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LOGIC OF THE NEW SYSTEM OF SOIL CLASSIFICATION

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Smith (7, 8) has dealt with the major objectives and basic assumptions that have determined the architecture of the system and with the reasons for their choice. It is the purpose here to examine only a few of the special attributes of the system in terms of principles that have determined them. The author has drawn heavily on Bridgeman's analysis, *Logic of Modern Physics* (1), because ideas developed in it have strongly influenced the character of the system.

THE ROLE OF HUMAN UNDERSTANDING

The Soil Survey Staff (10, p. 6) has emphasized that a classification system is not a truth that can be discovered but a contrivance of man to organize ideas in ways that seem useful. It rests on a current understanding of the experience of the past (4). Part of this understanding is derived from the data of observation and experiment, which we consider fact, even though it is fact only within the perspective of the operations by which the data were obtained (1). Another part of this understanding has to do with the purely empirical relationships among those facts, which include both those quantitative relationships we call laws and the qualitative correlations that have held in every case within our experience; both are the beginnings of "explanations," which Bridgeman (1) has concluded are the climax of our attempts to understand nature. Still another part of our understanding evidences itself in the hypotheses that explain to our satisfaction, for the moment at least, the empirical relationships in which explanations start.

Bridgeman concluded that explanation is primarily recognition of familiar correlations among phenomena in nature. He also concluded that "it is possible to analyze nature into correlations without . . . any assumption whatever as to the character of those correlations," and he argues that to go beyond empirical correlation into the realm of hypotheses of reasons for them is to "prejudice the future" (1, p. 37).

A classification system can prejudice the future (4). If its criteria are hypotheses without some device for constant and inescapable scrutiny in relation to fact, the hypotheses become accepted as fact. Such acceptance can mold research into patterns of the past and can limit understanding of even new experience to concepts based on knowledge of the past. Most soil classification systems have had these effects to some degree. The point is illustrated by the impact of the hypotheses of V. R. Williams on classification, thought, investigations, and applications of soil science in the Soviet Union, as reported by Vilenskii (11). Throughout the history of science, however, continuing experience has revealed new "facts" whose incorporation into our consciousness has demanded complete reorganization of understanding and of the classifications based on it (1, 4). To the extent feasible, the architects of this system have attempted to follow the thesis of Bridgeman that the scientist cannot afford to recognize "*a priori* principles which determine or limit the possibilities of new experience" (1, p. 3). This has been the most important single principle among those that have governed the character of the system.

PURPOSES, BASES, AND CRITERIA

Both Smith (8) and Kellogg (5) have emphasized that the new classification system is being developed primarily to serve the soil survey of the United States. Both have also emphasized that the soil survey is designed as a practical tool to be used mainly for applied objectives. There can be no doubt that the purposes that *motivated* the designers of the system are practical ones. The classes formed, however, are not interpretive groups designed for direct application to applied objectives. The "practical" role of the classes is to convey identity to otherwise unidentified real things in groups that can be inter-

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preted. Interpretation of them requires at least one additional step of reasoning.

Genetic bases of classes

The Soil Survey Staff (10) has described the system as a "natural" classification in the sense the term was used by Mill (6) and has distinguished it sharply from "technical" systems (3) designed as direct practical interpretations. Smith (8) has specified that the classes have been formed deliberately to group soils of similar genesis, and in this sense, the basis on which the categories and classes have been formed is primarily genetic. There are compelling reasons for this choice, including those that rest on relationships of classes to geographic bodies and those that involve the interests the system is intended to serve.

It is obvious that classes of the system must have at least approximate counterparts in mappable bodies of soil if the practical purposes described by Kellogg (5) and Smith (8) are to be served. Such bodies of soil are, however, real physical things within which one must accept pedons[2] and their geographic relationships, one to another, as he finds them. There is no *a priori* reason that groups of pedons organized on the basis of properties, or sets of properties, to conform to our concepts of order for either theoretical or applied objectives would correspond to more than single pedons separated by significant distances and distributed at random over the land surface of the earth. Classes formed in this way might be very useful to show relationships among sets of properties at points, but there would be no assurance that they could be used to identify bodies of soil significant for applied objectives.

