SOIL MICROSCOPY AND MICROMORPHOLOGY

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Summary

Soil micromorphology owes it popularity to the late Walter Kubiëna who saw its potential as a tool to investigate some of the properties and processes in soils. His two books “Micropedology” and “Soils of Europe” are landmarks in the development of Soil Science. He did not have the benefits of modern equipment and impregnating

resins, his thin sections were made with Canada balsam and hand ground. His work was followed by other researchers, in particular in the Netherlands and in Germany. Then followed a number of important publications on micromorphology by Brewer, FitzPatrick, Bullock *et. al*. and Stoops. The technique is now well established globally with investigations into every aspect of soil science including engineering and archaeology.

There have been many notable contributions but alas there is no consensus about terminology. There are those that have produced very elaborate terminologies and some like this author that plead for simple language and the use of accepted terms as used in this publication. The aim of this chapter is to present mainly, and in the simplest possible way the study of soil in thin sections. It starts with a very brief mention of methodology followed by definitions and concepts which are still being developed. Primary minerals and mineral weathering are discussed as well as the most important secondary minerals. This is followed by the organic fraction and its organisms, both microorganisms and mesofauna. Fine material, matrix, pores and structure are then presented followed by impregnations, nodules and concretions. Experimental results on the production of some features are included. Finally a number of relevant applications are briefly discussed.

1. Introduction

One of the first major microscopic investigations was made by Harrison (1933), who used thin sections and other procedures to study the weathering of different rock types under tropical conditions in Guyana. The great pioneer of soil micromorphology was, however, the late Kubiëna (1938), and contemporaneously with his work, other techniques were developed for studying soils in greater detail, in particular Transmission (TEM) and Scanning Electron microscopy (SEM). In addition, thin section studies have often been linked with X-ray diffraction and X-ray microprobe analyses, as well as with microbiological and other types of investigations.

The objective of this chapter is to outline the main developments and features of soil microscopy and micromorphology. These are presented in a somewhat pragmatic manner under what seem to be useful headings, and can be regarded as a summary of a CD recently released by the author (FitzPatrick, 2005).

2. Techniques

The basic technique in soil microscopy and micromorphology involves the preparation of thin sections of undisturbed soil materials, the samples being collected in boxes with double lids to avoid disturbance. The outstanding developments include the use of synthetic resins for improved impregnation and the increase in size of thin sections. The introduction of acetone as a diluent of the resins made it possible to remove water from the samples by acetone exchange thus reducing shrinkage.

Over 45 ancillary techniques are used, including fluorescence, image analysis and electron microscope analyses. Polished blocks may be adequate if a fluorescent dye is incorporated in the impregnating resin as the block can then be photographed with fluorescent light to show the distribution of the pore pattern.

3. Definitions, Concepts and Features

Fabric, Structure and Assemblage - Fabric is the mutual arrangement and relationship between particles within the soil as a whole and within the various features, while structure is the type and degree of aggregation. The totality of all features in a specimen is called an *ensemble* or *assemblage*. The main fabric relationships seen in thin sections are in the fine earth, including both mineral and organic materials. These may be observed in thin sections but in a number of cases SEM is required.

Fine material – This refers to the material with a diameter of less than about 20µm and which is beyond the resolving power of the optical microscope. It may be arranged as granules, masses, and links between grains or forms a complete matrix. Burnham (1970) suggested seven different ways in which clay particles might be arranged (Plate 1).

