23   24   25

88P3855M   0-  4   AP1     100  95  91  86  82  73  64  55  45  33  21  12   7  50  46  42  35  29 3.22 1.044 0.003  32  3 >100  0.3
88P3856M   4-  9   AP2     100  97  96  93  91  82  72  62  52  38  24  14   8  58  54  48  41  34 1.43 0.309 0.003        >100  0.3
88P3857M   9- 15   BS      100  88  80  68  59  56  52  47  41  30  19  11   6  45  42  38  32  2719.65 3.339 0.004        >100  0.1
88P3858M  15- 26   C1      100  99  98  97  96  96  95  91  81  60  36  22  12  88  83  76  65  53 0.08 0.043 0.001  28  2 56.2  1.3
88P3859M  26- 41   C2      100  90  83  73  66  52  37  22   9   7   5   4   2  14  10   8   7   614.23 8.791 0.514        27.7  1.4
88P3860M  41- 56   C3      100  94  90  84  80  75  70  62  54  45  31  21  14  59  55  51  46  42 1.33 0.210 0.001        >100  0.2

Tier 2:  Columns 26 - 50
-------- --------------------------------------------------------------------------------------------------------------------------
           (  W   E   I   G   H   T     F   R   A   C   T   I   O   N   S  )    ( W E I G H T   P E R    U N I T    V O L U M E    G/CC )(  VOID  )
            ---W H O L E     S O I L (mm)-  -<75 mm FRACTION--         ------WHOLE SOIL------   -------<2 mm FRACTION-------  --RATIOS--
 DEPTH      >2 250 250  75  75  20   5       75  75  20   5          SOIL SURVEY ENGINEERING   --SOIL SURVEY-- ENGINEERING  AT 1/3  BAR
 (In.)          -UP -75  -2 -20  -5  -2  <2  -2 -20  -5  -2  <2       1/3  OVEN  MOIST SATUR  1/3   15   OVEN  MOIST SATUR  WHOLE  <2
           <------PCT of WHOLE SOIL-----> <--PCT OF <75 mm->          BAR  -DRY        -ATED  BAR   BAR  -DRY         -ATED  SOIL   mm
            26  27  28  29  30  31  32  33  34  35  36  37  38  39    40    41    42    43    44    45    46    47    48    49    50

   0-  4     45  --  --  45  18  18   9  55  45  18  18   9  55     1.82
   4-  9     38  --  --  38   9  19  10  62  38   9  19  10  62     1.54  1.59  1.80  1.96  1.24  1.27  1.29  1.57  1.77  0.72  1.14
   9- 15     53  --  --  53  41   7   5  47  53  41   7   5  47     1.91  1.94  2.10  2.19  1.47  1.48  1.50  1.77  1.92  0.39  0.80
  15- 26     13  --   4   9   4   1   4  87   9   4   1   4  91     1.88  1.91  2.11  2.17  1.81  1.83  1.84  2.06  2.13  0.41  0.46
  26- 41     83  --  23  60  26  22  12  17  78  34  29  15  22     2.32
  41- 56     46  --  13  33  17   9   7  54  38  20  10   8  62     1.98  2.03  2.18  2.23  1.63  1.64  1.69  1.94  2.02  0.34  0.63

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APPENDIX I (continued)

*** SUPPLEMENTARY CHARACTERIZATION DATA ***

S88ME-003-001 PRINT DATE 08/01/94
CLASSIFICATION: CARIBOU ; LOAMY-SKELETAL, MIXED, FRIGID TYPIC DYSTROCHREPT
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 88P 722, SAMPLE 88P 3855- 3860

SUPPLEMENTAL SHEET 2

Tier 1: Columns 51 - 75

DEPTH (In.)	(VOLUME FRACTIONS												)(C/)	(RATIOS to CLAY)					(LINEAR EXTENSIBILITY)				(WRD)	
	----WHOLE SOIL (mm) at 1/3 BAR---												(/N)	--------<2 mm FRACTION-------					WHOLE SOIL		--<2 mm--		WHOLE SOIL	<2 mm
	>2	250 -UP	250 -75	75 -2	75 -20	20 -5	5 -2	<2	2- .05	.05- .002	LT .002	PORES D	PORES F	RAT -IO	FINE CLAY	---CEC-- SUM CATS	NH4- OAC	15 BAR H2O	LE 1/3 BAR	<-1/3 BAR to 15 BAR	OVEN -DRY	(PCT)---> 15 BAR	OVEN -DRY	<--In/In->	
	<---------------PCT of WHOLE SOIL---------------->																								
	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
0- 4	31	--	--	31	12	12	6	69	18	15	5	31		12	0.12	1.78	1.05	0.81							
4- 9	22	--	--	22	5	11	6	78	17	16	4	16	26	11	0.09	1.63	0.97	0.82	0.107	0.6	1.1	0.8	1.3	0.16	0.21
9- 15	38	--	--	38	29	5	4	62	15	15	4	9	19		0.11	1.18	0.80	0.94	0.057	0.2	0.5	0.2	0.7	0.08	0.13
15- 26	9	--	3	6	3	1	3	91	26	27	8	6	23		0.25	0.66	0.44	0.38	0.045	0.4	0.5	0.4	0.6	0.14	0.16
26- 41	73	--	20	53	23	19	11	27	11	3	2	12			0.30	0.83	1.04	0.61							
41- 56	35	--	10	25	13	7	5	65	13	18	9	5	20		0.31	0.55	0.44	0.70	0.052	0.2	0.8	0.2	1.2	0.03	0.05

Tier 2: Columns 76 - 100

DEPTH (In.)	(WEIGHT FRACTIONS - CLAY FREE)														(-TEXTURE--)		(--PSDA(mm)---)			(PH)	(-ELECTRICAL)			(CUMULT. AMOUNTS)	
	(--WHOLE SOIL--)						(--<2 mm FRACTION ----)								(DETERMINED)		(SAND	SILT	CLAY)					Inch of H2O	
	>2	75 -2	20 -2	2- .05	.05- .002	LT .002	------SANDS------- VC	C	M	F	VF	SILTS C	F	CL AY	IN FIELD	BY PSDA	2- .05	.05- .002	LT .002	CA- CL2 .01M	RES- IST. OHMS	CON- DUCT. MMHOS	SALT MG/ KG	1/3 BAR to 15BR	AIRDRY
	PCT of >2mm+SAND+SILT >						<------PCT of SAND+SILT------->								<---<2 mm-->		<---PCT of 2mm--->			<-------- <2 mm ------->				<WholeSoil>	
	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0- 4	48	48	29	28	24	7	11	8	9	13	13	17	29	14		L	47.0	40.8	12.2	5.3					
4- 9	41	41	31	30	29	8	8	8	10	14	13	19	30	14		L	45.1	42.8	12.1	4.8					
9- 15	56	56	13	22	22	6	6	7	9	13	14	18	33	14		L	43.2	44.5	12.3	4.6					
15- 26	15	10	6	41	44	13	4	6	9	14	15	22	30	15		L	41.8	44.9	13.3	4.5					
26- 41	85	61	35	12	3	2	40	22	10	4	3	6	14	13		COSL	71.1	17.6	11.3	4.9					
41- 56	53	38	18	20	28	14	7	8	8	9	8	24	35	30		L	31.6	45.2	23.2	6.9					

CRITERIA FOR MOLLIC SUBGROUPS:	CONTROL SECTION CENTIMETERS	SAND TO CLAY RATIO	ORGANIC CARBON PERCENT
	0-18	3.80	2.09
	0-40	3.67	1.56

APPENDIX II

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APPENDIX II

                              ***  P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S89CA-027-004                            (INYO COUNTY, CALIFORNIA                          )
                                                                                                                PRINT DATE 08/01/94
SAMPLED AS    : WILDMESA             ; FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
REVISED TO    : WILDMESA             ; FINE, MONTMORILLONITIC, MESIC XERALFIC PALEARGID
                                                                                                   U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 89P  65, (CP89CA091) CHINA LAKE                                                      SOIL CONSERVATION SERVICE
    - PEDON   89P 325, SAMPLES 89P 1799- 1804                                                      SOIL SURVEY LABORATORY
    - GENERAL METHODS  1B1A, 2A1, 2B                                                               NATIONAL SOIL SURVEY CENTER
                                                                                                   LINCOLN, NEBRASKA 68508-3866
                                                           PSDA SHEET

            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
--------- -------------------------------------------------------------------------------------------------------------------------
                             (- - -TOTAL - - -)(- -CLAY- -)(- -SILT- -)(- - - -  - -SAND- -  - - - -)(-COARSE FRACTIONS(MM)-)(>2MM)
                              CLAY  SILT  SAND  FINE   CO3  FINE COARSE   VF     F     M     C    VC    - - - - WEIGHT - - - -    WT
SAMPLE     DEPTH   HORIZON     LT   .002  .05    LT    LT   .002 .02    .05   .10   .25    .5      1     2     5    20    .1- PCT OF
 NO.       (CM)               .002  -.05    -2 .0002  .002  -.02 -.05  -.10  -.25  -.50    -1      -2    -5   -20   -75      75 WHOLE
                              <- - - - - - - - - - - - PCT OF <2MM  (3A1) - - - - - - - - - - - - ->  <- PCT OF <75MM(3B1)->  SOIL

89P1799S   0-  8   A           7.8  23.5  68.7              14.7   8.8  28.3  34.1   3.6   1.4   1.3    1     4    21     56   26
89P1800S   8- 15   AB         10.6  24.3  65.1   0.8        16.7   7.6  26.5  32.7   3.8   1.3   0.8    1     2     7     45   10
89P1801S  15- 46  2BT         34.9  21.8  43.3  10.9        15.1   6.7  20.7  18.1   2.6   1.0   0.9    1     1    --     24    2
89P1802S  46- 74  2BTK        38.1  26.7  35.2  10.2   0.3  16.9   9.8  18.2  13.6   2.2   0.9   0.3   TR    TR    --     17   TR
89P1803S  74-109  2BTK        44.0  26.5  29.5  10.3   0.9  17.1   9.4  13.9  12.2   2.1   0.9   0.4    1     1    --     17    2
89P1804G 109-153  3BQKM        7.0  19.0  74.0         1.4  12.4   6.6  15.2  16.5  12.0  14.9  15.4                            P

Tier 2:  Columns 1 - 20
--------- -------------------------------------------------------------------------------------------------------------------------
            ORGN TOTAL  EXTR TOTAL (- - DITH-CIT - -)(RATIO/CLAY)(ATTERBERG )(- BULK DENSITY -) COLE (- - -WATER CONTENT - -)  WRD
              C     N     P    S       EXTRACTABLE           15   - LIMITS -  FIELD  1/3  OVEN WHOLE FIELD  1/10   1/3    15  WHOLE
 DEPTH                               FE    AL    MN    CEC   BAR    LL    PI  MOIST  BAR  DRY   SOIL MOIST   BAR   BAR   BAR  SOIL
 (CM)       6A1c  6B3a  6S3   6R3a  6C2b  6G7a  6D2a   8D1   8D1  4F1     4F  4A3a  4A1d  4A1h  4D1   4B4   4B1c  4B1c  4B2a  4C1
            PCT   <2MM   PPM <- PERCENT  OF  <2MM -->             PCT <0.4MM  <- - G/CC - - -> CM/CM  <- - -PCT OF <2MM - -> CM/CM

  0-  8     0.45                                       1.54  0.65          NP        1.47  1.55 0.015              16.5   5.1  0.14
  8- 15     0.15                                       1.04  0.47                    1.60  1.70 0.019              14.6   5.0  0.15
 15- 46     0.19                                       0.82  0.51    42    27        1.45  1.72 0.058              24.3  17.7  0.09
 46- 74     0.15                                       0.85  0.43    51    33        1.38  1.63 0.057              29.6  16.3  0.18
 74-109     0.12                                       0.80  0.45                    1.26  1.62 0.087              37.8  20.0  0.22
109-153     0.09                                             1.24                                                         8.7

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        AVERAGES,   DEPTH  15- 65:  PCT CLAY   36  PCT  .1-75MM    21
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APPENDIX II (continued)

*** PRIMARY CHARACTERIZATION DATA ***

S89CA-027-004
SAMPLED AS : WILDMESA ; FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 89P 325, SAMPLE 89P 1799- 1804

PRINT DATE 08/01/94

SALT SHEET

Tier 1: Columns 1 - 20

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
	(- NH4OAC EXTRACTABLE BASES -)					ACID-ITY		(- -CEC- -)		EXCH NA	SAR	BASE SATURATION		CO3 AS CACO3	RES. OHMS /CM	CASO4 AS GYPSUM		(- - - -PH - - -)		
DEPTH (CM)	CA 5B5a 6N2e	MG 5B5a 6O2d	NA 5B5a 6P2b	K 5B5a 6Q2b	SUM BASES	6H5a		SUM CATS 5A3a	NH4-OAC 5A8b	5B5b	5E	SUM 5C3	NH4OAC 5C1	<2MM 6E1g	8E1	<2MM 6F1a	<20MM 6F4	SAT PASTE 8C1b	CACL2 .01M 8C1f 1:2	H2O 8C1f 1:1
	<- - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->									PCT		<- -PCT- >		PCT		<- -PCT ->				
0- 8	10.0	2.7	0.2	1.1	14.0			14.0	12.0	2		100	100	TR					7.2	7.9
8- 15	7.9	2.2	0.5	0.8	11.4			11.4	11.0	4		100	100	--					7.2	8.3
15- 46	20.3	4.1	4.1	0.7	29.2			29.2	28.7	14		100	100	--					7.4	8.5
46- 74		4.6	7.1	0.5					32.3	18	15	100	100	2				8.0	8.1	8.7
74-109		5.8	11.3	0.5					35.4	19	17	100	100	3	270	--		7.7	8.0	8.5
109-153																				

Tier 2: Columns 1 - 20

	(- - - - - - - - - - - -WATER EXTRACTED FROM SATURATED PASTE- - - - - - - - - - - - - - -)														PRED.
DEPTH (CM)	CA 6N1b	MG 6O1b	NA 6P1b	K 6Q1b	CO3 6I1b	HCO3 6J1b	F 6U1a	CL 6K1c	SO4 6L1c	NO2 6W1a	NO3 6M1c	H2O 8A	TOTAL SALTS EST. 8D5	ELEC. COND. 8A3a MMHOS /cm	ELEC. COND. 8I MMHOS /cm
	< - - - - - - - - - - - - - - - -MEQ / LITER - - - - - - - - - - - - - ->											<- -PCT- ->			
0- 8															0.08
8- 15															0.07
15- 46															0.19
46- 74	2.9	0.6	19.3	0.1	--	0.7	TR	20.4	4.1	--	--	63.6	0.1	2.28	0.96
74-109	21.6	4.8	60.8	0.1	--	0.4	2.8	80.6	18.5	--	--	71.9	0.4	7.61	3.16
109-153															

MMHOS/CM OF 1:2 WATER EXTRACT (8I) & EXCH NA AS EXTRACTABLE NA FOR LAYERS 1, 2, 3,

ANALYSES: S= ALL ON SIEVED <2mm BASIS G= <2mm ON GROUND <75mm BASIS P= FABRIC ON <75mm FRACTION

APPENDIX II (continued)

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                                 ***  P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S89CA-027-004                               (INYO COUNTY, CALIFORNIA                  )
                                                                                                   PRINT DATE 08/01/94
CLASSIFICATION: WILDMESA                  ; FINE, MONTMORILLONITIC, MESIC XERALFIC PALEARGID
                                                                                            U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 89P  65, (CP89CA091) CHINA LAKE                                               SOIL CONSERVATION SERVICE
    - PEDON   89P 325, SAMPLES 89P 1799- 1804                                               SOIL SURVEY LABORATORY
    - GENERAL METHODS  1B1A, 2A1, 2B                                                        NATIONAL SOIL SURVEY CENTER
                                                                                            LINCOLN, NEBRASKA 68508-3866
                                                              ACID-OXALATE SHEET

                  -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
-------------------------------------------------------------------------------------------------------------------------------------
                 ACID OXALATE EXTRACTION  PHOSPHOUS   KCL  TOTAL  (- -WATER  CONTENT- - )(- - - - WATER DISPERSIBLE - - - - ) MIN   AGGRT
                   OPT  FE    SI    AL          CIT-  MN    C     0.06   1-    2-    15  <- - PIPETTE - - >< - HYDROMETER - > SOIL  STABL
                   DEN                    RET   ACID                BAR   BAR   BAR   BAR  CLAY  SILT  SAND  CLAY  SILT  SAND  CONT  <5mm
SAMPLE  HZ         8J   6C9a  6V2   6G12  6S4   6S5   6D3   6A2d  4B1c  4B1a  4B1a  4B2b <- - - 3A1c - - -><- - - SML  - - -> 8F1   4G1
 NO.    NO              <- P C T  o f < 2 m m -><- P P M  -><- - - - - - - - - - - - P E R C E N T  o f  < 2 m m - - - - - - - - - - - - >< PCT>

89P1799  1
89P1800  2                                                                                                                           3
89P1801  3                                                                                                                          TR
89P1802  4
89P1803  5
89P1804  6

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APPENDIX II (continued)

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                                  ***   P R I M A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***

S89CA-027-004                                                                                              PRINT DATE 08/01/94
SAMPLED AS     : WILDMESA              ; FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 89P 325, SAMPLE 89P 1799- 1804

                                                        MINERALOGY SHEET

                 -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

Tier 1:  Columns 1 - 20
---------  -------------------------------------------------------------------------------------------------------------------
           < - - - - - - - - - - - - - - - - - - - - - - CLAY MINERALOGY (<.002mm) - - - - - - - - - - - - - - - - - - - - - - - >
           FRACT < - - - - - - X-RAY - - - - - - -><  - - - THERMAL - - - -><  - - - - - - - - ELEMENTAL - - - - - - - - -><  - -> EGME  INTER
SAMPLE      ION <                              >< - DTA - -><  - TGA - -> SiO2 AL2O3 Fe2O3  MgO   CaO   K2O   Na2O <    > RETN  PRETA
                 <  - - - - - -   7A2i - - - - - - -><  - 7A6  - ><  - 7A4b - ><  - - - - - - - - - - 7C3 - - - - - - - - - - -><    >  7D2   TION
NUMBER     <- - ><  - - - - peak size - - - - - -><  - - - Percent - - - -><  - - - - - - - - - Percent - - - - - - - - - -><  - -><mg/g><  - ->

89P1800     TCLY  MI 3  MT 2  MM 1  KK 1  LE 1                                  16.0   6.1              2.3
89P1801     TCLY  MT 3  MI 2  KK 1                                              17.0   6.7              1.8
89P1802     TCLY  MT 3  MI 2  KK 1                                              16.0   6.9              1.3

Tier 2:  Columns 1 - 20
---------  -------------------------------------------------------------------------------------------------------------------
           < - - - - - - - - - - - - - - - - - - - - - SAND - SILT MINERALOGY (2.0-0.002mm) - - - - - - - - - - - - - - - - - - - - - >
           FRACT < - - - - - - X-RAY - - -><  - - - THERMAL - - - -><  - - - - - - - -  OPTICAL - - - - - - - - - -><                     > INTER
SAMPLE      ION <                    >< - DTA - -><  - TGA - ->TOT RE< - - - - - - GRAIN COUNT - - - - - - -><                     > PRETA
                 <  - - - - -  7A2I - - - - ><  - 7A3b - ><  - 7A4b - ><  - - - - - - - - - -  7B1a - - - - - - - - - - -><                     >  TION
NUMBER     < - -><  - - - Peak Size - - -><  - - - Percent - - - -><  - - - - - - - - - - Percent - - - - - - - - - -><  - - - - - - - - - -><  - ->

89P1800     FS                                                   66   QZ57  FK17  OP 7  OT 6  HN 5  BT 4
89P1800     FS                                                        GE 1  ZR 1  GStr  RUtr  FPtr  CLtr

---------  -------------------------------------------------------------------------------------------------------------------

FRACTION INTERPRETATION:

   TCLY  Total Clay, <0.002mm            FS    Fine Sand, 0.1-0.25mm

MINERAL INTERPRETATION:

   MI  mica             MT  montmorill      MM  mont-mica       KK  kaolinite       LE  lepidocrocit     QZ  quartz
   FK  potas-feld       OP  opaques         OT  other           HN  hornblende      BT  biotite          GE  goethite
   ZR  zircon           GS  glass           RU  rutile          FP  plag-feld       CL  chlorite

RELATIVE PEAK SIZE:   5 Very Large   4 Large   3 Medium   2 Small   1 Very Small   6 No Peaks

INTERPRETATION (BY HORIZON):


PEDON MINERALOGY
    BASED ON SAND/SILT:
    BASED ON CLAY:
    FAMILY MINERALOGY:
    COMMENTS:
```

NARRATIVE PEDON DESCRIPTION

Pedon: Wildmesa Series
Soil Survey Number S89-CA-027-004
Location: Inyo County,
About 1.25 miles S of intersection with main access road into Wild
Horse Mesa, just off N side of dirt rd. A
Latitude: 35-58-26-N
Slope: 2% concave west facing
Precipitation: 18 cm - Aridic Moisture Regime.
MLRA: D-29
Water Table Depth:
Air Temperature: Ann: 13 Summ: Win:
Drainage: Well drained
Stoniness: Erosion or Deposition: None
Particle Size Control Section: 3 to 23 cm
Parent Material: alluvium from basaltic-ash material over cinders material
Classification: Fine, montmorillonitic, mesic Xerollic Paleargid
Vegetation: ATCA2 GRSP EPNE
Diagnostic Horizons: 0 to 3 cm Ochric, 3 to 43 cm Argillic
Described By:

NSSL Pedon Number: 89P0325
Print Date: 08/01/94
Longitude: 117-35-42-W
Elevation: 1564 m MSL
Permeability: Very slow
Land Use:
Runoff: Slow
Sample Date: 5/89

Physiography: basalt flow basins/alluvial fill basins. Site was disturbed from recent fire, very little vegetation left, may have had CORA on site before fire. Landuse: military, wildlife, and grazing. This soil occurs in associ

A -- 0 to 8 cm; brown (10YR 5/3) dry extremely cobbly very fine sandy loam and dark brown (10YR 3/3) moist extremely cobbly very fine sandy loam; moderate medium platy structure; slightly hard, very friable, slightly sticky, nonplastic; many very fine and fine roots; common very fine and fine tubular and common fine vesicular pores; slightly effervescent; mildly alkaline (pH=7.4); clear smooth boundary.
very close to a silt loam with high % silts but enough fine sand and medium sand to go with very fine sandy loam and loam
89P1799

Abt -- 8 to 15 cm; light brownish gray (10YR 6/2) dry loam and dark brown (10YR 3/3) moist loam; strong coarse platy structure parting to moderate medium subangular blocky; slightly hard, very friable, sticky, slightly plastic; common very fine and fine roots; common fine tubular and many fine vesicular pores; slightly effervescent; mildly alkaline (pH=7.7); abrupt wavy boundary.
very close to a silt loam with high % silts but enough fine sand and medium sand to go with very fine sandy loam and loam
89P1800

2Bt -- 15 to 46 cm; dark yellowish brown (10YR 4/4) dry clay and brown to dark brown (10YR 4/3) moist clay; strong fine and medium prismatic structure parting to strong medium and coarse angular blocky; very hard, firm, very sticky, very plastic; few fine and medium roots; common fine tubular pores; slightly effervescent; moderately alkaline (pH=8.0); clear wavy boundary.
sand and silt sized particles overplacing pressure faces on some ped faces
89P1801

2Btk -- 46 to 109 cm; dark yellowish brown (10YR 4/4) dry clay and brown to dark brown (10YR 4/3) moist clay; strong fine and medium subangular blocky structure parting to strong medium and coarse angular blocky; very hard, firm, very sticky, very plastic; few fine and medium roots; common fine tubular pores; slightly effervescent; moderately alkaline (pH=7.9); abrupt wavy boundary.
matrix is slightly effervescent with common to many (25-50% of surface) fine (1-3 mm in length) pred. rod-like and spherical segregated CaCO3 being strongly effervescent; sand and silt sized particles overplacing pressure faces on some
89P1802

3Bqkm --109 to 152 cm; white (10YR 8/1) dry and light brownish gray (10YR 6/2) moist; strong medium platy structure; extremely hard, extremely firm; violently effervescent.
a continuous highly fractured broken indurated duripan with a high % of cemented cobbles and stones; soil material and roots have penetrated fracture zones; a thick (1/2-3/4") laminar cap is continuous throughout pedon but broken and fr
89P1804

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APPENDIX II (continued)
                          ***   S U P P L E M E N T A R Y   C H A R A C T E R I Z A T I O N   D A T A   ***
S89CA-027-004                                  (INYO COUNTY, CALIFORNIA                              )
                                                                                                         PRINT DATE 08/01/94
SAMPLED AS     : WILDMESA              ; FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
REVISED TO     : WILDMESA              ; FINE, MONTMORILLONITIC, MESIC XERALFIC PALEARGID
                                                                                           U. S. DEPARTMENT OF AGRICULTURE
SSL - PROJECT 89P  65, (CP89CA091) CHINA LAKE                                              SOIL CONSERVATION SERVICE
    - PEDON   89P 325, SAMPLES 89P 1799- 1804                                              SOIL SURVEY LABORATORY
    - GENERAL METHODS  (ENGINEERING FRACTIONS ARE CALCULATED FROM USDA FRACTION SIZES)     NATIONAL SOIL SURVEY CENTER
                                                                                           LINCOLN, NEBRASKA 68508-3866
                                                           SUPPLEMENTAL SHEET 1

Tier 1:  Columns 1 - 25
-------- -------------------------------------------------------------------------------------------------------------
                              E   N   G   I   N   E   E   R   I   N   G      P   S   D   A     CUMULATIVE CURVE FRACTIONS(<75mm)  ATTER- GRADATION
                             P E R C E N T A G E      P A S S I N G        S I E V E    USDA    LESS   THAN   DIAMETERS(mm) AT   BERG  UNI- CUR-
SAMPLE      DEPTH   HORIZON   3    2  3/2   1  3/4 3/8   4  10   40 200   20   5    2    1.  .5   .25  .10  .05   60     50      10    LL PI FMTY VTUR
 No.        (In.)            <-----I N C H E S-----> <-N U M B E R-> <-MICRONS-> <--- MILLIMETER ---><--PERCENTILE--> <-PCT>  CU   CC
                              1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19     20      21    22 23   24   25

89P1799S    0-  3    A       100   94   90   83   79   77   75   74   71   35   17   10    6   73   72   69   44   23 0.18 0.124  0.005        NP 36.4  4.5
89P1800S    3-  6    AB      100   98   97   94   93   92   91   90   87   45   25   16   10   89   88   85   55   31 0.12 0.086  0.002           54.0  6.9
89P1801S    6- 18   2BT      100  100  100  100  100  100   99   98   95   68   49   40   34   97   96   94   76   56 0.06 0.023     --  42 27 >100  0.1
89P1802S   18- 29   2BTK     100  100  100  100  100  100  100  100   98   76   55   45   38  100   99   97   83   65 0.03 0.010     --  51 33 87.2  0.1
89P1803S   29- 43   2BTK     100  100  100  100  100  100   99   99   97   78   60   50   44   99   98   96   84   70 0.02 0.005     --        55.2  0.2
89P1804G   43- 60   3BQKM    100  100  100  100  100  100  100  100   67   35   19   12    7   85   70   58   41   26 0.29 0.163  0.004        81.8  3.6

Tier 2:  Columns 26 - 50
-------- -------------------------------------------------------------------------------------------------------------
           ( W   E   I   G   H   T     F   R   A   C   T   I   O   N   S  )   ( W E I G H T   P E R    U N I T    V O L U M E   G/CC )( VOID  )
            ---W H O L E     S O I L (mm)-  -<75 mm FRACTION--        ------WHOLE SOIL------   -------<2 mm FRACTION-------  --RATIOS--
 DEPTH      >2 250 250  75  75  20   5       75  75  20   5           SOIL SURVEY ENGINEERING   --SOIL SURVEY-- ENGINEERING  AT 1/3  BAR
 (In.)         -UP -75  -2 -20  -5  -2  <2   -2 -20  -5  -2  <2        1/3  OVEN  MOIST SATUR   1/3   15  OVEN  MOIST SATUR  WHOLE   <2
            <------PCT of WHOLE SOIL----->   <--PCT OF <75 mm->        BAR  -DRY        -ATED   BAR  BAR  -DRY        -ATED  SOIL    mm
            26  27  28  29  30  31  32  33   34  35  36  37  38   39   40    41    42    43     44    45    46    47    48    49    50

  0-  3     26  --  --  26  21   4   1  74   26  21   4   1  74        1.66  1.74  1.86  2.03  1.47  1.53  1.55  1.71  1.92  0.60  0.80
  3-  6     10  --  --  10   7   2   1  90   10   7   2   1  90        1.66  1.76  1.88  2.03  1.60  1.67  1.70  1.83  2.00  0.60  0.66
  6- 18      2  --  --   2  --   1   1  98    2  --   1   1  98        1.46  1.73  1.81  1.91  1.45  1.53  1.72  1.80  1.90  0.82  0.83
 18- 29     TR  --  --  --  --  --  TR 100   --  --  --  TR 100        1.38  1.63  1.79  1.86  1.38  1.51  1.63  1.79  1.86  0.92  0.92
 29- 43      1  --  --   1  --   1  TR  99    1  --   1  TR  99        1.27  1.63  1.74  1.79  1.26  1.45  1.62  1.74  1.78  1.09  1.10
 43- 60     --  --  --  --  --  --  -- 100   --  --  --  -- 100        1.45

--------- -----------------------------------------------------------------------------------------------------------
```