We know empirically, however, that soil properties do not vary at random among associated pedons. Some degree of geographic order exists; this knowledge is so commonplace that we have come to accept it unconsciously. Granting that it exists, however, we have no assurance that class ranges and limits chosen on conceptual bases independent of local geographic reality would approximate the ranges and limits of real bodies of soil that can be recognized and differentiated consistently in the field. Indeed, we know, from bitter experience with millions of acres mapped on the basis of presumably practical class limits of selected properties, that many do not. It is necessary to incorporate the geographic relationships among pedons into the definitions of classes deliberately if the classes are to have counterparts in mappable soil bodies consistently.

The obvious solution is to define classes in terms determined by direct investigation to be characteristics of mappable soil bodies. The Soil Survey Staff (10, p. 4) has defined the "soil individual"[3] to serve this purpose. The "soil individual" is a geographic unit that has restricted limits of variation among its constituent pedons and that is mappable at some scale, with only limited inclusions of pedons outside its range. It is the "soil individual," not the pedon, that is the basic real thing that is classified. This has not been understood by some workers (9). Soil properties and their variation within and among "soil individuals" are the criteria of classes. Pedons are the sampling units by means of which these characteristics are estimated in practice.

The principle involved, however, implies that "soil individuals" are bodies whose boundaries can be recognized in the field. This is not possible by methods dependent wholly on sampling to determine internal soil properties, except in special cases. It is not physically possible for a man who must map several hundred acres per day to sample one pedon per acre, yet that intensity of sampling represents only 0.02 per cent of the area. Contrary to popular opinion, a soil mapper samples internal properties primarily to verify and refine predictions of kinds and boundaries of mappable soil bodies. The predictions are based on correlations between sets of internal soil properties and distinctive landscapes whose

[2] The pedon (10, p. 2) has been defined primarily to give some measure of consistency to the three-dimensional bodies of soil that are drawn as sampling units (2). Characterization of mappable bodies of soil and the concepts of classes that identify them depends upon sampling. The units sampled must be three-dimensional. The need to define such a sampling unit has apparently not been recognized by the Soil Survey Committee of the Australian Society of Soil Science (9), which has found little virtue in the concept.

[3] The term suggests an individual of a population (2) in the statistical sense, which is analogous to a sampling unit and more nearly comparable to the pedon. One knows "soil individuals" by the pedons he draws as sampling units. The technical term will be changed, probably to "polypedon." For this reason the term is used in quotes throughout this paper.

boundaries are not completely arbitrary. Those intimately associated with the soil survey know empirically that such correlations exist and that they are repeated within modest limits of variability among geographically separated areas. In most surveys, these empirical facts make soil mapping possible.

These geographic correlations are "explanations" in the empirical sense discussed by Bridgeman (1). When they are extended to include both local and regional factors of the environment, it is found that the sets of soil properties are correlated with elements of five factors. This is the basic evidence on which the theories of soil genesis are based. Without going beyond the correlations into hypotheses of processes responsible for them, sets of soil properties consistently associated with sets of the elements of these factors are said to be genetic;[4] the existence of recognizable "soil individuals" is attributed to genetic control, and the classes composed of "genetically" similar "soil individuals" are called genetic classes.

The preceding discussion applies most directly to classes of the lowest category, which are the ones used most commonly as the nucleus of identity of map units. The fact that classes of higher categories must include whole soil series implies that whole genetic units are their components, but it does not ensure that the groups of series included are homogeneous genetically at the level of abstraction of the category. Genetic homogeneity must be incorporated deliberately.

Although classes of the four highest categories are used to identify map units of small-scale maps (5), this is only one, and not necessarily the most important, of their uses. The category of soil series gives identity to groups of "soil individuals." Each higher category can be considered to perform the same function at a higher level of generalization. Collectively, however, a system of categories organizes the population through relationships among categories in a fashion designed to satisfy our mental standards of reasonable relationships for some purpose. This may be a practical purpose and the resulting system a multicategoric technical grouping (3), like the capability classification. This was one of the alternatives open to the designers of the system. In any system, however, the higher categories serve well only those whose interests are directly related to the specific purposes for which criteria of the system have been selected (3). The classes of the lowest category can be used for a variety of objectives, because they are most homogeneous in terms of entire sets of soil properties. Those of each successively higher category are restricted in their applications progressively more closely to the purposes that dictated criteria, because homogeneity becomes progressively more closely restricted to those purposes with increasing generalization. It is folly to think of one and only one multicategoric system as *the* classification to serve all ends; many are needed. The designers of this system had to choose the primary interests to be served and the basis of classification that would serve them best.