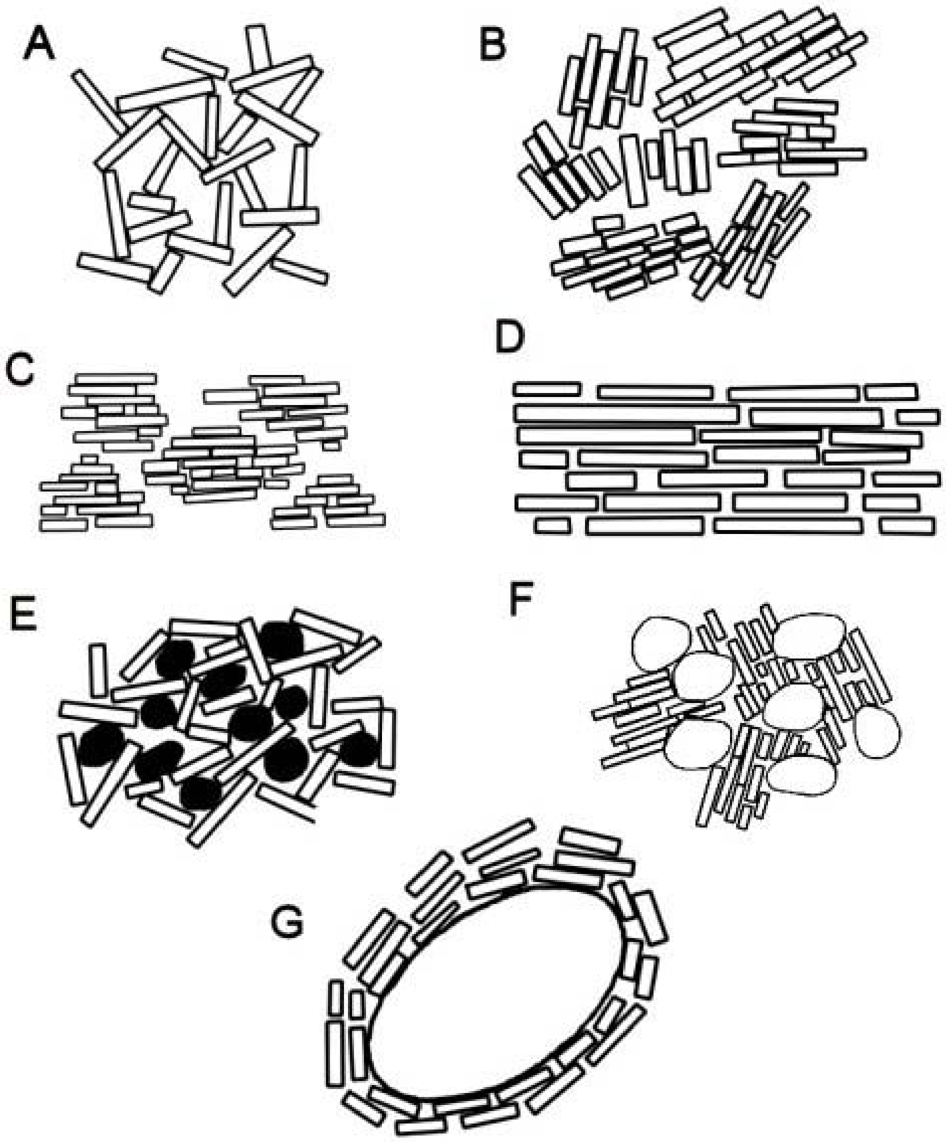

Plate 1. Arrangement of clay particles: (A) fabric composed of randomly orientated clay particles; (B) fabric composed or randomly orientated domains; (C) fabric of domains in parallel alignment; (D) fabric of parallel orientated clay particles with little differentiation of domains; (E) granular particles of iron oxide, organic matter or fine silt interfere with the parallel orientation of the clay particles; (F) randomly orientated domains may occur between grains if coarse silt; (G) large sand particles with clay particles aligned tangential to their surfaces.

Matrix - Material of any size forming a continuous phase surrounding and enclosing coarser particles. Thus, a matrix may be dominantly clay surrounding sand particles or silt surrounding particles of gravel.

Homogeneity and heterogeneity - The concepts of homogeneity and heterogeneity are difficult to apply since a given volume of soil may at the same time be homogeneous with regard to one property, for example color, and heterogeneous with regard to another property such as the sand mineralogy. Even the most uniform soils exhibit some degree of heterogeneity which might be just visible in the field, but conspicuous in thin sections. If, for example, a soil composed mainly of clay has a few grains of silt, and more particularly quartz sand these will appear conspicuous particularly when examined with circularly polarized light.

Recognition of individual features **-** One of the most difficult tasks in micromorphology is the recognition of individual features. Clay particles are themselves individuals; they cannot be recognized with the optical microscope but can only be identified with TEM or SEM techniques. Most thick clay coatings are easily recognized, but thin clay coatings are extremely difficult to identify. The frequency of clay coatings in a given soil can vary widely when estimated by different operators.