APPENDIX II (continued)

*** SUPPLEMENTARY CHARACTERIZATION DATA ***

```
S89CA-027-004                                                                                     PRINT DATE 08/01/94
CLASSIFICATION: WILDMESA              ; FINE, MONTMORILLONITIC, MESIC XERALFIC PALEARGID
USDA-SCS-NSSC-SOIL SURVEY LABORATORY ; PEDON 89P 325, SAMPLE 89P 1799- 1804

                                                   SUPPLEMENTAL SHEET 2

Tier 1:  Columns 51 - 75
-------- ---------------------------------------------------------------------------------------------------------------
         ( V O L U M E    F R A C T I O N S )(C/)(R A T I O S    to    C L A Y)( LINEAR EXTENSIBILITY )( W   R   D )
          ----W H O L E     S O I L (mm)   a t  1/3  B A R---(/N) --------<2 mm FRACTION-------  WHOLE SOIL  --<2 mm--   WHOLE   <2
 DEPTH      >2 250 250  75  75  20   5      2- .05-  LT   PORES RAT  FINE  ---C E C--    15    LE  <-1/3 BAR to (PCT)--->  SOIL    mm
 (In.)         -UP -75  -2 -20  -5  -2  <2 .05 .002 .002 D   F -IO  CLAY   SUM  NH4-   BAR   1/3    15  OVEN    15  OVEN
          <---------------PCT of WHOLE SOIL---------------->             CATS   OAC   H2O   BAR   BAR  -DRY   BAR  -DRY  <--In/In->
            51  52  53  54  55  56  57  58  59  60  61  62  63  64    65    66    67    68    69    70    71    72    73    74    75

  0-  3     16  --  --  16  13   3   1  84  32  11   4  17  20            1.79  1.54  0.65 0.231   1.2   1.6   1.3   1.8  0.14  0.17
  3-  6      6  --  --   6   4   1   1  94  37  14   6  15  22        0.08  1.08  1.04  0.47 0.189   1.4   2.0   1.4   2.0  0.14  0.15
  6- 18      1  --  --   1  --   1   1  99  23  12  19  10  35        0.31  0.84  0.82  0.51 0.169   1.8   5.8   1.8   5.9  0.09  0.10
 18- 29     TR  --  --  --  --  --  TR 100  18  14  20   7  41        0.27  1.44  0.85  0.43 0.150   2.8   5.7   3.0   5.7  0.18  0.18
 29- 43      1  --  --   1  --   1  TR 100  14  13  21   5  47        0.23  1.65  0.80  0.45 0.198   4.8   8.7   4.8   8.7  0.22  0.22
 43- 60     --  --  --  --  --  --  -- 100  40  10   4  45                            1.24

Tier 2:  Columns 76 - 100
-------- ---------------------------------------------------------------------------------------------------------------
         ( W E I G H T   F R A C T I O N S - C L A Y   F R E E )(-TEXTURE--)(--P S D A(mm)---)(PH )(-ELECTRICAL)(CUMULT. AMOUNTS)
         (--W H O L E  S O I L--) (--<2 mm  F R A C T I O N ----)(DETERMINED)(SAND  SILT  CLAY) CA-   RES-  CON-   SALT Inch of H2O
 DEPTH      >2  75  20  2- .05- LT  ------SANDS-------  SILTS   CL  IN    BY     2-   .05-   LT   CL2   IST.  DUCT.  MG/   1/3 BAR to
 (In.)          -2  -2 .05 .002.002 VC   C   M   F  VF   C   F  AY FIELD PSDA   .05  .002  .002 .01M  OHMS MMHOS  KG   15BR AIRDRY
           PCT of >2mm+SAND+SILT > <------PCT of SAND+SILT------><---<2 mm--><---PCT of 2mm---><-------- <2 mm -------><WholeSoil>
            76  77  78  79  80  81  82  83  84  85  86  87  88  89    90    91    92    93    94    95    96    97    98    99   100

  0-  3     28  28   5  54  18   6   1   2   4  37  31  10  16   8 VFSL   FSL   68.7  23.5   7.8   7.2
  3-  6     11  11   3  65  24  11   1   1   4  37  30   9  19  12 L      FSL   65.1  24.3  10.6   7.2
  6- 18      3   3   3  64  32  52   1   2   4  28  32  10  23  54 C      CL    43.3  21.8  34.9   7.4
 18- 29                 57  43  62  TR   1   4  22  29  16  27  62 C      CL    35.2  26.7  38.1   8.1         2.3
 29- 43      2   2   2  52  47  77   1   2   4  22  25  17  31  79 C      C     29.5  26.5  44.0   8.0   270   7.6
 43- 60                 80  20   8  17  16  13  18  16   7  13   8        COSL  74.0  19.0   7.0

-------- ---------------------------------------------------------------------------------------------------------------

        CRITERIA FOR MOLLIC SUBGROUPS:      CONTROL SECTION      SAND TO CLAY      ORGANIC CARBON
                                              CENTIMETERS           RATIO             PERCENT

                                                 0-18               6.51               0.29
                                                 0-40               3.61               0.23
```

APPENDIX III

LABORATORY PREPARATION CODES

Use Table 1 with the SSL preparation procedures 1B1, 1B2, 1B5, 1B6, and 1B7. Gravel codes also are defined in Table 1. In the "Code" column, "Char" refers to characterization sample. Laboratory preparation and >2-mm porosity are defined in footnotes on laboratory data sheet.

Table 1. Laboratory preparation codes and procedural summaries.

Code		Laboratory Preparation
Char	**>2mm**	
S	**Blank**	Weigh sample at field moisture content and record weight. Air-dry, weigh, and record weight. Sieve >2-mm fractions, weigh, record weights, and discard. Report all analytical results on <2-mm basis. Refer to procedure 1B1, Standard Air-dry.
S	**P**	Lab preparation is same as S-blank. However, report clod parameters and Cm (correction factor for >2-mm content moist soil) on an whole soil basis. Refer to procedure 1B1, Standard Air-dry.
N	**Blank**	Lab preparation is same as S-blank except do not record the weight of the >2-mm fraction. All analytical results are reported on a <2-mm basis. Refer to procedure 1B1, Standard Air-dry.
M	**Blank**	Lab preparation is same as S-blank except sieve <2-mm moist subsample for 15-bar moist analysis. Use <2-mm air-dry soil for all other analyses. Report all analytical results on <2-mm basis. Refer to procedure 1B2, Field Moist.
S	**K**	Lab preparation is same as S-blank except grind the 2- to 20-mm fraction to <2 mm and keep for CO_3 analyses, etc. Report the analytical results for the ground 2- to 20-mm fraction on a 2- to 20-mm basis and all other analytical results on a <2-mm basis. Refer to procedure 1B5, Coarse Fragments.

Table 1. Continued.

Code		**Laboratory Preparation**
Char	**>2mm**	
S	**R**	Lab preparation is same as S-blank except recombine the 2- to 20-mm fraction with the <2-mm fraction and grind the entire sample to <2 mm. Report all analytical results for ground sample on a <2-mm basis. Refer to procedure 1B5, Coarse Fragments
G	**P**	Weigh sample at field moisture content and record weight. Air-dry, weigh, and record weight. Grind entire sample to <2 mm. Report all analytical results for ground sample on a whole soil basis. Refer to procedure 1B6, Whole Soil.
W	**P**	Weigh sample at field moisture content and record weight. Air-dry, weigh, and record weight. Sieve >2-mm fractions, weigh, and record weights. Recombine the >2-mm fractions with the <2-mm fraction and grind entire sample to <2 mm. Report all analytical results on a whole soil basis. This procedure is no longer performed at the SSL.
H	**Blank**	Obtain a moist whole soil subsample for Histosol analysis. Obtain a <2-mm moist subsample for 15-bar moist analysis. Weigh remaining sample at field moisture content and record weight. Air-dry, weigh, and record weight. Sieve >2-mm fractions, weigh, record weights, and discard. Pulverize subsample of <2-mm air-dry soil to a <80-mesh size and use for lab analyses. Use <80-mesh air-dry for all analyses except AD/OD, 15-, 1/10- and 2-bar analyses. For the AD/OD, 15-, 1/10- and 2-bar analyses, use <2-mm air-dry soil. Use <2-mm moist subsample for 15-bar moist. Report all analytical results except fabric on a <2-mm basis. Refer to procedure 1B7, Organic Material.

Table 1. Continued.

Code		Laboratory Preparation
Char	**>2mm**	
A (L)	**Blank**	Lab preparation is same as N-blank except pulverize subsample of <2-mm air-dry soil to a <80-mesh size and use for lab analyses. Use <80-mesh air-dry for all analyses except AD/OD and 15-bar analyses. For the AD/OD and 15-bar analyses, use <2-mm air-dry soil. All analytical results are reported on a <2-mm basis. Refer to procedure 1B1, Standard Air-dry.

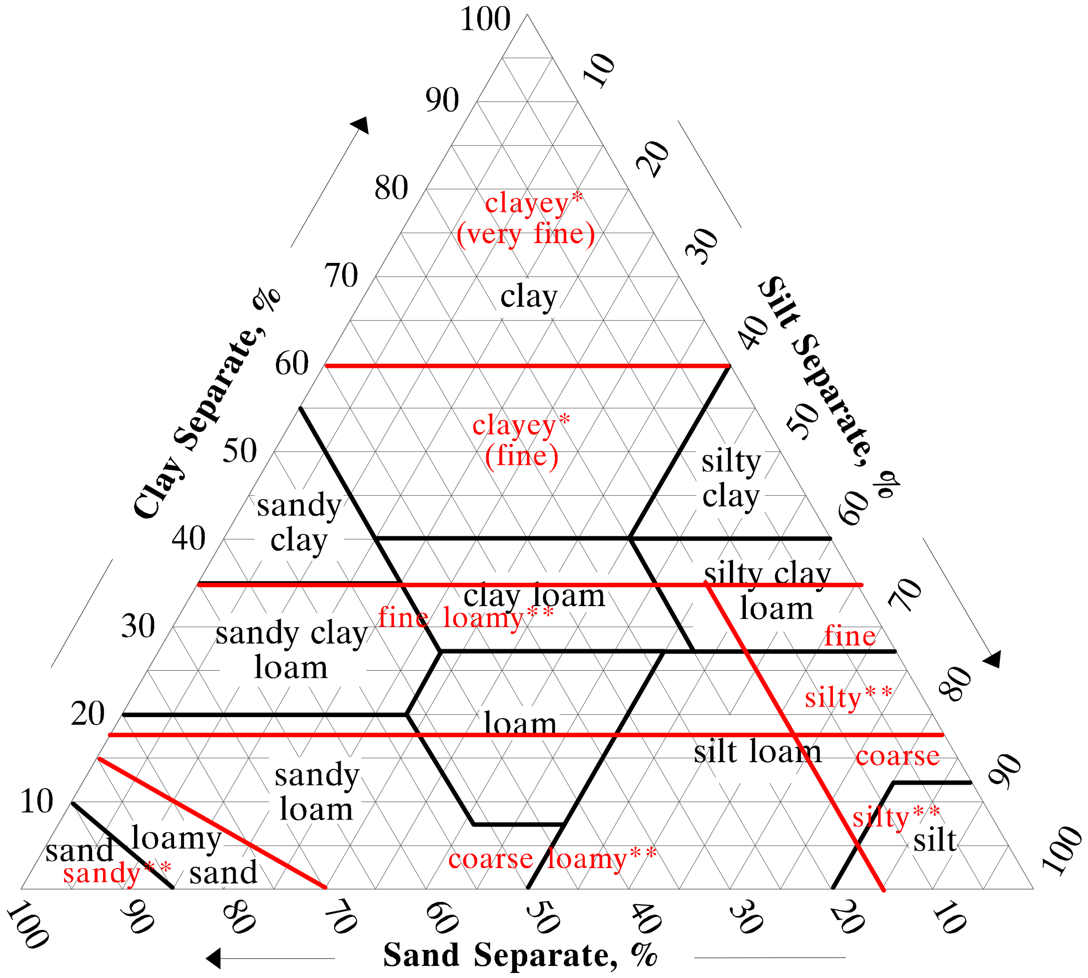
Gravel codes

P = porous >2-mm material that is considered soil is used for clod or core measurements.

V = volume estimate is used to calculate the weight percentage of a >2-mm fraction. If that fraction is porous (P), code the samples with "P" rather than with "V".

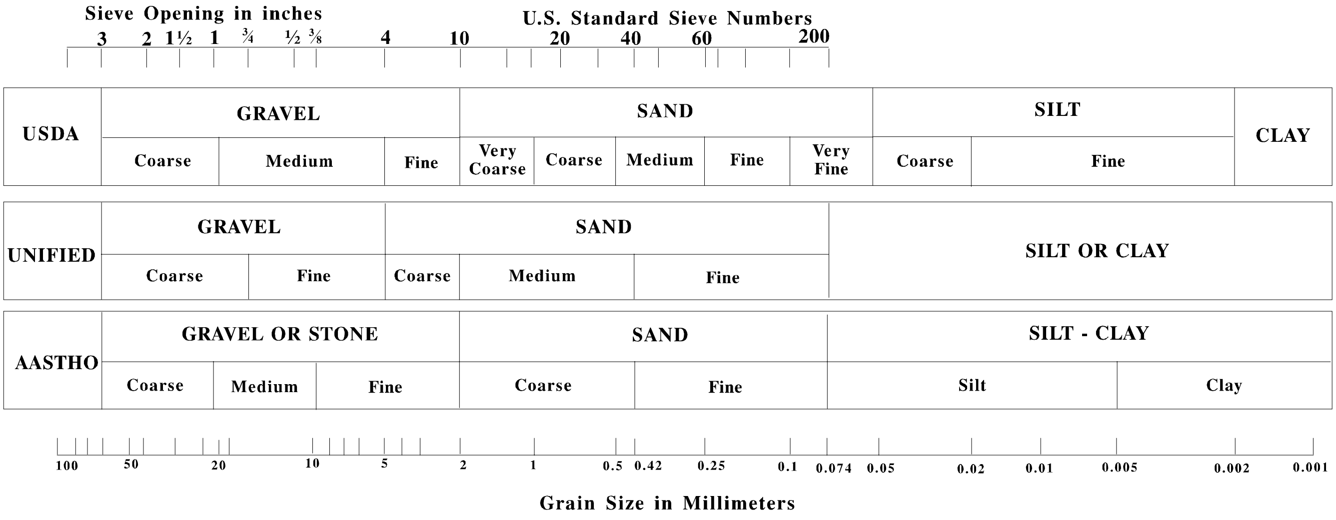
APPENDIX IV

GUIDE FOR TEXTURAL CLASSIFICATION IN SOIL FAMILIES



* Clay-size carbonate is treated as silt.
** Very fine sand (0.05 - 0.1 is treated as silt for family groupings; coarse fragments are considered the equivalent of coarse sand in the boundary between the silty and loamy classes.

COMPARISON OF PARTICLE SIZE SCALES



APPENDIX V

Grain-Size Distribution Curves

APPENDIX V - Caribou

Form SCS 353
9-64

LABORATORY NO.

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	**SOIL CLASSIFICATION**

PROJECT and STATE: WEPP Maine

SAMPLE LOCATION: Aroostook County

FIELD SAMPLE NO.

DEPTH

GEOLOGIC ORIGIN

TYPE OF SAMPLE

TESTED AT

APPROVED BY

DATE

SYMBOL

DESCRIPTION Pedon 88722, Ap2 Horizon, 11-24 cm

GRAIN SIZE DISTRIBUTION

C_c

C_u

D_{MAX}

D_{85}

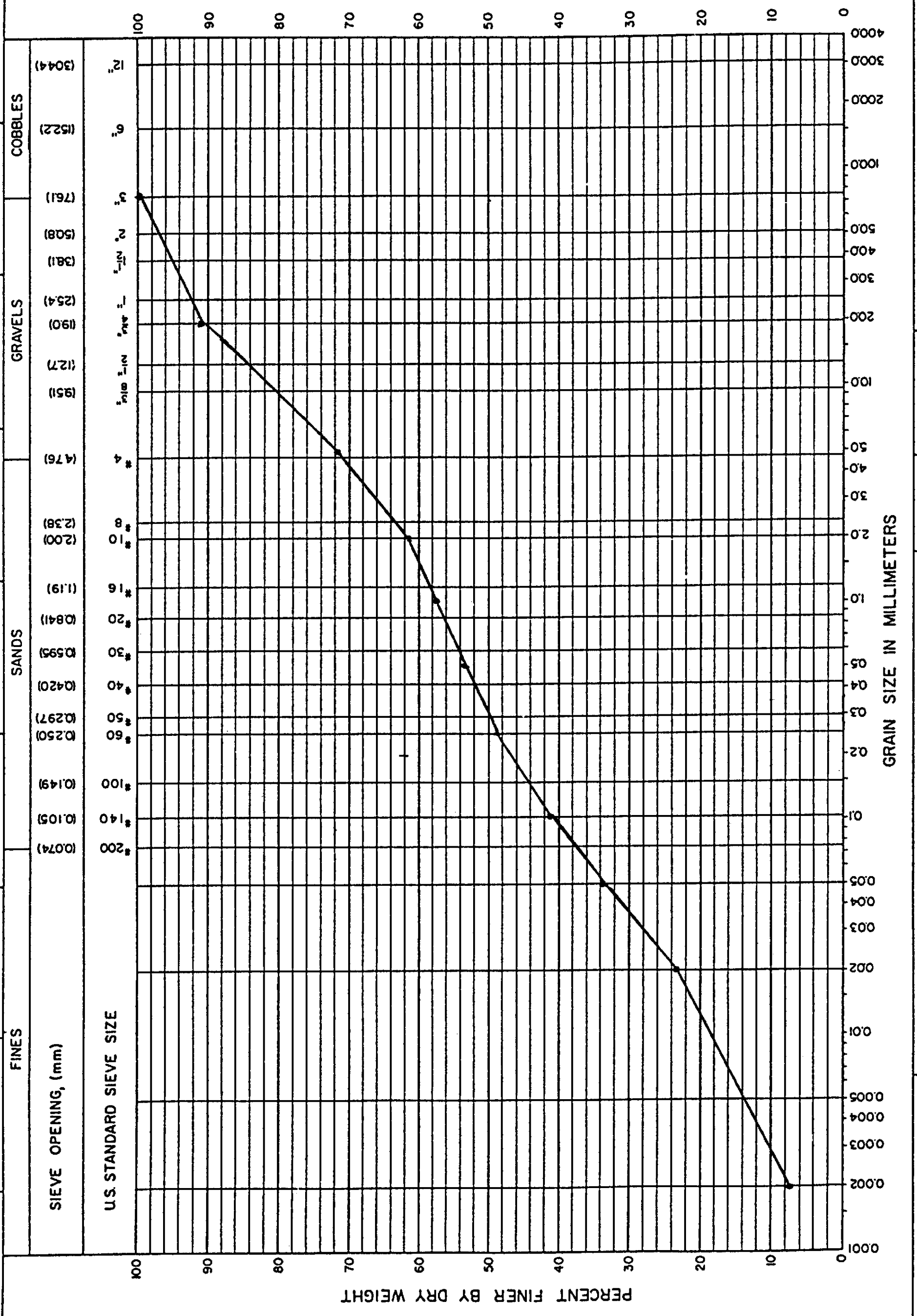
D_{60}

D_{50}

D_{30}

D_{15}

D_{10}



UNDISTURBED CONDITION

MOISTURE %

DRY UNIT WEIGHT g/cc pcf

SHRINKAGE LIMIT %

SOLUBLE SALTS %

ATTERBERG LIMITS

NATURAL MOISTURE LL PI

AIR DRY LL PI

OVEN DRY LL PI

SPECIFIC GRAVITY (G_s)

(-) #4

(+) #4

REMARKS: Fig. 1. Cumulative Particle-Size Distribution Curve, <75-mm Base.

APPENDIX V - Wildmesa

Form SCS 353
9-64

LABORATORY NO. ______

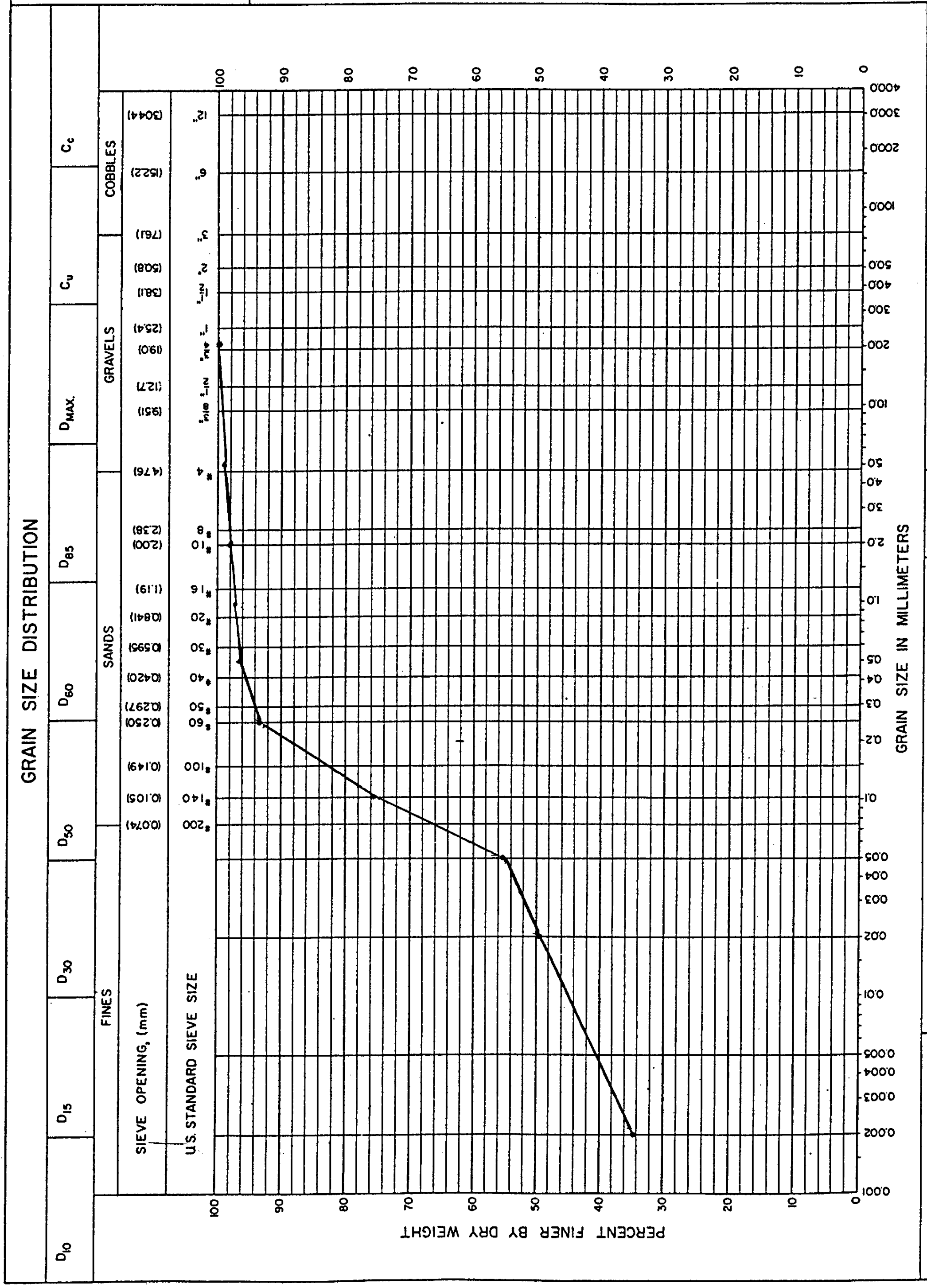
MATERIALS TESTING REPORT	**U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE**	**SOIL CLASSIFICATION**

PROJECT and STATE China Lake, California	SAMPLE LOCATION Inyo County

FIELD SAMPLE NO.	DEPTH	GEOLOGIC ORIGIN

TYPE OF SAMPLE	TESTED AT	APPROVED BY	DATE

SYMBOL	DESCRIPTION Pedon 89P325, Bt Horizon, 15-46 cm



UNDISTURBED CONDITION	MOISTURE	%	
	DRY UNIT WEIGHT	g/cc	pcf
SHRINKAGE LIMIT		%	
SOLUBLE SALTS		%	

ATTERBERG LIMITS		
OVEN DRY	PI	
	LL	
AIR DRY	PI	
	LL	
NATURAL MOISTURE	PI	
	LL	

SPECIFIC GRAVITY (G_s)	
(+) #4	
(-) #4	

REMARKS: Fig. 2. Cumulative Particle-Size Distribution Curve, <75-mm Base.