The higher categories of the system can serve people in many fields, but they are intended primarily to serve those who work with soils, and most particularly those who work with soil surveys. These men are charged with interpreting and correlating the phenomena of soils as natural bodies. To them, as Bridgeman (1) has concluded for science generally, "The climax of our task of interpreting and correlating nature is reached when we are able to find an explanation of phenomena." Explanations that accommodate past experience are the fabric of our understanding. Through them we weave discrete bits of fact into our conception of what "soil individuals" are and how they came to be. From the whole we derive concepts of order in and among "soil individuals." It is important, therefore, that the explanations of soil genesis be organized for those who define and map the classes of the lowest categories as groups of "soil individuals."

To the extent feasible, the designers of the system have tried to adhere to Bridgeman's (1) thesis that the scientist should work with empirical correlations without *dependence* upon hypotheses of reasons for them. This is to say that the soil scientist should use soil genesis in the form of the empirical geographic correlations discussed above but he should not make them dependent upon hypotheses of soil-forming processes and

[4] Properties that are inherited from parent material must be included in the sets of properties. They are genetic in the sense that a factor of soil genesis has left them as its mark. In very young deposits, they represent the zero degree of effects of the other four factors.

which *should* be as bases for classifying.

The empirical nature of correlations used for recognition of "soil individuals" as the potential elements of classes has been discussed. It is not generally appreciated that to a very high degree geographic correlations, not predetermined criteria, were the initial bases on which classes of this system were formed. It was decided, for example, that "There is a basic difference between soils in humid regions . . . and soils in arid regions . . ." (8). Behind that conclusion lies a vast experience with correlations between environment and sets of properties. The decision to differentiate these soils was made first. Then, and only then, were criteria that would separate them developed.

In spite of this, however, hypotheses have played an important role. The decision that "a basic difference" exists inevitably involved hypotheses of reasons for the correlations associated with that difference. Hypotheses inevitably influenced, and in many cases determined, the kinds of correlations for which the designers of the system looked. For these reasons the ordering of "soil individuals" within and among categories is almost certainly not that which would express understanding of soil at some time in the future. This has been accepted deliberately as inevitable. Nevertheless, the classes will still represent real things, and the empirical correlations that have been factors in their formation will still stand when new knowledge dictates the need for reorganization.

Criteria of classes

One must distinguish sharply between the criteria by means of which classes are differentiated when the system is applied to real soils and the bases on which the classes were formed when the system was being developed. Failure to do so results in meaningless arguments about whether the system is based on genesis or on soil properties. Genetic considerations governed the formation of classes, their character, and their organization in the system. From the perspective of one who applies the system to real things, however, the criteria that determine placement of a given "soil individual" in a specific class are soil properties.

Smith (8) has described an example of development of criteria of a class which illustrates the theory led first to a conclusion that certain soils of humid and arid regions should be differentiated on genetic grounds. This experience, and the theory that had evolved from it, also lead to the conclusion that the critical limit between the two lies in the distinction between ability or inability of leaching to remove soluble material from the soil. Having decided on that limit, theory and empirical correlations based on data from samples of real "soil individuals" were used to select measurable properties that would make the distinction empirically at the point desired. These criteria were tested on real soils in critical areas, found to be deficient, modified, tested again, and modified further to attain a *predetermined* segregation.

This has been the general procedure throughout the four highest categories. It would have been impossible to have applied the procedure to develop the present detail of the system without the accumulated factual information of 60 years of soil survey, especially that associated with the soil series. That kind of experience is limited or nonexistent for many areas. Consequently, the system is incomplete to varying degrees in its different parts. It is, however, "open-ended" and subject to addition and refinement as experience becomes available. Every class, however, is known to have a counterpart in reality, and the criteria by which it is differentiated are known to be properties of real things and to be definable in terms of operations.

