Concepts of Soil Mapping and Interpretation

Berman D. Hudson, USDA-SCS, Lincoln, NE

SOIL SURVEY HORIZONS - FALL 1990 - pgs. 63 to 72

Soil scientists classify and delineate bodies of soil on the landscape by directly examining < 1% of the soil below the surface. Those who have never mapped soils or who have had limited experience in the field do not understand how this can be done. Furthermore, we who specialize in mapping and interpreting soils do a poor job of explaining how and why the process works. When critics question the validity of the soil mapping process because of the small sample directly observed, we do not have a meaningful rebuttal. Our practical experience has convinced us that soil maps are reliable and provide valid interpretations. However, we have failed to describe a comprehensive conceptual model to explain how soils are mapped and interpreted.

This failure has created a crisis of confidence within the soil survey itself. Many in the soil survey are beginning to have doubts about our product. The numerous discussions and papers concerning the spatial variability of soils and the search for elaborate statistical procedures to characterize map unit variability are symptoms of a serious problem. Some in the National Cooperative Soil Survey (NCSS) have lost confidence in the reliability of our maps.

This paper discusses the historical reasons for this crisis of confidence. Specifically, the concepts or models we have developed to guide soil mapping and interpretation will be outlined. The following questions will be addressed: How did these concepts originate? Are they logical? Have these concepts contributed to our current problems? I will try to clarify some of the assumptions that have guided both soil mapping and soil interpretation. The mapping of soils and the interpretation of soils will be discussed separately.

Soil Mapping

"Even though soils form a continuum on the landscape, the objective of a soil survey is to break this continuum into a reasonable number of segments or units." This quote from Miller et al. (1980) expresses the generally accepted concept that soils form a continuum on the landscape. In order to break this soil continuum up into meaningful delineations, the mapper must have a basic concept of soil geography. That is, the soil scientist must have some model to explain how different kinds of soils are distributed on the landscape.

Two major concepts have been used to make sense out of soil variability on the landscape. One is the soil factor equation, outlined by Dokuchaev (Glinka, 1927) and Hilgard (1906). This well known model identifies the five factors of soil formation. This model implies that, by watching for changes in one or more of these factors as the landscape is crossed, one can predict where changes in the soil continuum are likely to occur. Since its introduction near the end of the 19^{th} century, this concept has served as a general model affirming that soils theoretically can be mapped.

Another concept applied to soil mapping could be called the plant ecology model or, more appropriately, the plant ecology analogy. This idea involves drawing parallels between soils and plants. Plant ecologists consider individual plants and natural bodies or groupings of plants on the landscape. Similarly, soil scientists have tried to conceptualize soil individuals and natural groupings or bodies of soils on the landscape. This influence is reflected in the terms borrowed from plant ecology to identify soil map units. Plant ecologists used the term *consociation* to identify a climax plant community dominated by one species. They used the term *association* to designate a climax plant community dominated by two or more species. Soil scientists borrowed these terms and applied them to bodies of soil with approximately the same meanings, except they are referring to the dominance of a soil map unit by soil taxa. A major reason for trying to draw this parallel was to lend credence to the idea that soils are organized, natural bodies on the landscape.

The problem with these two concepts is that they are very general and largely descriptive. It has been pointed out that less than 99 percent of the soil delineated by the field mapper is not observed below the ground surface. These models do not explain how it is possible to map something as variable as soil with so little ground truth. They do not explain how the soil within delineations can be identified consistently from only a few observations. Furthermore, they do not explain how accurate and precise boundaries can be drawn between soil delineations.

A better model clearly is needed. Fortunately, it already exists. However, it is present only in the minds of intelligent, perceptive soil mappers. The soil-landscape model is used daily by good field soil scientists. However, few of them can describe a generalized soil-landscape model to anyone else. This is because they arrived at it only tacitly and intuitively. They have internalized the concepts gradually by walking and observing soils, and landscapes day after day for many years. As far as I know, no one has tried to organize and write down the concepts used by the most astute field scientists in map- ping soils. With much trepidation, I will try to do this.

The Soil-Landscape Model

Understanding the soil-landscape model requires one to break faith with a long held tenet of soil science. That is the idea that soil is a continuum on the landscape. The word continuum is derived from the Latin continuus, meaning uninterrupted. However, the soil cover is interrupted frequently by nonsoil areas such as rock and water. Even within soil areas, the continuum is marked by frequent, often abrupt discontinuities. It is these fortuitous discontinuities that make soil maps possible at a reasonable cost. With this idea in mind, the major concepts of the soil-landscape model are presented.