APPENDIX VI

Soil Water Retention Curves

Caribou Pedon

Wildmesa Pedon

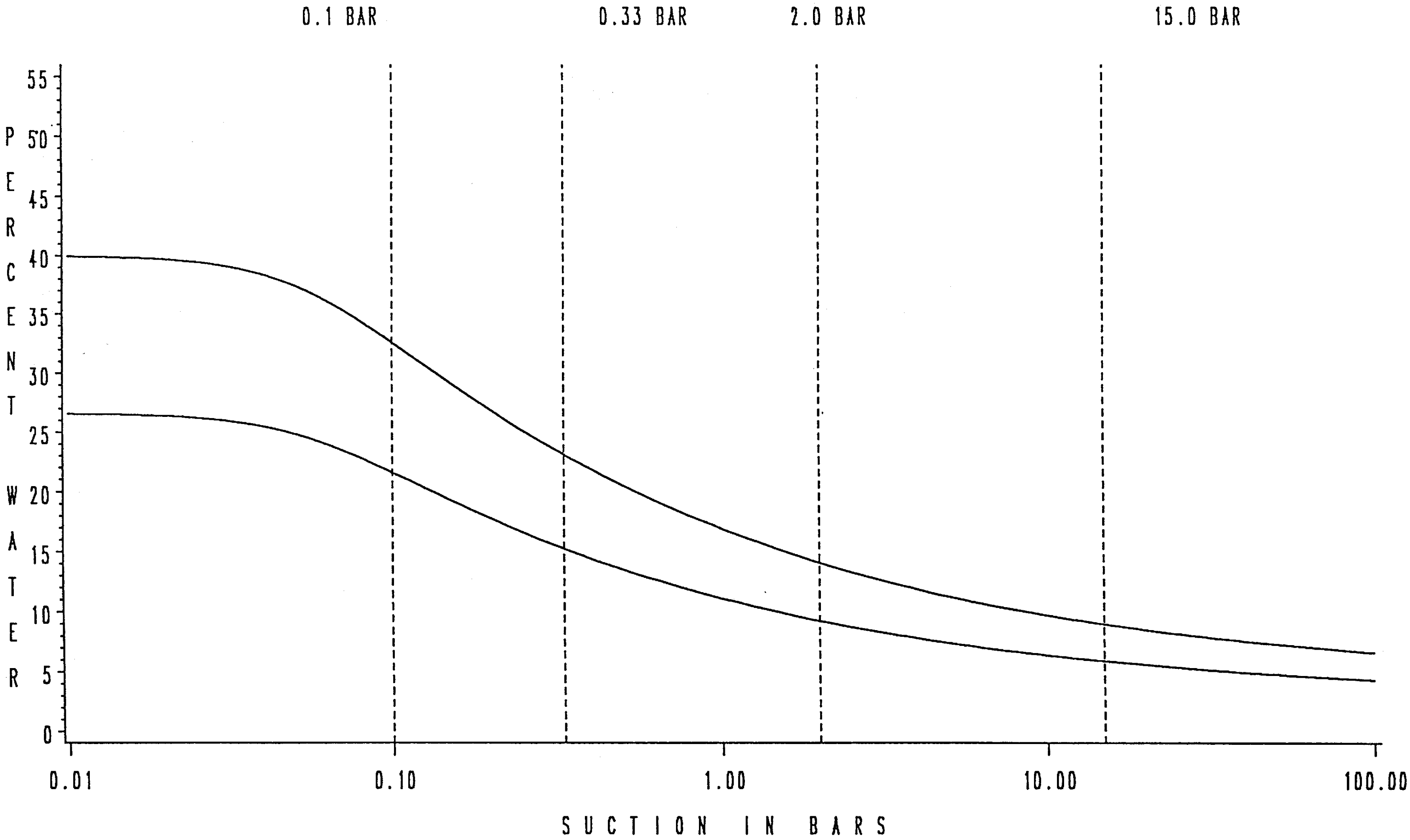
SOIL WATER RETENTION CURVE

State: MAINE
Soil Series Name: CARIBOU
Horizon: AP2 11- 24 cm

Of <2mm Fraction

Expected High Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	12.1-42.8-45.1	1.51(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 883856-1

APPENDIX IV - Caribou (continued)

```
          ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E  ***

                N.S.S.L. METHOD CODE X001              EXPECTED HIGH DENSITY             DATE PRINTED 07/22/94

STATE: MAINE                          COUNTY:   3          YEAR: 1988          PEDON:  722          SAMPLE:  3856            ID: 883856
SERIES NAME.... CARIBOU
SAMPLED AS..... FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
                                                                                                                            ADJUSTED
                          <------------------------ WEIGHT PERCENT ----------------------->                                 PARTICLE
HORIZON   DEPTH(CM)         CLAY  SILT  SAND   VFS   FS    MS   COS   VCOS  FSILT CSILT  OM      CEC   CO3    NA    EC  %H20   DENSITY
-----------------------------------------------------------------------------------------------------------------------------------
  AP2      11- 24          12.1  42.8  45.1  11.1  12.0   8.6   6.7   6.7  26.3  16.5  3.10   11.7   0.0   0.0   0.0   0.0     2.60

                      CLAY  MINERALOGY                             BULK DENSITY(G,CC)         ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION         THERMAL DIFFERENTIAL              OVEN DRY   0.33 BARS     FRAGMENT(WGT)        0.33 BARS    15.0 BARS
-----------------------------------------------------------------------------------------------------------------------------------
                                                                    1.57      1.51            36.8               15.2          5.9

                                                    COMPUTED SOIL WATER RETENTION VALUES
                                                ========================================================

SUCTION (BARS)                                 0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
-----------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                          26.6   26.6   26.0   24.8   21.5   17.6   15.1   12.8   11.1    9.2    7.4    6.4    5.9    4.3
VOLUME % WATER(<2MM)                          39.8   39.7   38.9   37.1   32.2   26.6   22.9   19.3   16.8   14.0   11.2    9.7    8.9    6.6
VOLUME % WATER(WHOLE SOIL)                    30.0   29.9   29.3   27.9   24.2   20.0   17.2   14.5   12.6   10.5    8.4    7.3    6.7    4.9

                                                       WATER RETENTION DIFFERENCES
                                                ========================================================

 SUCTION DIFFERENCES (BARS)                           0.1-0.33      0.1-2.0      0.1-15.0      0.33-2.0      0.33-15.0      2.0-15.0
-----------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                                    6.4          12.3          15.6          5.9           9.2           3.3
VOLUME % WATER(<2MM)                                    9.3          18.2          23.3          8.9          14.0           5.1
VOLUME % WATER(WHOLE SOIL)                              7.0          13.7          17.5          6.7          10.5           3.8
                                                  MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                                ========================================================

                                  N       ALPHA       M       RES. WATER        SAT. WATER         BDI         BDS           BUBP(BARS)
                              2.562094  0.017642  0.142829       2.8              26.6            1.53      -0.00130          0.0370


                                                   EQUATIONS FOR SOIL WATER RETENTION CURVE
                                                ========================================================

      ABBREVIATIONS:    WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                        RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
        WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
        VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
        VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

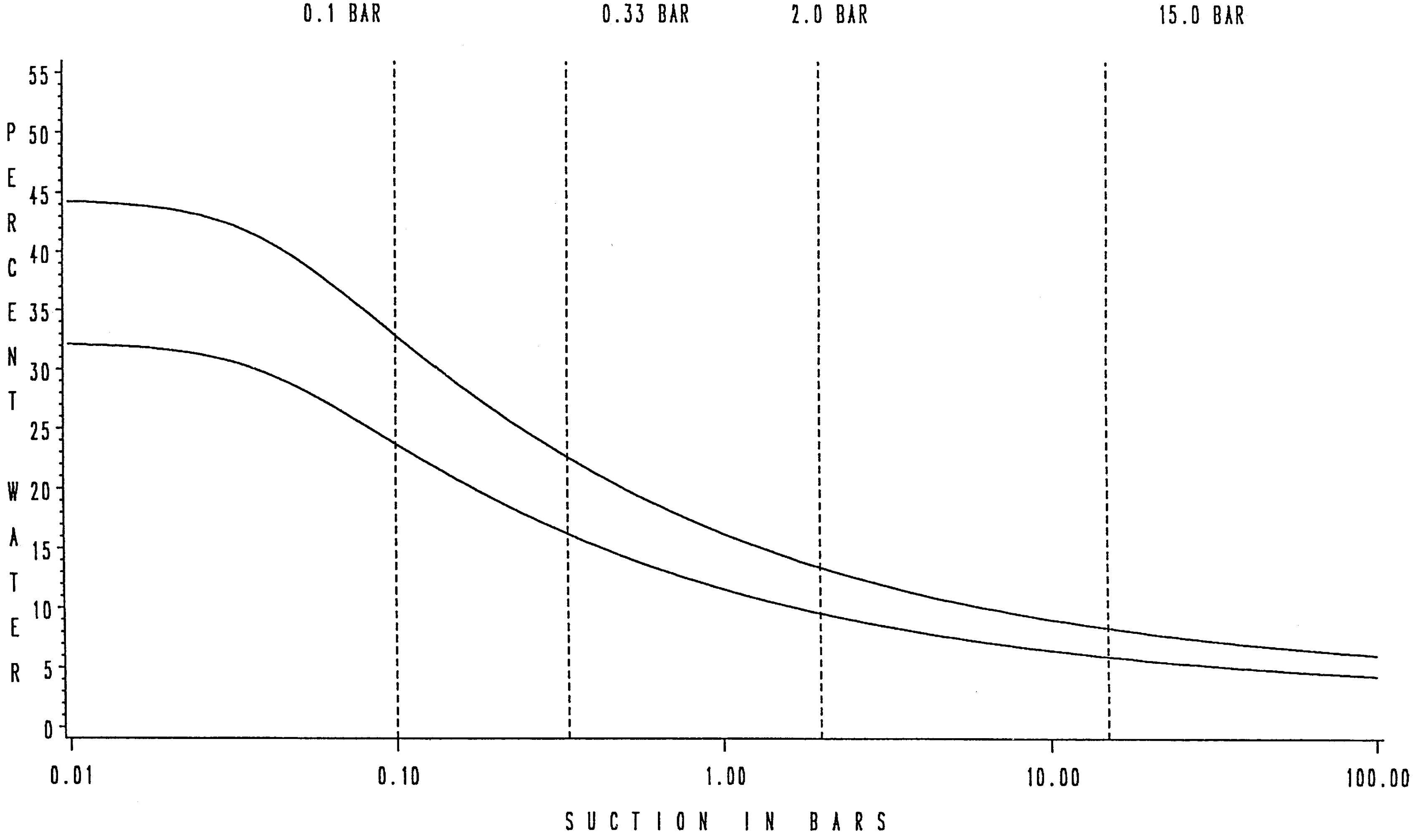
SOIL WATER RETENTION CURVE

State: MAINE
Soil Series Name: CARIBOU
Horizon: AP2 11- 24 cm

Of <2mm Fraction

Expected Medium Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	12.1-42.8-45.1	1.39(g/CC)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 883856-2

```
              ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E  ***

                   N.S.S.L. METHOD CODE X001           EXPECTED MEDIUM DENSITY          DATE PRINTED 07/22/94

STATE: MAINE                      COUNTY:   3         YEAR: 1988          PEDON:  722          SAMPLE:  3856           ID: 883856
SERIES NAME.... CARIBOU
SAMPLED AS..... FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
                                                                                                                         ADJUSTED
                          <------------------------- WEIGHT PERCENT ------------------------->                           PARTICLE
HORIZON    DEPTH(CM)       CLAY  SILT  SAND   VFS   FS    MS    COS   VCOS  FSILT CSILT  OM     CEC   CO3    NA    EC   %H20   DENSITY
---------------------------------------------------------------------------------------------------------------------------------------
  AP2        11- 24        12.1  42.8  45.1  11.1  12.0   8.6   6.7   6.7  26.3  16.5  3.10   11.7   0.0   0.0   0.0   0.0     2.60

                     CLAY  MINERALOGY                        BULK DENSITY(G,CC)          ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION        THERMAL DIFFERENTIAL         OVEN DRY   0.33 BARS     FRAGMENT(WGT)       0.33 BARS     15.0 BARS
---------------------------------------------------------------------------------------------------------------------------------------
                                                               1.45      1.39             36.8              16.2           5.9

                                                  COMPUTED SOIL WATER RETENTION VALUES
                                             =======================================================

SUCTION (BARS)                                0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
---------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                          32.2   32.2   30.8   28.4   23.6   18.9   16.1   13.4   11.6    9.5    7.6    6.5    5.9    4.3
VOLUME % WATER(<2MM)                          44.2   44.1   42.3   39.1   32.6   26.3   22.4   18.7   16.1   13.3   10.6    9.0    8.3    6.1
VOLUME % WATER(WHOLE SOIL)                    34.0   33.9   32.5   30.0   25.0   20.2   17.2   14.3   12.3   10.2    8.1    6.9    6.3    4.7

                                                     WATER RETENTION DIFFERENCES
                                             =======================================================

 SUCTION DIFFERENCES (BARS)                          0.1-0.33     0.1-2.0     0.1-15.0     0.33-2.0     0.33-15.0     2.0-15.0
---------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                                    7.5         14.1         17.7          6.6          10.2           3.6
VOLUME % WATER(<2MM)                                   10.2         19.3         24.3          9.1          14.1           5.0
VOLUME % WATER(WHOLE SOIL)                              7.8         14.8         18.6          7.0          10.8           3.8
                                                  MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                             =======================================================

                                 N       ALPHA       M       RES. WATER       SAT. WATER        BDI          BDS           BUBP(BARS)
                             2.651152  0.023690  0.143479       2.8              32.2           1.41       -0.00122          0.0222


                                                  EQUATIONS FOR SOIL WATER RETENTION CURVE
                                             =======================================================

     ABBREVIATIONS:   WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                      RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
       WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
       VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
       VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

APPENDIX IV - Caribou (continued)

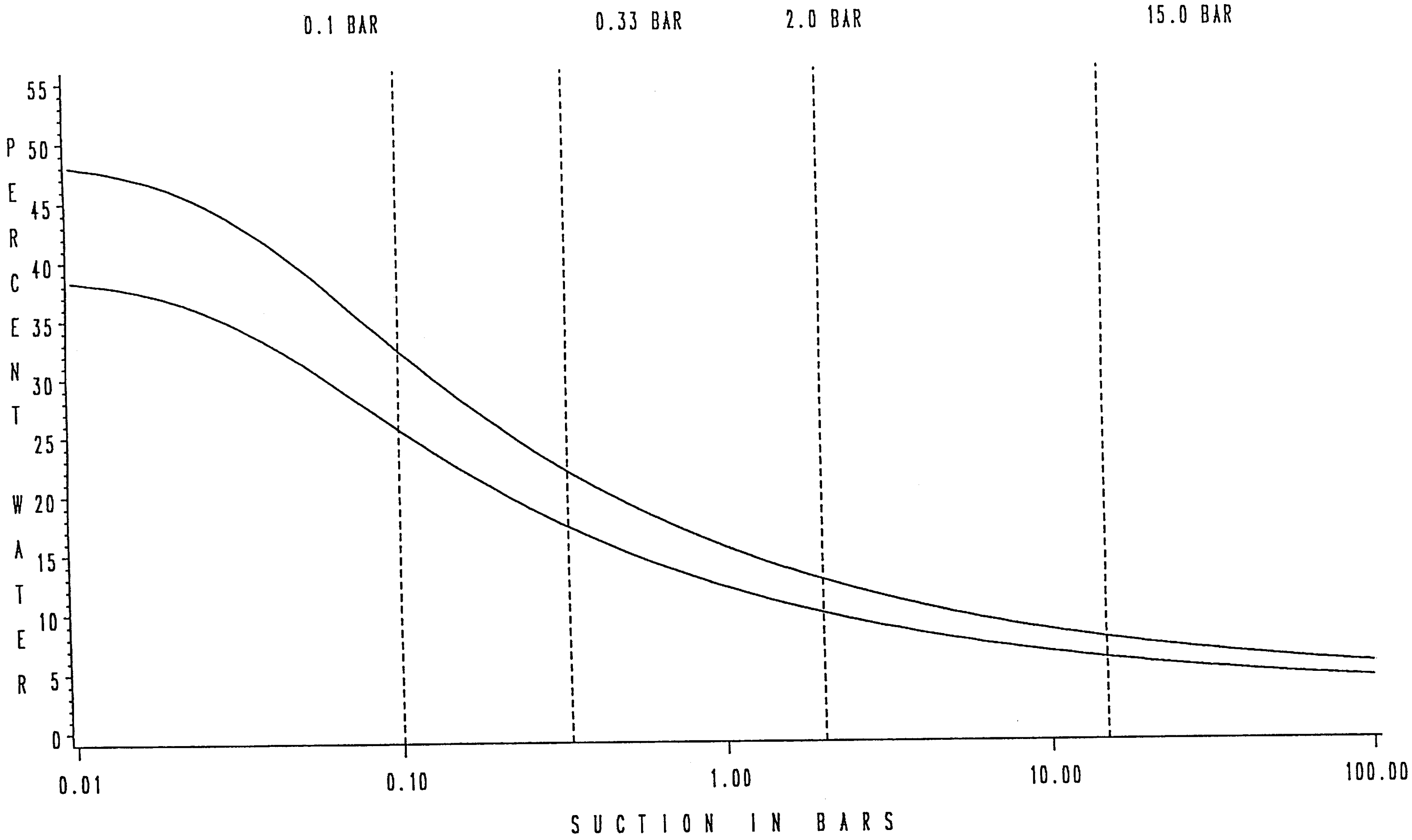
SOIL WATER RETENTION CURVE

State: MAINE
Soil Series Name: CARIBOU
Horizon: AP2 11- 24 cm

Of <2mm Fraction

Expected Low Density.

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	12.1-42.8-45.1	1.27(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 883856-3

APPENDIX IV - Caribou (continued)

```
                 ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E   ***

                       N.S.S.L. METHOD CODE X001              EXPECTED LOW DENSITY              DATE PRINTED 07/22/94

STATE: MAINE                          COUNTY:   3           YEAR: 1988           PEDON:  722            SAMPLE:  3856            ID: 883856
SERIES NAME.... CARIBOU
SAMPLED AS..... FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
                                                                                                                                 ADJUSTED
                                <----------------------- WEIGHT PERCENT ----------------------->                                  PARTICLE
HORIZON    DEPTH(CM)             CLAY  SILT  SAND   VFS   FS    MS   COS   VCOS  FSILT CSILT  OM       CEC   CO3    NA     EC  %H20   DENSITY
-------------------------------------------------------------------------------------------------------------------------------------------
  AP2       11- 24               12.1  42.8  45.1  11.1  12.0   8.6   6.7   6.7  26.3  16.5  3.10     11.7   0.0    0.0    0.0   0.0     2.60

                             CLAY  MINERALOGY                                BULK DENSITY(G,CC)          ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION             THERMAL DIFFERENTIAL                    OVEN DRY   0.33 BARS    FRAGMENT(WGT)          0.33 BARS     15.0 BARS
-------------------------------------------------------------------------------------------------------------------------------------------
                                                                              1.33       1.27            36.8                17.1          6.0

                                                    COMPUTED SOIL WATER RETENTION VALUES
                                              ==========================================================

SUCTION (BARS)                                 0.00    0.01    0.03    0.05    0.10    0.20    0.33    0.60    1.00    2.00    5.00   10.00   15.00  100.00
-----------------------------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                           39.0    38.3    34.8    31.1    25.4    20.2    17.1    14.1    12.1     9.9     7.7     6.5     6.0     4.3
VOLUME % WATER(<2MM)                           48.5    47.8    43.5    38.9    32.0    25.6    21.7    18.0    15.4    12.6     9.9     8.4     7.7     5.5
VOLUME % WATER(WHOLE SOIL)                     38.1    37.5    34.1    30.5    25.1    20.0    17.0    14.1    12.0     9.8     7.7     6.6     6.0     4.3

                                                         WATER RETENTION DIFFERENCES
                                              ==========================================================

 SUCTION DIFFERENCES (BARS)                          0.1-0.33        0.1-2.0        0.1-15.0        0.33-2.0       0.33-15.0        2.0-15.0
-----------------------------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                                   8.3            15.5            19.4            7.2            11.1            3.9
VOLUME % WATER(<2MM)                                  10.3            19.4            24.3            9.1            14.0            4.9
VOLUME % WATER(WHOLE SOIL)                             8.0            15.2            19.0            7.1            10.9            3.8
                                                    MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                              ==========================================================

                                   N        ALPHA        M       RES. WATER         SAT. WATER          BDI          BDS             BUBP(BARS)
                               1.993470  0.031035  0.197695       2.8                39.0              1.29       -0.00115           0.0056


                                                    EQUATIONS FOR SOIL WATER RETENTION CURVE
                                              ==========================================================

     ABBREVIATIONS:    WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                       RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
       WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
       VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
       VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

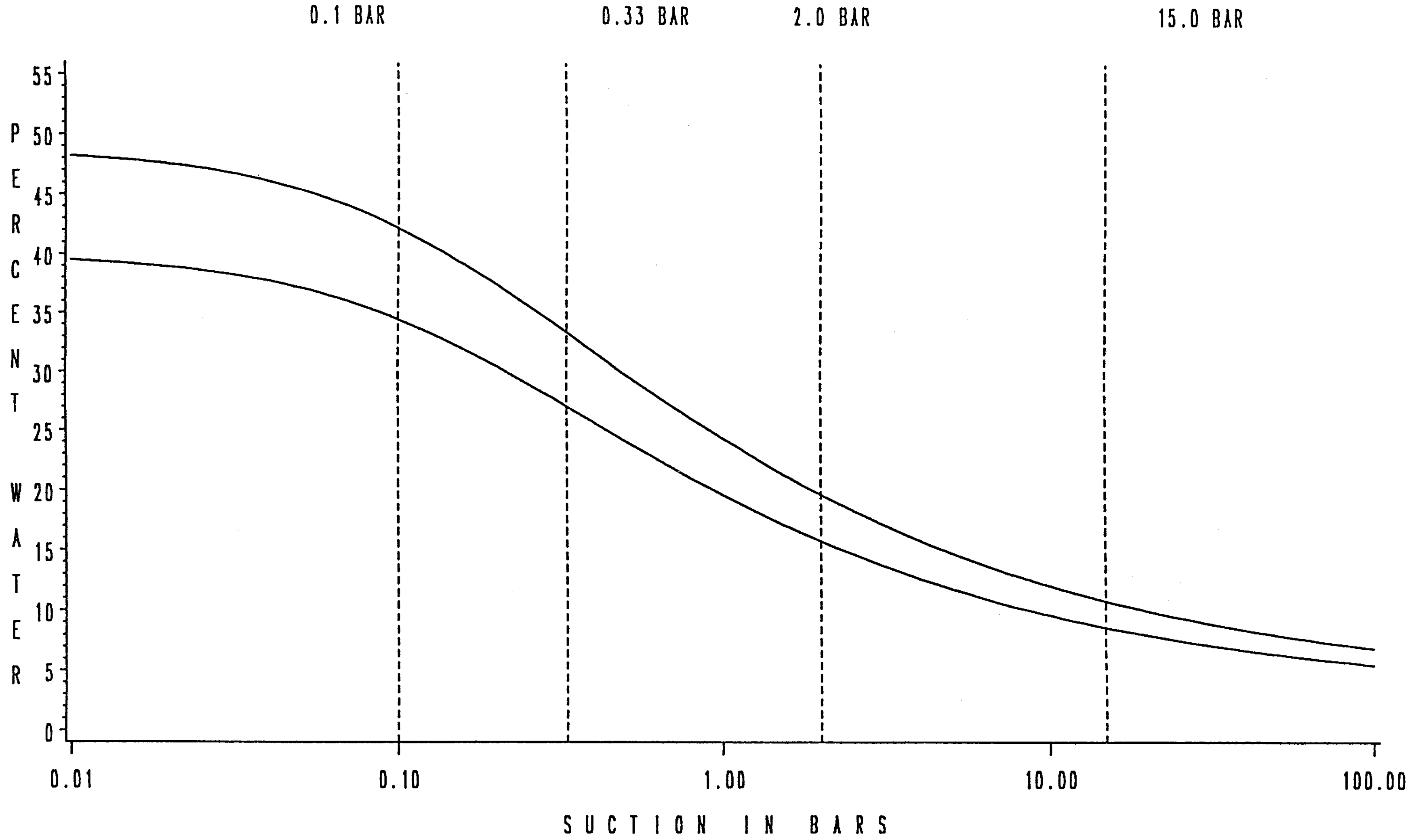
SOIL WATER RETENTION CURVE

State: MAINE
Soil Series Name: CARIBOU
Horizon: AP2 11- 24 cm

Of <2mm Fraction

Measured Field Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	12.1-42.8-45.1	1.24(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 883856-0

APPENDIX VI - Caribou (continued)

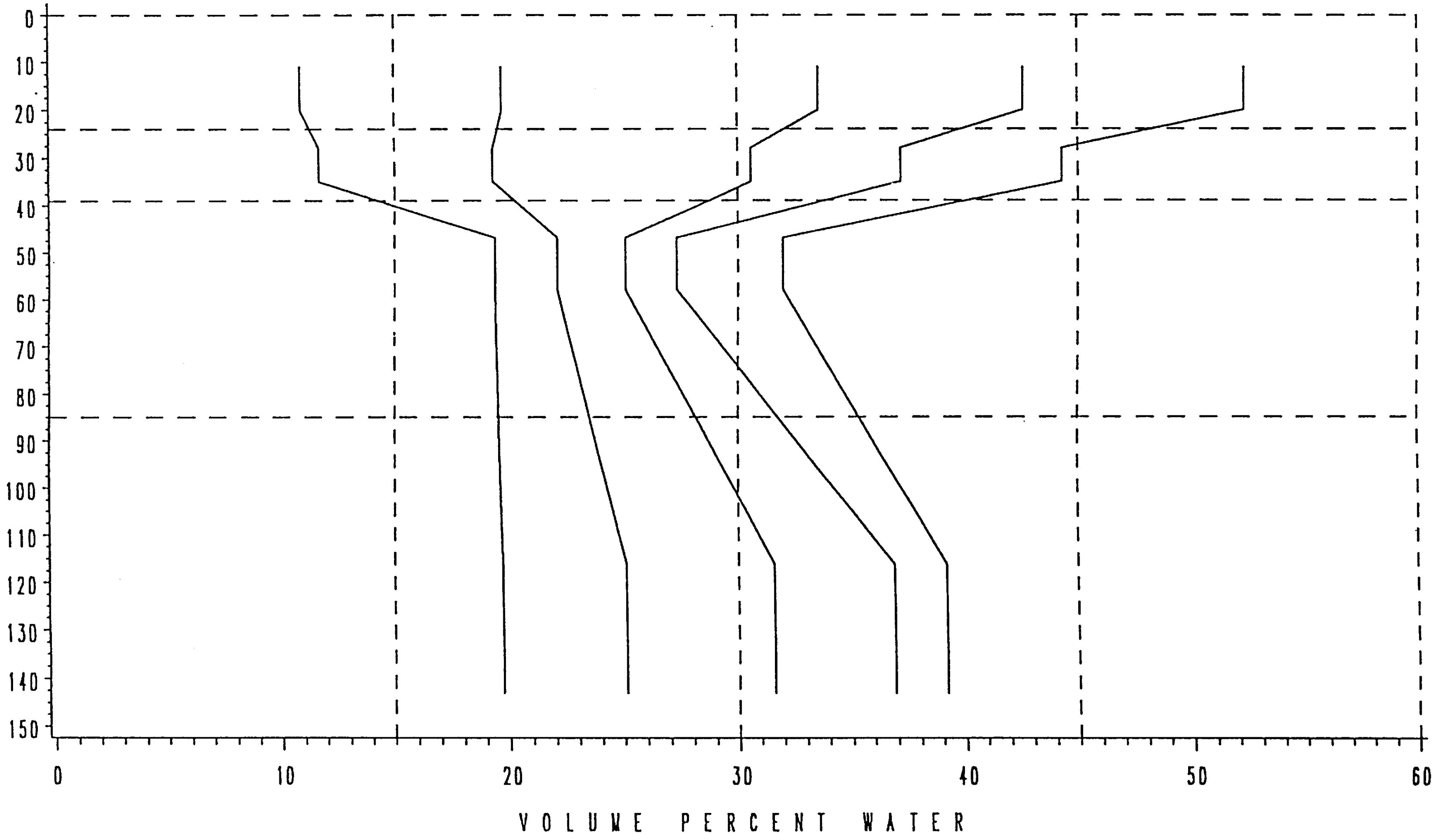
```
          ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E   ***

