Professor G.W. Leeper Memorial Lecture

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THE CLASSIFICATION OF SOIL*

(EXTENDED SUMMARY OF A TALK)**

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"When scientists discuss methods of analysing a solution for phosphate, they are practical, reasonable, and unemotional. When the same men discuss the classification of soils, these virtues are likely to evaporate."

- Leeper (1956, p.59)

* Principal reference:
LEEPER, G.W. (1956) The classification of soils. *Journal of Soil Science* **7**, 59-64.

**This extended summary provides an outline of the talk, especially prepared for the Leeper Memorial Lecture. The extended summary should be perused along with a PowerPoint presentation that provides the illustrative material.

0. Introduction

{ Slides 1 – 6}

It seems quite unfashionable these days to discuss soil classification. It seems to many a done deed, a finished job, a *fait accompli*, or worse, irrelevant. But to a few, the systems, we soil scientists have devised, rankle. So as one who is not a follower of fashion, I think it's timely to discuss the issues once again. In particular, in this lecture I think it is fitting to attempt to deconstruct (a wee bit) and discuss Professor Leeper's famous 1956 (LEEPER, 1956) paper on soil classification. This will be done in the light of knowledge at the time, and developments and advances since then. Hopefully, out of all this, I shall be able to suggest some future possibilities. I won't go into the question about why we wish to classify soil. I simply believe classification of objects or constructs is a process innate to humanity.

It is indeed a privilege to be asked to give this talk in memory of Professor Leeper. I chose his 1956 classification paper as a starting point because I remember as an undergraduate reading it in the Science Library at Aberdeen University. (The library was very close by the Soil Science Department, which at that time was an attic lodger in the pink granite Chemistry Building. Professor Leeper spent some time in Aberdeen around 1929.) I had an early, perhaps perverse, interest in soil classification, which has waxed and waned periodically since then. I should say, in admiration of my Scottish education that as undergraduates we studied 'comparative soil classification and taxonomy' including the Factual Key. As this is a talk, what I shall present is not a detailed work of science, or art, but is more an impression or a sketch, more memoir than monograph. Indeed, most of it is drawn from deep in some dry well of memory.

First, let me define some words in the way I (shall) use them.
Classification - the setting up or creation of classes
Taxonomy - the theory of classification
Classification system - the list of classes and their definitions
Allocation, identification - putting new unknowns into pre-existing classes

The word ‘soil’ can be tacked on the front to give the appropriate phrases and meanings. So, using these definitions, Isbell classifies, the rest of us allocate or identify, and hardly anyone bothers with soil taxonomy.

1. What did Leeper say?

{ Slides 7 – 15}

So what did Professor Leeper say in his paper? It is a paper on *soil classification* proper, an essay on the setting up of soil classes. He does not present *a classification system* per se. His *taxonomy* seems to be that of logical binary subdivision, based on properties, characters or attributes (three words used here synonymously) of a particular soil individual, in this case, the soil profile.

He follows an ‘a matter of fact, analytical approach’ with ‘no need for genetic hypotheses’ The object of classification, the soil individual, is the soil profile, described by n =15 to 20 soil (profile) properties, characters or attributes. Classification is based on a logical binary subdivision of n properties of a soil profile, e.g., 2^{15} (32 768) to 2^{20} (1 048 576) possible combinations. For, say n=3, we would have 8 possible soil profile classes, e.g., PQR, PQr, PqR, Pqr, pQR, pQr, pqR, pqr. He recognises that some combinations might not exist. He also discusses the need to consider the order of importance of n properties and he clearly believes there is an order of importance, but does not give examples. Leeper does not concern himself, or get bogged down, in the quagmire, in the gleysols, or hydrosols, of nomenclature.

He vehemently rejects genetic approaches, particularly that of Kubiena. ‘Kubiena claims to follow a *‘natural’* system which orders his objects according to *all* their characteristics and not on the basis of only a few properties…. In this arrangement he claims there is no arbitrary principle of division, but the *‘essential order of Nature itself is represented’* ….. this is the very thing Kubiena does not do…… All that needs to be done here is to destroy the notion there is some *‘essential order in Nature itself’* that we have to discover. If there is, who is to decide which discovery is right? Has Kubiena received a revelation? If four different revelations come, say, to an Austrian, a Russian, an American, and an Australian, are their countries to vote on it?’