In these criteria lie the insurance against "prejudice of the future." Part or all of the theory that directed their choice may prove to be false, but the criteria are facts. The criteria, not the theory, are applied in practice. If the "soil individuals" identified by these criteria do not fit existing theory, either the theory or the criteria are faulty, and both must be reexamined. Thus, the criteria become a built-in mechanism that forces re-examination of understanding. They have the power to destroy the system in whole or in part, and to compel constant re-evaluation of even dearly cherished concepts.

THE CHARACTER OF CLASSES

Depending upon the perspective in which one views them, classes may be visualized (*a*) as groups of soil individuals or of classes of lower categories, or (*b*) as subdivisions of classes of classes themselves assume attributes of unity, and attention is focused on the similarities within each class. In the second perspective, similarity within classes is subordinated to boundary distinctions and differences among classes. The soil series of the system are currently treated largely in the first perspective; the classes of the four highest categories, largely in the second.

To many people, the category of soil series and phases of them *are* the classification. Most of the practical purposes discussed by Kellogg (5) are served by soil series, primarily in the sense that they provide identity, and names that stand for identity, at the level of greatest homogeneity in the taxonomic system. To most people who work with soil surveys, a soil series is a very real concept. It is visualized as an aggregate of similar real soil bodies that are represented as areas on maps and that can be seen and characterized in the field as complete sets of soil properties of a single kind. This is partly due to soil series descriptions, which currently are primarily in terms of a single set of properties, intended to approximate a central concept of the class, with vague suggestions of class limits. This focuses attention on the properties of the series as an individual kind of thing. The vividness of series concepts is partly a consequence of correlation of the concept of the class with real things that can be seen and studied. Bridgeman (1) has emphasized that correlation with the familiar is the nucleus of understanding.

The vagueness of class limits, however, permits a substantial degree of personal judgement in their location and in the level of generalization at which the series may be defined.[5] This con- mappers and to shifting of class limits, with time, among survey areas and among parts of survey areas mapped by different men.

In its presentation of the seventh approximation of the system, the Soil Survey Staff (10) has treated the classes of the four highest categories primarily as subdivisions of classes at higher levels of generalization. In this perspective, the evident attributes of a given class are the accumulated differentiating criteria of all classes of which it is a member. To one who merely reads the book, a given subgroup is seen, for example, as one that (*a*) is usually moist; (*b*) *lacks* a spodic, argillic, natric, calcic, gypsic, salic, or oxic horizon; (*c*) *has* a thin A_1 or A_p horizon and an underlying cambic horizon; (*d*) *lacks* properties defined as criteria of wetness but *has* a fragipan; and (*e*) *lacks* detectable allophane and distinct or prominent mottles in the upper 30 cm. The example is necessarily reduced here to the barest essentials (much more specific information is given).

Given only this kind of definition, which must be assembled from different places in the text, many could enumerate a combination of selected properties that the soil must have and another that it cannot have, but few could visualize a soil that would belong in the class. Many could segregate elements of similarity, elements of dissimilarity, and elements that are not bases of comparison between this and another similarly defined class; few could comprehend the significance of the differences. Many could use the criteria to identify a given body of soil consistently.

The device is an ingenious mechanism to prevent the prejudice of future experience by existing theory inherited from the past and to permit uniformity of application. Many people can deal freely and consistently with the criteria that are enumerated; mainly those who have been intimately concerned with the development

[5] Definition of the limits of individual soil series and the level of generalization of the category remain major jobs facing the soil survey. They cannot be treated adequately in the space available here. Although the boundaries of single "soil individuals" are commonly identifiable as landscape boundaries within zones of limited width, an array of these mappable bodies according to differentiating series criteria commonly reveals overlapping ranges and indistinct or no clear discontinuities. Thus, *class* limits are commonly subject to personal judgement of genetic or practical significance. There are, furthermore, compelling reasons to define the soil series at some level substantially above that consistent with homogeneity for applied objectives. The soil phase is used outside the taxonomic system to provide homogeneity of single soil properties within the range of the series for those objectives. The need for flexibility of limits of some properties in surveys made for different purposes is met by this device. The level below which the flexibility of phase criteria and above which rigid sets of properties as criteria of series should be used remains to be determined in detail.

of criteria can discern the "explanations" (1) and the hypotheses that are the carefully concealed fabric of order in the system. To explain that fabric in detail would require many volumes, including a comprehensive treatise on current theories and hypotheses of soil formation that have been used.