                N.S.S.L. METHOD CODE X001            MEASURED FIELD DENSITY            DATE PRINTED 07/22/94

STATE: MAINE                          COUNTY:   3         YEAR: 1988          PEDON:  722          SAMPLE:  3856           ID: 883856
SERIES NAME.... CARIBOU
SAMPLED AS..... FINE-LOAMY, MIXED, FRIGID, TYPIC HAPLORTHOD
                                                                                                                          ADJUSTED
                        <------------------------ WEIGHT PERCENT ------------------------>                                 PARTICLE
HORIZON   DEPTH(CM)      CLAY  SILT  SAND   VFS   FS    MS   COS   VCOS  FSILT CSILT  OM      CEC   CO3    NA    EC  %H20  DENSITY
----------------------------------------------------------------------------------------------------------------------------------
  AP2      11- 24        12.1  42.8  45.1  11.1  12.0   8.6   6.7   6.7  26.3  16.5  3.10    11.7   0.0   0.0   0.0   0.0    2.60

                   CLAY  MINERALOGY                          BULK DENSITY(G,CC)           ROCK              WATER(WEIGHT PERCENT)
     X-RAY DIFFRACTION        THERMAL DIFFERENTIAL           OVEN DRY   0.33 BARS     FRAGMENT(WGT)       0.33 BARS     15.0 BARS
----------------------------------------------------------------------------------------------------------------------------------
                                                               1.29       1.24            36.8               26.9          8.6

                                                COMPUTED SOIL WATER RETENTION VALUES
                                          =======================================================

SUCTION (BARS)                        0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
----------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                  40.0   39.5   38.3   37.0   34.3   30.3   26.8   22.8   19.5   15.6   11.8    9.6    8.6    5.5
VOLUME % WATER(<2MM)                  49.3   48.7   47.2   45.7   42.4   37.5   33.3   28.3   24.2   19.5   14.7   12.0   10.8    6.9
VOLUME % WATER(WHOLE SOIL)            38.8   38.3   37.1   35.9   33.3   29.5   26.2   22.2   19.0   15.3   11.5    9.4    8.5    5.4

                                                   WATER RETENTION DIFFERENCES
                                          =======================================================

 SUCTION DIFFERENCES (BARS)                   0.1-0.33     0.1-2.0      0.1-15.0     0.33-2.0     0.33-15.0      2.0-15.0
----------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                            7.5          18.7         25.7         11.2         18.2           7.0
VOLUME % WATER(<2MM)                            9.1          22.9         31.6         13.8         22.5           8.7
VOLUME % WATER(WHOLE SOIL)                      7.1          18.0         24.8         10.8         17.7           6.8

                                             MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                          =======================================================

                   N        ALPHA       M        RES. WATER        SAT. WATER         BDI          BDS              BUBP(BARS)
               1.184516  0.006644  0.339539        2.8               40.0             1.26       -0.00061             0.0027


                                             EQUATIONS FOR SOIL WATER RETENTION CURVE
                                          =======================================================

      ABBREVIATIONS:   WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                       RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
        WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
        VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
        VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

SOIL WATER RETENTION DEPTH CURVE

STATE: MAINE
SOIL SERIES NAME: CARIBOU

DATE: 07/25/94

				CLAY SILT SAND <--PERCENT--->	BULK DENSITY (AT 1/3 BAR)
HORIZON:	AP2	11-24 CM	ID(YR-SN): 883856 MEASURED	12.1-42.8-45.1	1.24(G/CC)
HORIZON:	BS	24-39 CM	ID(YR-SN): 883857 MEASURED	12.3-44.5-43.2	1.47(G/CC)
HORIZON:	C1	39-66 CM	ID(YR-SN): 883858 MEASURED	13.3-44.9-41.8	1.81(G/CC)
HORIZON:	C3	104-143 CM	ID(YR-SN): 883860 MEASURED	23.2-45.2-31.6	1.63(G/CC)



NSSL - PEDON NO. 88-722

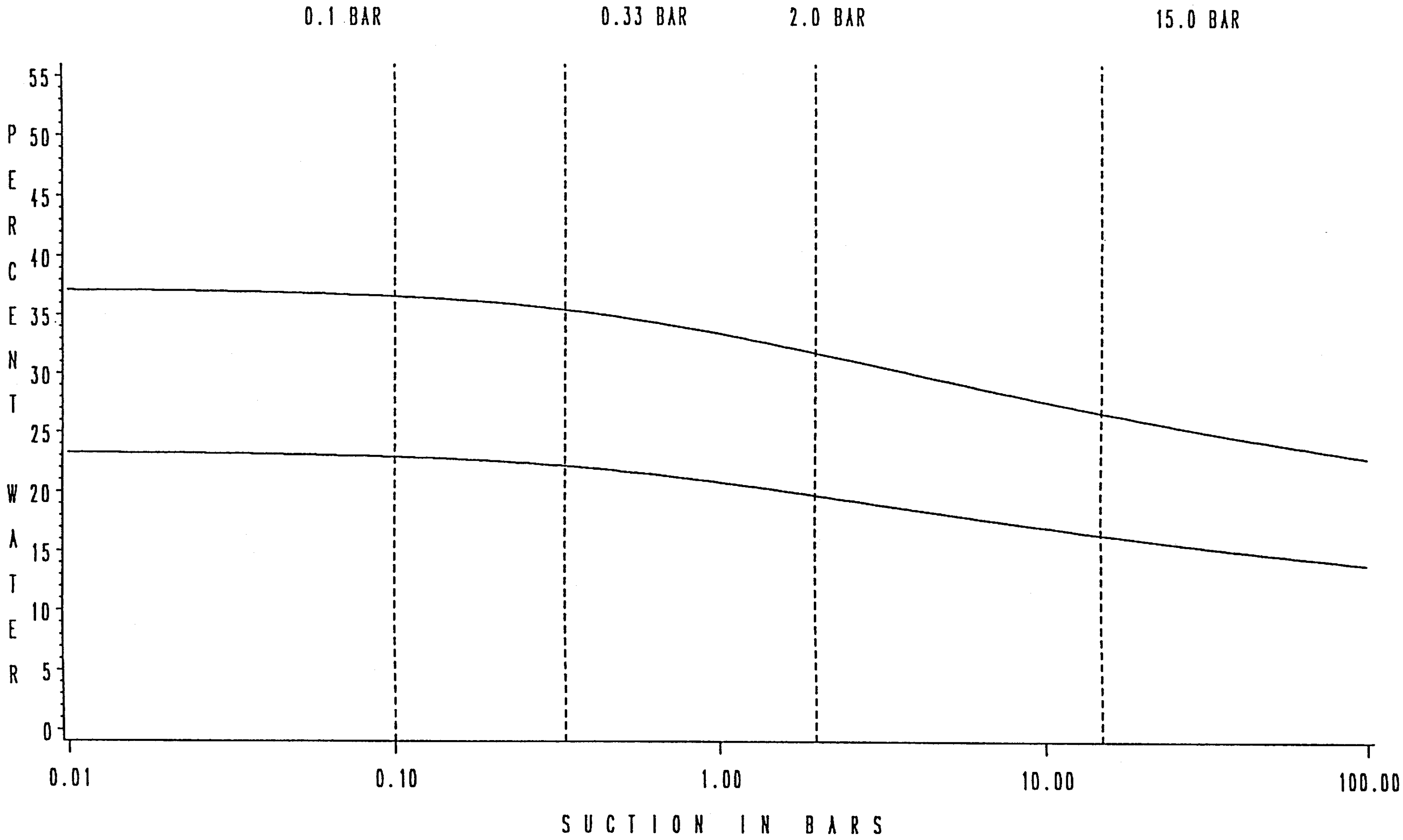
SOIL WATER RETENTION CURVE

State: CALIFORNIA
Soil Series Name: WILDMESA
Horizon: 2 BT 15- 46 cm

Of <2mm Fraction

Expected High Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	34.9-21.8-43.3	1.60(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 891801-1

APPENDIX VI - Wildmesa (continued)

```
         ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E  ***

                N.S.S.L. METHOD CODE X001            EXPECTED HIGH DENSITY           DATE PRINTED 07/22/94

STATE: CALIFORNIA              COUNTY:  27          YEAR: 1989          PEDON:  325          SAMPLE:  1801            ID: 891801
SERIES NAME.... WILDMESA
SAMPLED AS..... FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
                                                                                                                    ADJUSTED
                          <------------------------ WEIGHT PERCENT ------------------------>                         PARTICLE
HORIZON    DEPTH(CM)      CLAY  SILT  SAND   VFS   FS    MS    COS   VCOS  FSILT CSILT  OM     CEC   CO3    NA    EC  %H20  DENSITY
-------------------------------------------------------------------------------------------------------------------------------------
2  BT        15- 46       34.9  21.8  43.3  20.7  18.1   2.6   1.0   0.9  15.1   6.7   0.32   28.7   0.0   0.0   0.0   0.0    2.64

                    CLAY  MINERALOGY                          BULK DENSITY(G,CC)          ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION         THERMAL DIFFERENTIAL          OVEN DRY   0.33 BARS     FRAGMENT(WGT)        0.33 BARS    15.0 BARS
-------------------------------------------------------------------------------------------------------------------------------------
                                                                1.87       1.60            1.5                22.3         16.3

                                                COMPUTED SOIL WATER RETENTION VALUES
                                       =======================================================

SUCTION (BARS)                        0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
-------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                  23.3   23.3   23.2   23.1   22.9   22.5   22.1   21.5   20.7   19.6   18.1   17.0   16.3   13.9
VOLUME % WATER(<2MM)                  37.2   37.2   37.0   36.9   36.6   36.0   35.4   34.4   33.3   31.6   29.2   27.5   26.5   22.7
VOLUME % WATER(WHOLE SOIL)            36.9   36.9   36.7   36.6   36.3   35.7   35.1   34.1   33.0   31.3   28.9   27.2   26.3   22.5

                                                   WATER RETENTION DIFFERENCES
                                       =======================================================

 SUCTION DIFFERENCES (BARS)                   0.1-0.33     0.1-2.0     0.1-15.0     0.33-2.0     0.33-15.0      2.0-15.0
-------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                             0.8         3.3          6.6          2.5          5.8            3.3
VOLUME % WATER(<2MM)                             1.2         5.0         10.1          3.8          8.9            5.1
VOLUME % WATER(WHOLE SOIL)                       1.2         5.0         10.0          3.8          8.8            5.1
                                              MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                       =======================================================

                          N        ALPHA         M        RES. WATER        SAT. WATER        BDI         BDS            BUBP(BARS)
                      1.000000   0.001668   0.187469         8.1               23.3           1.69     -0.00383           0.0628

                                            EQUATIONS FOR SOIL WATER RETENTION CURVE
                                       =======================================================

     ABBREVIATIONS:   WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                      RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
       WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
       VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
       VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

APPENDIX VI - Wildmesa (continued)

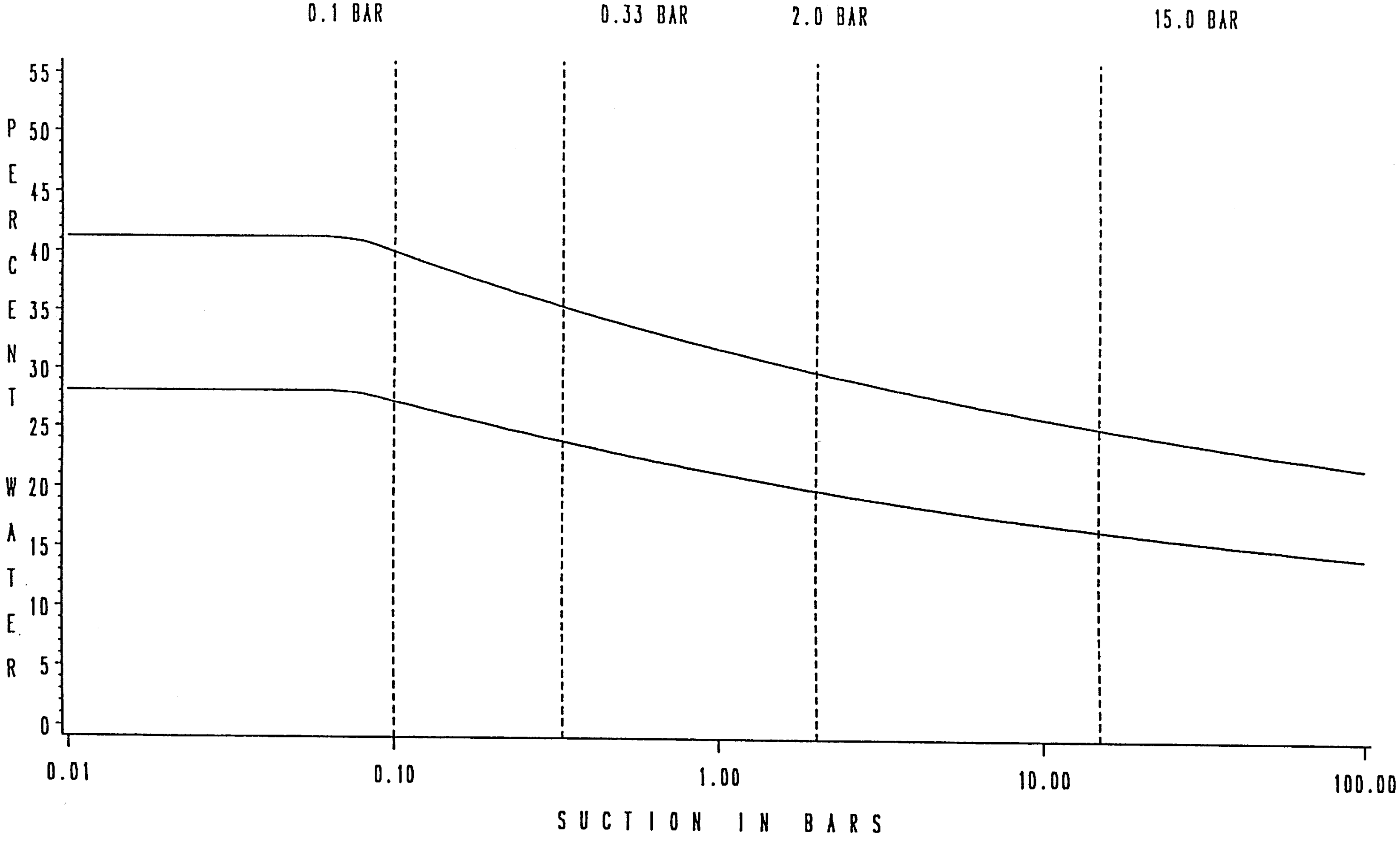
SOIL WATER RETENTION CURVE

State: CALIFORNIA
Soil Series Name: WILDMESA
Horizon: 2 BT 15- 46 cm

Of <2mm Fraction

Expected Medium Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	34.9-21.8-43.3	1.49(g/CC)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 891801-2

APPENDIX VI - Wildmesa (continued)

```
        ***  DATA  FOR  CALCULATED  SOIL  WATER  RETENTION  CURVE  ***

             N.S.S.L. METHOD CODE X001        EXPECTED MEDIUM DENSITY        DATE PRINTED 07/22/94

STATE: CALIFORNIA               COUNTY:  27           YEAR: 1989          PEDON:  325          SAMPLE:  1801           ID: 891801
SERIES NAME.... WILDMESA
SAMPLED AS..... FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID                                                          ADJUSTED
                         <------------------------- WEIGHT PERCENT ------------------------->                              PARTICLE
HORIZON   DEPTH(CM)      .CLAY  SILT  SAND   VFS   FS    MS   COS   VCOS  FSILT CSILT  OM     CEC   CO3    NA    EC  %H20   DENSITY
---------------------------------------------------------------------------------------------------------------------------------
2  BT       15- 46        34.9  21.8  43.3  20.7  18.1  2.6   1.0   0.9  15.1   6.7  0.32   28.7   0.0   0.0   0.0   0.0    2.64

                      CLAY  MINERALOGY                              BULK DENSITY(G,CC)         ROCK            WATER(WEIGHT PERCENT)
     X-RAY DIFFRACTION          THERMAL DIFFERENTIAL               OVEN DRY   0.33 BARS    FRAGMENT(WGT)      0.33 BARS    15.0 BARS
---------------------------------------------------------------------------------------------------------------------------------
                                                                     1.76       1.49           1.5              23.7         16.5

                                                   COMPUTED SOIL WATER RETENTION VALUES
                                             ==================================================

SUCTION (BARS)                               0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
-----------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                         28.1   28.1   28.1   28.1   27.1   25.0   23.7   22.3   21.1   19.8   18.1   17.1   16.5   14.3
VOLUME % WATER(<2MM)                         41.4   41.4   41.4   41.4   40.0   37.2   35.3   33.3   31.7   29.7   27.4   25.8   25.0   21.7
VOLUME % WATER(WHOLE SOIL)                   41.1   41.1   41.1   41.1   39.7   36.9   35.0   33.0   31.4   29.4   27.2   25.6   24.8   21.5

                                                      WATER RETENTION DIFFERENCES
                                             ==================================================

 SUCTION DIFFERENCES (BARS)                        0.1-0.33      0.1-2.0      0.1-15.0      0.33-2.0      0.33-15.0      2.0-15.0
-----------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                                  3.4          7.3          10.6           3.9           7.2           3.3
VOLUME % WATER(<2MM)                                  4.7         10.3          15.0           5.6          10.3           4.7
VOLUME % WATER(WHOLE SOIL)                            4.7         10.2          14.9           5.6          10.2           4.7
                                                   MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                             ==================================================

                            N        ALPHA       M       RES. WATER        SAT. WATER         BDI          BDS              BUBP(BARS)
                        12.435547  0.013388  0.013089       8.1               28.1            1.58       -0.00359             0.0377


                                                   EQUATIONS FOR SOIL WATER RETENTION CURVE
                                             ==================================================

    ABBREVIATIONS:    WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                      RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
      WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
      VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
      VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

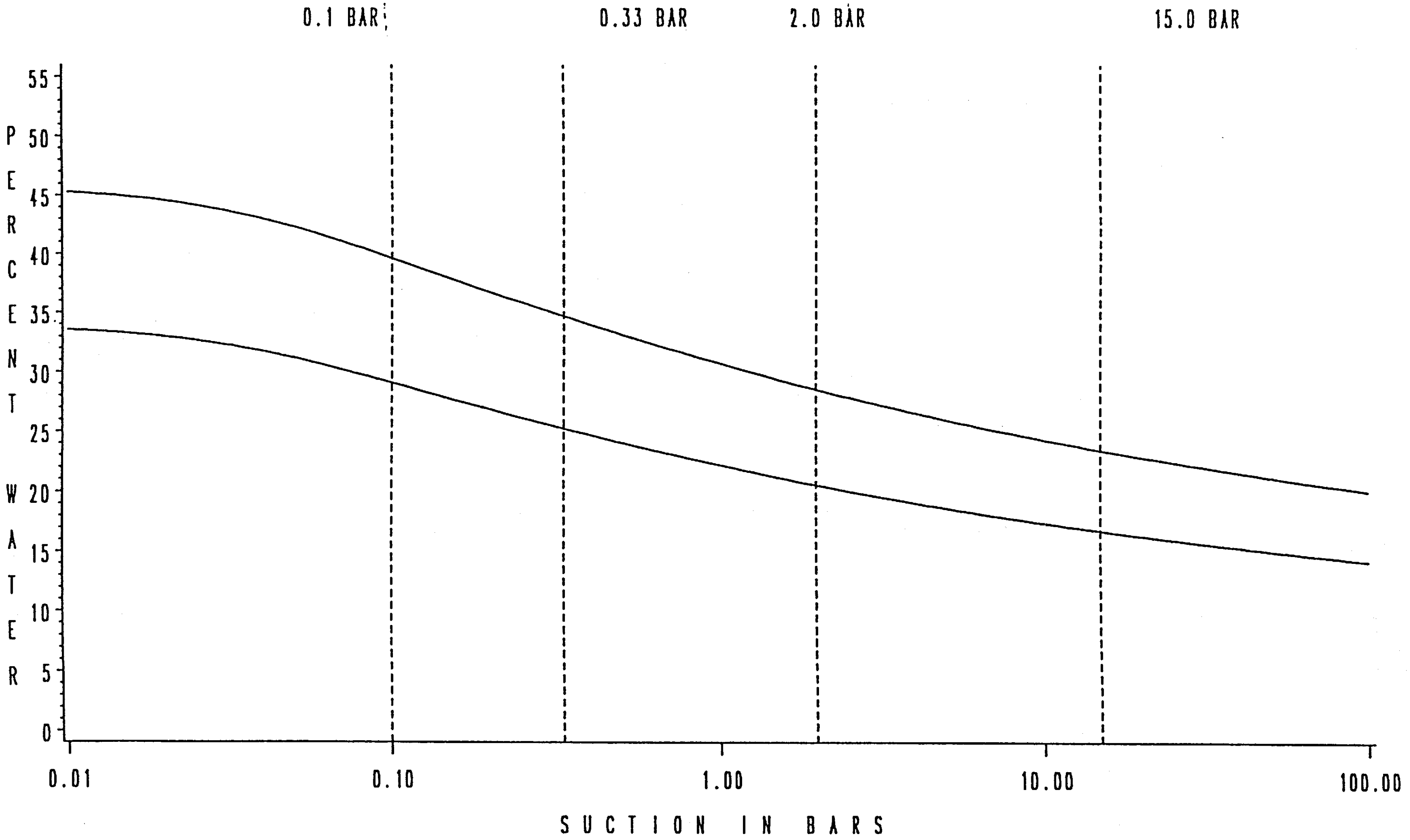
SOIL WATER RETENTION CURVE

State: CALIFORNIA
Soil Series Name: WILDMESA
Horizon: 2 BT 15- 46 cm

Of <2mm Fraction

Expected Low Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	34.9-21.8-43.3	1.37(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 891801-3

