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ABSTRACT

A review of systems for describing soil structure leads to the conclusion that soil porosity should be included as a basic aspect of structure description, perhaps the most important aspect for interpretations based on structure. Improvements are proposed in procedures for describing soil macrostructure in the field and refinements are suggested in definitions of terms related to soil structure. Such changes are shown to be necessary to foster uniformity of soil descriptions in soil survey. Preliminary data are presented that indicate a good possibility of making useful estimates of saturated hydraulic conductivity from observations of soil structure, including porosity. Preliminary testing of the British Soil Survey system of estimating the air porosity and available water capacity of soils from field observations are sufficiently promising to warrant further work to refine the guidelines involved.

RESUME

L'étude des systèmes de description de la structure des sols porte à conclure que la porosité doit être incluse comme aspect fondamental de la description, aspect peut-être le plus important pour ce qui est des interprétations basées sur la structure. L'ouvrage propose d'améliorer les méthodes dedescription de la macro-structure des sols sur le terrain et d'épurer les définitions des termes relatifs à la structure. Ces modifications s'avèrent nécessaires pour uniformiser les descriptions des sols en matière de prospection pédologique. Il présente des données provisoires qui soulignment la possibilité de faire des estimations utiles de la conductivité hydraulique à saturation à partir d'observaion de la structure, y compris la porosité. Les essais préalables du Système de prospection britannique qui consistent à estimer la porosité en air et la capacité de rétention de l'eau utile des sols à partir d'observations sur le terrain sont suffisamment prometteurs pour justifier de plus amples recherches en vue d'épurer les principes directeurs en cause.

BACKGROUND, SCOPE AND PURPOSE OF THIS REPORT

Description of soil structure has been a basic aspect of soil characterization practised by Canadian pedologists for several decades. The concept of structure and the system for describing it were those outlined in the U.S. Soil Survey Manual (Soil Survey Staff, 1951). Though new recruits to soil survey in Canada usually are given some guidance in describing soil morphology, including structure, it is commonly assumed that experienced pedologists describe soils more-or-less uniformly. Soil structure is considered to be an important soil property but no systematic interpretations of soil behavior in Canada are based on structure.

The current focus on the field soil water regime (Topp *et al.*, 1980; Nowland, 1980) and concern about soil degradation (Coote *et al.*, 1981) have stimulated interest in soil structure and its interpretation. Interpreting structure in relation to the soil water regime and soil degradation requires reconsideration of the concept of structure and attempts to characterize soil structure in more quantitative terms. Adequate characterization of soil structure should make possible improved field estimates of soil hydraulic conductivity and drainability. It should aid in the assessment of the effects (adverse and beneficial) of tillage practices on the physical condition of the soil as a medium for plant growth.

This report presents a view of the state-of-the-art in soil structure work and suggests for trial some possible improvements in the description and interpretation of structure. It begins with a critical review of concepts of soil structure and systems of describing it, considers the uniformity of characterization of structure, and proposes improved definitions, description and interpretation of soil structure. Results are included of attempts at quantifying soil structure, and of predicting saturated hydraulic conductivity from structure observations. The report reflects the point of view that soil structure is characterized mainly to permit improved interpretations of soil processes and behavior. The test of adequate soil structure characterization is viewed as the checking of the validity of estimates based on structure.

The purpose of the report is to contribute toward improved characterization and interpretation of soil structure by pedologists in Canada. Critical comments and suggestions for improvement are invited from readers.

REVIEW OF SOIL STRUCTURE CONCEPTS, DESCRIPTION AND DEFINITIONS

Concepts of soil structure deal with some aspects of the physical constitution of soil; they differ in specificity and in the physical attributes that are encompassed (Hodgson, 1978). Some concepts of structure are restricted to the arrangement of compound particles, and other include the shape, size and arrangement of primary particles, compound particles, and the voids between particles. According to Jongerius (1957) definitions of soil structure fall into four classes:

1. Only arrangement and aggregation of the solid soil constituents are included;
2. Soil pores are considered to be an important feature;
3. Soil water is included;
4. Notions of genesis as well as soil properties are included; the soil fabric concept of Kubiena.

Some of the differences in concepts are reflected in the definitions that follow:

Nikiforoff (1941). The term 'soil structure' denotes an arrangement of the soil material into aggregates in which the primary particles of such a material are held together by ties stronger than the ties between adjacent aggregates.

Robinson (1950). The structure of the soil is the extent to which the primary particles of the soil are built up into aggregates, and the character of these aggregates or structural elements.

Soil Survey Staff (1951). Soil structure refers to the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining aggregates by planes of weakness.

Jongerius (1957). Soil structure is the spatial arrangement of the elementary constituents and any aggregates thereof, and of the cavities occurring in the soil.

Brewer (1964). Soil structure is the physical constitution of the soil material as expressed by the size, shape, and arrangement of the solid particles and voids, including both the primary particles to form compound particles and the compound particles themselves; fabric is the element of structure which deals with arrangement.

U.S. Soil Survey Staff (revised, draft of Manual, 1979). Soil structure (pedality) refers to the natural organization of primary soil particles into units that are separated from adjoining units by planes of weakness or by thin, roughly planar voids, and that have evidence that they persist through many cycles of wetting and drying in place.

British Soil Survey Handbook (Hodgson, ed. 1976). The term soil structure refers to the shape, size, and degree of development of the aggregation, if any, of the primary soil particles into naturally or artificially formed structural units (peds, clods, artificial and natural fragments), and the spatial arrangement of these units including the description of voids (pores and fissures) between and within the aggregates.

CanSIS Manual (Dumanski, ed. 1978).Soil structure refers to the aggregates of primary soil particles (compound particles or clusters of primary particles), which are separated from adjoining aggregates by surfaces of weakness.

These definitions indicate only a part of the concepts of soil structure intended; the concepts involved may be evident in the systems for describing structure.

Systems for Describing Structure

The material that follows will provide brief comparisons of the systems outlined by Jongerius (1957), Brewer (1964), Soil Survey Staff (1979 draft), Hodgson, ed. (1976) and Dumanski , ed. (1978) with that given in the old U.S. Soil Survey Manual (Soil Survey Staff, 1951). The focus will be on differences from the latter system. First the system given in the U.S. Manual (1951) will be outlined briefly.

The 1951 system focuses on three attributes of soil aggregates or peds, which are distinguished from clods, fragments and concretions. The following attributes are designated:

1. Type (shape and arrangement of peds) - platy, prismlike, blocklike, and spheriodal or polyhedral with unaccommodated faces (for example, a convex curved ped face against a planar ped face). Subdivisions of the basic types include:
   - columnar - prismatic with rounded top
   - granular - spheroidal, or polyhedral with unaccommodated faces, relatively nonporous
   - crumb - spheroidal, very porous
   - subangular blocky - a type of blocky with many rounded vertices

2. Class (size) - most types are subdivided into four classes.

3. Grade (strength) includes both durability of the aggregates and proportions between aggregated and unaggregated material. Grade terms defined are: structureless, weak, moderate and strong.

   Assignment of grade is based on observations of the soil in place and of disturbed soil material.

   Provision is made for describing compound structure.

Jongeruis' (1957) system differs from that in the U.S. Manual in several respects:

- It includes porosity and arrangement of primary particles as aspects of structure.
- It provides a mechanism for differentiation of the two aspects of grade: durability of peds and degree to which peds adhere to each other.
- It names a number of kinds of macrostructure without peds, based largely on aspects of porosity. Terms used include: collapse (puddled) structure; massive, sponge, tunnel, etc.
- It presents a shorthand for indicating macrostructures and "added" characteristics (films, voids, etc). For example: A3aII Spherical peds, 1-2 mm diameter,

  A3bIV Many-faced granular, 5-10 mm diameter,

  G3 Tunnel structure. The apedal soil mass is interlaced by worm tunnels that are not connected.

  G3a At least 75 tunnels/m^2 of horizontal section.

  H Finely layered sediments with varying grain size

  B3aIII3 Coarse prisms composed of blocky elements(2-5 mm), macrovoids (100 µm) separate the prisms.
- The nature of prism faces is indicated: smooth or rough, occurrence of root traces, surface films and their nature.

  Slager (1966) refined Jongerius' system and emphasized numbers of vertically-oriented channels.

Brewer's (1964) system differs from that in the U.S. Manual (1951) by including the size, shape and arrangement of voids and primary particles as attributes of structure, and in being much more precise in the definition of shape and size of peds. The size and shape concepts are adopted from sedimentary petrology. The system includes much more specificity on the arrangement of peds, accommodation, and it is adaptable to any scale of magnitude. It does not deal with the concept of grade. It provides for detailed description of various kinds of voids: interpedal, planar, channels, intrapedal. It also provides improved guidelines for distinguishing clods, fragments and peds.