The difficulty of visualizing real bodies of soil represented by classes at high levels of generalization is not unique to this system. How, for example, does one visualize a "zonal soil"? High levels of generalization demand abstractions which are difficult, if not impossible, for the mind to conceive as real things. One must ask whether a mental impression of an abstract class as a real thing or group of things is either possible or desirable. Yet to those who built the system, one suspects that the classes are visualized as aggregates of real things, for they placed real things that they knew in some fashion into the classes. If Bridgeman's (1, p. 37) analysis is correct, understanding to a very high degree involves reduction of unfamiliar situations to elements that are familiar. It is highly significant that when the criteria are taken to the field and real "soil individuals" are identified with classes at various levels in the system, much of the unreality disappears. The concepts are usually biased by an inadequate sample, but they acquire reality. The descriptions and data given as "epitomes of a class" (7) are also helpful, as are the necessarily abbreviated explanations, in the text of the seventh approximation of the system (10). Nevertheless, mainly those who make the effort necessary to establish correlations with familiar things should expect to develop substantial understanding of the higher categories. This is not unique to this system. The task can be made very much easier, however, when soil series have been incorporated into the system, particularly if some effort is made to proceed from the familiar things of lower categories to the abstract concepts of higher categories, in conformity with Bridgeman's analysis of understanding (1).

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SOIL CORRELATION AND THE NEW CLASSIFICATION SYSTEM

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Whenever a system of soil classification is replaced or modified appreciably, the correlation of soils is affected for a long time to come. Some of the effects follow promptly, others appear much later. Because of the importance of the soil classification system in use to soil correlation, an effort is made in this paper to illustrate the impacts of past systems and to outline probable consequences of the new system being developed. Since not all the effects of a new system can be foreseen, the outline cannot be complete, but it is believed that an effort to appraise the probable effects of the new system (11) may be helpful. The nature and functions of soil correlation must be kept in mind, however, for an understanding of the probable impacts of the new system. Soil correlation is, therefore, reviewed before the effects of classification systems are considered. It should also be pointed out that this discussion is centered primarily on soil classification and correlation as they have been carried forward in the United States.

GENERAL NATURE AND PURPOSE OF SOIL CORRELATION

In a narrow sense, soil correlation is concerned with the *definition, mapping, naming,* and classifying of the kinds of soils in specific survey areas. In a wider sense, soil correlation is concerned as well with the improvement of standards and techniques for describing soils and with the application and development of soil classification. (5).

Relating the soil bodies represented on maps to taxonomic classes at some level in a classification system is accomplished through soil correlation. The process of correlation, as used in soil surveys, thus requires scrutiny and testing of the concepts of individual soil series and of the series category as a whole. The use of soil series in the correlation process is a major application of classes in that category, and such use is also an important application of a system of soil classification.

The data obtained and recorded in the study of soils, both in the field and in the laboratory, form the evidence upon which correlations rest. The validity of these data depends upon the available standards and techniques for description and characterization of soils. These standards and techniques, described earlier (10, 12), thus form part of the foundation for soil correlation.

Any system of soil classification affects the kinds of observations made in the study of soils, whether these studies are outdoors or in the laboratory. The system in current use also governs in large measure the selection and weighting of characteristics as criteria for defining and differentiating soil series. Consequently, classification systems also form part of the foundation for the correlation process. Moreover, classification systems themselves are modified as a result of their application and testing in completing the correlation of soils in specific survey areas. In the past, several systems of soil classification have been used in this country (1, 4, 9), and some of the effects of these systems will be considered in a subsequent part of this paper.

The ultimate purposes of correlation are to ensure that kinds of soils are adequately defined, accurately mapped, and uniformly named in all soil surveys. These are large objectives. If they are to be achieved they demand concerted effort on the part of every soil scientist concerned with every soil survey. The work required for satisfactory correlation of soils in a survey area begins with the onset of preliminary studies for construction of the initial legend and continues until a final legend is approved for the published soil survey report. The quality of soil correlation in each survey area thus depends upon the caliber of work done at every stage of the survey, beginning with the construction of the initial mapping

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needed taxa, and alter the nomenclature. Nevertheless, there are still difficulties of definitions that stem both from lack of methods for the measurement of some soil properties, and from lack of specific knowledge about the properties of many soils. Many imperfections will remain in the system when we begin to use it, but we can go no further than our knowledge permits.