APPENDIX VI - Wildmesa (continued)

```
          ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E   ***

                 N.S.S.L. METHOD CODE X001            EXPECTED LOW DENSITY           DATE PRINTED 07/22/94

STATE: CALIFORNIA                COUNTY:  27         YEAR: 1989         PEDON:  325          SAMPLE: - 1801            ID: 891801
SERIES NAME.... WILDMESA
SAMPLED AS..... FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
                                                                                                                       ADJUSTED
                              <----------------------- WEIGHT PERCENT ----------------------->                         PARTICLE
HORIZON   DEPTH(CM)          . CLAY  SILT  SAND   VFS   FS     MS   COS   VCOS  FSILT CSILT  OM      CEC   CO3    NA    EC  %H20  DENSITY
---------------------------------------------------------------------------------------------------------------------------------------
2  BT       15- 46            34.9  21.8  43.3  20.7  18.1   2.6   1.0   0.9  15.1   6.7  0.32    28.7   0.0   0.0   0.0   0.0     2.64

                    CLAY  MINERALOGY                            BULK DENSITY(G,CC)          ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION        THERMAL DIFFERENTIAL            OVEN DRY  0.33 BARS      FRAGMENT(WGT)        0.33 BARS    15.0 BARS
---------------------------------------------------------------------------------------------------------------------------------------
                                                                 1.64      1.37             1.5                 25.1         16.7

                                                          COMPUTED SOIL WATER RETENTION VALUES
                                                 ==========================================================

SUCTION (BARS)                              0.00    0.01    0.03    0.05    0.10    0.20    0.33    0.60    1.00    2.00    5.00   10.00   15.00  100.00
------------------------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                        33.9    33.5    32.3    31.0    28.9    26.7    25.1    23.4    22.1    20.4    18.5    17.3    16.7    14.2
VOLUME % WATER(<2MM)                        45.4    45.0    43.4    41.9    39.3    36.4    34.4    32.2    30.5    28.3    25.8    24.2    23.3    19.9
VOLUME % WATER(WHOLE SOIL)                  45.1    44.7    43.1    41.6    39.0    36.1    34.1    31.9    30.3    28.1    25.6    24.0    23.1    19.7

                                                             WATER RETENTION DIFFERENCES
                                                 ==========================================================

 SUCTION DIFFERENCES (BARS)                        0.1-0.33      0.1-2.0      0.1-15.0      0.33-2.0      0.33-15.0      2.0-15.0
------------------------------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                                  3.8           8.5          12.2           4.7            8.4           3.7
VOLUME % WATER(<2MM)                                  4.9          11.0          16.0           6.1           11.1           5.0
VOLUME % WATER(WHOLE SOIL)                            4.9          10.9          15.9           6.1           11.0           5.0
                                                       MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                                 ==========================================================

                                  N       ALPHA       M       RES. WATER        SAT. WATER        BDI         BDS             BUBP(BARS)
                            1.634395  0.028675  0.110797       8.1               33.9            1.45      -0.00337            0.0094


                                                         EQUATIONS FOR SOIL WATER RETENTION CURVE
                                                 ==========================================================

     ABBREVIATIONS:   WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                      RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
       WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
       VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
       VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

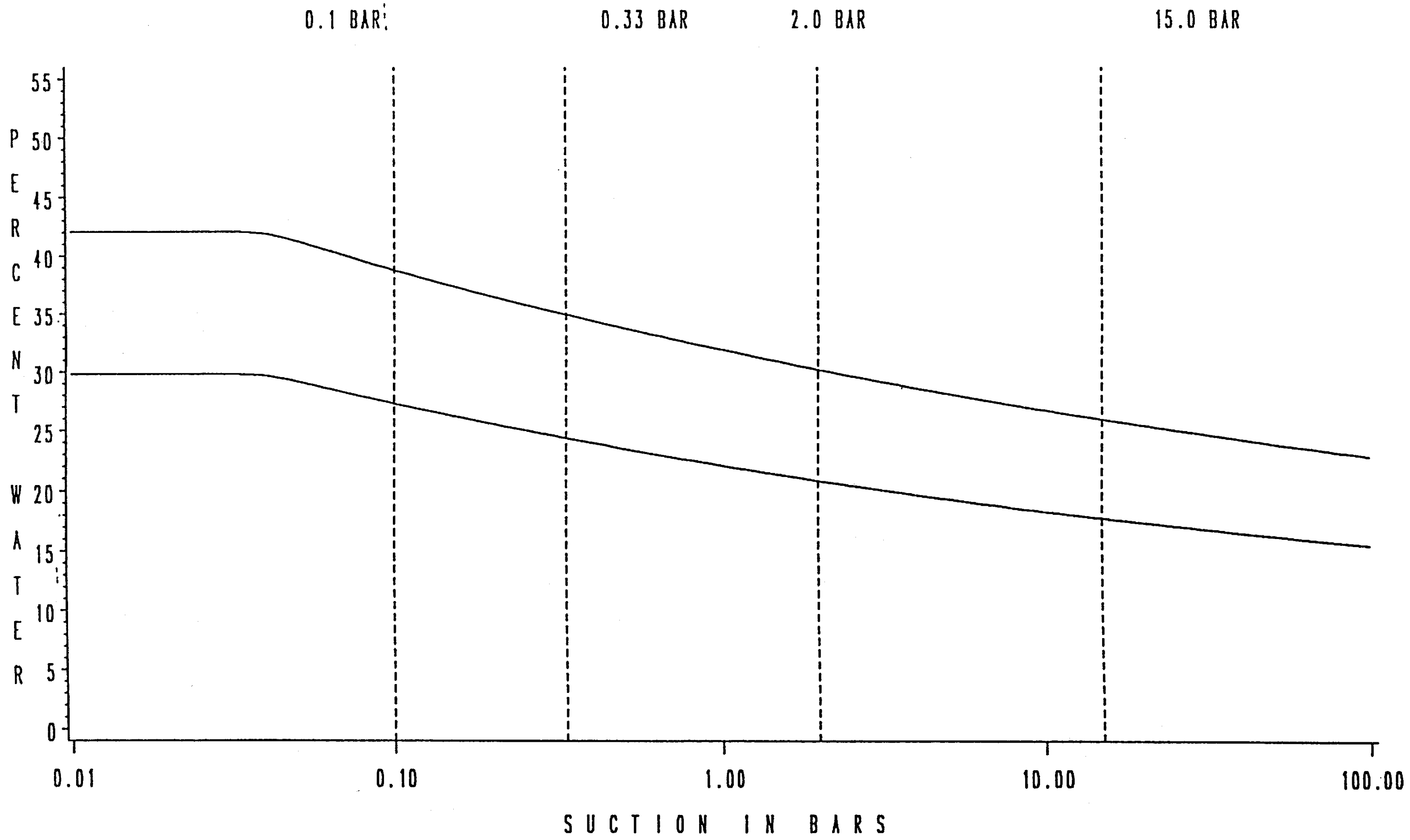
APPENDIX VI - Wildmesa (continued)

SOIL WATER RETENTION CURVE

State: CALIFORNIA
Soil Series Name: WILDMESA
Horizon: 2 BT 15- 46 cm

Of <2mm Fraction
Measured Field Density

Rockfr. Pct.Vol	Clay Silt Sand <Percent WGT.>	Bulk Density (At 1/3 Bar)
0.0	34.9-21.8-43.3	1.45(g/cc)



NOTE: Volume Graph Is Greater Than The Weight Graph

NSSC-SSL: ID 891801-0

APPENDIX VI - Wildmesa (continued)

```
         ***  D A T A   F O R   C A L C U L A T E D   S O I L   W A T E R   R E T E N T I O N   C U R V E  ***

               N.S.S.L. METHOD CODE X001          MEASURED FIELD DENSITY          DATE PRINTED 07/22/94

STATE: CALIFORNIA               COUNTY:  27          YEAR: 1989          PEDON:  325          SAMPLE:  1801          ID: 891801
SERIES NAME.... WILDMESA
SAMPLED AS..... FINE, MONTMORILLONITIC, MESIC XEROLLIC PALEARGID
                                                                                                                     ADJUSTED
                      <------------------------ WEIGHT PERCENT ------------------------>                              PARTICLE
HORIZON    DEPTH(CM)   CLAY  SILT  SAND   VFS   FS    MS    COS   VCOS  FSILT CSILT  OM     CEC   CO3    NA    EC  %H20   DENSITY
--------------------------------------------------------------------------------------------------------------------------------
2  BT       15- 46     34.9  21.8  43.3  20.7  18.1   2.6   1.0   0.9  15.1   6.7  0.32   28.7   0.0   0.0   0.0   0.0    2.64

               CLAY  MINERALOGY                          BULK DENSITY(G,CC)          ROCK              WATER(WEIGHT PERCENT)
      X-RAY DIFFRACTION       THERMAL DIFFERENTIAL        OVEN DRY   0.33 BARS    FRAGMENT(WGT)       0.33 BARS      15.0 BARS
--------------------------------------------------------------------------------------------------------------------------------
                                                             1.72      1.45             1.5              24.3           17.7

                                           COMPUTED SOIL WATER RETENTION VALUES
                                       =================================================

SUCTION (BARS)                      0.00   0.01   0.03   0.05   0.10   0.20   0.33   0.60   1.00   2.00   5.00  10.00  15.00 100.00
--------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                29.8   29.8   29.8   29.1   27.2   25.5   24.3   23.0   22.0   20.8   19.3   18.2   17.7   15.5
VOLUME % WATER(<2MM)                42.6   42.6   42.6   41.7   39.1   36.8   35.2   33.5   32.1   30.4   28.3   26.8   26.1   23.0
VOLUME % WATER(WHOLE SOIL)          42.3   42.3   42.3   41.4   38.8   36.5   34.9   33.2   31.8   30.1   28.1   26.6   25.9   22.8

                                              WATER RETENTION DIFFERENCES
                                       =================================================

 SUCTION DIFFERENCES (BARS)                 0.1-0.33     0.1-2.0     0.1-15.0     0.33-2.0     0.33-15.0      2.0-15.0
--------------------------------------------------------------------------------------------------------------------------------
WEIGHT % WATER(<2MM)                           2.9          6.4          9.5          3.5          6.6           3.1
VOLUME % WATER(<2MM)                           3.9          8.7         13.0          4.8          9.1           4.3
VOLUME % WATER(WHOLE SOIL)                     3.9          8.6         12.9          4.8          9.0           4.3
                                          MODEL PARAMETERS  (WEIGHT PRECENT WATER)
                                       =================================================

                      N         ALPHA       M        RES. WATER          SAT. WATER          BDI          BDS              BUBP(BARS)
                  11.530192  0.024807  0.011888       8.1                 29.8             1.53       -0.00350              0.0219


                                          EQUATIONS FOR SOIL WATER RETENTION CURVE
                                       =================================================