Recognition of patterns **-** Probably the most important aspect of micromorphology is the recognition of patterns, not only the pattern of single individuals but also the relationships between the individuals themselves. The types of pattern range from the relatively simple distribution of individual quartz grains to the often complex distribution pattern of clay coatings. Probably the most difficult patterns to recognize are those of the anisotropism of matrices. It is often difficult to describe individuals and patterns. In many cases a true representation can only be achieved with good photographs and diagrams.

Quantification of features **–** It has been shown that over 20 cores with two thin sections from each core are required to characterize quantitatively coatings, matrices, pores and concretions in horizons with translocated clay. However, considerable success is being achieved by the application of many image analysis techniques to thin sections and polished blocks.

Interpretation of features and patterns **-** This is based on a combination of experience, intuition and guess-work. Most workers agree that the majority of clay coatings have been formed by the translocation of clay particles and their deposition on surfaces. They also agree that clusters of calcite and gypsum crystals have been formed by the translocation of calcium bicarbonate and calcium sulfate and crystals growth. However the interpretation of some concretionary material in very old tropical soils is extremely difficult.

Confirmation of the interpretations will probably require experimentation. It may, however, not always be possible to reproduce in the space of a few weeks or even months, those features that have taken hundreds or thousands of years to form. Some researchers have nevertheless been able to produce clay coatings similar to those found in natural soils in the field, while others have demonstrated that certain forms of matrix anisotropism can be produced by stress and shearing.

Properties of features and minerals **-** The main properties are: color, prominence, size, shape frequency, roundness, sphericity, surface characteristics, boundaries, distribution pattern, relationships between features and orientation. It is beyond the scope of this chapter to present fundamental mineralogical data and principles (For more details see *Soil Mineralogy*) but it is imperative that all soil micromorphologists have a thorough grounding in mineralogy.

It is also beyond the objectives of this chapter to discuss the mineralogical properties of rocks. However, their morphology may indicate a good number of relevant diagnostic processes, in particular because rock fragments often form nuclei. It is also common to find rock fragments with coatings and/or pendants of calcite. Another common feature is the occurrence of a thin coating of silt on the tops of stones and peds, used as evidence for active or relic freezing and thawing.

4. Mineral Soil Material

4.1. Primary Minerals and Particle Size Classes

The mineral material in soils ranges in size from the very smallest particle, such as single grains of hematite >0.1 µm in highly weathered tropical soils up to the largest erratic boulders found in glacial drift or core stones in weathered rocks. The origin of these components may be different but they are part of the soil system.

It is noteworthy that hematite and large erratics occur in some glacial deposits and soils in north-east Scotland derived from Old Red Sandstone. The shapes of the large separates often give a clear indication of the processes which have influenced the formation of the parent material and/or the soil itself.

Sand varies in shape from smooth and rounded to rough and angular. Smooth and rounded shapes are found in wind-blown materials and beach sands, sub-rounded grains occur in alluvium and beach deposits, and angular grains dominate in glacial deposits.

Minerals in a strongly weathering environment usually develop a variety of forms as determined by the nature of the weathering and the crystal structure of the mineral. Silt grains for instance are invariably irregular in shape. The shapes of some particles are controlled largely by their structure.

The primary micas and chlorite keep their marked platy form in all size fractions and the amphiboles always tend to be fibrous. Some of the hard resistant minerals such as zircon tend to retain their euhedral form, even after prolonged weathering, but they do loose their form when subject to strong abrasion.

The particle classes have different degree of mobility within the soil. The large separates tend to be very mobile under arctic conditions where they are readily heaved by freeze-thaw processes. Silt and clay fractions are easily translocated and are very mobile soil components being readily moved by earthworms, enchytraeid worms, termites, ants, insect larvae and in suspension.

The clay fraction is often considered as being the most mobile and forms clay coatings, but by far the greatest amount of material is translocated by the soil fauna including earthworms and termites. Therefore, thin sections should always be carefully examined for any evidence of movement particularly by biological processes.