Draft of New U.S. Manual (Soil Survey Staff, 1979 draft) - The system is nearly identical to that in the 1951 manual but it is more specific in some definitions and some minor changes are introduced. Examples are:

- Lenticular is added as a subdivision of platy.
- More information is given about distinguishing peds from fragments and clods.
- The size classes are extended by the provision that actual sizes are given if the minimum size of very coarse is exceeded by a factor of two. In addition, the dimension to be measured to determine size class is specified.
- The attributes of structure are named: grade, size and shape (not grade, class and type).

  Pores and organized elements on ped surfaces (morphons) are described separately from soil structure.

<u>British Handbook</u> (Hodgson, ed. 1976).The British system differs markedly from that in the U.S. Manual (1951).

- It includes voids as an attribute of structure and indicates procedures for estimating their size and abundance.
- It includes clods and artificial or natural fragments, in addition to peds, as structural units.
- It recognizes the difficulty of assigning pedal structure to some surface horizons, especially Ap horizons, and provides a mechanism for describing the physical attributes of such horizons.
- It extends the grade classes by including very weak; weak, adherent; and very strong.

<u>CanSIS Manual (Dumanski ed. 1978</u>).The system is that of the U.S. manual (1951) with these exceptions:

- Intergrades are named for grade and class, e.g. weak to moderate (grade), very fine to fine (class).
- Modifiers (pseudo, stratified, bedded, laminated) are used with kind terms: e.g. moderate, medium, angular pseudo blocky.
- Blocky and granular indicate shape only, not accommodation of peds.
- “Kind" is introduced as a subdivision of "type", e.g. subangular blocky is a kind of the type block-like.
- Cloddy (not a structure) is included with the "kind" terms. It indicates a condition (not defined) of some plowed surfaces.
- Porosity and clay films are described separately from structure.

Perhaps the major differences in the systems outlined is that some include voids as a part of structure and others do not. Thus before evaluating the systems for describing structure it is desirable to outline briefly the associated systems for describing pores.

Systems for Describing Soil Porosity

The U.S. Soil Survey Manual (Soil Survey Staff, 1951) included nothing on the description of pores. Since it was the basic reference for soil description in North America, pores were rarely noted in soil descriptions in Canada until about 10 years ago and they are not recorded in most soil descriptions today.

Jongerius (1957) included porosity in his structure terms and symbols but he did not develop a complete system; according to Hodgson (1978), the Netherlands Soil Survey more-or-less follows the U.S.D.A. system for soil morphology.

Brewer (1964) included voids as an aspect of structure; gave a detailed classification of the size, shape, arrangement and kind of void; and suggested ways of describing megascopic voids in the field.

The 1979 draft of the U.S. Soil Survey Manual (Soil Survey Staff, 1979 draft) treats pores as a part of soil description distinct from "Physical organization of soil".The latter heading includes: structure, clods and fragments, organized elements on surfaces and organized bodies within the soil. The system for describing pores is modified from one proposed by Johnson et al. (1960). Pores are described in terms of quantity, size and shape as follows:

Quantity (based on a unit area of 1 cm^2 for pores less than 2 mm in diameter, and of 1 dm^2 for pores larger than 2 mm).

Few:	less than 1 per unit area
Common:	1 to 5 per unit area
Many:	more than 5 per unit area

Size (diameter)

Very fine:	less than 0.5 mm
Fine:	0.5 to 2 mm
Medium:	2 to 5 mm
Coarse:	5 to 10 mm

Pores smaller then 0.075 mm are micropores, rarely practical to describe in the field. Those larger than 10 mm are counted and recorded as number per unit area.

Shape - most are either vesicular (spherical or elliptical), tubular, or irregular.
(The pores described are those occurring within the ped; planar voids separating peds are assumed from structure description).

In the CanSIS Manual (Dumanski, ed. 1978) porosity description differs in several respects from that outlined in the 1979 draft of the U.S. Manual.

1. General porosity classes are defined as follows:
   - slightly porous, less than 20% pore volume (implies bulk density of 2.1 g/cm^3)
   - moderately porous, 20-40% pore volume (implies bulk density of 1.6-2.1 g/cm^3)
   - highly porous, more than 40% pore volume (implies bulk density of 1.6 g/cm^3).

2. Numbers of pores required for a named abundance class are markedly different from those in the U.S. system in some cases. For example, common medium pores in CanSIS means 4-14 pores per m^2 with diameters of 2-5 mm. In the U.S. system the same name indicates 1-5 pores per dm^2 or 100 to $500/m^2$.

3. In coding porosity on CanSIS forms, only one kind of pore can be recorded per horizon.

<u>British system, Soil Survey Field Handbook</u> (Hodgson, 1976). Pores are included as a part of the description of structure. The system differs markedly from the others as follows:

1. Procedures are outlined for estimating volumes of pores greater than 0.2 µm and greater than 60 µm in diameter. (These pores sizes are roughly equivalent to air filled porosity at 15 bars and 0.05 bars respectively).

2. It includes the description and size classification of fissures (planar voids), as well as of more-or-less spherical or cylindrical voids.

3. It includes figures to facilitate estimation of percentages of macropores in a given size range. Abundance classes are not defined.

In all of the systems outlined for describing structure (and porosity) ambiguities remain and some of the systems have not been tested adequately.

TENTATIVE EVALUATION OF SYSTEMS FOR DESCRIBING STRUCTURE AND POROSITY.

This evaluation will be focussed on the British (Hodgson, ed. 1976) and United States (Soil Survey Staff, 1979 draft) systems of describing structure. The Canadian system (Dumanski, ed. 1978) is basically similar to the U.S. system. Concepts and definitions of Jongerius (1957), Brewer (1964) and others will be included.

In principle it seems that systems including porosity as an integral part of soil structure are preferable to those that do not. Porosity is the most important aspects of the physical organization of soil with respect to air-water relationships. Pore shapes and sizes are influenced by the size, shape and arrangement of the primary particles and aggregates. The soil may be considered as a system of holes in which water and air may flow or be retained. Thus, it seems appropriate to define and describe voids as a part of structure, perhaps the most important part.

It may appear to be a matter of no practical consequence whether voids are described as a part of soil structure (Jongerius, 1954; Brewer, 1964; Hodgson, ed. 1976) or as a separate aspect of soil morphology (Dumanski, ed., 1978; Soil Survey Staff, 1979, draft) but this is not so. In assessing the pedality of a soil, the pedologist looks for the traces of planar voids that partly or completely separate peds. In evaluating peds to determine differences between surfaces and interiors, he sees inped pores larger than 0.5 mm or so. The voids can be described more efficiently during the process of describing soil structure than as an independent operation.

Perhaps a more important reason is related to the fact that Canadian pedologists generally accept the need to describe structure but give little attention to description of porosity. Considering porosity as a basic attribute of structure might help to improve this neglected aspect of soil description and facilitate interpretations based on structure.

British System (Hodgson, 1976).This system has numerous attractive features:

1. It includes the description of fragments, clods and pores as well as peds in the characterization of structure. Inclusion of fragments and clods is important for two reasons:

- the air water relationships of a soil horizon are influenced by the sizes, shapes and arrangements of solid particles or aggregates and voids formed by the disturbance of soil (such as by cultivation).

- it is not always clear whether aggregates of soil that separate when the soil mass is disturbed for description of morphology are peds, fragments or clods. All peds do not have surfaces that differ clearly in appearance from the interiors. Aggregates in cultivated horizons are designated as fragments if smaller than 10 cm and as clods if larger.

2. It includes a simple field system for estimating pores greater than 0.2 µm (15 bar water) and greater than 60 µm (0.05 bar water, readily drained). This system is based on estimates of packing density and texture; it requires testing.

3. The system provides relatively clear definitions of grade, size and shape of peds (and fragments) and of shapes and sizes of macropores. Figures are provided to aid in estimating sizes of peds and voids, and abundance of tubular or spherical voids.

4. It appears to be feasible to apply the system in the field.

The British system has some weaknesses:

1. Like the Canadian and U.S. systems, it is not adequately explicit on the operations involved in assessing the grade of structure to ensure adequate uniformity of characterization.

2. Limits between platelike and blocklike; and between blocklike and prismlike are not stated specifically. This results in a degree of ambiguity. For example, is a ped 2.5 cm x 2 cm x 1 cm high blocklike or platelike?

3. The dimension of blocklike and prismlike peds to be measured for determining size is not stated. Consider a ped in the form of a 19 mm cube. If the orthogonal axes of the cube are the key dimensions, it is medium blocky; but if the oblique dimension of the cube is the key, it is coarse blocky.

4. Two attributes (degree of organization of the soil mass into distinct peds, and consistence of peds) are combined in the concept of grade. Suppose that the soil

mass is composed almost entirely of distinct, readily separated, medium subangular blocky peds but the peds are crushed very easily. It is not clear whether the grade of structure is weak, moderate or strong.

5. It does not consider the arrangement of blocky and prismatic peds (aligned in x, y and z directions or offset; see Brewer, 1964).

6. The procedure for estimating pores greater than 0.2 µm and greater than 60 µm requires testing.

U.S. System (Soil Survey Staff, 1979 draft).

Though the terms are generally well defined, this system of describing structure and porosity has several weaknesses, including those listed already (points 1, 2, 4 and 5) as weaknesses of the British system. It avoids one weakness of the British system as the dimensions that determine size classes are stated.