    ABBREVIATIONS:   WP=WEIGHT PERCENT  VP=VOLUME PERCENT  H=SUCTION(MEASURED IN CM OF WATER; E.G., 1 BAR=1020 CM OF WATER)
                     RES.=RESIDUAL  SAT.=SATURATED  BDI=BULK DENSITY INTERCEPT  BDS=BULK DENSITY SLOPE  BUBP=BUBBLING PRESSURE
      WATER  PERCENT EQUATION:  WATER(WP)=RES. WATER + ((SAT. WATER - RES. WATER)/(1 + (ALPHA * H) ** N) ** M))
      VOLUME PERCENT EQUATION:  WATER(VP)=WATER(WP) * (BDI + BDS * WATER(WP))
      VOLUME PERCENT EQUATION(ROCK FRAGMENTS):  WATER(VP WITH ROCK FRAGMENTS)=WATER(VP)*(1-ROCK FRAGMENT FRACTION(VOLUME))
```

APPENDIX VI - Wildmesa (continued)

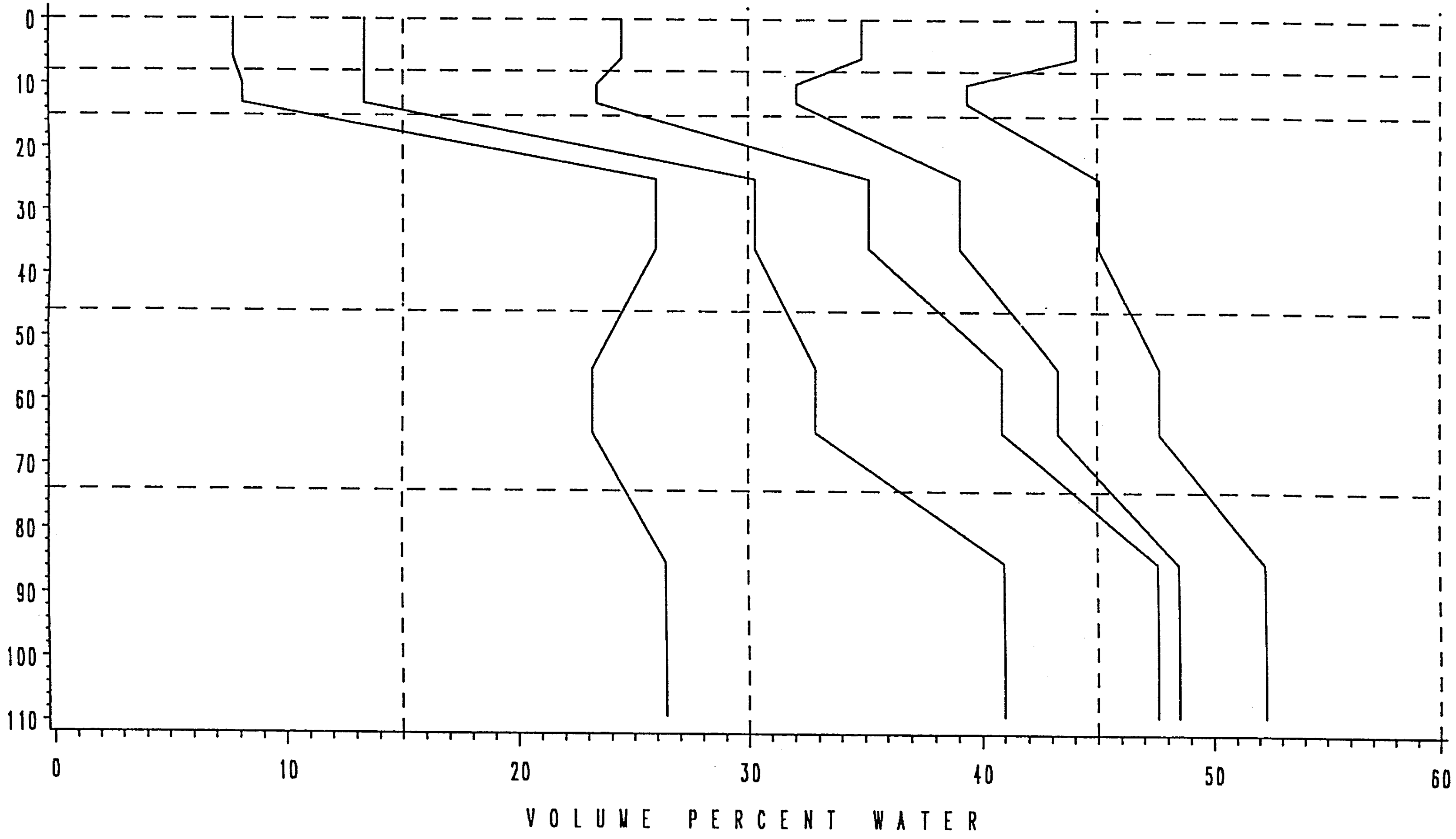
SOIL WATER RETENTION DEPTH CURVE

STATE: CALIFORNIA

DATE: 07/22/94

SOIL SERIES NAME: WILDMESA

				CLAY SILT SAND <--PERCENT--->	BULK DENSITY (AT 1/3 BAR)
HORIZON:	A	0-8 CM	ID(YR-SN): 891799 MEASURED	7.8-23.5-68.7	1.47(G/CC)
HORIZON:	AB	8-15 CM	ID(YR-SN): 891800 MEASURED	10.6-24.3-65.1	1.60(G/CC)
HORIZON: 2	BT	15-46 CM	ID(YR-SN): 891801 MEASURED	34.9-21.8-43.3	1.45(G/CC)
HORIZON: 2	BTK	46-74 CM	ID(YR-SN): 891802 MEASURED	38.1-26.7-35.2	1.38(G/CC)
HORIZON: 2	BTK	74-109 CM	ID(YR-SN): 891803 MEASURED	44.0-26.5-29.5	1.26(G/CC)



APPENDIX VII

Basic Chemistry Terminology[1]

[1] Basic chemistry terminology is extracted *in total* from Clarke (1988) and Brady and Humiston (1982).

Acid - Acid is a proton donor. An acid is a substance which increases the concentration of hydronium ion in solution. Acids are usually soluble in water.

Atom - Atom is the smallest particle of an element that can exist and take part in chemical reactions.

Atomic number - The atomic number is the number of protons in the nucleus of an atom. It equals the number of orbital electrons of the neutral atom. The atomic number identifies the element.

Base - Base is a proton acceptor. A base is a substance that increases the concentration of hydroxide ion in solution and reacts with an acid to produce a salt and water. Few bases are soluble in water, e.g., alkali is a soluble base.

Chemical Reaction - Chemical reaction is a change in which chemical substances act upon each other to produce one or more new substances. *Reagents* or *reactants* are the initial substances in a reaction. *Products* are the resulting substances in a reaction. When a new substance is made, a chemical change or *reaction* has resulted. Refer to Table 1 (Clarke, 1988)for some general differences between physical and chemical changes.

Table 1. Differences between physical and chemical changes[2]

Parameter	Physical Change	Chemical Change
Substances	stay the same	new ones formed
Easy to reverse	yes (generally)	no
Heat (energy) change	small	large
Solvents	stay the same	new ones formed
Chemical behavior	no different	very different

[2] Clarke, 1988.

Compound - Compound is a substance which contains two or more elements joined together in a way that its properties are different from those of its component elements. A compound is characterized by having its constituent elements always present in the same proportions by mass. For example, water is composed of two elements, hydrogen and oxygen. All samples of pure water contain these two elements in the proportion of one part by weight hydrogen to eight parts by weight oxygen. Many inorganic compounds can be classified as acids, bases, and salts or as oxidizing and reducing substances.

Element - Element is a substance which cannot be split into two or more substances by chemical reactions. Elements can be classified as metals and nonmetals or as oxidizing and reducing substances. Refer to Tables 2 and 3 (Clarke, 1988) for some general physical and chemical properties, respectively, (there are exceptions) of metals and nonmetals. Refer to Table 4 (Clive, 1987) for the Modern Periodic Table for Elements.

Table 2. Physical properties of metals and nonmetals[3]

Property	Metals	Nonmetals
Melting Point	high	low
Boiling Point	high	low
State	solids (usually)	gases (usually)
Density	high	low
Conductivity of heat and electricity	high	low
Ductile	yes	no
Strength	high	low
Hardness	high	low
Malleable	yes, and sonorous	no, and brittle
Color	grey	many colorless
Shininess (luster)	bright	dull

[3] Clarke, 1988.

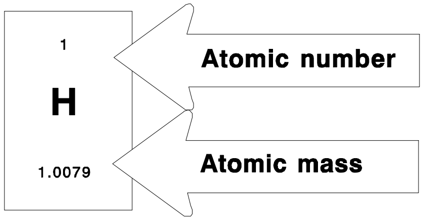
Table 3. Chemical properties of metals and nonmetals[4]

Property	Metals	Nonmetals
Type	reducing agent	oxidizing agent
Ions formed	cations	anions
With nonmetals	form ionic compounds	form covalent compounds
With metals	form alloys	form ionic compounds
With dilute acids	give metal salt and hydrogen	no reaction
With alkalis	many do not react; few are amphoteric	many react, but in complex way
With oxygen	form basic oxides	form acidic oxides
With chlorine	form salts which which are stable to water	form compounds which are unstable to water (hydrolysis)
With hydrogen	few react to produce compounds	many react to produce compounds

[4] Clarke, 1988.

TABLE 4

The Modern Periodic Table of the Elements



PERIODS	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	NOBLE GASES 0
1	1 H 1.00797																	2 He 4.00260
2	3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.01115	7 N 14.0067	8 O 15.9994	9 F 18.99840	10 Ne 20.179
3	11 Na 22.98977	12 Mg 24.305											13 Al 26.98154	14 Si 28.086	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.90	23 V 50.9414	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 KR 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc 98.9062	44 Ru 101.079	45 Rh 102.9055	46 Pd 106.4	47 Ag 107.868	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.30
6	55 Cs 132.9054	56 Ba 127.34	57 *La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.9665	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.9804	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.0254	89 †Ac (227)	104 Ku (261)	105 Ha (260)	106	107		109									

*	58 Ce 140.32	59 Pr 140.9077	60 Nd 144.24	61 Pm (147)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dv 162.50	67 Ho 164.9304	68 Er 166.264	69 Tm 168.9342	70 Yb 174.06	71 Lu 174.97
†	90 Th 232.0381	91 Pa 231.0359	92 U 238.029	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (255)	103 Lr (256)

CLIVE (1987)

Half-life - Half life is the time required for half the atoms of a radioactive isotope to decay. Refer to the term *Isotope*.

Ions - Ion is a charged particle composed of one or a few atoms. If an atom loses an electron, it becomes a positively charged ion termed a *cation*. If an atom gains an electron, it becomes a negatively charged ion termed an *anion*. Most but not all cations are single atoms, e.g., Ca^{2+}, K^+, and NH_3^+. Most but not all anions are groups of atoms, e.g., SO_4^{2-}, HCO_{3-}, and Cl^-.

Isotopes - Isotope is the form of an element that differs in the number of neutrons in the nucleus of the atom and differ in mass number. Isotopes of one element have the same number of protons in the nucleus and the same number of orbital electrons. *Radioactive isotopes* have nuclei that are not stable. They emit radiation as the nuclei disintegrate randomly at a constant rate. The intensity of radiation decreases with time as the amount of the radioactive isotope is exhausted.

Law of Conservation of Mass - The total mass at the beginning of a chemical reaction is equal to the total mass at the end of the reaction.

Law of Constant Composition - All pure chemical substances contain the same elements joined together in the same proportions by mass.

Metal - Metal is an element in which the number of electrons in the outer shell is ≤ to the Period Number (Table 4, Clive, 1987).

Mineral - Mineral is a naturally occurring substance which has definite physical properties and chemical composition.

Mixture - Mixture forms when substances do not join together, even if heated. Many mixtures can be easily separated again into its components without changing the chemical characteristics of these components. This separation is usually accomplished through the use of a physical process. However, there are some mixtures that can be separated only through the use of chemical processes. Mixtures may be homogeneous or heterogeneous. A homogeneous mixture is one with uniform properties throughout, e.g., solution. A mixture differs from elements and compounds in that it may be of variable composition.

Molecule - Molecule is the smallest particle of an element or compound which can exist on its own.

Nonmetal - Nonmetal is an element which has more electrons in its outer shell than its Period Number (Table 4, Clive, 1987).

Nucleus - Nucleus is the part of an atom composed of one or more protons and, except for the lightest isotope of hydrogen, one or more neutrons. The mass of the nucleus is approximately equal to the mass of the atom, yet the nucleus occupies only a very small fraction of the volume of the atom.

Oxidation-Reduction - Oxidation-reduction is a chemical reaction in which one substance is reduced and another is oxidized. Reduction is a chemical transformation involving a gain of electrons to an atom, molecule, or ion. Usually, reduction involves the loss of oxygen; gain of hydrogen; or an increase in the proportion of a metal in a compound. Oxidation is a chemical transformation involving a loss of electrons from an atom, molecule, or ion. Usually, oxidation involves the gain of oxygen; loss of hydrogen; or an increase in the proportion of a nonmetal in a compound.

Periodic Table - Atomic Structure - Refer to the Modern Periodic Table for Elements (Table 4, Clive, 1987). Rules for atomic structure (Clarke, 198) are as follows:

(1) With increasing atomic number, elements in Periods 1, 2, and 3 add electrons in the outer shell. In Periods 4 through 7, with increasing atomic number, some elements add electrons in the outer shell and some, termed *Transition Elements*, add electrons in the shell next to the outer shell.

(2) The elements are put into columns termed *Groups*. The elements in a group have the same number of electrons in the outer shell of their atoms. The transition elements are in groups that have the same number of electrons in the outer shell and also in shell next to the outer shell.

Periodic Table - Bonding - Refer to the Modern Periodic Table for Elements (Table 4, Clive, 1987). Rules for bonding of elements (Clarke, 1988) are as follows:

(1) If the two elements are a metal and a nonmetal, i.e., they are from the left and the right sides of the Periodic Table, then they combine to form a compound by ionic bonding.

(2) If the two elements are both nonmetals, i.e., they are both from the right side of the Periodic Table, they combine to form a compound by covalent bonding.

(3) If the two elements are both metals, i.e., they are both from the left side of the Periodic Table, they join together to form an alloy by metallic bonding.

Proton number - The number of neutrons plus the number of protons equal the mass number of an atom.

Salt - Salt is a compound produced when an acid reacts with a base. Usually water is also produced. Salts are composed of anions and cations. Most salts are composed a metal with any nonmetal except oxygen or a hydroxyl (OH^-) group.

Solution - Solution is a mixture of a solid, liquid, or gas dispersed at the molecular level in a solid, liquid or gas without chemical reaction. Many familiar solutions consist of a solid (solute) dissolved in a liquid (solvent). The solubility of a solid in a solvent is the mass of the solid needed to saturate 1 kg of solvent, at a particular temperature. *Solute + solvent --> solution*.

Substance - Substance is recognized by its characteristics or properties. Substances can be classified as solids, liquids, and gases (three states of matter) or as elements, compounds, and mixtures.

Valency - Valency of an element equals the number of hydrogen atoms that combine with (or replace) one atom of the element. Hydrogen has a valency of one.

APPENDIX VIII

MINERALOGY CODES

Resistant Minerals

AE = Anatase
AN = Andalusite
BA = Barite
BE = Boehmite
BK = Brookite
BY = Beryl
CD = Chalcedony (Chert, Flint, Jasper, Agate, Onyx)
CN = Corundum
CR = Cristobalite
CT = Cassiterite
DI = Diatoms
FE = Iron Oxides (Goethite, Magnetite, Hematite)
GD = Gold
GE = Goethite
GI = Gibbsite
GN = Garnet
HE = Hematite
KH = Halloysite
KK = Kaolinite
KY = Kyanite
LE = Lepidocrocite
LM = Limonite
LT = Lithiophorite
LU = Leucoxene
MG = Magnetite
MH = Maghemite
OP = Opaques
OR = Other Resistant Minerals
PI = Pyrite
PK = Perovskite
PO = Plant Opal
PY = Pyrophyllite
QC = Clay-Coat Quartz
QG = Glass-Coat Quartz
QI = Iron Oxide-Coat Quartz
QZ = Quartz
RA = Resistant Aggregates
RE = Resistant Minerals
RU = Rutile
SA = Siliceous Aggregates
SL = Sillimanite
SO = Staurolite
SP = Sphene
TM = Tourmaline
TP = Topaz
VI = Vivianite
ZR = Zircon

Weatherable Minerals

AC = Actinolite
AF = Arfvedsonite
AG = Antigorite
AH = Anthophyllite
AL = Allophane
AM = Amphibole
AO = Aragonite
AP = Apatite
AR = Weatherable Aggregates
AU = Augite
AY = Anhydrite
BC = Biotite-Chlorite
BR = Brucite
BT = Biotite
BZ = Bronzite
CA = Calcite
CB = Carbonate Aggregates
HB = Hydrobiotite
HG = Glass Coated Hornblende
HN = Hornblende
HY = Hypersthene
ID = Iddingsite
IL = Illite
JO = Jarosite
LC = Analcime
LO = Lepidomelane
LP = Lepidolite
MB = Mirabilite
MC = Montmorillonite-Chlorite
ME = Magnesite
MI = Mica
MM = Montmorillonite-Mica
MR = Marcasite
MS = Muscovite

Weatherable Minerals (cont'd)

CC = Coal
CL = Chlorite
CM = Chlorite-Mica
CO = Collophane
CY = Chrysotile
CZ = Clinozoisite
DL = Dolomite
DP = Diopside
DU = Dumortierite
EN = Enstatite
EP = Epidote
FA = Andesite
FB = Albite
FC = Microcline
FD = Feldspar
FF = Foraminifera
FG = Glass Coated Feldspar
FH = Anorthoclase
FK = Potassium Feldspar
FL = Labradorite
FM = Ferromagnesium Mineral
FN = Anorthite
FP = Plagioclase Feldspar
FO = Oligioclase
FR = Orthoclase
FS = Sanidine
FU = Fluorite
GA = Glass Aggregates
GC = Glass Coated Grain
GG = Galena
GL = Glauconite
GM = Glassy Materials
GO = Glaucophane
GS = Glass
GY = Gypsum
MT = Montmorillonite
MV = Montmorillonite-Vermiculite
MZ = Monazite
NX = Non-Crystalline
OG = Glass Coated Opaque
OV = Olivine
OW = Other Weatherable Minerals
PD = Piedmontite
PG = Palygorskite
PJ = Plumbojarosite
PL = Phlogopite
PR = Pyroxene
PU = Pyrolusite
RB = Riebeckite(Blue Amphibole)
RO = Rhodocrosite
SE = Sepiolite
SG = Sphalerite
SI = Siderite
SR = Sericite
SS = Sponge Spicule
SU = Sulphur
TA = Talc
TD = Tridymite
TH = Thenardite
TE = Tremolite
VC = Vermiculite-Chlorite
VH = Vermiculite-Hydrobiotite
VM = Vermiculite-Mica
VR = Vermiculite
WE = Weatherable Minerals
WV = Wavellite
ZE = Zeolite
ZO = Zoisite
OT = Other

APPENDIX IX

OPTICAL ANALYSIS (7B)[1]
Grain Studies, Analysis and Interpretation (7B1)

[1] The discussion of identification and significance of minerals, microcrystalline aggregates, and amorphous substances in optical studies of grain mounts is extracted *in total* from material prepared by John G. Cady (1965) and modified in part by Warren C. Lynn, Research Soil Scientist, NSSC, NRCS, Lincoln, NE.

1. Minerals

Identification criteria: Important properties in grain identification are listed below in approximate order of ease and convenience of determination. Estimates of several of these properties often allow identification of a grain so that detailed or extremely accurate measurements are seldom necessary. In the finer soil separates, grain identification may be impossible because the grains may be too small or not in the right position to permit measurement of some properties, e.g., optic angle or optic sign. A process to help practice estimating properties is to crush, sieve, and mount a set of known minerals and to compare these known standards to unknowns.

Refractive index can be estimated by relief or can be accurately determined by using calibrated immersion liquids. When relief is used to estimate refractive index, the grain shape, color, and surface texture must be considered, i.e., thin platy grains may be estimated low, whereas colored grains and grains with rough, hackly surface texture may be estimated to be high. Estimation is aided by comparing an unknown with known minerals.

Relief is an expression in the difference in refractive index between the grain and the mounting medium. The greater the difference, the greater the relief. The analogy is to topographic relief. When viewed through the microscope, grains with high relief are distinguished, whereas grains with low relief tend to fade into the background. The SSL selects a mounting medium with an index of refraction close to quartz, i.e., quartz has low relief. Most other minerals are distinguished by comparison.

Becke line is a bright halo of light that forms near the contact of the grain and the mounting grain medium because of the difference in refractive index of the two. As the plane of focus is moved upward through the grain, the Becke line appears to move into the component with the higher refractive index. In Petropoxy 154$_{\text{TM}}$, the Becke line moves away from potassium feldspar (index of refraction <1.54) but moves into mica (index of refraction >1.54).

Birefringence is the difference between the highest and lowest refractive index of the mineral. Accounting for grain thickness and orientation, the birefringence is estimated by interference color. Interference color is observed when an anisotropic mineral is viewed between crossed-polarized light. Several grains of the same species must be observed because the grains may not all lie in positions that show the extremes of refractive index. For example, mica has high birefringence but appears low when the platy mineral grain is perpendicular to the microscope axis because the refractive indices of the two crystallographic directions in the place of the plates are very close together. The carbonate minerals have extremely high birefringence (0.17 to 0.24). Most of the ferrogmagnesian minerals are intermediate (0.015 to 0.08). Orthoclase feldspar and apatite are low (0.008) and very low (0.005), respectively.

Color helps to discriminate among the heavy minerals. Pleochroism is the change in color or light absorption with stage rotation when the polarizer is inserted. Pleochroism is a good diagnostic characteristic for many colored minerals. Tourmaline, hypersthene, and staurolite are examples of pleochroic minerals.

Shape, cleavage, and crystal form are characteristic or unique for many minerals. Cleavage may be reflected in the external form of the grain or may appear as cracks within the grain that show as regularly repeated straight parallel lines or as sets of lines that intersect at definite repeated angles. The crystal shape may be different from the cleavage-fragment shape. Plagioclase feldspars, kyanite, and the pyroxenes have strong cleavage. Zircon and rutile usually appear in crystal forms.

Extinction angle and character of extinction observed between crossed-polarized light are important criteria for some groups of minerals. To measure extinction angles, the grain must show its cleavage or crystal form. These angles may be different along different crystallographic axes. Some minerals have sharp, quick total extinction, whereas other minerals have more gradual extinction. In some minerals with high light dispersion, the interference color dims and changes at the extinction position.

Optic sign, optic angle, and sign of elongation are useful, if not essential, determinations but are often difficult, unless grains are large or in favorable orientation. Determination of optic sign requires that the grains show dim, low-order interference colors or show no extinction. Grains with bright colors and with sharp, quick extinction rarely provide usable interference figures.

Particular mineral species: The following are the outstanding diagnostic characteristics of the most commonly occurring minerals and single-particle grains in the sand and silt fractions of soils. The refractive indices that are provided are the intermediate values.

Quartz has irregular shapes. The refractive index of quartz (1.54) approximates that of the epoxy (Petropoxy 154$_{TM}$) mounting medium. The Becke line may be split into yellow and blue components. The interference colors are low order but are bright and warm. There is sharp extinction with a small angle of rotation, i.e., "blink extinction". Crystal forms are sometimes observed and usually indicate derivation from limestone or other low-temperature secondary origin.

Potassium feldspars: Orthoclase may resemble quartz, but the refractive index (1.52) and birefringence are lower than that of quartz. In addition, orthoclase may show cleavage. *Microcline* has a refractive index of 1.53. The Becke line moves away from the grain with upward focus. A twinning intergrowth produces a plaid or grid effect between crossed-polarized light that is characteristic of microcline. *Sanidine* has the same refractive index and birefringence as other potassium feldspars. Grains are usually clear and twinning is not evident. In sanidine, the 2V angle is low (12°) and characteristic. The 2V angle is the acute angle between two optic axes, or more simply, the optical axial angle.

Plagioclase feldspars have refractive indices that increase with an increase in the proportion of calcium. The refractive index of the sodium end-member albite (1.53) is lower than that of quartz, but the refractive index of the calcium end-member anorthite (1.58) is noticeably higher than that of quartz. Some *oligoclase* has the same refractive index as quartz which prevents distinctions by the Becke line. Plagioclase feldspars usually show a type of twinning that appears as alternating dark and light bands between crossed-polarized light. Cleavage is good. Lath and prismatic shapes are common.

Micas occur as platy grains that are often very thin. The plate view shows very low birefringence, whereas the edge view shows a very high birefringence. Plates are commonly equidimensional and may appear as hexagons or may have some 60° angles. *Biotite* is green to dark brown. Green grains may be confused with chlorite. Paler colors, a lowering of refractive index, and a distortion of the extinction and interference figure indicate weathering to *hydrobiotite* or *vermiculite*. *Muscovite* is colorless. Muscovite has a moderate refractive index (1.59) in the plate view and an interference figure that shows a characteristic 2V angle of 40° which can be used as a standard for comparing 2V angles of other materials.

Amphiboles are fibrous to platy or prismatic minerals with slightly inclined extinction, or occasionally with parallel extinction. Color and refractive index increase as the Fe content increases. Amphiboles have good cleavage at angles of ~ 56 and 124°. Refractive index of the group ranges from 1.61 to 1.73. *Hornblende* is the most common mineral of the amphiboles. Hornblende is slightly pleochroic; usually has a distinctive color close to olive-green; has inclined extinction; and is often used as an indicator of weathering.

Pyroxenes: Enstatite and hypersthene are prismatic and have parallel extinction. Hypersthene has unique and striking green-pink pleochroism. *Augite* and *diopside* have good cleavage at angles close to 90° and large extinction angles. Colors usually are shades of green. Refractive indices in the pyroxenes (1.65 to 1.79) are higher than in the amphiboles.

Olivine is colorless to very pale green and usually irregular in shape (weak cleavage). Olivine has vivid, warm interference colors. Olivine is an easily weathered mineral and may have cracks or seams filled with serpentine or goethite.

Staurolite is pleochroic yellow to pale brown and sometimes contains holes, i.e., the "Swiss cheese" effect. The refractive index is ~ 1.74. Grains may have a foggy or milky appearance which may be caused by colloidal inclusions.

Epidote is a common heavy mineral, but the forms that occur in soils may be difficult to identify positively. Typical epidote is unmistakable with its high refractive index (1.72 to 1.76), strong birefringence, and a pleochroism that includes the pistachio-green color. Commonly, grains show an optic axis interference figure with a 2V angle that is nearly 90°. However, epidote is modified by weathering or metamorphism to colorless forms with lower birefringence and refractive index. *Zoisite* and *clinozoisite* are close relatives of *epidote* and are more abundant than some of the literature indicates. These minerals of the epidote group commonly appear as colorless, pale-green, or bluish-green, irregularly shaped or roughly platy grains with high refractive index (1.70 to 1.73). Most of these minerals show anomalous interference colors (bright pale blue) and no complete extinction and can be confused with several other minerals, e.g., kyanite and diopside. Identification usually depends on determination of properties for many grains.

Kyanite is a common mineral but is seldom abundant. The pale blue color, the platy, angular cleavage flakes, the large cleavage angles, and the large extinction angles usually can be observed and make identification easy.

Sillimanite and *andalusite* resemble each other. These minerals are fibrous to prismatic with parallel extinction. However, their signs of elongation are different. In addition, sillimanite is colorless, and andalusite commonly has a pink color.

Garnet is found in irregularly shaped, equidimensional grains that are isotropic and have high refractive index ($\geq$1.77). Garnet of the fine sand and silt size is often colorless. Pale pink colors are diagnostic in the larger grains.

Tourmaline has a refractive index of 1.62 to 1.66. Prismatic shape, strong pleochroism, and parallel extinction are characteristic. Some tourmaline is almost opaque when at right angles to the vibration plate of the polarizer.

Zircon occurs as tetragonal prisms with pyramidal ends. Zircon has very high refractive index (>1.9), parallel extinction, and bright, strong interference colors. Broken and rounded crystals frequently are found. Zircon crystals and grains are almost always clear and fresh appearing.

Sphene, in some forms, resembles zircon, but the crystal forms have oblique extinction. The common form of sphene, a rounded or subrounded grain, has a color change through ultrablue with crossed polarizers instead of extinction because of its high dispersion. Sphene is the only pale-colored or colorless high-index mineral that provides this effect. The refractive index of sphene is slightly lower than that of zircon, and the grains are often cloudy or rough-surfaced.

Rutile grains have prismatic shape. The refractive index and birefringence are extremely high (2.6 to 2.9). The interference colors usually are obscured by the brown, reddish-brown, or yellow colors of the mineral. Other TiO_2 minerals, *anatase* and *brookite*, also have very high refractive indices and brown colors and may be difficult to distinguish in small grains. The anatase and brookite usually occur as tabular or equidimensional grains.

Apatite is common in youthful soil materials. Apatite has a refractive index slightly <1.63 and a very low birefringence. Crystal shapes are common and may appear as prisms. Rounding by solution produces ovoid forms. Apatite is easily attacked by acid and may be lost in pretreatments.

Carbonates: Calcite, dolomite, and siderite, in their typical rhombohedral cleavage forms, are easily identified by their extremely high birefringence. In soils, these minerals have other forms, e.g., scales and chips; cements in aggregates; microcrystalline coatings or aggregates; and other fine-grained masses that are often mixed with clay and other minerals. The extreme birefringence is always the identification clue and is shown by the bright colors between crossed-polarized light and by the marked change in relief when the stage is rotated with one polarizer in. The microcrystalline aggregates produce a twinking effect when rotated between crossed-polarized light. These three minerals have differences in their refractive indices which may be used to distinguish them. Siderite is the only one with both indices >Petropoxy 154_{TM}. It is more difficult to distinguish calcite from dolomite, and additional techniques such as staining may be used.

Gypsum occurs in platy or prismatic flat grains with refractive index approximately equal to orthoclase.

Opaque minerals, of which *magnetite* and *ilmenite* are the most common, are difficult to identify, especially when they are worn by transportation or otherwise affected by weathering. Observations of color and luster by reflected light, aided by crystal form if visible, are the best procedures. Magnetic separations help to confirm the presence of magnetite and ilmenite. Many grains that appear opaque by plain light can appear translucent if viewed between strong crossed-polarized light. Most grains that behave in this way are altered grains or aggregates and are not opaque minerals.

2. Microcrystalline Aggregates and Amorphous Substances

Identification criteria: Most microcrystalline aggregates have one striking characteristic feature, i.e., they show birefringence but do not have definite, sharp, complete extinction between crossed-polarized light. Extinction may occur as dark bands that sweep through the grain or parts of the grain when the stage is turned or may occur in patches of irregular size and shape. With a few exceptions, e.g., well-oriented mineral pseudomorphs and certain clay-skin fragments, some part of the grain is bright in all positions. Aggregates and altered grains should be examined with a variety of combinations of illumination and magnification in both plain and polarized lights. The principal properties that can be used to identify or at least characterize aggregates are discussed below.

Color, if brown to bright red, is usually related to Fe content and oxidation. Organic matter and Mn may contribute black and grayish-brown colors.

Refractive index is influenced by a number of factors, including elemental composition, atom packing, water content, porosity, and crystallinity. Amorphous (noncrystalline) substances have a single index of refraction, which may vary depending on chemical composition. For example, allophane has a refractive index of 1.47 to 1.49, but the apparent refractive index increases with increasing inclusion of ferrihydrite (noncrystalline Fe oxide) in the mineral.

Strength of birefringence is a clue to the identity of the minerals. Even though the individual units of the aggregate are small, birefringence can be estimated by interference color and brightness. Amorphous substances, having only a single index of refraction, exhibit no birefringence and are isotropic between crossed-polarized light.

Morphology may provide clues to the composition or origin of the aggregate. Some aggregates are pseudomorphs of primary mineral grains. Characteristics of the original minerals, i.e., cleavage traces, twining, or crystal form can still be observed. Morphology can sometimes be observed in completely altered grains, even in volcanic ash shards and basalt fragments. Other morphological characteristics may be observed in the individual units or in the overall structure, e.g., the units may be plates or needles, or there may be banding.

Particular species of microcrystalline aggregates and amorphous substances: For purposes of soil genesis studies, the aggregates that are present in sand or silt fractions are not of equal significance. Some are nuisances but must be accounted for, and others are particles with important diagnostic value. Useful differentiating criteria for some of the commonly occurring aggregate types are discussed below.

Rock fragments include chips of shale, schist, and fine-gained igneous rocks, e.g., rhyolite. Identification depends on the recognition of structure and individual components and the consideration of possible sources.

Clay aggregates may be present in a wide variety of forms. Silt and sand that are bound together into larger grains by a nearly isotropic brownish material usually indicate faulty dispersion. Clay skins may resist dispersion and consequently may appear as fragments in grain mounts. Such fragments are usually brown or red and translucent with wavy extinction bands. Care is required to distinguish these fragments from weathered biotite. Clay aggregates may be mineral pseudomorphs. Kaolin pseudomorphs of feldspar commonly are found. Montmorillonite aggregates, pseudomorphic of basic rock minerals, have been observed. In this form, montmorillonite shows high birefringence and an extinction that is mottled or patchy on a small scale.

