xx Soil in Space and Time

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Editorial Introduction to Volume I

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Introduction

Precediously recognizing the natural diversity of soil, Shakespeare’s Henry IV remarked:

Here is a dear, a true industrious friend,
Sir Walter Blunt, new lighted from his horse.
Stair’d with the variation of each soil
Be wistful that Holmedon and this seat of ours.

This volume concerns the natural distribution and evolution of soil in space and time, and as such it largely refers to pedology. Etymologically, pedology is the scientific study of soil, including its origin, characteristics and uses. Within the realm of soil science, a narrower definition of pedology is used: the study of the formation, properties, classification and management of soil. More simply, pedology is the study of soil as a natural phenomenon in its environmental setting and has often been further abridged to the study of soil genesis and soil classification.

Although humanity has used the soil for some ten millennia and soil husbandry has developed with the continual waxing and waning of societies over that time, the study of soil of itself is relatively new to natural science, having emerged as a discipline in the 19th century. The concept that soil could be studied as a natural body came from the latter half of the 19th century although descriptions were extant prior to that. The German scientist F. A. Fallou introduced the term ‘pedology’ (Fallou, 1862). The Russian scientist V. V. Dokuchaev is regarded as the person who rendered pedology a scientific discipline in its own right (Etvohov, 2005). He did so by recognizing that soil is an ‘independent natural-historical body’ and that the formation of soil is governed by five factors, namely, climate, organisms, topography, parent material and (geological) age. The subsequent 100 or so years have seen a thorough exploration of this idea aided by new technologies and ideas from other disciplines. The early work concerned mapping of soil for land taxation, agricultural development or proper husbandry (which continues to this day), the latter work has concerned detailed understanding of processes of soil
formations in the landscape. This represents a transition from description to deep understanding of genesis (perhaps somewhat sidetracked by an excursion to classification). The earlier work focused on knowing that soil exists and the latter work has shed light on how soil exists.

There have been several key questions into which pedology has delved. What kinds of soil individuals are there (or have there been) in the world? Where do these exist? Do they form natural classes? How is soil formed?

This and the other three volumes represent the arrangements and themes of our modes of discovery in the International Union of Soil Sciences at the turn of the millennium, and not necessarily the historic one which emphasized soil physics, chemistry, biology and pedology; nevertheless, it serves to put some structure on the tens of thousands of pedological papers. It should be said, however, that many of the great developments in pedology have appeared as books and long reports, Jenny’s (1941) monograph being a prime example. Here we have concentrated on the shorter reports, largely scientific papers. What we have is some combination of representative sample and seminal work.

Soil Morphology and Micromorphology

One of the first tasks that pedologists studying soil in the field had to tackle was that of description. Being a different phenomenon from plants and rocks, a whole system of terminology and description had to be invented to describe the unique features of soil horizons, profiles and pedons. This emerged from the mid 19th century (Feller et al, 2006), but with systematic surveys of the soil resources of nations came an imperative for standardization, none more so than in the US. Largely due to its economy and insight, the morphological description of soil has served as the principal mechanism for the recognition of soil classes from series to orders. Nikiforoff (1937) gives an early example. In the paper included here, Nikiforoff (1941, this volume) sets up a system for describing the unique forms of soil peds that can be found in nature, e.g. platy, prismatic, blocky and granular, and this is largely still used. Such methods of description are still being developed (although more slowly than in the past) all over the world, often aided by technology, because there is a large degree of international concurrence. The Soil Survey Manual (Soil Survey Staff, 1951) and its update (Schoeneberger et al, 2002) and their homologues in other jurisdictions, are notable milestones on this road that eventually leads to explanation. There is almost always an implicit assumption that the description of soil morphological properties in the field correlates well with more difficult-to-measure properties. This assumption is rarely put to the proof. The paper by Torrent et al (1983, this volume) is an exception. We see the development of an explicit relationship between the field-observed Munsell soil colour and the hematite content of soils from Europe and Brazil, which upholds faith in field-based descriptive systems.