Other weaknesses are:

1. Porosity is not treated as an aspect of structure and planar voids are not described.

2. Though clods and fragments are defined, there is no indication that they should be described. It seems relevant to describe the size, shape and arrangement of the solid units and voids in cultivated horizons even if these are ephemeral. A related point is that difference in surface and interior is indicated as a general way of distinguishing peds from fragments. As stated by Hodgson (1976) surfaces of peds in A horizons may appear the same as broken surfaces.

3. It is implied that pores as small as 75 µm can be described in the field. In fact, this is not generally feasible and it is more useful to focus on the abundance, shape and continuity of pores larger than about 0.5 mm and to estimate finer pores by indirect methods.

This tentative evaluation suggest that no fully adequate system of describing soil structure has been developed. The discussion was based upon principles; another approach is to test a system in practice.

UNIFORMITY OF DESCRIPTION OF SOIL STRUCTURE

In 1979, four sites were selected in the Ottawa area for detailed studies of soil structure and soil water regime by participants in the Soil Water-Structure project of LRRI. An initial phase of the work was to describe and sample a pedon at each site. Soil pits were dug at each site; a south-facing profile 1 to 2 m wide was exposed and examined by members of the project group to ensure that horizonation and structure were relatively uniform in each profile. Pedologists from the LRRI-Ottawa and two from Guelph who were surveying Carleton Co. were invited to describe the macrostructure of each pedon according to the system outlined in the CanSIS manual (Dumanski ed, 1978). A total of eight pedologists participated and three of them described all of the pedons. The descriptions were made independently, there was no discussion of structure until after the pedon had been described by all participants present. Most of the descriptions were made on the day the soil pit was dug and the others were made the following day. Descriptions of macrostructure of each pedon by the four to seven participants are summarized in Tables 1 to 4. The soil names with the exception of Carp (Hills *et al.,* 1944) are according to the report of Gloucester and Nepean townships of Carleton Co. (Marshall *et al.*, 1979).

Most of the descriptions of structure of a given pedon were similar, but there were some discrepancies in designations of each of the attributes of structure; grade, class and type. In addition, some pedologists commonly indicated compound structure and others rarely noted compound structure. Some specific discrepancies in descriptions of each pedon are pointed out.

D3

Brandon pedon in 4.1 unit (Marshall *et al.*, 1979), Orthic Humic Gleysol (Table 1).

1. Ap horizon; Three pedologists indicated the type (kind) of structure to be subangular blocky, three indicated granular and one (G) a combination of the two. Three noted compound structure and four indicated simple structure. Designations of grade ranged from weak to strong but most indicated moderate to strong.

2. Bg1 horizon: Most pedologists indicated weak structure but one (F) recorded strong and two (D and G) indicated moderate for the subangular blocky peds. Similar discrepancies in the designation of grade occurred for the Bg2 horizon.

3. BCg and Cg horizons: Discrepancies occurred in the designations of kind of structure: for the BCg, two indicated angular blocky and five subangular blocky; for the Cg the numbers were reversed. Two other kinds of compound peds were indicated: platy (A), columnar (D).

4. In general there were fewer differences in class designations than in those for grade and type. For the Bgl, however, class designation of the finer blocky elements of compound peds, or of simple peds, ranged from medium (A) to very fine to fine (E). Similar differences in class designations occurred for most of the horizons.

R3

Rideau pedon in 4/5.1 unit (Marshall *et al.,* 1979) Gleyed Melanic Brunisol (Table 2).

1. Ap1 horizon: Grade designations ranged from moderate-strong (A) to weak (C). Kind of structure indicated included subangular blocky (usually), granular, angular blocky and cloddy (not a kind of structure but a "condition").

2. Ap2 horizon: Grade designations ranged from moderate-strong (A) to weak (C).

3. Bm1 horizon: Grade designation ranged from weak-moderate (B) to strong (E). These pedologists (B and E) both recorded moderate grade for the Bm2.

4. CBgj and Cgj horizons: Opinion was divided on the kind of blocky structure, angular or subangular. Included as kind of structure were:
platy (A and B), pseudo angular blocky (E) and massive,
(H). Class designation for the Cgj ranged from very coarse (E) to fine-medium (D).

P4-J5

Carsonby pedon in 2.1/2 unit (Marshall *et al.*, 1979), Orthic Humic Gleysol (Table 3).

1. The grade of structure was generally weak. Some discrepancies in aspects of structure designation were:
   - The Ap was designated as moderate very coarse cloddy by one pedologist (C).Thus, cloddy was used as a kind of structure.
   - Some (D and H) noted compound structure in the CBkg horizon which was massive to others (A and B).

Carp pedon in Cc1 unit (Hills et al. 1944) Gleyed Melanic Brunisol (Table 4).

1. For the Ap, grade designations ranged from moderate-strong (A and H) to weak (C). Pedologist C generally rated the grade of the other horizons weaker than grade designations by A, B and H.
2. For the Bmgj2 and CBg horizons, some pedologists (A, B and H) noted compound structure and B indicated simple peds of a range of size classes.
3. For the Cg, two pedologists (A and B) noted platy structure and two (C and H) did not. Class designations for the simple peds ranged from fine and medium (C) to coarse-medium (B).

The foregoing material summarizes only the major discrepancies in abbreviated descriptions of structure. Some additional variability was evident in the more detailed descriptions prepared by some of the pedologists. Differences in designation of grade of structure were the most obvious but type and class designations were variable also. The fact that the structure of these pedons was described more carefully than in normal field operations may suggest a need for further effort devoted to quality control of soil descriptions. It will be pointed out in the next section, however, that at least some of the differences were due, at least in part, to ambiguities in definitions of structure terms and vagueness in recommended procedures for describing structure. The differences were not due to local soil variability. Uniformity of the exposed profiles was checked at the time; subsequently the authors described several (6 to 12) nearby pedons in the experimental areas and found the structure to be remarkably uniform in each area.

ANALYSIS OF REASONS FOR DISCREPANCIES IN STRUCTURE DESIGNATION

This material is based upon observation of procedures used by pedologists in assessing structure, discussion with colleagues and study of the references cited. The discussion includes consideration of both ambiguities in definitions and differences in operations used to describe structure. The CanSIS Manual (Dumanski, ed. 1978) is the reference used for definitions. It is recognized, however, that most of these definitions were adopted from other sources and that ambiguities, gaps in information, etc. would apply to other systems of describing structure.

Grade - The relevant definitions from the Manual are listed: Grade of structure is the degree of distinctness of aggregation; it expresses the differential between cohesion within the aggregates and adhesion between aggregates, and is determined mainly by noting the durability of the aggregates and the proportions of aggregated and disaggregated material when the aggregates are displaced or gently crushed.

Weak - Weakly formed peds that are barely observable in place.

Moderate - Moderately well formed peds that are moderately evident in place. Soil material of this grade, when disturbed, breaks down into a mixture of many distinct entire peds, some broken peds, and little disaggregated material.

Strong - Strongly formed peds that are quite evident in undisplaced soil. They adhere to one another and withstand displacement and separation when the soil is disturbed. When displaced, soil material of this grade consists very largely of entire peds and includes few broken peds and little disaggregated material.

According to the definition, the determination of grade involves noting two features: 1. durability of aggregates, and 2. proportions of aggregated and disaggregated material.

Durable aggregates presumably retain their form when the soil is disturbed and resist deformation; ways of assessing durability are not indicated. Presumably durability implies ped consistence, which may be different from consistence of the soil mass if peds are smaller than 3 cm.

For the other aspect of grade, "proportions of aggregated and disaggregated material when the aggregates are displaced or gently crushed" more specific guidelines would be useful. Pedologist A might assess this aspect of grade by removing a shovelful of soil from the side of the pit, allowing the shovel plus contents to drop 15 cm (30 cm? 50 cm?) to hit the soil surface, and estimating the proportion of aggregated material. Pedologist B might assess the proportion of aggregates visible *in situ*.

The definitions of the three grades of structure (weak, moderate, strong) allow much scope for interpretation.

Weak indicates "weakly formed" (the same as low durability?) peds barely observable in place. Thus, the detection of weak structure may involve only looking at a section (usually vertical) of the soil in place. The assessment of moderate grade, however, involves observations in situ and observation of disturbed soil. Suppose that for a given soil, peds are barely visible in place but that 50% of the disturbed material consists of entire peds. Is the grade weak or moderate? In the present definition of 'strong' there are one or more misprints. The second sentence probably should read: They adhere weakly to one another, maintain their shape and separate easily when the soil is disturbed".

It is not obvious how a pedologist decides whether peds in place are "moderately evident" (moderate grade) or "quite evident" (strong grade). The definition of strong goes on to state that disturbed material consists very largely of entire peds and includes few broken peds and little disaggregated material. Suppose that a given horizon has medium blocky peds that are at least moderately evident in place (depending on how well the face of the pit is cleaned) and that, when disturbed, consists of 70% entire peds, 25% broken peds and 5% disaggregated material. What is the grade of structure?