Coarse kaolinite flakes, books, and vermicular aggregates resist dispersion and may be abundant in sand and silt. These particles may resemble muscovite, but they are cloudy; show no definite extinction; and have very low birefringence. Many cases of anomalously high cation exchange capacity (CEC) of sand and silt fractions that are calculated from whole soil CEC and from clay CEC and percent content, can be accounted for by the occurrence of these aggregates in the sand and silt fractions.

Volcanic glass is isotropic and has a low refractive index, lower than most of the silicate minerals. The refractive index ranges from 1.48 in the colorless siliceous glasses to as high as 1.56 in the green or brown glasses of basalt composition. Shapes vary, but the elongated, curved shard forms, often with bubbles, are common. This glassy material may adhere to or envelop other minerals. Particles may contain small crystals of feldspar or incipient crystals with needles and dendritic forms. The colorless siliceous types (acidic, pumiceous) are more common in soils as the basic glasses weather easily. Acidic glasses are more commonly part of "ash falls", as the magma usually is gaseous and explosive when pressure is released. Basic glasses are more commonly associated with volcanic flow rocks which are usually not gaseous.

Allophane is present in many soils that are derived from volcanic ash. Allophane seldom can be identified directly, but its presence can be inferred when sand and silt are cemented into aggregates by isotropic material with low refractive index, especially if volcanic ash shards are also present.

Opal, an isotropic material, occurs as a cementing material and in separate grains, some of which are of organic origin, i.e., plant opal, sponge spicules, and diatoms. The refractive index is very low (<1.45), which is lower than the value for volcanic ash. Identification may depend in part on form and occurrence.

Iron oxides may occur as separate grains or as coatings, cementing agents, and mixtures with other minerals. Iron oxides impart brown and red colors and raise the refractive index in the mixtures. *Goethite* is yellow to brown. Associated red areas may be hematite. These red varieties have a refractive index and birefringence that are higher and seem to be better crystallized, often having a prismatic or fibrous habit. Aggregates have parallel extinction. In oriented aggregates, the interference colors often have a greenish cast. *Hematite* has higher refractive index than goethite and is granular rather than prismatic. Large grains of hematite are nearly opaque.

Gibbsite often occurs as separate, pure, crystal aggregates, either alone or inside altered mineral grains. The grains may appear to be well-crystallized single crystals, but close inspection between crossed-polarized light shows patchy, banded extinction, indicating intergrown aggregates. Gibbsite is colorless. The refractive index (1.56 to 1.58) and the birefringence are higher for gibbsite than the corresponding values for quartz. The bright interference colors and aggregate extinction are characteristic of gibbsite.

Chalcedony is a microcrystalline form of quartz that was formerly considered a distinct species. Chalcedony occurs as minute quartz crystals and exhibits aggregate structure with patchy extinction between crossed-polarized light. It may occur in nodules of limestone deposits and may be a pseudomorphic replacement in calcareous fossils. The refractive index is slightly lower than that of quartz, and the birefringence is lower than that of gibbsite. *Chert* is a massive form of chalcedony.

Glauconite occurs in aggregates of small micaceous grains with high birefringence. When fresh, glauconite is dark green and almost opaque, but it weathers to brown and more translucent forms. Glauconite is difficult to identify on optical evidence alone.

Titanium oxide aggregates have been tentatively identified in the heavy mineral separates of many soils. These bodies have an extremely high refractive index and high birefringence similar to rutile. The yellow to gray colors are similar to those of anatase. The TiO_2 aggregates are granular and rough-surfaced. This growth habit with the little spurs and projections suggests that TiO_2 aggregates may be secondary.

APPENDIX X

MICROMORPHOLOGY (4E)[1]
Thin Sections (4E1)
Interpretation (4E1b)

1. Background

Micromorphology may be defined as the study of microfabrics of soils in their natural undisturbed arrangement (Cady, 1986). Examination of thin sections with a polarizing light microscope can be considered an extension of field morphological studies. The results of micromorphological studies are most useful when they are combined with other field and laboratory information (Cady, 1965). Micromorphology is used to identify illuviation of argillans, fabric types, skeleton grains, weathering intensity, and to investigate genesis of soil or pedological features.

Initially, the investigator should scan the overall features of a thin section and determine those features that require emphasis. This initial scanning may include all the thin sections from a soil profile or all those related to a particular problem. Different kinds of illumination should be used with each magnification. Strong convergent light with crossed polarizers elucidates structures in dense or weakly birefringent material that may appear opaque or isotropic. Structures in translucent specimens become more clearly visible if plain light is used, and the condensers are stopped down. Everything should be viewed in several positions of the stage or during slow rotation with crossed polarized light.

A thin section is a two-dimensional slice through a three-dimensional body. The shapes of mineral grains and structural features are viewed in one plane, and the true shapes must be extrapolated. A grain that appears needle-shaped may be a needle or the edge of a flat plate. An elliptical pore may be an angular slice through a tube. A circular unit is probably part of a sphere. With a three-dimensional perspective in mind as well as an awareness of section thickness, repeated viewing of similar features that appear to be cut at different angles is the best way to accustom oneself to a volume rather than a planar interpretation of shape. A well-prepared section is 20- to 30-µm thick. Grains smaller in thickness are stacked and cannot be viewed as individual grains. Similarly, pores smaller than 20 to 30 µm cannot be seen clearly. A pore size of 20-µm diameter equates to a soil moisture tension of 0.15 bar (15 kPa) (Rode, 1969) so that visible pores in thin section are mostly drained at water contents below field capacity.

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[1] W. Dennis Nettleton, Research Soil Scientist, NSSC, NRCS, Lincoln, NE wrote the procedure for description and interpretation of soil micromorophology as seen in thin sections.

Sand and silt grains in thin sections are identified by standard methods presented in petrography texts. The general analytical approach is the same for grain studies (procedure 7B1) as it is for thin sections. However, in grain studies, the refractive index is used only as a relative indicator, and other optical and morphological properties are more important. Furthermore, in thin sections, a concern with minerals that occur in small quantities or an attempt to quantify mineralogical analysis is seldom necessary. The separate particle-size fractions should be used for the identification and mineralogical analyses that are important to a study, whereas the thin sections should be used mainly for information about component arrangement. Recognition of aggregates, concretions, secondary pseudomorphs, and weathered grains is more important in thin section studies than in sand and silt petrography. Recognition of these components in thin section are easier because interior structures are exposed. Although grain studies are important in soil genesis studies, the arrangement of components is destroyed or eliminated by sample preparation procedures that separate the sand, silt, and clay.

In the United States, emphasis in micromorphology has been on clay arrangement. Clay occurs not only in the form of aggregates but also in massive interstitial fillings, coatings, bridges, and general groundmass. Even though the clay particles are submicroscopic, they can be described, characterized and sometimes identified, e.g., the 1:1 and 2:1 lattice clays can be distinguished. Completely dispersed, randomly arranged clay of less than 1 µm exhibits no birefringence and appears isotropic in crossed polarized light. Clay in a soil is seldom all random and isotropic. Clay develops in oriented bodies, either during formation or as a result of pressure or translocation. If enough plate-shaped particles are oriented together in a body that is large enough to see, birefringence can be observed.

With the exception of halloysite, the silicate clay minerals in soils are platy. The a and b crystallographic axes are within the plane of the plate, and the c axis is almost perpendicular to this plane. Even though the crystals are monoclinic, the minerals are pseudohexagonal, as the distribution of stems along the a and b axes is so nearly the same, and the c axis is so nearly perpendicular to the other axes. The optical properties, crystal structure, and general habit of clay are analogous to those of the micas, which can be used as models to analyze and describe clay properties.

The speed of light that travels in the direction of the c axis and vibrates parallel to the a axis is almost the same as that light that vibrates parallel to the b axis. Therefore, the refractive indices are very close, and the interference effects in crossed polarized light are small when observed along the c axis. Light that vibrates parallel to the c axis travels faster than in other directions. Hence, the refractive index is lower. If the edge of the crystal or aggregate of crystals is viewed along the a-b plane between crossed polarizers, two straight extinction positions are viewed, and interference colors are manifested in other positions. If a clay concentration is organized so that most of the plates are parallel, the optical effects can be observed. The degree and quality of optical effects depend on the purity, continuity, and the orientation process of the clay body.

Kaolinite has low birefringence and has refractive indices slightly higher than quartz. In the average thin section, interference colors for kaolinite are gray to pale yellow. In residual soils that are derived from coarse-grained igneous rocks, kaolinite occurs as book-like and accordion-like aggregates of silt and sand size.

Even though halloysite can form oriented aggregates, it should not show birefringence because of its tubular habit. Halloysite may show very faint, patternless birefringence, which is caused by impurities or by refraction of light at the interfaces between particles.

The 2:1 lattice minerals have high birefringence and show bright, intermediate-order, interference colors if the edges of aggregates are viewed. In the clay-size range, distinctions among smectite, mica, vermiculite, and chlorite in thin section are seldom possible. These clay minerals are usually mixed in the soil and seldom occur pure. In many soils, these clay minerals are stained and mixed with iron oxide and organic matter.

Residual clay has been in place since its formation by weathering. Although it may have been transported within fragments of weathered material, it remains in place relative to the fabric of these fragments. This clay may be random, have no orientation, and thus be isotropic; however, more often, it shows some birefringence. In transported materials, silt-size flakes and other small aggregates are common. In many residual materials, clay is arranged either in forms that are pseudomorphs of rock minerals or in definite bodies of crystal aggregates, e.g., vermicular or accordion-like kaolin books. The regular, intact arrangement of these materials is usually diagnostic of residual material.

Clay rearrangement may result from differentially applied stress that produces shear. Platy particles become oriented by slippage along a plane, e.g., slickenside faces in a Vertisol or in clayey layers. Platy particles also are oriented inside the blocks. Root pressure, mass movement, slump, and creep can produce stress orientation.

If the faces on structural units are smooth and do not have separate coatings, stress orientation can be inferred. Otherwise, in plain light, stress orientation cannot be observed. In plain light, clay in the thin section may be homogeneous and featureless. In crossed polarized light, the orientation pattern is reticulate, consisting of bright lines showing aggregate birefringence, often intersecting at regular angles. The effect is that of a network in a plaid pattern. There may be numerous sets of these slippage planes, which appear in different positions as the stage is turned. Stress-oriented clay may be near rigid bodies, e.g., quartz grains, or along root channels.

Stress-oriented clay is often strongly developed on ped faces. Stress can also orient mica flakes and any other small platy grain.

Location features that distinguish translocated clay from residual clay are its occurrence in separate bodies, usually with distinct boundaries, and its location on present or former pore walls, channel linings, or ped faces. Translocated clay may have a different composition than matrix clay, especially if its origin is another horizon. This clay is more homogeneous and is usually finer than the matrix clay. Translocated clay displays lamination, indicating deposition in successive increments, and manifests birefringence and extinction, indicating that these translocated clay bodies are oriented aggregates. If these bodies are straight, they have parallel extinction. If these bodies are curved, a dark band is present wherever the composite c axis and the composite a and b axes are parallel to the vibration planes of the polarizers. When the stage is rotated, these dark bands sweep through the clay aggregate.

Other substances such as goethite, gibbsite, carbonate minerals, and gypsum may form pore linings and ped coatings. These substances can be identified by their mineralogical properties.

Amorphous coatings of organic matter, with or without admixed Fe and Al, are common, especially in spodic horizons. This material is dark brown to black, isotropic or faintly birefringent, and often flecked with minute opaque grains. Amorphous coatings of organic matter occur as the bridging and coating material in B horizons of sandy Spodosols and as thin coatings or stains on pore and ped faces in other soils.

2. Description

Terms have been defined for distribution patterns of the components of soil thin sections (Brewer, 1964 and 1976; Brewer et al., 1983; Stoops and Jongerius, 1975; and Bullock et al., 1985). As these terms have become more widely adopted in the literature, the Soil Survey Laboratory (SSL) increasingly uses them in Soil Survey Investigations Reports (SSIR's) and in soil project correspondence. At this time, the five "coarse-fine related distribution patterns" of Stoops and Jongerius (1975) are in common usage. The nomenclature of these distribution patterns, as described by Stoops and Jongerius (1975), are intended to be broadly defined. There are no restrictions on material type, absolute size, orientation, granulation, or origin. The system may be used to describe the distribution of primary particles, e.g., quartz grains, as well as compound units, e.g., humic micro-aggregates. The coarser particles may be silt, sand, or gravel, whereas the finer material may be clay, silt, or sand.

The monic type (granic type of Brewer et al., 1983) consists of fabric units of only one size group, e.g., pebbles, sand, or lithic fragments. In the gefuric type, the coarser units are linked by bridges of finer material but are not surrounded by this material. In the chitonic type (chlamydic type of Brewer et al., 1983), the coarser units are surrounded by coatings of finer material. In the enaulic type, the larger units support one another, and the interstitial spaces are partially filled with finer material. The enaulic fabric consists of material finer than is found in either the gefuric or chitonic type but is not so fine as is found in the porphyric type. In the end member of the sequence, the porphyric type, the large fabric units occur in a dense groundmass of smaller units, and there is an absence of interstitial pores. This type is equivalent to the earlier porphyroskelic class of Brewer (1964) or to the current porphyric class (Brewer et al., 1983). The class may be divided into types based on the spacing of the coarser units.

The s-matrix is the material within which pedological features occur (Brewer, 1976). Skeleton grains of a soil material are individual grains that are larger than colloidal size. The soil plasma includes all the colloidal size material as well as the relatively soluble material that is not bound in skeleton grains. The description of plasmic fabrics is based on the interpretations of optical properties under crossed-Nicols, especially extinction phenomena. Plasma concentrated or crystallized into pedological features is not included in the description of plasmic fabrics. In general, the descriptive terms for the s-matrix are those as defined by Brewer (1976). The s-matrix plasma fabrics are divided into two groups, the asepic and sepic types. The asepic fabrics are those with anisotropic plasma in which the domains, i.e., the plasma separations, are not oriented relative to each other. The sepic fabrics are those with anisotropic domains with various orientation patterns. Using a scanning electron microscope (SEM), Eswaran (1983) characterized the <25-μm^2 size domains of monomineralic soils. These features are smaller than some domains described by Brewer (1976). However, these small features provide the detail expected of the interparticle relationships present in the larger separations. The domains in allophanic soils are composed of globular aggregates. The halloysitic soils differ in that the halloysite tubes generally may be seen as protrusions from globular forms. The domains in micaceous soils retain the face-to-face packing that is common in micas and may retain some of the book-like forms as well. The domains in montmorillonitic soils are bent to conform to the shape of skeletan grains. However, the packing is essentially face-to-face and, upon drying, the fabric is very dense and compact. In kaolinitic soils, the domains frequently are present as booklets that are packed face-to-face, unless iron hydrous oxide has disrupted the platelets, in which case, the platelets may still be packed face-to-face in subparallel stacks. The asepic plasmic fabrics are subdivided into two groups, argillasepic and silasepic types. Argillasepic fabrics are dominated by anisotropic clay minerals and have a random orientation pattern of clay-size domains. Overall, the asepic fabrics have flecked extension patterns. Silasepic fabrics have a wider range of particle sizes than argillasepic types. However, a careful observer may view silt-size domains or plasma bodies that give the matrix an overall flecked extinction pattern.

The sepic plasmic fabrics have recognizable domains with various patterns of orientation. Internally, the domains, i.e., plasma separations, have striated extinction patterns. Brewer (1964) recognizes seven kinds, most of which are widely adopted.

Insepic fabrics consist of isolated, striated plasma domains within a flecked plasma matrix. Mosepic fabrics consist of plasma domains with striated orientation that may adjoin each other or be separated by small plasma areas with flecked orientation that are not oriented relative to each other. The fabric is vosepic when the plasma separations with striated orientation are associated with channel or pore (void) walls. The fabric is skelsepic when the plasma separations occur at the skeleton grain s-matrix contact.

The remaining three sepic plasmic fabrics are most common in fine-textured soils. In masepic fabrics, the plasma separations occur as elongated zones within the s-matrix and apparently are not associated with void walls or skeleton grains. The striations have parallel orientations to zone length. Lattisepic fabrics are similar to masepic fabrics except that the acicular and prolate domains occur in lattice-like patterns. In omnisepic fabrics, all of the plasma has a complex striated orientation pattern.

Three other kinds of plasmic fabrics are characteristic of particular minerals or kinds of soils. Undulic plasmic fabrics have practically isotropic extinction patterns at low magnification, and the domains are indistinct even at high magnification. Isotic plasmic fabrics have isotropic plasma, even at highest magnifications with high light intensity. The crystic plasmic fabrics have anisotropic plasma with recognizable crystals, usually of soluble materials.

The term, cutan, and definitions of its respective types (Brewer, 1964) have been widely adopted by soil scientists. Cutan is defined as a modification of the texture, structure, or fabric at natural surfaces in soil materials due to the concentration of particular soil constituents or as in-place modification of the plasma. Generally, the cutans are subdivided on the basis of their location, composition, and internal fabric. The cutan locations are surfaces of grains, peds, channels, or voids. The mineralogical nature of cutans is characterized, e.g., argillans, ferri-argillans, or organo-argillans. Argillans are composed dominantly of clay minerals; ferri-argillans have iron oxides as a significant part of their composition; and organo-argillans have significant color addition by addition of organic matter.

Sesquan is a general term used for a cutan of sesquioxides or hydroxides. Sesquans that are specific for goethite, hematite, or gibbsite are called goethans, hematans, or gibbsans, respectively. Similarly, cutans of gypsum, carbonate, calcite, halite, quartz, silica, and chalcedony are called gypsans, calcans, calcitans, halans, quartzans, silans, and chalcedans, respectively. Skeleton grains that adhere to the cutanic surface are called skeletans.

Glaebules (Brewer, 1964) are pedological units within the s-matrix whose morphology is incompatible with their present occurrence. They are usually prolate to equant. A glaebule is recognized as a unit either because of a greater concentration of a constituent, or difference in the s-matrix fabric, or because of the presence of distinct boundaries of a constituent within the enclosing s-matrix. Glaebules include papules, nodules, concretions, and pedodes. Papules are pedogenic features composed of clay minerals with continuous and/or laminar fabric, sharp external boundaries, and commonly prolate to equant, somewhat rounded shapes. Nodules are pedological features with undifferentiated internal fabric. Concretions are pedological features with concentrically laminated structures about a center. Pedodes are pedological features with hollow interiors, often lined with crystals.

Voids are the empty spaces within the s-fabric. Those voids with diameters of 20 μm to ≈ 2 mm can be studied and measured in thin section. Brewer (1976) classifies these voids as follows: (1) simple packing voids (empty spaces due to random packing of single skeleton grains); (2) compound packing voids (empty spaces between peds or other compound individuals); (3) vughs (relatively large spaces that are not formed by packing of skeleton grains; (4) vesicles (relatively large empty spaces with smooth, regular outlines); (5) chambers (empty spaces with smooth, regular outlines that connect to other voids); (6) joint planes (plane-shaped, empty spaces that traverse the s-matrix in a regular pattern); (7) skew planes (plane-shaped, empty spaces that traverse the s-matrix in an irregular pattern); (8) craze planes (plane-shaped, empty spaces that traverse the s-matrix in a highly irregular pattern of short flat or curved planes); and (9) channels (mostly cylindrical-shaped, empty spaces that are larger than packing voids).

3. Interpretations

Related Distribution Patterns

Usually, the basic descriptive terms for soil fabrics do not imply any specific genesis of the feature. However, modifiers commonly are added when fabric descriptions are complete enough to understand the means of formation, i.e., stress cutan, or in-place plasma modification, is the result of differential forces, e.g., shearing, whereas an illuviation cutan is formed by movement of material in solution or suspension and later deposited (Brewer, 1964). In an experimental study of soil microfabrics by anisotropic stresses of confined swelling and shrinking, Jim (1986) showed that with an increase in the activity and proportion of the clay fraction, the related distribution patterns alter from dominantly matrigranic (monic, with the units being aggregates) to matrigranodic (enaulic) to porphyric.

Some monic fabrics are inherited, and include soil fabrics formed in sand dunes, sandy sediments deposited by streams and rivers, beach deposits, and gruss. Fauna can produce monic fabrics that are mostly fecal pellets. Monic fabrics also can form by fracturing and flaking of organic coatings in the upper B horizons of the Spodosols (Flach, 1960) and by freezing and thawing (Brewer and Pawluk, 1975).

Several kinds of finer material (plasma) can bridge the coarser particles (skeleton grains) to form gefuric related distribution patterns. Gefuric patterns are common in weakly developed argillic and spodic horizons and in duripans. Silicate clays can bridge skeleton grains in some argillic horizons; the organic matter, iron, and aluminum complexes in some kinds of spodic horizons; and the amorphous silica in some kinds of duripans.

In soils that are slightly more developed than those with gefuric patterns, chitonic related distribution patterns form. These are common in argillic and spodic horizons and in duripans. Bridges as well as complete coatings of skeleton grains are present. Usually, the cement or plasma is material that adheres to skeleton grains. These cements have covalent bonds and commonly include silica, iron, aluminum, and organic matter (Chadwick and Nettleton, 1990).

The enaulic related distribution patterns are more common in soil material in which the cement bonds to itself more strongly than to skeleton grains. In sandy soils, ionic-bonded calcite and gypsum tend to bond to themselves more strongly than to skeleton grains, thereby producing open porphyric related distribution patterns (Chadwick and Nettleton, 1990). Even though organic matter has covalent bonds and usually surrounds grains, organic material forms pellets in void spaces between skeleton grains in some spodic horizons.

Porphyric related patterns form from the normal packing of grains in materials with a high proportion of fine material. These patterns can be the end member of several kinds of sequences (Brewer et al., 1983). In porphyric related patterns, there may or may not be skeleton grains of primary minerals, pedorelicts, organics, lithic fragments of shale, sandstone, or other rocks. In the porphyric related patterns, the material consists of silt and clay, and the interstices tend to be filled with minimal formation of coatings. In precursors of the porphyric related distribution patterns, the silt to clay ratio is used to identify the kind of sequences by which the porphyric pattern forms (Brewer et al., 1983). The porphyric patterns are common in loessial soils, especially in argillic and petrocalcic horizons, duripans, and orstein.

Plasmic Fabrics

The asepic plasmic fabrics differ in composition mainly in silt to clay ratios. Argillasepic fabrics have the higher clay contents, usually <30 percent but may have as much as 70 percent (Brewer et al., 1983). The birefringence of the plasma is masked by organic matter or iron stains, resulting in a flecked distribution pattern. Argillasepic fabrics are important fabrics in many fine-textured B horizons. Silasepic plasmic fabrics have low clay contents and have more silt than clay. The silasepic fabrics are common in porphyric related distribution patterns in A and B horizons of Solonetz; Solodized Solonetz and Solodic Soils; Soloths; Red Podzolic Soils; Lateritic Podzolic Soils; and are also associated with some sedimentary deposits (Brewer et al., 1983). Silasepic plasma fabrics are common in A and B horizons of loessial soils in association other kinds of plasma separations. Even if there is high clay content, the horizons with asepic plasmic fabrics have low effective linear extensibilities (LE) either because the clays are low-swelling types or because the soils do not dry enough to undergo the full range of laboratory-measured LE.

In soils that form in the same climate, the kind of sepic plasmic fabrics form a sequence relative to increasing linear extensibility (Nettleton et al., 1969; Holzhey et al., 1974). In increasing order of shrink-swell stress, the plasmic fabric sequence is insepic, mosepic, lattisepic, omnisepic, and masepic. Using X-ray diffraction (Clark, 1970) and scanning electron microscopy (Edil and Krizek, 1976), observations of deformation experiments indicate that the degree of clay orientation increases with an increase in applied stress. In an experimental study of soil microfabrics by anisotropic stresses of confined swelling and shrinking, Jim (1986) shows that with an increase in the activity and content of the clay fraction, there is an increase in the long and narrow plasma separations, i.e., a progression from insepic to mosepic to masepic plasmic fabrics.

Insepic plasmic fabrics are very common in finer-grained porphyric B horizons of a wide range of soil groups (Brewer et al., 1983). Soil horizons with insepic fabrics generally have an LE of <4 percent. In some insepic plasmic fabrics, the plasma islands or papules are pseudomorphs of some weatherable mineral, whereas in other insepic fabrics, the papules are clay skin fragments or are eolian sand-size clay aggregates (Butler, 1974). In some samples, the pseudomorphs do not disperse well in particle-size analysis (PSA).

Mosepic plasmic fabrics commonly have more clay than insepic fabrics because they contain more islands of plasma. However, in mosepic plasmic fabrics, LE also remains low. Shrink-swell forces have not been sufficient or have not operated long enough to have homogenized the islands of plasma into the soil matrix.

Vosepic plasmic fabrics occur in soil horizons that have undergone stress either due to shrink-swell forces or to tillage. Even though root growth is adequate to increase the percentage of oriented clay near the root-soil interface (Blevins et al., 1970), root growth does not appear adequate to form vosepic or other highly stressed plasmic fabrics. Usually, vosepic fabrics are present in soil horizons in which the main fabric type is masepic or skelsepic. The vosepic plasmic fabric rarely occurs as the only fabric in a soil horizon.

There are at least two types of origins for orientation of plasma on sands. One is a result of clay illuviation. By definition, this type would not be included with skelsepic fabric. The related distribution patterns associated with this fabric commonly are monic, gefuric, or enaulic. The other origin is commonly the porphyric related distribution patterns with LE's that are >4 percent for dryland soils, i.e., soils in aridic, xeric, or ustic soil moisture regimes. These are the true skelsepic fabrics. Shrink-swell forces have been involved in their formation as shown by relatively few papules or clay skins remaining, and there are vosepic areas.