1. Soil-landscape units are natural terrains resulting from the same five factors conventionally cited in the functional equation for soil formation. A soil-landscape unit has a recognizable form and shape on the surface of the earth**.** A soil-landscape unit is similar to a landform, but is more narrowly defined. For example, two areas could be designated as slopes and, thus, would be the same landform. However, the soil on a south-facing slope might be drastically different from the soil on a north-facing slope. Therefore, at least two soil-landscape units would be recognized on this landform***.*** *A soil-landscape unit can be thought of as a landform further modified by one or more of the soil forming factors*. See Hawley and Parsons (1980) for a comprehensive definition of the term landform.
2. Soil-landscape units have a predictable spatial relationship to one another. For example, one kind will always be located below another, etc.
3. In a given soil survey area, there are relatively few soil-landscape units. These few are replicated again and again.
4. Generally, the more different two adjacent soil-landscape units are, the more abrupt and striking the discontinuity separating them. An example is the boundary between a steep side slope and an alluvial flat at its base. Conversely, the more nearly alike two adjacent soil-landscape units are, the less striking the discontinuity separating them.
5. The boundaries between distinct soil-landscape units can be observed and mapped as discontinuities on the earth's surface. As a result, they can be delineated accurately by trained mappers.
6. A distinctive, relatively homogenous soil cover develops on each soil- landscape unit. Two distinctively different soil-landscape units typically sup- port soil covers that are significantly different from each other in appearance and behavior. The more stable the landscapes, the higher the covariance between soil and landscape unit. Once the soil-landscape relationships are determined in an area, the soil cover can be inferred by examining the landscape. Soil is examined directly only as needed to validate this relationship.
7. Since the boundaries between distinctly different landscape units tend to be abrupt and prominent, the boundaries between their associated soils tend to be abrupt and prominent.
8. As a result of no.6 and 7 previously, adjacent soils that are distinctly different will tend to be on distinctly different landscape units separated .by abrupt discontinuities. As a general rule, the more different two adjacent soils are, the easier it is to locate the boundary between them accurately and precisely. This is a fortuitous relationship. Because of it, adjacent soils that differ markedly in appearance and behavior tend to be separated in map- ping with precision and accuracy.
9. Within a given soil-landscape unit, soil variation, at the human scale of perception, is mostly cyclic. Adjacent soils tend to be similar and the boundaries between them tend to be indistinct and gradational. Soils within the same landscape unit normally cannot be separated with precision.

Summary

Soil mapping is possible because of observable discontinuities between landscape units and the strong covariance between landscape units and soils.These relationships make it possible to accurately delineate bodies of soil with limited observations.

A small percentage of the time one encounters adjacent soils that differ markedly in behavior due: to someproperty not reflected in the landscape. *These rare situations require special* procedures. *However, in most cases,* *extreme difficulty in delineating soils is a result of poor survey design.* For example, attempts are sometimes made to separate soils having only a minor difference in subsoil color. The covariance between this kind of difference and landscape units is very low. As a result, the mapping is frustrating and he product is poor.

The validity of the soil-landscape model assures that soil boundaries can be located accurately and precisely. The model explains how this can be done using affordable field procedures. It provides a strong theoretical basis for he way we map soils. Assuming that soil boundaries can be located accurately, we still have the following important question to consider: Are the soil bodies we draw lines around uniform enough that we can make reasonable interpretations? This issue is addressed in the next section.

Interpretation of Soils

Statements such as the following (Miller et al., 1980) are made frequently concerning soil maps.

...The user should be aware of how soil landscapes are sampled by the soil scientist and how inferences derived from such observations are extrapolated to produce the delineations that result in the map. The user should also be aware of the composition of the map units with respect to inclusions, the relationship of taxonomic heterogeneity to interpretive accuracy, the different degrees of variability of soil properties, and the confidence limits of the statements that can be made about the behavior of the soil map units it delineates.

Many soil scientists totally agree with such statements. They believe that there are so many inclusions in soil map units that they cannot be interpreted unambiguously. They maintain that to properly interpret a map unit, one must identify and characterize inclusions, explain variation in the map unit, and convey all of this information to the user. Furthermore, if the statements above are any indication, the user must have an extremely high level of technical knowledge. Otherwise, the user cannot understand the spatial variability within map units, the relationship of taxonomic heterogeneity to interpretive accuracy, etc. The fact that statements such as this are being written by so many is a sad commentary on the soil survey. It indicates a loss of confidence in our product.