It is obvious that a large measure of subjectivity is involved in assigning the grade of structure. It is also obvious that developing definitions that can be applied more objectively and outlining clear-cut operations for assessing grade of structure are difficult tasks.

Some reasons for the differences in designation of grades of structure as discussed in the previous section are:

1. Some pedologists based their judgment almost entirely on observations of the soil *in-situ*. Others examined disturbed material without much attention to the appearance of the peds in place. Several did both. The focus on disturbed materials resulted in designation of stronger structure for some horizons.
2. Some pedologists focused on the durability of peds; others on the proportion of the material that occurred as peds. This made a major difference for some horizons that were more or less pedal but that had friable peds.
3. Procedures differ for disturbing the soil to observe the proportion of peds. Some picked at the bank with a knife and looked at the material that fell into their hand; others tossed clods upwards and caught them as they fell; others banged a shovelful of soil on the ground.
4. Soil variability might account for a minor proportion of the differences.

Both concepts of the most important attributes of structural grades and operations used to assess grades probably contributed to the discrepancies indicated in Tables 1 to 4.

<u>Class (Size).</u> Ambiguities in relation to the definitions and procedures for evaluation of class are fewer than those for grade. Some discrepancies in class designations are evident, however, in Tables 1 to 4. In some cases, these are associated with very weak grades of structure; the main problem is to decide whether the soil is pedal or apedal. Disturbance of

a sample of such a horizon usually results in breakdown to some fragments or indistinct peds of reasonably regular size and shape and to many fragments of assorted shapes and sizes. The method of disturbing the sample commonly affects the apparent degree of pedality.

Other, more easily corrected, reasons for discrepancies in class designation are:

1. Though the dimensions to be measured are specified in the Manual (Dumanski ed. 1978) some pedologists are not aware of this. For example, suppose that blocky peds are 4 cm cubes, one oblique dimension is $(4^2 + 4^2)^{0.5}$ = 5.65 cm (very coarse) the longest oblique dimension is $(4^2 + 4^2 + 4^2)^{0.5}$ = 6.93 cm, but the orthogonal dimension (4 cm) is that of coarse blocky. Some pedologists do not estimate the oblique dimension of blocky peds. In the case of irregularly shaped polyhedral peds, the correct oblique dimension is not obvious.
2. The Manual includes intergrade terms for class (see 10 M 12) but the sizes of very fine blocky, very fine to fine blocky, etc. are not indicated. In our descriptions (Table 1 to 4) some used the intergrade class terms and others did not.
3. Concepts of compound structure differ. Some pedologists focus on the ped class of strongest grade especially if this is the smaller class. The area of profile examined may affect the judgment of compound structure. In some cases (fragipan) it is useful to look at a horizontal section through the horizon to note very large peds.

<u>Type</u> (shape). The following paragraph quoted from the CanSIS Manual (Dumanski, ed. 1978) defines types and kinds (subtypes) of structure.

> "Table 3 indicates four main types of structure: structureless, in which there is no observable aggregation or definite orderly arrangement around natural lines of weakness; blocklike, in which the soil particles are arranged around a point and bounded by flat or rounded surfaces; platelike, in which the soil particles are arranged around a horizontal plane and generally bounded by relatively flat horizontal surfaces; and prism-like, in which the soil particles are arranged around a vertical axis and bounded by relatively flat vertical surfaces. Most such types are subdivided into kinds or subtypes. Thus, under structureless, the single grain kind consists of an incoherent mass of individual particles whereas amorphous (massive) consists of a coherent mass showing no evidence of any distinct arrangement along natural lines of weakness. The blocklike type includes three kinds: angular blocky, whose faces are rectangular and flattened, bounded by planes intersecting at relatively sharp angles; subangular blocky, whose faces are subrectangular, or consist of mixed rounded forms; and granular, which are spheroidal, characterized by rounded vertices. Each

type of structure includes peds that vary in shape, and detailed soil descriptions require supplemental statements about the shape of the individual peds".

The manual includes kind modifiers as follows: Pseudo - A kind of soil structure inherited from the parent material; for example, pseudoplaty, pseudoblocky. Stratified - A stratum is a layer with certain unifying characteristics, properties, or attributes that distinguish it from adjacent layers.

<u>Bedded</u> - A bed is a unit layer in a stratified sequence that is visually or physically more or less distinctly separate from other layers above and below and is 1 cm or more thick. Laminated - A lamina is a unit layer similar to a bed but less than 1 cm thick.

Several reasons for discrepancies in designation of structure type and kind are evident.

1. No indication is given of limits between some of the types. For example, suppose that relatively uniform peds have dimensions as follows:
   a) 3 cm X 3 cm X 1 cm thick. Platy or blocky?
   b) 3 cm X 3 cm X 5 cm high. Blocky or prismatic?

   Some of the discrepancies indicated in Tables 1-4 may have been due to different concepts of the limits of these types.

2. Probably few pedologists are aware that the definitions of granular and blocky differ from those in the old U.S. Manual (Soil Survey Staff, 1951). The U.S. manual definition of granular includes unaccommodated fine blocky-shaped peds as well as more or less spherical peds; the CanSIS Manual includes only spheroidal peds as granular. Similar "blocky" in the U.S. Manual implies accommodated peds as well as peds of a certain shape; the CanSIS definition implies only shape. The above is a probable explanation of some of the differences among pedologists in designating granular and fine blocky structure. Some probably restricted "granular" to spherical peds; others designated in addition as granular, angular and subangular blocky peds that were unaccommodated.

3. The limits between subangular and angular blocky are not specified and interpretations differ. "Angular" indicates "rectangular, flattened ped faces intersecting at relatively sharp angles".

   Subangular faces are subrectangular, or consist of mixed rounded forms. Many blocky peds, however, have neither rectangular nor subrectangular faces. They may be 3, 6 etc. sided. In addition, the degree of rounding of angles necessary for subangular is not clear. No provision is made for designating irregular blocks with re-entrant angles.

4. Some pedologists use "cloddy" as a structure type but it is not defined.

5. Some of the structure "kind modifiers" are not really used to modify kinds of structure. Stratified, bedded and laminated are not used to modify platy or other kinds of structure. Pseudo is used to modify types; pseudo blocky etc. Guidelines for the use of pseudo are necessary. Suppose that horizons designated B and C both have moderate, medium subangular blocky structure. Should the modifier pseudo be used with the structure designation of the C horizon? If it is a C horizon, presumably the structure is inherited. But, if the structure of the B is the same probably it was inherited too.

Though porosity was not included in this comparison of structure description, some serious weaknesses in the current system (Dumanski, ed. 1978) of describing porosity are evident.

1. The general porosity classes defined are not very useful as "highly porous", for example, begins above 40% pores by volume. In fact, 40% is a reasonable upper limit for low porosity. Surface horizons commonly have 60% pores by volume.

2. The porosity abundance classes are not appropriate. For example, 15 pores with diameters of 3 mm in 1 m^2 of surface should not be designated as "many". Probably 1 dm^2 is the appropriate unit area, not 1 m^2.

3. The requirement to record only one kind of pore (abundance, size, shape) per horizon results in very incomplete porosity information for some horizons.

PRELIMINARY WORK ON QUANTIFICATION OF ASPECTS OF MACROSTRUCTURE

In this and subsequent sections, the term structure implies Brewer's (1964) definition, "The physical constitution of the soil material as expressed by the size, shape, and arrangement of the solid particles and voids, including both the primary particles to form compound particles and the compound particles themselves;"

Macrostructure includes those aspects of structure that can be seen in the field. It is restricted to particles larger than approximately 1 mm, to tubular or spherical voids larger than approximately 0.5 mm and to planar voids that are visible to the unaided eye (probably 0.2 mm). Description of macrostructure includes arrangement of primary particles larger than 1 mm if the arrangement is other than random. For example, in a horizon of gravelly sandy loam texture in which the gravel consists mainly of thin shale fragments oriented horizontally, the shape, size and arrangement of these fragments would be indicated in the description of structure.

Quantification of Macropores

Biopores (tubular pores). The first step in quantification was to try counting biopores larger than 2 mm following several European pedologists (Jongerius, 1957; Slager, 1966; Ehlers, 1975). Horizontal sections measuring 5 to 25 dm^2 were exposed successively in the various horizons, loose material was removed, and the holes were counted as the surface was cut with a sharp, rigid knife.