In summary, this is a very clear exposition of an approach that seems to be novel in soil science at that time. Much of the argument raged between a few omniscient scientists who could read the arcane ‘book of soil’, and those who were trying to fit pre-existing classes (mainly great soil groups) into national and international hierarchical schemes using observable properties, such as was achieved around 1960 in the USDA’s 7^{th} Approximation.

The approach proposed by Professor Leeper does not guarantee success, because although it might be unequivocal it does not necessarily partition the variation in the soil universe in an optimal way. To be fair, this idea came much later as discussed below. Leeper could not have foreseen at the time major generic developments such as the information revolution, the increased and real demand for soil information brought about by environmental awareness, or the birth of pedometrics.

2. Developments in (Australian) national soil classification systems

{ Slides 16 – 25}

Developments in Australian soil classification systems are discussed in detail by Isbell (1992). Northcote’s Factual Key from 1962 (Nortchote, 1979) and subsequent editions. This appears to be the closest manifestation to date of Leeper’s (1956) ideas. This was used widely, although some said it was an identification system is search of a classification system. This set a precedent for clear allocation systems which was the downfall of the other major approach of the ‘sixties to the ‘eighties that of the 47 Great Soil Groups published in Stace et al. (1968). No kind of identification system was provided and allocation often involved consulting a few judicious experts. Some attempts were made to succumb to American pedological hegemony but the USDA’s Soil Taxonomy (ST) with its 12 orders and some 315 great groups, the de facto world standard - the Microsoft Windows of soil science, has not been accepted as the basic system in Australia. This mantle has been taken up by a home-grown ST-like creation called the Australian Soil Classification (Isbell, 1996) (which is need of the word ‘System’ at the end.). This has an effective keying system, but with potentially more than 550 great groups it is not fully tested. It is very similar to the new Brazilian system (EMBRAPA, 1999) with its 14 orders and 142 great groups.

All these systems are very similar in structure and use fairly similar diagnostic criteria. The Soil Taxonomy family of classification systems dominate. They use more-or less measurable properties and have fairly unequivocal keys. This does not guarantee success in classification however. I think the great group lies at the heart of many of them and in the one of the few studies that tested the ’quality of classification’ by measuring how well these kinds of systems partitioned variation in other soil properties (Yost and Fox, 1991) it was clearly shown that was the categorical level at which the classification (ST) performed. Nothing effective happened at lower categorical levels! Existing systems might be improved by performing this kind of test.

3. Philosophical developments

{ Slides 26 – 34}

While Soil Taxonomy and its nephews and nieces were being conceived, some thoughtful soil scientists concerned themselves with more philosophical matters. I mention just a few here.

The question of the soil individual still remains to be addressed properly. What is an appropriate soil individual? A point (really a small Representative Elementary Volume), a horizon, a profile or pedon, a polypedon or tessera etc? Holmgren (1988) in a very thoughtful paper called for a point representation of soil.

Webster (1968) criticised the basic premise of Soil Taxonomy with its multi-categorical and monothetic nature. He called for polythetic classifications and coordinate classifications. Butler(1980) re-emphasised Webster’s criticism and called the phenomenon of using single characters at a categorical level the taxonomic chop. He also recognised the real problem of relating national systems to classes on the ground – a problem he termed the taxonomic hiatus. Beckmann (1984) asked whether there was a place for ‘genesis’ in soil classification. He showed how the great soil groups in terms of developmental sequences. Classifcation systems might be made apparently without genetic considerations but quite understandably pedologists will arrange the classes in appropriate sequences to unravel sequences of development.

In short, these, and other, philosophical developments have not be incorporated in operational systems of soil classification. Perhaps the biggest philosophical development has been numerical classification. As such it is treated under a separate heading.

4. Numerical classification

{ Slides 35 – 47}

This idea-rich, data-poor, movement, began in the late ‘fifties, with the invention of the digital computer which allowed the calculation of taxonomic distances – distances between points in multi-dimensional spaces, the axes defined by the characters or attributes of soil profiles. This movement was based on a taxonomic principle from Adanson (Moore & Russell, 1966) – classifications should be based on many characters, and each should have equal weight.