We have developed the system for our own use, but if we have done our work well it should be useful for other purposes. Yet we cannot expect everyone to agree on any classification at this time. We believe that common genesis is the primary basis for deciding what soils belong together, but our knowledge of soil genesis is still fragmentary and at times our evidences conflict. If beliefs differ about genesis, so will the beliefs differ about what belongs together in the classification.

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– Soil Profile Description –

– Descriptive features, their possible descriptive aspects and the levels of generalisation

(• = eventually possible combination ; X = possible combination

Soil profile descriptive features

Mode of description		Composition	Origin	Shape	Orientation	Situation	Hardness	Weathering degree	Degree of development	Minimum size (or "size", if only one axis)	Maximum size	Abundance	number/dm² of horizontal plane	Mesh diameter (cm)	Boundary sharpness	Colour contrast	Colour dry	moist	texture modifier	Relationship of II to I
	Descriptive classes (several levels possible)	X	X	X	X	X	X	X	X							X				X
	Numerical classes (several levels possible)						•				X	X	X	X	X		X	X	X	
	Numerical, continuous						•			X	X	X	X	X	X		X	X		

Aspects of feature description.

Kinds of features

less detailed	detailed level	Composition	Origin	Shape	Orientation	Situation	Hardness	Weathering degree	Degree of development	Minimum size (or "size", if only one axis)	Maximum size	Abundance	number/dm² of horizontal plane	Mesh diameter (cm)	Boundary sharpness	Colour contrast	Colour dry	moist	texture modifier	Relationship of II to I
X	Horizon symbol.																			
	" " I.SSS																			
X	Depth									X	X									
X	Colour I : dry																X			
X	moist																	X		
	" II dry																X			
	moist.																	X		
X	Mottles - patches I	X	X	X	X	X				X	X	X		•	X	X	X	X		
	II	X	X	X	X	X				X	X	X		•	X	X	X	X		X
X	Texture class											X								
	clay	•										X								
	silt											X								
	sand.	•										X								
	Fine class									X		•								
	~~very fine~~											•								
	~~fine~~											•								
	~~medium~~											•								
	~~coarse~~											•								
X	Structure I			X	•				X	X	X	•		•						
	II			X	•				X	X	X	•		•						X
X	Consistency - dry								X											
	moist								X											
	wet - stickiness								X											
	plasticity								X											
	Cementation	X	X				X		X											
X	Cutans - films. I	X	X	X	X	X				X	•					•	X	X		
	II	X	X	X	X	X				X	•					•	X	X		X
	Slickensides				X	X			X	X	X						•	•		
	Pressure surfaces			X	X	X			X	X	X						•	•		
	Skeletans	X	X	X	X	X				X	•					•	X	X		
	Cracks			X	X	X				X	X			X						
	Pan	X	X	X		•	X			•	•						•	•		
	Stones I	X	X	X	X	X	X	X		X	X	X					•	•	X	
	II	X	X	X	X	X	X	X		X	X	X					•	•	X	X
	Concretions	X	X	X	X	X	X			X	X	X					•	•		
	Nodules	X	X	X	X	X	X			X	X	X					•	•		
	Pedodes	X	X	X	X	X	X			X	X	X					•	•		
	Septarias	X	X	X	X	X	X			X	X	X					•	•		
	Crystals	X	X	X	X	X				X	X	X								
	Casts		X	X	X	X	•			X	X	X					•	•		
	Nests		X	X	X	X	•			X	X	X					•	•		
	Human artefacts	X	X	X	X	X				X	X	X								
	Organic material.	X	X	X	X	X			X	X	X	X					•	•	X	
X	Pores and galeries. I		X	X	X	X				X	X	X	X							
	II		X	X	X	X				X	X	X	X						X	
X	Roots I			X	X	X				X	X	X	X							
	II			X	X	X				X	X	X	X						X	
	pH - field																			
	HCl reaction.		X	X	X	X			X	X	X	X								
X	Horizon boundary			X											X					

"others" or "observations"

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