Independent counts by two or three pedologists were recorded and the mean number of biopores per m^2 was calculated (Table 5).The results show some major differences in counts by different pedologists especially for Ap horizons. The dark colored soil material and the relative looseness of the peds in some Ap horizons made it difficult to expose the holes clearly. Variability was marked in numbers of biopores in different sections of the same horizon. The experience gained in counting biopores led to the following conclusions:

- subsequent careful counting of sections for which numbers of biopores recorded by two pedologist differed widely showed that usually the higher count was the better estimate. Considerable care must be taken to avoid missing biopores.
- as with most measurement techniques, reliability of results improved with experience.
- as with most measurements of soil physical properties, several replicates would be necessary to estimate an average number of biopores in a horizon.
- during the process of digging to prepare horizontal surfaces, it was possible to note the direction and continuity of biopores. The latter aspect was facilitated by adding dyed (methylene blue) water and tracing dyed pore walls.
- it became obvious that biopores should be segregated into size classes during counting, as most systems suggest. Possible classes might be: 0.5 to 2 mm, 2-5 mm and 5-10 mm (as in the British and U.S. systems). Suitable areas for counting these size classes might be: 0.5-2 mm, 1 dm^2; 2-5 mm, 10 dm^2; 5-10 mm, 10 dm^2 or preferably larger.
- preliminary comparisons of area estimates of biopores by using figures in the British

Handbook (Hodgson, ed. 1976) and by actual counts of biopores of various size classes (and calculating area) were promising. Useful estimates of biopores can probably be made by using figures with appropriate dot patterns.

The biopores larger than 2mm in diameter were nearly all earthworm channels. Earthworms found in the Ap horizons at the four sites were dominantly *Apporrectodea turgida* with a few *Eisenia rosen*. The only species found in B and C horizons was *Lumbricus terrestris*. These large worms (*L. terrestris*) were responsible for the continuous, nearly vertical channels through the B and into the C horizons.

Estimating Pores Larger Than 0.2 µm and Larger Than 60 µm

Following guidelines in the British Handbook (Hodgson, ed. 1976) we tried estimating porosity from packing density and texture. Water characteristic data were available for horizons of the four soils from the soil water-structure project sites. Though estimated and measured values differ markedly for some samples (Table 6), the results are encouraging enough to promote further testing. Such estimates based on simple field observations and measurements are not intended as substitutes for estimates based on hard data for particle size, organic matter, etc. (DeJong and Lobel, 1982). For most pedons, hard data are not available and reasonable field estimates could be useful.

Quantifying Planar Voids

Widths of cracks at the surface and at 20 cm were measured in a Rideau pedon in July 1980. An area 60 cm x 140 cm was examined in detail, the crack pattern was sketched and widths of cracks were measured. At the surface, widths ranged from 1 mm to 10 mm.

Widths of planar voids separating or partly separating peds were not estimated because they are usually much less than 1 mm in width and useful estimates could not be made. The widths of such voids and the diameters of small tubular and spherical voids can be measured more effectively in thin sections.

Attempts at Quantifying Pedality

Aspects of Grade - The two aspects of grade (degree to which the soil mass is separated into distinct peds, and durability of peds) were separated.

The degree of separation into peds was assessed by examination of the profile and by gently sieving a mass of soil as follows:

- a mass of soil from the horizon, about 1 L, was parted gently, major roots were removed and it was placed on a nest of sieves,
- the sieves were dropped 20 times approximately 4 cm onto the soil surface and shaken gently horizontally for 20 seconds,
- the volumes of soil on each sieve and that passing through the sieves were measured the fractions were checked to assess uniformity of size and shape of soil units.

Results for several horizons (Table 7) snowed that reasonably consistent results could be obtained for moist samples and that estimates of pedality from profile observations were closely related to results obtained by sieving. Sieving was not useful for wet samples as the material formed balls. The material that passed through the finer sieves was mainly apedal as follows: Carp Ap - smaller than 2.4 mm; Rideau Apt and BCgj - smaller than 4.8 mm; Brandon Ap - smaller than 1.2 mm.

Sieving was also useful in assessing the sizes and shapes of peds as it separated the peds from broken peds and apedal material.

INTERPRETATIONS BASED ON SOIL MACROSTRUCTURE

Estimating Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (Ksat) is controlled to a major extent by the size, abundance and continuity of macropores. Thus, it should be possible to make reasonable estimates of Ksat from observations of macrostructure. Preliminary tests were made of this hypothesis using the air entry permeameter, AEP (Topp and Binns, 1976) to measure Ksat. Results were promising though some poor estimates were made (Table 8). Slightly more than half of the estimates placed Ksat in the correct SWIG class (Nowland, 1981) and most of the others were off by only one class. Most of the soils, however, were familiar; more problems might be encountered with a wide range of soils.

Estimating Available Water Capacity

The method of the British Soil Survey (Hodgson, ed. 1976) was used to estimate pores larger than 60 µm and larger than 0.2 µm, and hence available water in the 0.2 to

60 µm pores (15 to 0.05 bar). Guidelines followed were developed for soils in Britain; different guidelines may be necessary for some soils in Canada. Estimated available water values are similar to measured values for some samples and markedly different from others (Table 6). Improved procedures for estimating porosity (Hall *et al.* 1977) should result in more reliable estimates of available water.

POSSIBLE IMPROVEMENTS RELATIVE TO MACROSTRUCTURE

Improvements are suggested in the concept of soil macrostructure, in the definition of related terms, and in the specifications of operations involved in describing macrostructure. The suggested changes will require trial and modification before they become an accepted part of the system of describing soil morphology. The proposals that follow are intended as an initial step along the path toward improved definition, description and interpretation of soil macrostructure.

Concepts

As stated previously, we favor a concept that includes porosity as an important aspect of structure. It seems desirable also to include as structural entities compound particles whether they are peds with surfaces clearly different from the ped interior, peds with surfaces that appear the same as a broken surface, fragments or clods. One reason for this is that the size, shape and arrangement of fragments and clods in a disturbed horizon (e.g. Ap) influence the air-water relationships of that horizon. Another is that commonly it is not evident whether compound particles in some soils are peds or fragments. It may be impossible to assess whether similar compound particles will recur throughout several seasons.

Definitions

Macrostructure (Based on Brewer, 1964). Soil macrostructure is the physical constitution of the soil material visible to the naked eye; it encompasses the size, shape and arrangement of solid particles and voids, including both primary particles larger than about 2 mm and compound particles including peds, fragments and clods.

The reason for including primary particles in the definition is that the size, shape and arrangement of these particles in gravelly soils have a major influence on porosity.

Ped. Peds are natural, uncemented aggregates, separated or partly separated from each other by natural voids, or bounded by cutans. They are thought to persist through cycles of wetting and drying. Peds may separate along natural voids into one or more sets of smaller peds. These peds are referred to in order of the largest to the smallest as primary, secondary and tertiary peds. Such compound pedality is described as follows: compound strong, coarse prismatic (primary peds) parting to moderate, medium blocky (secondary peds) parting to weak fine blocky (tertiary peds).

Note: The phrase, "persist through cycles of wetting and drying" is used commonly in definitions of peds. Checking the persistence of peds, however, is difficult. Persistence is inferred from evidence such as the following: cutans on ped surfaces, and peds of a similar range of sizes and shapes through several seasons. The surfaces of peds in some Ah horizons, however, appear the same as a freshly broken surface from the interior of the ped.

Fragments and Clods (Based on Hodgson, *et. al.*, 1976). These are aggregates formed by disturbance of the soil, by cultivation or other means. Clods are larger than 10 cm and fragments are smaller than 10 cm. The aggregates in Ap horizons tilled within one year are assumed to be fragments or clods, not peds. They are described in the same way as peds, e.g. weak, fine and medium granular fragments.

Note: Brewer (1964) defined a fragment as an aggregate, "caused by rupture of the soil mass across natural surfaces of weakness", and a clod as an aggregate, "caused by disturbance, ... , that molds the soil to a transient mass that slakes with repeated wetting and drying".

The U.S. Soil Survey Staff (1979 draft) defined clods in much the same way as Brewer, and stated that soil fragments, form when the soil cracks or is broken and that they are bounded by ephemeral planes that do not reappear in the same place on drying. The basic difference in these concepts of fragments and clods is that clods are due to disturbance, and fragments are due to natural but ephemeral planes of weakness.

Our point of view is that the definitions are ambiguous and that the simpler British approach (Hodgson ed. 1976) is clearer and equally useful. Following Brewer's (1964) definitions, it is very difficult to differentiate some peds from fragments. Presumably the distinction is based largely on whether there are cutans on the surfaces of the aggregates. Similarly the definition of a clod (Brewer, 1964) would include some peds; unconfined peds commonly slake on repeated wetting and drying.

The U.S. definition of fragments implies a technique for recognizing ephemeral planes; we do not know how this is done. The concept of fragment seems useful but a definition that can be applied consistently is necessary.

Operations Involved in Describing Macrostructure

Choice of Site. Though this is perhaps the most important single operation in soil characterization, it is difficult to suggest useful guidelines on site selection. In part, the reason for this is that site selection depends on the purpose of the work and on the existing knowledge of soil-landscape relationships in the area. One general rule is that the site should be chosen with a clear purpose in mind. Another is that the site should be away from roads, abandoned farmsteads, and other features that may have caused aberrant soil properties. A few examples may be useful in indicating other factors to be considered.