There is a growing feeling that something is fundamentally wrong with soil maps and no one can figure out how to fix it. One symptom of this problem is the obsession with variability in map units. Recently, no technical meeting has been complete without a discussion of transects and new computer programs to calculate statistics. There is unending discussion of how information about map unit variability can be presented in soil survey reports.**Over the last decade, numerous work groups and committees have been formed to examine the problem of map unit variability and inclusions. Despite all of this discussion, no real progress has been made. We are still having the same arguments and discussions that were going on 15 years ago.**

Much of the concern about and obsession with the variability in map units is unfounded. This perceived problem results largely from using a poor conceptual model to explain how we interpret map units. The problem is not what we do to interpret map units. The problem is how we think about what we do. In order to develop this argument it is necessary to consider the concepts we have chosen to use in interpreting soils. The development of these concepts and how they have contributed to our present dilemma will be discussed.

Historical Perspective

One cannot deny the fact that there is variability among pedons making up a soil map unit. In that respect, map units are no different from any other natural population. However, the way soil scientists chose to view the variability of map units was atypical. Originally, they vastly underestimated the natural variability of the pedon population in soil map units. Because of this, they chose an unlikely statistic to characterize them. Early in the soil survey the decision was made to use the mode to make inferences about the population of pedons in a soil map unit. To do this, the class of soil found to occur most frequently in the map unit was determined. A modal pedon, selected to represent this class, then used to mane the map unit and as a basis for interpreting it.

The mode was chosen to name and interpret map units because of early assumption about map unit variability. At the time it seemed to be an extremely logical decision. Map units were assumed to be very homogeneous. It was thought that the modal soil would make up 80 to 90 percent or more of the map unit. With these assumptions, using the modal class to represent the map unit made perfect sense.

However, it soon became apparent that soil map units were not as homogeneous originally assumed. Soil scientists had to face the following embarrassing fact: What was designated as the modal class of soil for a map unit typically made up a relatively small part of the map unit area. Over the years, a number of things were done in attempts to cope with or explain away the deficiency.

One approach taken was to increase the percentage of inclusions permitted in a soil map unit. For example, the Soil Survey Manual (Soil Survey Staff, 1951) allowed up to 15 percent inclusions in a map unit named for one soil. By 1967, Soils Memo 66 allowed up to 50 percent similar inclusions in a map unit.

In addition to increasing the allowable inclusions in map units, a number of qualifying phrases were coined to help identify and explain such inclusions. For example, phrases such as limiting and non-limiting inclusions and similar and dissimilar soils came into common usage. During this period a number of formal studies reinforced the growing perception that soil map units had inclusions of unknown magnitude (McCornack and Wilding, 1969; Amos and Whiteside, 1975; Powell and Springer, 1965; Wilding et al., 1965; Campbell, 1978). The need to quantify map unit variation was stressed. Although they did a good job of pointing out the problem, none of these studies offered a good solution. The increasing realization that map units were being named and interpreted based on a modal class that often made up only a small part of the map unit area led to the development of another concept. This idea, invalid in my view, can be called the *Taxonomic Unit-Map Unit Duality*. It asserts that taxonomic units are pure concepts, whereas soil map units are real. This duality was created in an attempt to disassociate the concepts of map units and taxonomic units.

If one thing is considered real, while the other is deemed conceptual, then the lack of correspondence between them can be dismissed. Whether map units and taxonomic units are considered real depends upon one's assumptions, i.e., how the two things are defined and what in those definitions is considered acceptable evidence of reality. I believe this supposed dichotomy between taxonomic units and map units was accepted without rigid philosophical scrutiny because the perceived need to put some instance between them was so great.

Despite steps taken to increase the percentage of allowable inclusions, to create the map unit-taxonomic unit duality, and the use of new terms to describe inclusions, no real progress has been made in resolving this problem. We still do not know how to deal with variability in soil map units. We are still setting up committees and working groups, and publishing studies, all to no avail.

The latest proposed solution is elaborate statistics coupled with computer analysis. The thinking is thus: If we take enough transect data and analyze it properly, we can account for and explain the variability in map units. This statistical information (means, standard deviations, confidence intervals, etc.) will be presented to users along with the maps. The user will evaluate the statistics, thereby determining the level of confidence he can place in each map unit. Then he can proceed to use the soil survey report properly, i.e., understanding all of our caveats and disclaimers.