Similarities were calculated between profiles, represented as shaded similarity matrices, these were transformed to distances, which allowed a representation of the multi-dimensional space in a few dimensions to be calculated. This is called ordination (Hole & Hironaka, 1960; Rayner, 1966). For the first time, a view of soil property universe was revealed. The numerous studies showed local areas of higher density (weak clusters) with area of smaller density of individuals grading in all directions.

Classifications were created both hierarchically (*inter alia* Webster & Burrough, 1972) and non-hierarchically (Crommelin & de Gruijter, 1973) using various clustering algorithms. A number of profile models was tested (Campbell et al., 1970; Norris & Dale, 1971; Moore et al., 1972; Little & Ross, 1985).

Australia was very much at the forefront of soil taxonomic research (Campbell et al., 1970; Norris & Dale, 1971; Moore et al., 1972) at the beginning of the 'seventies. The work largely fizzled out by the nineteen eighties because sufficient national (and international) data were not available to go to the next step - to create national numerical classification systems. A rough rule of thumb is that to create and define k classes requires something like k^2 individuals, i.e., to create a 200-group classification system, something like 40 000 profiles would be required. The work (summarised in Webster, 1977) succeeded in unraveling the structure of the soil character space, i.e., weak clustering with intergrades in all directions of the taxonomic space. The work also allowed the creation of multivariate polythetic classes using hierarchical and non-hierarchical schemes

5. More recent developments

This section largely concerns work with which I have been involved, and therefore I can admit a bias to my recollection of the recent history of (numerical) soil taxonomy.

(a) Continuous classification

{ Slides 48 – 63}

The intergrading nature of the soil population was recognised in a formal way using the concept of fuzzy sets. This allowed the creation of non-hierarchical continuous classes defined by their centroids. In addition to intergrades (more correctly intragrades), extragrades were also recognised. This allowed for more continuous soil mapping, more natural when using geostatistical methods. (McBratney & de Gruijter, 1992; Triantafilis & McBratney, 1993; Triantafilis et al., 2001)

(b) Continuous allocation

{ Slides 64 – 68}

Isbell (1992) writing on numerical classification said 'classes produced are normally polythetic. Hence the allocation of new members is not a simple matter and it can be very difficult to construct an identification key'. This statement led me to devise to a quick and easy numerical procedure for allocating unknowns to the continuous classes discussed in the previous section (McBratney, 1994). (This is quite different in concept from computer-implemented or computer-constructed identification keys.) A continuous allocation scheme was also devised for the Australian Great Soil Groups Soil Classification System (Mazaheri et al., 1995). This scheme has not been taken up perhaps because of the advent of the Australian Soil Classification System (Isbell, 1996). The same approach could easily be applied to the sub-orders or great groups – the levels that probably do the work - of Isbell's scheme.

(c) Genetic classification?

{ Slides 69 – 119}

More recently work has begun on the development of quantitative soil-landscape models. The first model (Minasny & McBratney, 1999) coupled sediment transport with rock weathering through a non-linear partial differential equation, which can be solved numerically. This predicts soil thickness and composition in terms of the amount of transported or *in-situ* weathered material as a function of space and time. Perhaps to the disapprobation of Professor Leeper, the equations attempt to describe 'the essential order of nature'. This allows one to classify the soil mantle using the thickness and composition at all places and times – the classes produced have a degree of continuity in space and time – and as such they can be regarded as (pedo)genetic. Further work is planned to refine the model to include soil-forming processes leading to horizonation.

6. Conclusions - the future

{ Slides 120 – 123}

There has been much conceptual development since 1956. To-day's formal national classification systems are based on ideas from the 'fifties or earlier, however. New concepts need to be incorporated. The availability of national databases of more than 100 000 profile observations, such as the Australian Soil Resources Information System, will, for the first time, make numerical classification feasible at a national level. Genetic classification will be developed formally and quantitatively as a logical consequence of sophisticated quantitative pedogenetic models. Finally, a poem.

THE UNITY OF 1

Once
There was only one soil
In all our worlds

For you
A Martock brown earth
In a cider orchard
On the Isle of Avalon

No need for maps
No doubts
No arguments

You were the one
Who often asked
Why did we have to
Find another
And another?

- *David van der Linden*

7. Acknowledgments

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