Soil morphology refers to the description of soil at length scales of millimetres to metres. (Some would argue for larger structures but these will be dealt with in the section on Soil geography below.) In the 1930s, pedologists began looking at the fine morphology of soil (length scales of millimetres to micrometres) using undisturbed thin sections and petrological microscopes, originally called micropedology (Kubička, 1938). This has become known as micromorphology and has continued on its development (Bullock et al, 1985; Stoops, 2003); technology (from electron microscopy to synchrotrons) has allowed finer and finer structures to be revealed and in three dimensions. Some of the principal uses of micromorphology have been (i) to understand soil-forming processes, particularly those of weathering and pedological reorganization, and (ii) to unravel the effect of human activities on soils, e.g. tillage and human settlement. Dalrymple (1958, this volume) used micromorphology and gives examples of identifying fossil horizons and man-made deposits from archaeological sections.

Brewer and Sleeman (1960, this volume) used a micromorphological approach to continue Nikiforoff’s (1937, 1941) work to finer scales. They reveal and describe microstructures and fabrics and define concepts of skeleton and plasma (introduced by Kubička) more specifically, and emphasize the importance of scale of observation on description.

One imagines there should be a clear link between micromorphology, macro-morphology and soil behaviour. As long ago as 1881, Lawes et al (1881) at Rothamsted showed that the response of drains from storms had a very fast, and a slower, phase. Nevertheless, the soil physics theory of most of the 20th century did not really account for this (see discussion and papers on soil physics in Volume 2). Bouma (1981, this volume) in a much cited paper, drew together the links between soil pore-structural form and behaviour discussing the concepts of ‘preferential flow’ and ‘short-circuiting’ – recognizing that well-connected macro pores contributed to the very fast phase observed by Lawes et al (1881) (see discussion of soil physics in Volume 2). (Micro)morphological methods provided essential data that could not have been obtained by physical methods alone.

Some key papers that could not be included and deserve perusal are Nikiforoff’s original report on soil description (Nikiforoff, 1937), Bouma’s earlier work on preferential flow (Bouma et al, 1977) and a much cited detailed study on the conditions giving rise to surface crusts (Valentijn and Bresson, 1992).

Soil Geography

Soil makes distinct spatial patterns in the landscape. Soil geography is concerned with the form and origin of these patterns. As such it is concerned with the length scale above that of soil morphology, discussed immediately above, therefore scales of metres up to hundreds and thousands of kilometres. The patterns are strongly affected by terrain form and indeed we can recognize combinations of soil and terrain called soil landscapes or soils.
In the opus of soil geography there appear to be two threads deeply entwined. The first is the recognition of the geographic patterns themselves and the second is the interaction between pedology and geomorphology (Gerrard, 1981; Gennadiyev and Bockheim, 2006).

In a brief communication, Milne (1935, this volume), working in east Africa, recognized the catena – a topographic complex of soil – as a soil–landscape phenomenon. The Russians, principally V. M. Fridland, developed a whole system of individuals and descriptions of their patterns (Gennadiyev and Bockheim, 2006). This work was largely in Russian, which unfortunately hampered the recognition of its significance. The paper by Fridland (1974, this volume) is one of the few works in English. He recognized elementary soil areals, and genetically linked elementary soil areals with a distinct spatial pattern, called soil combinations. Hole and Campbell (1985) presented an analysis of soil-cover patterns. The variation of the pattern within a given area of interest has given rise to the concept of pedodiversity (Ibañez et al, 1995).

The second thread is the interaction between landform and soil distribution – the so-called soil-geomorphic models that are much used in soil surveys. The greatest single contribution here is regarded as Milne’s (1935, this volume) catena. A catena is named after the conception of a chain of different soils hanging between two summits. The concept was further developed by Butler (1959) with his K-cycle model (where the soils in the sequence are not formed on the same parent material) and by Ruhe and Walker (1968) and Conacher and Dalrymple (1977) with their five- and nine-unit landscape models. The book by Burrough (1986) brought the breakthrough of information technology with the advent of geographic information systems. In a highly cited paper, Moore et al (1992, this volume) bring together digital terrain analysis developed by geomorphologists in the 1980s for soil prediction in a formal quantitative approach.


Soil Genesis

Soil genesis is the heart of pedology and consequently has the richest literature. Understanding under which conditions soil has formed and elucidating the key processes has been the major goal of pedology since the early scientific description and realization of the uniqueness of soil towards the end of the 19th century. Sibertsev (1900) summarizes the early view. Since then, and with the help of advances, particularly in chemistry, mineralogy and microscopy, the understanding of the processes of weathering and reorganization has been elucidated. More recently, the link between soil and the landscape in which it forms an upper boundary has been unravelled. The current understanding is well described by Schaerz and Anderson (2005).