Field Perspective

If variation within map units is such a problem, it should be affecting the use of soil maps in the field. Most users of soil maps are totally oblivious to all of our concerns about such things as map unit purity, dissimilar inclusions and spatial variability. In fact, nearly all users do exactly what so many are afraid they will do. Being unaware of the uncertainties about inclusions and map unit variability, they assume that map units are largely homogeneous. Furthermore that a map unit is mostly made up of the soil used to name it. Therefore, they see no problem in using interpretations for this named soil to make decisions concerning the map unit.

Surprisingly, this process has worked well. Planners, sanitarians, real estate appraisers, tax officials; all of these and others have used soil maps and interpretations at face value for many years with few problems. Having worked in two rapidly developing areas of the country, I can speak from personal experience. In North Carolina and Maryland soil maps were relied upon heavily to make decisions about street location, suitability for onsite sewage disposal, wetland determinations, crop insurance, and many other uses. During more than ten years in the field, I know of no cases in which relying on a soils map resulted in a bad decision. In fact, after people had used soil maps and became familiar with them, they were convinced of their reliability. I recently queried several soil scientists who have spent many years in the field interpreting soil maps. Their experience was similar to mine; they found that soil maps performed very well, even for very specific interpretations. With all of the inclusions and variability we maintain in soil map units, how is this possible? Considering these theoretical problems, soil maps should not work nearly as well as they do.

In order to explain why soil maps function well in practice despite theoretical shortcomings, it is necessary to present a model or, more correctly, a paradigm for map unit interpretation. This model is really just an accounting of what we actually have been doing for many years.

Model for Interpreting Soil Map Units

For purposes of illustration, this model assumes the simplest case, a stable landscape and relatively uniform parent material. This simplest case actually is very common in the USA. The main points of a functional model for interpreting soil map units follow.

1. **Stable** soil-landscape units in relatively uniform parent material have a uniform soil cover.
   a) Within the **soil-landscape unit**, most of the soils do not differ greatly in depth, texture, drainage and other important properties.
   b) No general statements can be made about taxonomic purity, because some soils that are very similar physically and chemically can be far apart in Soil Taxonomy.
   c) However, many **soil-landscapes** are dominated by similar series or similar soil families. Most of the soil variation, at the scale of human observation, is continuous and cyclic over the landscape unit. This dominant area, or dominant population of pedons, typically covers 90 percent or more of the landscape unit.
2. Interpretations for a soil map unit can be based on the mean soil condition of the dominant pedon population in the soil landscape unit. Using **transects or other methods**, the soil that represents the average condition in the dominant pedon population with respect to depth, texture, drainage, and other important properties is selected. This pedon is used to name the map unit and interpret it. Variation in the dominant pedon population is mostly cyclic over the soil-landscape unit. Therefore, the mean pedon, which averages out cyclic, short distance variability within a map unit, is a good predictor of how an area of soil will behave.
3. There often is a small component of the soil-landscape unit, typically < 10%, containing soils significantly different from the dominant population. An example is small intermittent wet spots scattered throughout a landscape unit dominated by well drained soil. Such irregularities are common in many map units. The user can be informed about the possibility of encountering small areas of very dissimilar soils.

Comparison of Mode and Mean to Interpret Map Units

The statistic one uses to make inferences about the pedon population in a map unit depends upon how one views soil variability within map units. The widely held modal concept assumes that individual soils occur as discrete, identifiable areas within the map unit. Therefore, the soil chosen to name and interpret the map unit is the one that covers the largest area in the map unit. **<u>However, any modal soil chosen, unless defined very broadly, will make up only a small part of the map unit area.</u>** Therefore, one feels compelled to account for and explain the variability of all of the non-modal pedons. Furthermore, thinking about all of those unexplained, non-modal inclusions has cast serious doubts on the reliability of the soil maps.

Despite the perceived problems with variability and inclusions, those using soil maps have found that they work very well. **<u>The problem is not what we are doing. The problem is how we think about what we are doing</u>.** The modal concept is based on a questionable assumption about the spatial variation of soils in a map unit. In contrast to the widely held modal concept, the approach outlined above asserts that most variation within a soil delineation, at the human scale of perception, is continuous and cyclic. This variation tends to occur randomly over small distances within delineations.

Soil maps have worked well despite all of the theoretical reasons they should not for the following reasons. In most cases, when the modal pedon has been selected, the mean pedon also was selected by default, because the mean tends to fall within the modal class. The mean pedon is one which, over a typical decision-making area of a map unit, represents the average, or mean soil condition. As mentioned before, this mean soil condition tends to average out cyclic, short distance variability within a map unit, and is a good predictor of how an area of soil will behave. Therefore, using the modal soil to name and interpret map units has not caused problems in interpretation.