Masepic, lattisepic, and omnisepic plasmic fabrics are evidence of stress >4 percent in dryland soils. Clay contents are usually >35 percent, but the threshold amount is dependent on clay mineral type and on degree of dryness common to the environment. In masepic, lattisepic, and omnisepic plasmic fabrics, papules and clay skins rarely are found, but areas of skelsepic and vosepic areas commonly are present.

Undulic plasmic fabrics seem to be associated with basic parent materials, especially basalt, and with moderate to strong weathering (Brewer et al., 1983). The fabric commonly is stained deeply by iron minerals, and kaolinite and halloysite are the important clay minerals. Clays in these horizons do not disperse well in PSA, but high 15-bar (1500-kPa) water contents suggest that the horizons belong in clayey families. Some papules and clay skins commonly are present, but these plasma separations also are stained deeply by iron.

Isotic plasmic fabrics are common in spodic horizons and in Andisols. The clays in these horizons are amorphous and disperse poorly in PSA. The water-holding capacities of these soil horizons are relatively high. Some unweathered volcanic ash may be present.

Crystic plasmic fabrics are common in B horizons of soils formed in dryland areas. In soil horizons with large areas of interlocking crystals, there is restricted soil permeability, increased unconfined compressive strength, and limited particle dispersion, depending on the degree of cementation.

Cutans and Pedogenic features

Most argillans are formed, at least in part, by illuviation. The content of strongly oriented clay (usually argillans plus papules), in texture-contrast soils (soils with argillic horizons) is usually <5 percent of the soil volume (Brewer et al., 1983). In some sandy soils that are low in silt, the argillans and papules are as much as 30 percent of the soil material (Brewer et al., 1983). The measured illuviated clay rarely accounts for the difference in clay content between the A and B horizons. Some of the clay may originate from weathering in place and some from a destruction of argillans and papules.

If argillans and papules are present in argillic horizons in dryland soils, the soil LE is usually <4 percent (Nettleton et al., 1969). In some humid environments, argillans and papules may be present even where the LE is >4 percent. As soils in humid environments do not dry to the same degree as those in the desert, the clay skins may survive because only part of the linear extensibility is effective.

Papules may originate by the weathering of primary minerals, the isolation of clay skins by the channel and void migration within the soil matrix (Nettleton et al., 1968; Nettleton et al., 1990) or by the introduction of eolian sands and silts that are composed of clays (Butler, 1974; Brewer and Blackmore, 1976). The comparison of size and shape of papules and minerals, as well as of parent material, may help to determine if the papules are pseudomorphs of one of the primary minerals. Internal fabric resemblances and residual parts of the primary mineral within the papules help to determine if a papule is a pseudomorph.

The determination of whether or not a papule is an illuvial feature is important for classification purposes. Arcuate forms and laminar internal fabrics are evidence that the feature is illuvial. If the feature partially surrounds an oval body of silt, illuvial origin of the feature is relatively certain (Nettleton et al., 1968).

The origin of the papule as eolian may be determined by studying its size and shape; its internal fabric; and the number and degree of its alterations relative to other particles. Microlaminae may suggest an origin as sediment. Unlike soil pedorelicts or rock fabrics (lithorelicts), nodules, or glaebules rich in soluble plasma, probably form by accretion (Brewer, 1976). Most concretions, as well as pedodes, are accretionary and usually form in place.

A study of soil voids may be useful in predicting the clay activity and shrink-swell behavior of soils. In an experimental study of soil microfabrics by anisotropic stresses of confined swelling and shrinking, Jim (1986) shows that with an increase in the activity and content of the clay fraction, there is a drastic decrease in void volume, especially the >30µm. Furthermore, the void shapes change from compound packing voids to planar voids and vughs. With an increase in stress from shrink-swell forces, aggregates become flattened at contacts, resulting in more angular and eventually fused compound units.

A possible objective of micromorphological studies may be the measurement of porosity and the prediction not only of soil water content at various suctions but also of hydraulic conductivity. In thin section studies of voids in sands and sandy soils, there is a close correlation between microscopic and suction methods (Swanson and Peterson, 1942). However, in those soils whose volumes change with changes in water content, pore size distribution is undefined, and no constant void size distribution exists (Brewer, 1976). Furthermore, there are several unvalidated assumptions that commonly are made in relating porosity to permeability (Nielsen et al., 1972 p. 11). The assumptions that especially relate to soil fabric are that no pores are sealed off; pores are distributed at random; and pores are generally uniform in size. A more serious difficulty may be that a thin section, even if reduced to a 20-µm thickness, may make the examination of the <20-µm diameter pores impossible, if these pores pass through the section at an angle of ≤45°. This means that many voids that are involved in unsaturated water flow in soils will not be visible in thin section (Baver, 1956 p. 271).

The size, shape, and arrangement of skeleton grains determine the nature of simple packing voids, but the origin of compound packing voids is not so straightforward. The unaccommodated peds of the compound packing voids may be formed by faunal excreta, shrink-swell action, man's activities, or by other unknown causes.

Vughs usually occur in soil materials with a wide range in size of particles, including silicate clays. Some vughs form by the weathering and removal of carbonate, and others form by faunal activity or the normal packing of plasma and skeleton grains. The very regular outline of vesicles is of interest (Nettleton and Peterson, 1983). Lapham (1932) states that in Sierozems (Aridisols), the vesicles that are near the surface are the result of air entrappment by rainfall following dry dusty periods. Laboratory studies verify this phenomenon (Springer, 1958). If high silt soils are allowed to dry before each irrigation, the vesicle size increases with the number of irrigations (Miller, 1971). As a result of studies of infiltration rates and sediment production in rangelands in central and eastern Nevada, Blackburn and Skau (1974) and Rostagno (1989) conclude that the infiltration rates are the lowest and the sediment yields are the highest on sites that have vesicular surface horizons. The failure of most vesicles to connect to other voids and the low strength of the crust in which vesicles occur help to explain the low infiltration rates and the high sediment yields that commonly are found on these soils.

Joint planes are produced in relatively uniform fine-textured soils by a relatively regular system of cracking upon drying (Brewer, 1976). Once formed, these joint planes tend to open in the same place during successive drying cycles. Skew planes are produced in more heterogeneous materials or by irregular drying (Brewer, 1976). Craze planes often occur in Chernozems (Mollisols), possibly as a result of the high humic acid content (Brewer, 1976). Because of their size, cross-sectional shape, and kind of branching pattern, channels probably form by faunal activity, plant root systems, or by certain geological processes (Brewer and Sleeman, 1963).

APPENDIX XI

QUALITY ASSURANCE TERMINOLOGY[1]

[1]Quality Assuarance terminology is extracted *in total* from Taylor (1988) and Steel and Torrie (1980)

Absolute Error - The difference between the experimental or measured value and the true or expected value.

Accuracy - The degree of agreement of an experimental or measured value with the true or expected value of the quantity of concern. Accurate values cluster around the true value or bull's eye (Fig. 1) for a specific analytical procedure. Different procedures often yield different bull's eyes for the same property, e.g., different methods for cation exchange capacity yield different answers. For the most part, it is assumed that analytical methods are used in an unbiased manner and the methods provide accurate values. Accuracy of the value is important, but it is important to know when to use a given analytical method and to know its limitations, e.g., if organic C is determined by a combustion method yielding total C, the method is of little use in calcareous soils or in soils that contain appreciable amounts of inorganic C unless a correction for inorganic C is made.

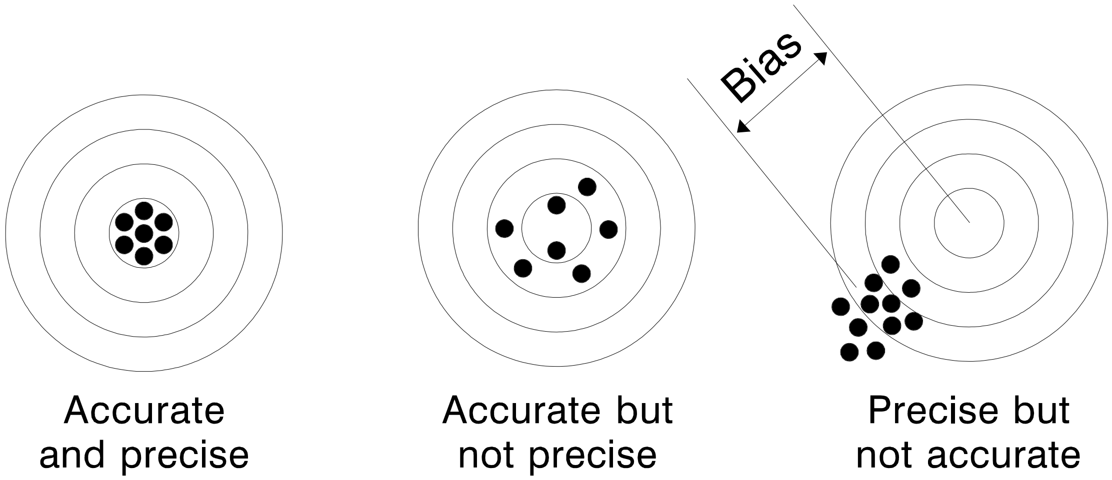

Fig. 1. Accuracy and Precision

Analyte - The specific component measured in a chemical analysis.

Bias - A systematic error inherent in a method (e.g., temperature effects and extraction inefficiencies) or the result of some artifact or idiosyncrasy of the measurement system (e.g., blanks, contamination, mechanical losses, and calibration errors). Bias may be both positive and negative, and several kinds can exist concurrently. Net bias is all that can be evaluated except under special conditions.

Bulk Sampling - Sampling of a material that does not consist of discrete, identifiable, constant units, but rather of arbitrary, irregular units. Bulk sampling does not preserve the spatial configuration and mutual orientation of constituents (including pore space) of the field material.

Coefficient of Variation (CV) - The sample standard deviation expressed as a percentage of the sample mean. The CV can be used to evaluate results from different experiments involving the same character. The CV is a relative measure of variation, in contrast to the standard deviation, which is in same units as observations. The CV is a ratio of two averages and is independent of the measurement unit. Refer to the example calculation of the CV and other statistical parameters.

Composite Sample - A sample composed of two or more increments that are combined to reduce the number of individual samples needed to determine average composition.

Confidence Interval - The range of values, calculated from an estimate of the mean and standard deviation, which is expected to include the population mean with a stated level of confidence. Confidence intervals in the same context may also be calculated for standard deviations, lines, slopes, and points.

Decile - Any one of the ten values of a variable that divide the distribution of ranked values into tenths. The fifth decile is the median.

Detection Limit - The smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence.

Determinate or Systematic Errors - Errors with a definite value or assignable cause. The analyst can generally, n principle but not always in practice, measure, account, and correct for determinate errors, e.g., instrument errors, method errors, and analyst errors.

Error - Difference between the true or expected value and the measured value of a quantity or parameter.

Geometric Mean - A measure of central tendency obtained by taking the nth root of the product of n values. Useful in calculation of relative values, e.g., index numbers. Refer to the example calculation of the geometric mean and other statistical parameters. Geometric mean is calculated as follows:

$$G = (Y_1\ Y_2\ \ldots.Y_n)^{1/n}$$

Indeterminate or Random Errors - Uncertainties in a measurement from sources that are unknown and uncontrollable by the analyst. Random behavior of indeterminate errors make it possible to treat their effects by the method of statistics.

Intuitive Sampling Plan - A sampling plan based on the judgment of the sampler. General knowledge of similar materials, past experience, and present information about the universe of concern, ranging from knowledge to guesses, are used in designing such a plan.

Mean - Measure of central tendency. Mean is an arithmetic average of a set of observations. Refer to the example calculation of the mean and other statistical parameters.

Median - Measure of central tendency. Median is the value for which 50 percent of the observations, when arranged in order of magnitude, lie on each side. Refer to the example calculation of the median and other statistical parameters.

Mode - A measure of central tendency. Mode is the value of most frequent occurrence.

Method - An assemblage of measurement techniques and the order in which they occur.

Percentile - A percentile is any one of the 99 values of a variable that divide the distribution of ranked values into hundredths. The 50th percentile is the median.

Precision - The degree of mutual agreement characteristic of independent measurements as the result of repeated application of the process under specified conditions. Precision is a measure of random errors in analytical technique and describes the reproducibility of results. Laboratory precision involves sample processing (homogeneity) and analyte processing. If laboratory analyses are precise, the values fall in a compact cluster (Fig. 1).

Probability - The likelihood of the occurrence of any particular form of an event, i.e., the ratio of the number of ways or times that the event may occur in that form to the total number of ways or times that it could occur in any form.

Procedure - A set of systematic instructions for using a method or measurement or sampling or of the steps or operations associated with them.

Protocol Sampling Plan - A sampling plan specified for decision purposes in a given situation. Regulations often specify the type, size, frequency, sampling period, and even location and time of sampling related to regulatory decisions. The protocol may be based on intuitive or statistical considerations but is indisputable once established.

Quality - An estimation of acceptability or suitability for a given purpose of an object, item, or tangible thing.

Quality Assessment - The overall system of activities whose purpose is to provide assurance that the quality control activities are done effectively. Quality assessment involves a continuing performance evaluation of the production system and the product quality.

Quality Assurance - A system of activities whose purpose is to provide to the producer and/or to the user of a product or service the assurance that defined standards of quality have been met. Quality assurance consists of quality control and quality assessment, i.e., two separate but related activities.

Quality Control - The overall system of activities whose purpose is to control the quality of a product or service so that it meets the user's needs, i.e., to provide quality that is satisfactory, adequate, dependable, and economic.

Quartile - A quartile of the three values of a variable that divide the distribution of ranked values into quarters. The second quartile is the median.

Random Sample - A sample selected from a population, using a randomization process to eliminate questions of bias in selection and/or to provide a basis for statistical interpretation of measurement data.

Range - For a finite number of values, the simplest measure of variability is the range, which is the difference between the largest and smallest values. Like the median, the range is sometimes useful in small sample statistics but generally speaking it is an inefficient measure of variability. Refer to the example calculation of the range and other statistical parameters.

Ratio - Indicated quotient of two mathematical expressions. The relationship in quantity, amount, or size between two or more things. Proportion. Precision of ratios is dependent on the precision of both the numerator and denominator values. Base saturation is a ratio (expressed as a percent) of the sum of extractable bases, each of which is determined separately, divided by the cation exchange capacity (CEC), either by sum of cations (CEC-8.2) or by NH_4OAc, pH 7.0 (CEC-7.0). The precision of ratios is poorest when the magnitude of the denominator is low.

Replicate - A counterpart of another, usually referring to an analytical sample or a measurement.

Representative Sample - A sample considered to be typical of the universe of concern and whose composition can be used to characterize the universe with respect to the parameter measured.

Routine Method - A method used in recurring analytical problems.

Sample - A portion of a population or lot. A sample may consist of an individual or groups of individuals and refers to objects, materials, or measurements, conceivable as part of a larger group that could have been considered.

Sensitivity - Capability of methodology or instrumentation to discriminate between samples having differing concentrations or containing differing amounts of an analyte.

Significant Figures - Historically, all digits that are certain plus one, which contains some uncertainty, are said to be significant figures, i.e., the convention is that data are reported one decimal beyond the dependable digit, e.g., if a value is reported as 19.4 units the 0.4 is not certain. Repeated analyses of the same sample would vary more than one-tenth but generally less than a whole unit. It is incorrect for one to say "use the appropriate number of significant figures". Rather, one should say "only significant figures should be recorded". One can record too many digits but not too many significant figures. The principal advantage of this procedure is that it is less laborious than the calculations of actual uncertainties, particularly those based on indeterminate errors. The principal disadvantage is that only a rough estimate of uncertainty is obtained. In most situations encountered in analyses, an estimate is all that is needed, and hence significant figures are widely used.

Standard Deviation - An arithmetic measure of the spread or range of observations. Standard deviation is the positive square root of the variance. Refer to the example calculation of the standard deviation and other statistical parameters. The standard deviation is calculated as follows:

$$s = \sqrt{\frac{\sum (x_i - \ddot{x})^2}{n-1}}$$

where:

s = Standard deviation (s) is positive square root of variance

Xi = X_i is value of *i*th observation.

X = Arithmetic mean

N = Number of observations

Standard Method - A method (or procedure) that has been developed by a standard-writing organization, based on consensus opinion or other criteria and often evaluated for its reliability by a collaborative testing procedure.

Standard Operations Procedure (SOP) - A procedure adopted for repetitive use when performing a specific measurement or sampling operation. A SOP may be for a standard method or for a method developed by the user.

Statistical Sampling Plan - a sampling plan based on statistical sampling of the universe of concern that ordinarily can provide the basis for probabilistic conclusions. Hypothesis testing can be involved, predictions can be made, and inferences can be drawn. Ordinarily, a relatively large number of samples will need to be measured if the significance of small apparent differences is of concern.

Subsample - A portion taken from a sample. A laboratory sample may be a subsample of a gross sample. Similarly, a test portion may be a subsample of a laboratory sample.

Systematic Sample - A sample taken according to a systematic plan, with the objective of investigating systematic variability of the universe of concern. Systematic effects due to time or temperature are typical matters of concern.

Technique - A physical or chemical principle utilized separately or in combination with other techniques to determine the composition (analysis) of materials.

Tolerance Interval - The range of values, calculated from an estimate of the mean and standard deviation, within which a specified percentage of individual values of a population (measurements or sample) are expected to lie with a stated level of confidence.

Traceability - The ability to trace the source of uncertainty of a measurement or a measured value.

Uncertainty - The range of values within which the true value is estimated to lie, i.e., the best estimate of possible accuracy due to both random and systematic error.

Validation - The process by which a sample, measurement method, or a datum is determined useful for a specified purpose.

Variance - The value approached by the average of sum of squares of deviations of individual measurements from the limiting mean. Mathematically, variance may be expressed as only its estimate. Refer to the example calculation of the variance and other statistical parameters. The variance is calculated as follows:

$$s^2 = \frac{\sum (x_i - \ddot{x})^2}{n-1}$$

where:

s^2 = Variance. Standard deviation (s) is positive square root of variance

$\underline{X}$i = X_i is value of *i*th observation.

X = Arithmetic mean

N = Number of observations

Example Calculations of Statistical Parameters:

The clay percent is determined by four separate measurements (N = 4) with the results being 30, 32, 35, and 36 percent. Calculate the arithmetic mean, geometric mean, median, range, variation, standard deviation, and the coefficient of variation (CV).

$$\text{Mean} = \frac{30 + 32 + 35 + 36}{4} = 33.3\ \%\ \text{clay}$$

$$\text{Geometric Mean} = \sqrt[4]{(30x32x35x36)} = 33.2\%\ \text{clay}$$

$$\text{Median} = \frac{32 + 35}{2} = 33.5\ \%\ \text{clay}$$

Range = 36 - 30 = 6 % clay

$$\text{Variance} = \frac{(3.3)^2 + (1.3)^2 + (1.7)^2 + (2.7)^2}{4 - 1} = 7.6\ \%\ \text{clay}$$

$$\text{Std. Dev.}\ \sqrt{7.59} = \pm 2.8\ \%\ \text{clay}$$

$$\text{CV} = \frac{2.75}{33.3} \text{ X } 100 = 8.3 \quad \text{(no units)}$$

APPENDIX XII

Conversion Factors for SI and non-SI Units[1]

[1] Conversion factor table for SI and non-SI units are extracted *in total* from Soil Science Society of America (1993).

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-Sl Unit	To convert Column 2 into Column 1, multiply by
	Length		
0.621	kilometer, km (10^3 m)	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, μm (10^{-6} m)	micron, μ	1.0
3.94×10^{-2}	millimeter, mm (10^{-3} m)	inch, in	25.4
10	nanometer, nm (10^{-9} m)	Angstrom, Ä	0.1
	Area		
2.47	hectare, ha	acre	0.405
247	square kilometer, km^2 $(10^3\ m)^2$	acre	4.05×10^{-3}
0.386	square kilometer, km^2 $(10^3\ m)^2$	square mile, mi^2	2.590
2.47×10^{-4}	square meter, m^2	acre	4.05×10^{3}
10.76	square meter, m^2	square foot, ft^2	9.29×10^{-2}
1.55×10^{-3}	square millimeter, mm^2 $(10^{-3}\ m)^2$	square inch, in^2	645
	Volume		
9.73×10^{-3}	cubic meter, m^3	acre-inch	102.8
35.3	cubic meter, m^3	cubic foot, ft^3	2.83×10^{-2}
6.10×10^{4}	cubic meter, m^3	cubic inch, in^3	1.64×10^{-5}
2.84×10^{-2}	liter, L (10^{-3} m^3)	bushel, bu	35.24
1.057	liter, L (10^{-3} m^3)	quart (liquid), qt	0.946
3.53×10^{-2}	liter, L (10^{-3} m^3)	cubic foot, ft^3	28.3
0.265	liter, L (10^{-3} m^3)	gallon	3.78
33.78	liter, L (10^{-3} m^3)	ounce (fluid), oz	2.96×10^{-2}
2.11	liter, L (10^{-3} m^3)	pint (fluid), pt	0.473
	Mass		
2.20×10^{-3}	gram, g (10^{-3} kg)	pound, lb	454
3.52×10^{-2}	gram, g (10^{-3} kg)	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
0.01	kilogram, kg	quintal (metric), q	100
1.10×10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
1.102	tonne, t	ton (U.S.), ton	0.907

Conversion Factors for SI and non-SI Units

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-Sl Unit	To convert Column 2 into Column 1, multiply by
	Yield and Rate		
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb acre^{-1}	1.12
7.77 x 10^{-2}	kilogram per cubic meter, kg m^{-3}	pound per bushel, lb bu^{-1}	12.87
1.49 x 10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 60 lb	67.19
1.59 x 10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 56 lb	62.71
1.86 x 10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 48 lb	53.75
0.107	liter per hectare, L ha^{-1}	gallon per acre	9.35
893	tonnes per hectare, t ha^{-1}	pound per acre, lb acre^{-1}	1.12 x 10^{-3}
893	megagram per hectare, Mg ha^{-1}	pound per acre, lb acre^{-1}	1.12 x 10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton acre^{-1}	2.24
2.24	meter per second, m s^{-1}	mile per hour	0.447
	Specific Surface		
10	square meter per kilogram, m^2 kg^{-1}	square centimeter per gram, cm^2 g^{-1}	0.1
1 000	square meter per kilogram, m^2 kg^{-1}	square millimeter per gram, mm^2 g^{-1}	0.001
	Pressure		
9.90	megapascal, MPa (10^6 Pa)	atmosphere	0.101
10	megapascal, MPa (10^6 Pa)	bar	0.1
1.00	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1.00
2.09 x 10^{-2}	pascal, Pa	pound per square foot, lb ft^{-2}	47.9
1.45 x 10^{-4}	pascal, Pa	pound per square inch, lb in^{-2}	6.90 x 10^3
	Temperature		
1.00 (K - 273)	Kelvin, K	Celsius, °C	1.00 (°C + 273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F - 32)

Conversion Factors for SI and non-SI Units

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-Sl Unit	To convert Column 2 into Column 1, multiply by
	Water Measurement		
9.73 x 10^{-3}	cubic meter, m^3	acre-inches, acre-in	102.8
9.81 x 10^{-3}	cubic meter per hour, $m^3 h^{-1}$	cubic feet per second, $ft^3 s^{-1}$	101.9
4.40	cubic meter per hour, $m^3 h^{-1}$	U.S. gallons per minute, gal min^{-1}	0.227
8.11	hectare-meters, ha-m	acre-feet, acre-ft	0.123
97.28	hectare-meters, ha-m	acre-inches, acre-in	1.03 x 10^{-2}
8.1 x 10^{-2}	hectare-centimeters, ha-cm	acre-feet, acre-ft	12.33
	Concentrations		
1	centimole per kilogram, cmol kg^{-1} (ion exchange capacity)	milliequivalents per 100 grams, meq 100 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10
1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1
	Plant Nutrient Conversion		
	Elemental	***Oxide***	
2.29	P	P_2O_5	0.437
1.20	K	K_2O	0.830
1.39	Ca	CaO	0.715
1.66	Mg	MgO	0.602

APPENDIX XIII

NRCS-SOIL-8:

APPENDIX XIII - Caribou

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                          S C S -- S O I L S -- 8                  Ver. JUN91
                             NSSL  08/01/94

 886 3      (N) O  X  F       88P  722     BY:KJL   09/91    46N 00 55    68W 01 11
01 REC     02 STAT(Circle)    03 PED No    04 INIT  MO/YR    05 LAT       06 LON

CARIBOU             I     ___/___    _________   _F__L__R_(T)_V__S_   _I__M__O__T_(U)
07 CURRENT NAME     I    08 DATE     09 PUB         10 TAX CODE         11 SOURCE
   (Max 16)                             SYMBOL         (Circle)            (Circle)

CARIBOU             T    __________   88P 3855- 3860   NE  S (L) C  M  O    (Y) N  U
12 SAMPLED AS      L,T,  13 FIELD     14 LAB SAMPLE    15     LABORATORY    16 SAMPLE
   (Max 16)        V,P      SYMBOL       NUMBERS       (STATE)  (Circle)     (Circle)

S  88  ME  -   3  -  001/_   R/146/_    09/91                                 UD
S  YR  ST      CO    PEDON   18 MLRA   19 DATE        20 SS AREA           21 MOIST
17 SOIL SURVEY SAMPLE No               CLASSIF          (Max 4)               REGIME

__________________________________/__    I  OC  DY  AA/__    50   34   2   4   2
22 REFERENCE CITATION (Max 24)      P   OR  SO  GG  SGMOD   PS   MIN  PH TEM OTH
                                    U   23   T A X O N O M Y    C O D E S

TYPIC                                        DYSTROCHREPT
24 SUBGROUP MODIFIER (Max 28)                25 GREAT GROUP (Max 16)

LOAMY-SKELETAL                               MIXED
26 PARTICLE SIZE FAMILY (Max 42)             27 MINERALOGY FAMILY (Max 30)

DEFAULT                 FRIGID                     DEFAULT
28 REACTION FAMILY      29 TEMPERATURE FAMILY      30 OTHER CHARACTERISTICS
     (Max 14)                 (Max 16)                     (Max 18)

   31 NOTES:  APPEARS SPODIC HOR. MXD W/SRFCE LAYERS
                                 (Max 40)

              SUMMARY OF KINDS AND AMOUNT OF ANALYSES AVAILABLE
KIND                                     KIND
ANAL   AMT SUB                           ANAL AMT
 39=    6    5 PS, FRAGMENTS UNSPECIFIED 48=     -ELECTRICAL CONDUCTIVITY,
 PS          6 PS, FRAGMENTS MEASURED               RESISTIVITY, SALT
             7 PS, FRAGMENTS ESTIMATED   49=     -SATURATION EXTRACT SOLUBLE,
           ->8 PS, FRAGMENTS MEAS. & EST.           CATIONS & ANIONS
                                         50=  6 -EXTRACTABLE IRON (PYROHOS,
 40=    4    5 BULK DENSITY WITHOUT COLE            DITH-CIT, OXALATE)
 BD        ->6 BULK DENSITY WITH COLE    51=  6 -CATION EXCHANGE CAPACITY
                                         52=  6 -ALUMINUM (PYROPHOS, KOH,
 41=    2    5 CLAY FRACTION                        DITH-CIT, NAOH, OXALATE)
 MIN         6 SAND A/O SILT FRAC(S)     53=  2 -ATTERBERG LIMITS
           ->7 CLAY,SAND A/O SILT FRAC(S) 54= 6 -CLAY:  CARBONATE OR FINE
             8 FAMILY MINEROLOGY         55=     -FIBER
                                         56=     -GYPSUM (TOTAL)
 42=         5 STANDARD ITEMS (MECHANICAL 57=    -MINERAL CONTENT ORGANIC SOIL
 HL            ANALYSIS & ATTERBERGS)    58=     -MANGANESE (ANY METHOD)
             6 STANDARD ITEMS & MAXIMUM  59=  2 -NITROGEN
               DENSITY                   60=     -PHOSPHOROUS (TOTAL)
             7 STANDARD ITEMS, MAXIMUM   61=     -SULFUR (TOTAL)
               DENSITY, & SHRINK-SWELL   62=     -FIELD MEASURED WATER CONTENT
                                                    OR TABLE, PERK RATE, ETC.
 43=    6    - WATER CONTENT OR TENSIONS 63=     -THIN SECTIONS
 44=    6    - ORGANIC CARBON OR MATTER  64=     -TOTAL ELEMETAL ANALYSES
 45=    6    - PH                        65=     -HYDRAULIC CONDUCTIVITY
 46=    6    - EXTRACTABLE CATIONS/BASES 66=     -AVAILABLE PHOSPHOROUS
 47=         - CARBONATE                 67=     -AVAILABLE POTASSIUM
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APPENDIX XIII- Wildmesa

S C S -- S O I L S -- 8 Ver. JUN91
NSSL 08/01/94

945 6	(N) O X F	89P 325	BY:SBS	05/93	35N 58 26	117W 35 42
01 REC	02 STAT(Circle)	03 PED No	04 INIT	MO/YR	05 LAT	06 LON

WILDMESA		05/93		F L R T V S	I M O T (U)
07 CURRENT NAME (Max 16)	I	08 DATE	09 PUB SYMBOL	10 TAX CODE (Circle)	11 SOURCE (Circle)

WILDMESA		1080	89P 1799- 1804	NE	S (L) C M O	Y N U
12 SAMPLED AS (Max 16)	L,T, V,P	13 FIELD SYMBOL	14 LAB SAMPLE NUMBERS	15 (STATE)	LABORATORY (Circle)	16 SAMPLE (Circle)

S	89	CA	-	27	-	004/	D/ 29/	05/93	0695	AR
S	YR	ST		CO		PEDON	18 MLRA	19 DATE CLASSIF	20 SS AREA (Max 4)	21 MOIST REGIME
17 SOIL SURVEY SAMPLE No										

	/	D	AR	PA	XE/	126	37	2	16	2
22 REFERENCE CITATION (Max 24)	P U	OR	SO	GG	SGMOD	PS	MIN	PH	TEM	OTH
		23	TAXONOMY CODES							

XERALFIC	PALEARGID
24 SUBGROUP MODIFIER (Max 28)	25 GREAT GROUP (Max 16)
FINE	MONTMORILLONITIC
26 PARTICLE SIZE FAMILY (Max 42)	27 MINERALOGY FAMILY (Max 30)

DEFAULT	MESIC	DEFAULT
28 REACTION FAMILY (Max 14)	29 TEMPERATURE FAMILY (Max 16)	30 OTHER CHARACTERISTICS (Max 18)

31 NOTES: ______ (Max 40)

SUMMARY OF KINDS AND AMOUNT OF ANALYSES AVAILABLE

KIND ANAL	AMT	SUB	
39= PS	6	5	PS, FRAGMENTS UNSPECIFIED
		->6	PS, FRAGMENTS MEASURED
		7	PS, FRAGMENTS ESTIMATED
		8	PS, FRAGMENTS MEAS. & EST.
40= BD	5	5	BULK DENSITY WITHOUT COLE
		->6	BULK DENSITY WITH COLE
41= MIN	3	5	CLAY FRACTION
		6	SAND A/O SILT FRAC(S)
		->7	CLAY,SAND A/O SILT FRAC(S)
		8	FAMILY MINEROLOGY
42= HL		5	STANDARD ITEMS (MECHANICAL ANALYSIS & ATTERBERGS)
		6	STANDARD ITEMS & MAXIMUM DENSITY
		7	STANDARD ITEMS, MAXIMUM DENSITY, & SHRINK-SWELL
43=	6	-	WATER CONTENT OR TENSIONS
44=	6	-	ORGANIC CARBON OR MATTER
45=	5	-	PH
46=	5	-	EXTRACTABLE CATIONS/BASES
47=	5	-	CARBONATE

KIND ANAL	AMT	
48=	5	-ELECTRICAL CONDUCTIVITY, RESISTIVITY, SALT
49=	2	-SATURATION EXTRACT SOLUBLE, CATIONS & ANIONS
50=		-EXTRACTABLE IRON (PYROHOS, DITH-CIT, OXALATE)
51=	5	-CATION EXCHANGE CAPACITY
52=		-ALUMINUM (PYROPHOS, KOH, DITH-CIT, NAOH, OXALATE)
53=		-ATTERBERG LIMITS
54=	5	-CLAY: CARBONATE OR FINE
55=		-FIBER
56=	1	-GYPSUM (TOTAL)
57=		-MINERAL CONTENT ORGANIC SOIL
58=		-MANGANESE (ANY METHOD)
59=		-NITROGEN
60=		-PHOSPHOROUS (TOTAL)
61=		-SULFUR (TOTAL)
62=		-FIELD MEASURED WATER CONTENT OR TABLE, PERK RATE, ETC.
63=		-THIN SECTIONS
64=		-TOTAL ELEMETAL ANALYSES
65=		-HYDRAULIC CONDUCTIVITY
66=		-AVAILABLE PHOSPHOROUS
67=		-AVAILABLE POTASSIUM

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