There are three main thrusts in this body of work. The first concerns an understanding of the factors of soil formation – which external factors drive pedogenesis? The most famous relationship in pedology is Jenny’s state factors of soil formation (Jenny, 1941). This has its basis in the work of Dokuchaev and an equation formulation by Shaw (1932). Jenny (1961) amended his formulation in response to criticisms of the requirement for the invariance of the remaining factors when examining the effect of a particular factor. The paper by Yaalon (1975, this volume) outlines progress with providing graphical and numerical solutions of lithofunctions, climofunctions, topofunctions, biofunctions and chronofunctions and appeals for the further development of such univariate functions with the eventual development of multivariate relationships. He alludes to a (computer) simulation approach.

The second principal advance is that of process. This is exemplified by the paper of Simonson (1959, this volume). He recognizes that soil genesis comprises the accumulation of parent materials and the differentiation of horizons in the profile. Horizon differentiation depends on: (a) additions, e.g. organic matter; (b) removals, e.g. salts and carbonates, clay; (c) transfers, e.g. humified organic matter and sesquioxides; and (d) transformations, e.g. of primary minerals to secondary ones, all within the soil system. This process view has a different focus to the factorial formulation. Bockheim and Gennadiyev (2000) expanded this approach to 17 processes. The processes were illustrated in simple diagrams and included: (i) argiluviation, (ii) biological enrichment of base cations, (iii) andisolization, (iv) paludization, (v) gleyization, (vi) melanization, (vii) ferrallitization, (viii) podzolization, (ix) base cation leaching, (x) vertization, (xi) cryotorurbation, (xii) salinization, (xiii) calcification, (xiv) solonization, (xv) solodization, (xvi) silicification and (xvii) anthroposolization.

Bryan and Teakle (1949) in a brief visionary report, unable to be reproduced here, discussed an assumption that if a climate persists unchanged it will bring about a convergence of initially diverse soils towards ‘one type of soil normal for that climate’ – the zonal concept. They suggest that soil processes once under way will continue in ‘spite of changes in the environment to conditions which are not normally favourable to the process’. They called this ‘pedological inertia’. They go on to say ‘in addition to resisting convergence, pedogenic inertia may actively lead to increasing divergence. For example, under climatic conditions almost equally favourable to the development of two alternative soil types, an apparently trivial variation in the other conditions, such as drainage or slope, might result in the initiation of the two alternative soil-forming processes side by side on the same parent material.’ This last statement is amazingly prescient, written long before chaos theory was invented. In today’s language we would interpret their paper in terms of non-linear dynamics (chaos theory) and negative and positive feedback processes. Chadwick and Chorover (2001) discussed pedogenetic inertia further and Phillips (1999) looked at the non-linear dynamics of soil genesis.

The third leading push relates to the recognition of the co-evolution of soils and landforms. Ollier (1959, this volume), working in Uganda, developed a two-cycle
theory of tropical pedogenesis; current soil profiles are formed on pre-weathered rock. He appealed to geomorphic as well as pedological principles to establish this. Such ideas of combined pedological and geomorphic approaches were advanced further by Huggett (1975, this volume) who developed the Soil Landscape Systems model. A soil landscape system is a three-dimensional body, a catchment, that is (1) bounded by the soil surface, valley watershed and weathering front at the base of the soil; (2) forms part of a more extensive valley basin network; and (3) functions as an open system. In another important paper reprinted here, Kirkby (1977, this volume), who had worked on slope models, recognized the need to quantify soil processes to improve them. He formulated a number of processes related to the inorganic and organic materials in soil profiles that could be used to develop soil-landscape models, and such models are still being developed (e.g. Yoo and Mudd, 2008). The work by Huggett and Kirkby are, for the most part, conceptual and theoretical. The paper by Brimhall and Dietrich (1987, this volume) gives a detailed field and laboratory experimental study of soil-landscape processes particularly chemical weathering and associated (volumetric) strain, and such approaches are used in contemporary pedology.