1. Suppose that a detailed survey of an area is in progress; general soil-landscape patterns are known and a tentative legend has been developed. Two tentative new series (E and W) that occur on broad upper terraces of valleys in the eastern (E) and western (W) parts of the area are similar but the western series appears to be slightly coarser in texture and less strongly structured. Sampling is required to decide whether series E and W should be differentiated. The first step might be to run random transects (Wang, 1982) through areas of E and W and make brief descriptions at ten or more regularly-spaced points in each. From the information thus obtained plus the information from preliminary survey operations it should be possible to select for more detailed study typical pedons of E and W. The judgment on the need for two series (E and W) could be based on information thus obtained.

2. Suppose that the purpose is to determine the effects on soil physical properties of different cropping practices, specifically continuous corn versus hay (grass-legume). Site selection would involve mainly finding fields of continuous corn (at least 5 years, perhaps) and of hay on the same soil. The specific sites compared would be chosen so as to be in comparable positions relative to microrelief.

Site Description - This involves description of features of an area in which the pedon to be described occurs (see Dumanski, ed. 1978 for details).The area described depends on the feature. For example, description of the tall trees in a mixed forest at the site would require observation of an area of several decameters but description of ground vegetation such as lichens can be restricted to approximately the area of the pedon surface.

For structure-related features also, the area or volume described depends on the feature. Burrows of rodents may be considered as very large macropores and they may have an appreciable influence on infiltration of water. An area of approximately 50 X 50 m (¼ hectare) should be checked to determine the frequency and size of such features. For surface cracks, a surface of approximately 2 x 2 m including the pedon should be examined; if the pedon is larger than this, examine its entire surface. Note the pattern of cracks and the range of widths; this can be done conveniently on graph paper.

Soil Macrostructure Description - the procedure outlined is intended for detailed soil characterization; less detailed descriptions are adequate for daily soil survey operations. Only macrostructure description is outlined although many of the steps are the same for complete description of macromorphology.

1. Select a time for description, if possible, such that the soil is moist but not saturated (humid areas) and dry to moist in semiarid areas.

2. Dig a soil pit approximately 1.3 x 0.7 m so that one side faces the sun. If there are cyclic horizons, the pit should expose at least ½ of the cycle. Dig the pit to a depth of approximately 1 to 1.3 m and continue to the depth of the control section in one half of the pit. Observe structure, consistence, depth of cracks etc. while digging. Complete the description the day the pit is opened if possible; if not, dig back 20 cm or so to expose a fresh profile.

3. Examine the walls of the pit and note degree of homogeneity of the exposed profiles. If the morphology appears to be relatively uniform, select for description a typical profile approximately 30 cm wide on the side facing the sun. If horizons appear to be cyclic or irregular, sketch the profile to scale using graph paper indicating horizon thickness, irregularities in morphology, etc. Sample so as to include the different subhorizons that occur and mark on the sketch where the samples were taken. If the morphology indicates atypical disturbance, select another site for description. Record general observations on uniformity of morphology.

4. Pick the profile to be described so as to reveal pedality, if any; note changes with depth, and mark horizon boundaries. String held in place by nails inserted at horizon boundaries can be used for this purpose.

5. Note the depths and widths of any cracks extending from at or near the surface, preferably on a sketch of the profile.

6. Expose a horizontal area of approximately 30 cm X 30 cm at the surface of the pedon. If vegetation is too thick to permit seeing biopores, cut a few mm below the surface with a sharp knife. Estimate biopores using figures in the British Handbook pp. 42-46 (Hodgson, ed. 1976). Check estimates periodically by counting biopores 0.5-2 mm, 2-5 mm, 5-10 mm and 10 mm and calculating area of biopores. For biopores 0.5-2 mm, examine a 10 x 10 cm area; for the larger biopores, study the entire exposed area. Repeat this procedure at or near the surface of each horizon or every 30 cm if horizons are absent or very thick. Check continuity of biopores and planar voids while digging to the next horizon. This can be facilitated by inserting a metal frame (10 X 10 cm or so) approximately 1 cm into the upper surface of the horizon, adding approximately 1 cm of methylene blue dyed water (0.1%) and tracing the dyed pore walls.

   Sketch crack patterns or other major features of horizontal sections.

7. Note approximate water status of horizons (dry, moist, wet, saturated).Planar void widths depends on shrinkage that may have occurred on drying.

8. Note planar void pattern, if any, on horizontal and vertical faces of horizons. Note completeness of separation of peds by planar voids and widths of planar voids if possible. Note sizes and shapes of peds bounded by planar voids, and whether peds are: aligned vertically and horizontally or offset. Break peds and note abundance, size and shape of inped pores, if possible.

9. Complete the description of pedality as follows:
   - note whether the soil is apedal or pedal; if apedal, note whether massive (coherent) or single grained.
   - note whether peds are compound or simple; if compound, note the general sizes and shapes of primary, secondary, tertiary peds.
   - after examining peds *in-situ* in the exposed picked profile, disturb a sample of the horizon (unconfined at the surface of the horizon) by inserting a shovel or trowel horizontally near the base of the horizon and pushing down on the handle. Note the degree to which the material separates into peds, and their sizes and shapes.
   - remove a shovelful of soil from the horizon and drop the shovel blade with soil approximately 20 cm onto a hard surface, remove major roots that bind the peds together, and note: the degree to which the material separates into peds (distinctness), the sizes and shapes of primary, secondary (and tertiary) peds,

and the consistence of the peds. (Note that consistence of peds is not the same as consistence of soil; a friable soil could consist of firm, fine blocky peds that separate readily).

Thus pedality is described under the following headings:

<u>distinctness</u> - the degree to which the soil mass separates readily into peds:

<u>strong</u> - peds clearly visible in-situ and at least ¾ of the mass separates readily into unbroken peds;

<u>weak</u> - peds barely observable in-situ and less than ¼ of the material separates readily into unbroken peds;

<u>moderate</u> - peds are visible in-situ and more than ¼ but less than ¾ of the material separates readily to unbroken peds. (The proportion of peds can be checked by gently sieving through a nest of sieves of appropriate sizes.)

<u>Shape</u> - modified from new U.S. Manual draft; Soil Survey Staff, 1979 draft; only modifications are noted.

<u>Platy</u> - mean of x and y dimensions more than 3 times the z dimension.

<u>Lenticular platy</u> - plates thickest in the middle

<u>Primatic</u> - the z dimension exceeds the mean of the x and y dimensions by more than 2 times.

<u>Colummar</u> - tops of prisms are rounded

<u>Blocky</u> - peds are more-or-less equi-dimensional and accommodated. The z dimension is between $^{1}/_{3}$ and 2 times the mean of the horizontal dimensions.

<u>angular blocky</u> - faces intersect at sharp angles.

<u>subangular blocky</u> - angles are mostly rounded.

<u>granular</u> - more-or-less spherical, or blocky with unaccommodated ped faces.

<u>Size</u> - see new U.S. Manual draft (Soil Survey Staff, 1979 draft). Size limits are tabulated; they refer to the smallest dimensions of plates, prisms and columns, and the largest of nearly equal dimensions of blocks and granules.

Size classes	Ped Shape			
	Platy	Prismatic and Columnar	Blocky	Granular
	Smallest dimension		largest dimension	
	- - - - - - - - - - - - - mm - - - - - - - - - - - - -			
Very fine	1	10	5	1
Fine	1-2	10-20	5-10	1-2
Medium	2-5	20-50	10-20	2-5
Coarse	5-10	50-100	20-50	5-10
Very Coarse	>10	>100	>50	>10

Ped Consistence - This is based on the new U.S. Manual draft. The test is made on peds of the size that is most distinct. The sizes of the peds tested are noted.

Field test	Force	Ped Consistence	
		Air-dry	0.1 bar
Ped crushes or breaks under very slight pressure	8N	soft	very friable
Ped crushes or breaks under slight force applied by thumb and forefinger	8-20N	Slightly hard	friable
Ped crushes or breaks under moderate force applied by thumb and forefinger	20-40N	Slightly hard	firm
Ped crushes or breaks under strong force applied by thumb and forefinger	40-80N	hard	very firm
Ped cannot be broken by thumb and forefinger but can be by squeezing between hands	80-160N	very hard	extremely firm
Ped cannot be broken in hands but can be crushed under foot by person weighing 80 kg applying weight slowly.	160-800N	extremely hard	extremely hard

10. Describe fragments or clods of Ap horizons in the same way as peds of other horizon. For example, weak, fine and medium angular blocky fragments of firm consistence.

11. Estimate packing density and texture and assign air porosity class (pores >60 µm) and storage pore space (>0.2 µm) as in British Handbook pp. 39-46 and 91-93 (Hodgson, ed. 1976). This provides an estimate of the porosity that can not be seen directly.

CONCLUSIONS

Based on a review of the literature and field testing, we concluded that soil porosity should be treated as an important aspect of soil structure. The size, shape, arrangement and continuity of voids determine the air-water relationships in a soil. Macroporosity which can be considered to include planar voids wider than approximately 0.2 mm and channels, vesicles etc. more than 0.5 mm in diameter can be estimated semi-quantitatively in the field.