However, thinking about doing it has caused severe problems. Trying to cope with the theoretical problems inherent in using the mode to make interpretations about a population has caused great inefficiency. There has been a perceived need to totally characterize map unit variability and account for non-modal inclusions only because we have been trying to make an unsuitable concept work. The obsession with map unit variability and all of the concern about inclusions and taxonomic purity are the result of conceptual, not technical deficiencies. The use of the mode to interpret map units has made variability the major issue in interpreting soils.

We have been operating with faulty concepts. In order to make proper inferences about the pedon populations of map units, a statistic that averages out cyclic variation and estimates the mean soil condition of the dominant pedon population is required. Interpretations are made for areas of land. They should not be unduly controlled by pedon-to-pedon variation within delineations.

Using the mean soil condition of the dominant pedon population to interpret map units does not require that we do anything drastically different. It simply requires that we bring the theory of interpreting map units into line with practice. Basing interpretations on the average soil condition assumes that pedon populations of map units vary, just as in any population. However, the model rejects the idea that pedon-to-pedon variation can be assimilated, understood and used in making decisions about areas of land. Land use and management are based on the average soil condition in a decision-making area. This model is consistent with the way soil maps are interpreted in the field.

Recognizing that interpretations are based on the average condition the dominant population in a map unit has one more advantage. Interpretations are no longer viewed as being based on a modal group of soils within the map unit. Therefore, one is not forever trying to quantify and justify a large percentage of non-modal inclusions.

Early soil mappers recognized, as we do, that most map units are dominated by large bodies of relatively uniform soil. They found, through experience, that this body of soil could be used to characterize and interpret the map unit. However, they assumed that it was sufficiently homogeneous to be represented by a modal class of soil. When discussing the dominant pedon population, I am referring to this same dominant body of soil. However, although this body of soil is uniform enough to interpret well, it has too much short distance cyclic variabilities to represent a reasonable modal class. Therefore, the mean soil condition should be used to characterize this body of soil - and to name and interpret the map Unit.

Researchers must continue to study soil geography including the nature of variation in soil delineations and the relationships between taxonomic units and map units. However, such issues will not significantly affect the way in which most soil maps are made and interpreted. Therefore, field soil scientists need not be overly concerned with them. Many soil scientists struggle with such issues as similar inclusions and soil variability in attempts to overcome conceptual, not operational problems. They hope that by extensively documenting map unit inclusions and taxonomic variability they somehow can make an invalid concept work. However, such efforts will be in vain. Using the modal class of soil to interpret map units will continue to create conceptual dilemmas that cannot be resolved.

References

Amos, D.F. and EP Whiteside, 1973,Maping accuracy of a contemporary soil survey in an urbanizing area. Proc. Soil Soc.AM.39:93-942

Campbell, J .B. 1978. Spatial variation of sand content and pH within single contiguous delineations of two soil mapping units. Soil Sci. Soc. Am. J. 42.460-464.

Glinka, K.D. 1927. The great soil groups of the world and their development. (Translation by C.F. Marbut.) Edwards, Ann Arbor, MI.

Hawley, J .W ., and R.B. Parsons. 1980. Glossary of selected geomorphic and geologic terms. Mimeogr. USDA-SCS, West Tech. Ctr., Portland, OR.

Hilgard, E.G. 1906, Soils, their formation, properties, composition, and relation to climate and plant Growth. MacMillan, New York,

McCormack, D.E. and L.P. Wilding, 1969. Variation of soil propertries within mapping units of soil with contrasting substrata in northwestern Ohio. Proc. Soil Sci. Am. 33:587-593.

Miller, F.P., D.E. McCormack, and J.R. Talbot. 1980. Soil surveys, review of data collection methodologies, confidence limits, and uses. p. 58-65. In Transportation Research Record 733, National Academy of Sciences, Transportation Research Board, Washington, DC.

Powell, J .C. , and M.E. Springer. 1965. Composition and precision of classification of several mapping units of the Appling, Cecil, and Lloyd series in Walton County, Georgia. Proc. Soil Sci. Soc. Am. 29:454-458. Soil Survey Staff. 1951. Soil survey manual. Agric. Handb. 18. U.S. Gov. Print. Office, Washington, DC.

Wilding, L.P., R.B. Jones, and G.M. Schafer. 196.5. Variation of soil morphological properties within Miami, Celina, and Crosby mapping units in west-central Ohio. Proc. Soil Sci. Am. 29:711-716.