**Soil Classification**

Of all the subjects that soil science has addressed, there is none more controversial than soil classification. Leeper (1956, this volume) writes, ‘When scientists discuss methods of analysing a solution for traces of phosphate, they are practical, reasonable and unemotional. When the same men (sic) discuss the classification of soils, these virtues are liable to evaporate.’ He attributed this to national prestige and a lack of clarity of purpose and approach. Unlike plant taxonomy, there is no truly universal classification system for soil. The principles of soil systematics have been varied and polemical (Strzemski, 1975). Arguments have raged between ‘genetic’, ‘natural’ and ‘functional’ approaches, and on the fundamental object to be classified — horizon, profile or pedon. The paper by Leeper (1956, this volume) brings out some of the arguments; he favours a ‘matter-of-fact analytical’ (agenetic) approach.

A large number of countries have invented their own systems, e.g. US (Soil Survey Staff, 1975), France (Baize and Girard, 1990), Australia (Isbell, 1996) and Brazil (Embrapa Solos, 2006), each with their own foci and idiosyncrasies. Avery (1973, this volume) gives an example for England and Wales that is typical of such national systems. ‘The things classified are soil profiles, and classes are defined by relatively permanent characteristics that can be observed or measured in the field, or inferred within limits from field examination by comparison with analysed samples. Profile classes are defined at four categorical levels by progressive division, and are termed major groups, groups, subgroups and soil series respectively. Classes in the three higher categories are defined partly by the composition of the soil material and partly by the presence or absence of particular diagnostic horizons, or evidence of recent alluvial origin, within specified depths. Soil series are distinguished by other characteristics, chiefly lithologic, not differentiating in higher categories.’

There are two global soil classification systems extant, however. Both Soil Taxonomy (Soil Survey Staff, 1960, 1975), and the World Reference Base (WRB) for Soil Resources (FAO, 1998) developed from the legend of the Food and Agriculture Organization (FAO) soil map of the world (FAO-UNESCO, 1974), classifying soils objects using diagnostic horizons, properties and materials. According to Bockheim and Gennadijev (2000), ‘although these systems are based on genetic principles, the approaches used have de-emphasized the role of soil processes in soil taxonomic systems. ... Specific soil processes are determined by the soil-forming factors and are expressed in diagnostic horizons, properties, and materials, which are then used to classify soils: soil-forming factors → soil-forming processes → diagnostic horizons, properties, materials → soil taxonomic system.’

Many believe that classification is intrinsic to humanity; it's simply something we do; and in a sense sits apart from the scientific method. If this is the case, we would expect many indigenous cultures to have developed soil categories. From the 1980s, soil scientists led by anthropologists began to study and document scientifically the considerable soil knowledge of indigenous cultures; a pursuit known as ethnopedology. In many societies this knowledge has been structured hierarchically into local soil and land classification systems. Sandor and Furbee (1996, this volume) investigated indigenous soil classification in the Colca Valley in southern Peru, where terrace agriculture has been practised for more than 1500 years. Anthropological research revealed an indigenous soil classification system with three to four hierarchical levels and some 50 soil material names with an emphasis on soil texture and other properties useful for soil and crop management. They found some correspondence between the indigenous texture classes and those used in scientific classifications.

Marbut (1922), Kellogg (1940), Cline (1949), Kubiena (1958), Pierre (1958), Muir (1962), van Wambreke (1962), FitzPatrick (1967) and Webster (1968) are worthy of further consultation.
Pedometrics has developed quickly over the past 20 or so years. It concerns the application of mathematical and statistical methods for the study of the distribution and genesis of soils – essentially pedology with a mathematical bent. The main areas of development have been quantitative models for soil variation, soil sampling theory, numerical classification of soil and spatial prediction of soil attributes. The earlier work was well summarized in Webster’s (1977) monograph.

Soil variation can render management problematic and makes efficient sampling difficult. The early work of Youden and Mehlich (1937, this volume) outlined an efficient method for sampling in order to elucidate the scale of variation. Using a hierarchical sampling scheme and a variance components analysis – effectively a variogram – Youden and Mehlich, working in the eastern US states of New York and New Jersey, showed that for soil pH ‘samples from widely separated points vary more than samples taken closer together’. Intervals as low as 3m or 10m were too small to constitute an effective method for sampling these areas. The work was motivated by crop fertility, soil classification and environmental concerns. Beckett and Webster (1971, this volume) reviewed the work on soil variability. From some 80 studies, they found that ‘variance and coefficient of variation (CV) increase with the size of the area sampled’. Up to half the variance within a field may be present in any square metre in it. Additionally, Beckett and Webster (1971) found that the total variances of soil properties (expressed as a CV) within mapped soil Series or Types were 20 per cent for those properties unaffected by management and 60 per cent for those most affected by management, and ‘50 per cent of the randomly chosen sites are occupied by soil profiles which match the definition of the profile class for which the unit is named’. Burgess and Webster (1980, this volume) took the study of soil variation much further using regionalized variable theory. They defined the soil variogram, which gives an indication of variation at all scales and even more importantly showed how this function could be used for optimally predicting soil properties at unvisited locations using kriging. Although there has been much work on describing soil variability and the problems of considerable short-range variation, there has been little explanation of this phenomenon. Phillips (1993) offers a possible mechanism.