Smaller voids can be estimated (Hall *et al.*, 1977), from packing density and texture of the soil according to a procedure used by the British Soil Survey (Hodgson, ed. 1976). Reasonable estimates of saturated hydraulic conductivity and available water (0.05 to 15 bars) can possibly be made from these approximate values for soil porosity (Hall *et al.*, 1977). Better estimates of available water can probably be made if hard data are available (DeJong and Lobel, 1982).

Improvements proposed in the definitions of some terms related to pedality and guidelines on procedures to use in describing soil structure should contribute toward improved uniformity of structure description. For example, the "grade"aspect of pedality that includes both the degree to which the soil mass separates into peds and the strength of the peds was divided into the two attributes, ped distinctness and ped strength. The proposed system of describing and interpreting soil structure requires extensive field testing and probably a series of revisions.

Addendum

Further testing in 1981 of the feasibility of estimating saturated hydraulic conductivity from macromorphological observations showed that useful estimates can be made. Results of further testing of the feasibility of estimating air porosity and available water from texture and packing density were less promising.

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REFERENCES

Brewer, R.1964. Fabric and mineral analysis of soils. Wiley. 470 pp.

Coote, D.R., Dumanski, J., Ramsey, J.F. 1981. An assessment of the degradation of agricultural lands in Canada. L.R.R.I. Publ. 118, Agr. Can. Ottawa.

DeJong, R. and Lobel, K. 1982. Empirical relations between soil components and water retention at $^1/_3$ and 15 atmosphere. Can. J. Soil Sci. 62.(in press).

Dumanski, J. ed. 1978. Manual for describing soils in the field. LRRI, Ottawa.

Ehlers, W.1975.Observation on earthworm channels and infiltration on tilled and untilled loess soil. Soil Sci.119, 242-249.

Hall, D.G.M., Reeve, M.J., Thomasson, A.J. and Wright, V.F. 1977. Water retention, porosity and density of field soils. Soil Survey Technical Monograph No. 9. Harpenden, England.

Hills, G.A., Richards, N.,R. and Morwick, F.F. 1944. Soil survey of Carleton Co. Rept. No. 7, Ont. Soil Survey.

Hodgson, J.M. ed. 1976. Soil survey field handbook. Tech. Monograph No. 5.Soil Survey of England and Wales. Harpenden.

Hodgson, J.M. 1978. Soil sampling and soil description. Clarendon Press. Oxford.

Johnson, W.M., McClelland, J.E., McCaleb, S.B., Ulrich, R., Harper, W.G. and Hutchings, T.B. 1960. Classification and description of soil pores. Soil Sci. 89, 319-321.

Jongerius, A. 1957. Morphological investigations of soil structure (English summary of article in Dutch). Mededelingen van de Stichting voor Bodenkartering.

Marshall, I.B., Dumanski, J., Huffman, E.C. and Lajoie, P.G. 1979.Soils, capability and land use in the Ottawa urban fringe. Ont. Soil Surv. Rep. 47. Agr. Can. Ottawa.

Nikiforoff, C.C. 1941. Morphological classification of soil structure. Soil Sci. 52, 193-212.

Nowland, J.L. 1980. Soil water regime classification. pp.36-56 in Minutes 2nd Meet. Expert Comm. Soil Survey, Ottawa. J.H. Day, ed.

Nowland, J.L. 1981. Soil water regime classification pp. 64-74 in Minutes 3rd Meet. Expert Comm. Soil Survey, Ottawa, J.H. Day, ed.

Robinson, G.W. 1950.Soils-Their origin, constitution and classification. Thomas Murby, London.

Slager, S.1966. Morphological studies of some cultivated soils. Pudoc Centre for Agricultural Publications and Documentation, Wageningen.

Soil Survey Staff, 1951.Soil Survey Manual. U.S.D.A. Handbook No. 18.

Soil Survey Staff, 1979 draft. Revised U.S. Soil Survey Manual draft. U.S.D.A. Washington, D.C.

Topp, G.C. and Binns, M.R. 1976. Field measurement of hydraulic conductivity with a modified air-entry permeameter. Can. J. Soil Sci. 56, 139-147.

Topp, G.C., Zebchuk, W.D. and Dumanski, J. 1980. The variation of in situ measured soil water properties within soil map units. Can. J. Soil Sci.60, 497-510.

Wang, C. 1982. Application of transect method to soil survey problems. Land Resource Research Institute Publ.82-02. Agr. Can. Ottawa.

Table 1. Descriptions of macrostructure of a Brandon pedon by seven pedologists[1].

Pedologist /Horizon	A	B	C	D	E	F	G
Ap 0-17 cm	mod-str fine sbk	mod-str fine and med gran	weak fine-med sbk to weak fine sbk	weak co sbk to mod fine-med sbk	weak-mod v fine-fine gran	str fine gran to weak v fine gran	mod-str fine sbk and gran
Byl 17-24 cm	weak med sbk, weak fine pl *in situ*	weak fine sbk	weak fine-med sbk	weak med sbk to mod fine sbk	weak v fine-fine abk	str med sbk to str fine-med gran	weak fine prism to mod fine-med sbk
Bg2 24-53 cm	weak fine and med sbk	weak-mod fine and med sbk	weak-mod med-co sbk to weak fine-med sbk	weak mod sbk to mod fine sbk	v weak v fine fine abk	mod-str co sbk to mod fine-med sbk	weak co sbk to mod-weak fine sbk
BCg 53-75 cm	mod med sbk	mod fine - med sbk	mod med-co sbk	weak med-co sbk to mod fine-med sbk	weak fine-v fine abk	mod co sbk to mod fine-med sbk	weak co sbk to mod-str med abk
Cg 75-100 cm	str med abk co pl *in situ*	mod-str med abk	mod med-co sbk	str med-co col to mod-str med sbk	mod-str med-co abk to mod fine-med abk	str med-co abk to mod-str fine-med abk	mod med abk to mod-str fine abk

[1] Some terms are abbreviated for convenience, e.g. mod for moderate; abk and sbk indicate angular and subangular blocky respectively. "To" in the description indicates compound structure, the larger units parting to form the smaller ones. The pedon was described on May 31 and June 1, 1979 when the water table was at 52 cm.

Table 2. Descriptions of macrostructure of a Rideau pedon by six pedologists[1].

Pedologist /Horizon	A	B	C	D	E	H
Apl 0-12 cm	mod-weak med sbk to mod-str fine sbk and med gran	weak-mod fine and med sbk	weak v fine-fine sbk	weak-mod co sbk to mod med sbk	weak-mod fine abk and weak med gran	mod v co cloddy to mod med co gran
Ap2 12-27 cm	mod-str med and fine sbk	weak co sbk to weak-mod fine sbk	weak v fine-fine sbk	weak med sbk to mod fine-med sbk	weak v co pris to mod med and fine abk	weak-mod med-co sbk to mod fine-med sbk
Bml 27-33 CM	weak-mod med sbk to mod fine sbk	weak med sbk to weak mod fine sbk	weak-mod fine and med sbk to mod fine sbk	mod-str med sbk to mod med and fine sbk	str fine abk	mod fine-med sbk to mod fine-med sbk and gran
Bm2 33-55 cm	mod med and fine sbk to mod fine sbk and fine gran	mod med and fine sbk	weak fine sbk to mod fine sbk	v weak med sbk to mod fine sbk	mod fine and med abk	mod fine-med sbk
CBgj 55-75 cm	str med abk	mod-str med sbk and abk	med fine-med sbk to str fine-med sbk	mod-str med-co sbk to mod-str fine-med sbk	str med and co ps abk	mod-str med - co sbk to mod-str med sbk
Cgj 75-100 cm	weak v co pl to str med and co abk	mod co sbk and pl to mod- str fine and med abk	str med-co sbk	str med-co sbk to mod- str fine-med sbk	str co and v co ps abk	massive to str med-co abk

[1] Abbreviations are as indicated for Table 1. The pedon was described on June 13 or 14, 1979 when the water table was at 80 cm

Table 3. Description of macrostructure of a Carsonby pedon by five pedologists[1].

Pedologist /Horizon	A	B	C	D	H
Ap 0-17 cm	mod-weak fine sbk and med gran to mod-weak fine and med gran	weak - mod fine sbk and fine and med gran	mod v co cloddy to weak-mod med-co gran	v weak co sbk to weak fine sbk	weak-mod med sbk to weak-mod fine-med sbk
Bgl 17-30 cm	massive to v weak med and fine sbk	massive weak fine pl	v weak fine-med pl to weak fine pl	massive-v weak fine pl	weak fine pl
Bg2 30-60 cm	massive	massive v weak pl	weak fine-v fine sbk	v weak med pl to v weak fine sbk	weak v co sbk to weak co sbk
CBkg 60-84 cm	massive	massive-v weak pl	weak fine sbk	v weak med sbk to v weak fine sbk	weak v co sbk to weak-med co sbk
IICkgl 84-105 cm	massive to weak med and co sbk	weak co pl to weak med sbk	mod fine-med sbk	v weak med sbk to weak fine sbk	weak-mod co sbk to weak-mod med-co sbk
IICkg2 105-120 cm	weak med and co pl to weak med and co sbk	v weak co pl to co and med abk-sbk	mod med-co sbk	v weak med sbk to weak fine sbk	mod med sbk

[1] Abbreviations are as indicated in Table 1. The pedon was described on June 18, 1979 when the water table was at 110 cm.