In the previous section, soil classification was seen as a somewhat controversial subject. With the advent of computers a numerical approach could be taken for the first time. Rayner (1966, this volume) worked with 23 soil profile descriptions from Glamorganshire in Wales. He calculated the similarities between the 91 individual horizons and based on these calculated average similarities between the profiles, which then allowed clustering and the production of a dendrogram and a principal coordinate diagram. Numerical classification like traditional classification needs individuals and attributes. In the 1960s, large data sets and fast computers were not available. They are today and numerical taxonomy should be attempted with large global data sets to test the validity of global classification systems.


Palaeopedology

Palaeopedology is the study of palaeosols, that is, the soils of past landscapes, both buried and exhumed (Ruhe, 1956; Yaalon, 1971). Such materials have been studied for more than 100 years; geologists and botanists first speculated on ‘fossil soils’ in coal measures. Palaeosols are now recognized as important research objects in the reproduction of past environmental conditions important for the understanding of issues such as climate change and human development (Broner and Catt, 1998).

Mack et al (1993, this volume) recognized that pedogenic features preserved in palaeosols can be modified by chemical diagenesis and compaction. Thus diagnosti attempts related to specific colours or certain thicknesses of horizons, are not applicable to palaeosols. The classification is based on the relative prominence of six pedogenic features: organic matter content, horizonation, redox conditions, sit mineral alteration, illuviation of insoluble minerals/compounds, and accumulation of soluble minerals. This allows allocation to one of the nine palaeosol orders, the first four of which also occur in Soil Taxonomy; namely, histosol, spodosol, oxisol, vertisol, calcarosol, gypseisol, gleysol, agrisool and protosol.

Verosub et al (1993) and Mäger (1998) have also contributed key papers in palaeopedology.

How Far Have We Come?

Bockheim et al (2005) reviewed the history of the key concepts in pedology. They presented a table (Bockheim et al, 2005, p32) which we have modified slightly and added the papers reproduced in this volume (Table 1). We see that the papers chosen cover the development of pedology and especially reflect the great upsurge in scientific activity in the half century of economic growth after WWII.
<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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<tr>
<td>1880</td>
<td>Concept of soil as a medium for plant growth and as a weathered rock layer</td>
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<tr>
<td>1900</td>
<td>Appearance of fundamental pedological concepts: soil as a natural body; soil horizons/profiles; soil-forming factors; early ideas of soil geography</td>
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<td>1910</td>
<td>Global acceptance of concepts of soil as a natural body and soil-forming factors; development of first regional soil classification systems; soil surveys initiated; identification of key soil-forming processes</td>
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<tr>
<td>1941</td>
<td>Factors of soil formation and genesis of soils clarified; development of global soil taxonomic systems; intensified soil mapping</td>
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<tr>
<td>1961</td>
<td>Refinement of global soil taxonomic systems; identification of pedon concept; development of early soil models and soil cover pattern concept; recognition of co-evolution of soils and landforms</td>
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<tr>
<td>1991</td>
<td>Increased understanding of soil processes; refinement of global soil models; further refinement of global soil taxonomic systems; development of pedometrics</td>
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Strzelecki, M. (1975) *Ideas Underlying Soil Systematics* (translation of Myśli Polskie Systematyki Gleb), Foreign Scientific Publication, Department of the National Centre for Scientific, Technical and Economic Information, Warsaw, Poland


Further Reading (by Theme and in Chronological Order)

**Soil morphology and micromorphology**


**Soil geography**


**Soil genesis**


**Soil classification**


Cline, M. G. (1949) 'Basic principles of soil classification', *Soil Science*, vol 67, pp.81-91


FitzPatrick, E. A. (1967) 'Soil nomenclature and classification', *Geoderma*, vol 1, pp91–105

**Pedometrics**


**Palaeopedology**