Table 4. Description of macrostructure of a Carp pedon by four pedologists[1].

Pedologist /Horizon	A	B	C	H
Ap 0-28 em	mod-str fine sbk	mod fine-med sbk and med gran	weak fine sbk to weak v fine sbk	mod-str med-co sbk to mod-str med-fine sbk
Bmgjl 28-43 cm	mod fine-med sbk	mod fine-med sbk	weak fine-med sbk	mod med sbk
Bmgj2 43-70 cm	mod med sbk to mod fine and med sbk	mod med-fine sbk	weak-mod fine-med sbk	mod-str med-co sbk to mod-str fine-med sbk
CBg 70-95 cm	weak-mod med-co sbk to mod fine and med sbk	mod co-med and fine sbk	weak-mod med sbk to weak-mod fine and med sbk	mod-str co sbk to mod-str med sbk
Cg 95-115 cm	weak co pl to weak-mod med sbk	weak co pl to weak-mod co-med sbk	weak-mod med sbk to weak-mod fine and med sbk	mod-str co sbk to mod-str med sbk

[1] Abbreviations are as indicated for Table 1. The pedon was described on June 26, 1979 when the water table was at 107 cm.

Table 5. Counts of biopores larger than 2 mm in horizontal sections of four soils.

Horizon	Area counted cm	Counts [1] 1	2	3	Biopores/m^2 mean
Brandon pedon					
Ap	50X50	58	32		180
Bg1	50X50	55	122		360
Bg1	30X30	38	46	50	500
Bg2	50X50	42	46		180
Bg2	50X50	90	88		360
Bg2	25 diam	31	32		640
BCg	50X50	25	42		130
Rideau pedon					
Ap	50X50	18	59		200
Ap	50X50	46	85		260
Ap	38X37	35	61		340
Ap	36X37	50	48		360
Ap	30X30	34	17		280
Bm1	50X50	22	49		160
Bm1	50X50	40	45		170
Bm1	30X36	53	40		360
Bm1	30X30	25	19		240
Bm2	50X50	24	38		120
Bm2	50X50	40	54		190
Bm2	50X50	28	27		110
Bm2	35X35	38	35		290
BCgj	50X50	16	14		60
BCgj	50X50	12	20		60
Cgj	50X50	10	9		40
Cgj	50X50	12	12		50
Carsonby Pedon					
Ap	50X50	22	51		160
Ap	50X50	52	54		210
Bg1	50X50	18	12		60
Bg1	50X50	43	46		180
Bg2	50X50	4	5		20
Bg2	50X50	21	22		80
BCkg	50X50	4	12		32
BCkg	50X50	14	14		56
Ckg	50X50	19	30		100
Carp Pedon					
Ap	50X50	14	32		120
Ap	50X50	116	36		320
Ap	33X31	16	19		180
Bmgj1	50X50	120	99		440
Bmgj1	50X50	88	110		400
Bmgj1	50X50	139	140		560
Bmgj1	36X38	27	24	35	200
Bmgj2	50X50	128	170		600
Bmgj2	50X50	142	119		520
Bmgj2	34X38	48	77	66	500
Bmgj2	33X37	74	78	62	600
BCg	50050	87	85		340
BCg	50X50	67	108		340
Cg1	50X50	34	42		160
Cg1	50X50	42	42		170
Cg1	35X33	37	40		330

[1] Counts by different observers

Table 6. Comparison of estimated 0.2 µm (15 bar) and 60 µm (0.05 bar) porosity with measured values for horizons of four soils.

Horizon	Packing Density	Texture	>60 µm porosity by volume		>0.2 µm porosity by volume		Available[1] water capacity	
			Est.	Meas.	Est.	Meas.	Est.	Meas.
			%		%		%	
Rideau								
Ap	Med.	SiC	10-15	14	23-36	36	18	22
Bmgj	Med.	SiC	10-15	11	23-36	31	18	20
BCgj	Med.	C	5-10	9	23-36	28	23	19
Cg	High	C	<5	8	< 23	23	17	15
Carp								
Ap	Low	l	10-15	9	>36	41	28	32
Bmgj	Low	SiCl	15-20	11	>36	33	23	22
Cg	Med.	SiCl	10-15	7	23-36	36	18	29
Brandon								
Ap	Low	SiC	10-15	16	>36	50	28	34
Bg	Med.	C	5-10	10	23-36	29	23	22
Cg	High	C	<5	11	<23	34	18	29
Carsonby								
Ap	Low	l*	15-20	14	>36	46	23	32
Bg	Med.	Sl*	10-15	7	23-36	35	18	28
Cg	Med.	Sl*	10-15	7	23-36	35	18	28

* rated as sandy silt loam (Hodgson, 1975)

[1] Available water capability was calculated by subtracting the volume of pores >60 µm from the volume of pores >0.2 µm. The following assumptions were made in order to calculate available water from estimated porosity: 5-10% = 7%; 10-15% = 12%; 15-20% = 17%; 23-36% = 30%; <5% = 3%; <23% = 20%; >36% = 40%.

Table 7. Percentage by volume of size fractions of material separated by gentle sieving of soil.

	Size, mm						
	>25	13-25	9.5-13	4.8-9.5	2.4-4.8	1.2-2.4	<1.2
				Carp Ap (0-18 cm)			
Run 1	0	1	1	45	40	15	2
2	0	0	1	35	40	20	10
3	0	1	2	35	35	15	15
4	0	1	2	30	35	15	17
Mean (approx)	0	0	2	36	38	16	10
				(Estimate from profile, $^2/_3$ pedal, peds 3-7 mm).			
				Rideau Ap2 (12-22 cm)			
	0	7	20	50	15	8	0
				(Estimate, nearly all pedal, peds 0.5 to 2 cm)			
				Rideau BCgj (56-80 cm)			
	35	15	20	10	7	7	6
				(Estimate, mostly pedal, blocky peds, range of sizes 0.5-4 cm)			
				Brandon Ap (0-20 cm)			
Run 1	0	1	1	8	40	34	18
2	0	0	0	16	39	26	18
3	0	0	0	13	39	28	20
Mean (approx)	0	0	0	12	39	29	19
				(Estimate, more than $^3/_4$ pedal, peds 2 to 7 mm)			

Table 8. Estimated and measured values of saturated hydraulic conductivity at four sites; SWIG classes are indicated in parentheses.

Depth	Estimate 1	Estimate 2 m/day	Estimate 3	Measured
		Carp Site		
0-15cm	20 (H^1)	12 (H_2)		7.3 (H^2)
0-15cm		12 (H_2)		14.8 (H_1)
11-26	27 (H_1)	20 (H_1)		5.7 (H_2)
11-26cm	7 (H_2)	10 (H_2)		6.4 (H_2)
24-39 cm		12 (H_2)		8.7 (H_2)
24-39 cm		12 (H_2)		11.1 (H_2)
24-39cm		12 (H_2)		28.4 (H_1)
64-79cm		1 (M_2)		5.7 (H_2)
64-79cm		1 (M_2)		16.4 (H_1)
92-107cm	6 (M_2)	1 (M_2)		7.3 (H_2)
92-107cm	12 (H_2)	12 (H_2)		4.5 (H_2)
135-150cm	1 (M_2)	0.5 (M_2)		2.8 (M_1)
135-150cm	3.3 (M_1)	3.5 (M_1)		4.4 (H_2)
		Rideau Site		
0-15	15 (H_1)	8 (H_2)		28 (H_1)
0-15	15 (H_1)	10 (H_2)		32 (H_1)
17-32	15 (H_1)	10 (H_2)		8.8 (H_2)
17-32	5 (H_2)	10 (H_2)		10 (H_2)
23-38		10 (H_2)		9 (H_2)
44-59	8 (H_2)	13 (H_1)		27 (H_1)
		Dalhousie Site		
0-15	5 (H_2)	10 (H_2)		20 (H_1)
0-15	20 (H_1)	20 (H_1)		14.5 (H_1)
20-35	12 (H_2)	7 (H_2)		7.2 (H_2)
20-35	12 (H_2)	8 (H_2)		10 (H_2)
47-62	5 (H_1)	12 (H_2)		9 (H_2)
50-65		8 (H_2)		7 (H_2)
53-68	12 (H_2)	8 (H_2)		5.7 (H_2)
		Field West of Parking Lot CEF		
0-15	1 (M_2)	2 (M_1)	0.5 (M_2)	0.9 (M_2)
0-15	1 (M_2)	2 (M_1)	0.5 (M_2)	1.9 (M_1)
13-28	0.2 (M_3)	0.2 (M_3)	0.1 (L_1)	0.02 (L_2)
25-40	0.05 (L_1)	1 (M_2)	0.3 (M_3)	0.28 (M_3)