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Bibliography

Bouma, J., Jongerius, A., Boersma, O.H., Jager, A. and Schoonderbeek, D. (1977). *The Function of Different Types of Macropores during Saturated Flow through Four Swelling Soil Horizons.* Soil Science Society of America Journal, 11, 945-50. [A very interesting experimental approach to the study of water movement in soils].

Brewer, R. (1976). *Fabric and Mineral Analysis of Soils*. Robert. E. Krieger Eds., New York, pp. 482. [Comprehensive treatment of soil micromorphology with new terminology; at first quickly accepted but little used at present].

Bullock, P., Federoff, N., Jongerius, A., Stoops, G. and Tursina, T. (1985). *Handbook for Soil Thin Section Description*. Wain Publications, pp. 152. [Comprehensive publication for thin section description, used extensively but with some difficult terminology].

Burnham, C.P. (1970). *The Micromorphology of Argillaceous Sediments: Particularly Calcareous Clays and Siltstones*. In: Osmond, D.A. and Bullock, P., eds, Micromorphological Techniques and Applications. Tech. Mono. No.2, Rothamsted Experimental Station, 83-96. [A good theoretical basis for clay particle arrangement].

FitzPatrick, E.A. (1984). *Micromorphology of Soils*, Chapman and Hall, London and New York, pp. 433. [A fully comprehensive treatment of soil micromorphology including methodology and applications].

FitzPatrick, E.A (2005). *Soil Microscopy and Micromorphology*. CD, Interactive Soil Science, Aberdeen, www.interactivesoils.com. [A fully interactive and comprehensive program lavishly illustrated. This is the electronic version of a book of the same name].

Goldberg, P. (1983). *Applications of Micromorphology in Archaeology*. In: Bullock, P. and Murphy, C.P. (Eds), Soil Micromorphology, A B Academic Press, Berkamsted, 139-50. [An example of the application of soil micromorphology].

Harrison, Sir J.B. (1933). *The Katamorphism of Igneous Rocks under Humid Tropical Conditions*. Imperial Bureau of Soil Science, Rothamsted Experimental Station, Harpenden, 79p. [The classical paper on the study of tropical soil weathering – must be read].

Kubiëna, W.L. (1938) *Micropedology*, Collegiate Press, Ames, Iowa. pp.243. [A Classic - the first modern treatment of soil micromorphology].

Mackie-Dawson, L.A., Mullins, C.E., FitzPatrick, E.A. and Court, M.N. (1989). *Seasonal Changes in the Structure of Clay Soils in Relation to Soil Management and Crop Type. I. Effects of Crop Rotation at Cruden Bay, NE Scotland.* Journal of Soil Science, 40, 269-81. [An attempt to show the dynamics of soil structure].

Ringrose-Voase, A.J. and Bullock, P. (1984). *The Automatic Recognition and Measurement of Soil Pore Types by Image Analysis and Computer Programs*. Journal of Soil Science, 35, 673-84. [An attempt to use more objective methods in a fuzzy subject].

Smart, P. and Tovey, N.K. (1981). *Electron Microscopy of Soils and Sediments*: *Examples.* Clarendon Press, Oxford. [A good example of the experimental approach to soil micromorphology].

Steven, I. (1960). *Pedology*. *Clay Orientation in Soils*. Science Progress, 48**,** 322-31.[A standard publication on various types of clay movement and clay orientations in soils]

Stoops, G. (2003). *Guidelines for Analysis and Description of Soil and Regolith Thin Sections*. Soil Science Society of America, Inc. Madison, Wisconsin, USA. pp.184. [The update of Bullock et al.; an attempt to compartment a subject that has no fixed boundaries].

Wattez, J., Courty, M.A. and MacPhail, R I. (1990). *Burnt Organo-mineral Deposits related to Animal and Human Activity in Prehistoric Caves*. In: Douglas, L.A (Ed.), Soil Micromorphology, Elsevier, pp. 431-9. [A good example of the application of micromorphology in archaeology].

Biographical Sketch

Ewart Adsil FitzPatrick is a retired Senior Lecturer in Soil Science in the University of Aberdeen. He holds the Diploma of the Imperial College of Tropical Agriculture (DICTA) (1948) Trinidad, West Indies; and a PhD in Soil Science (1951), University of Aberdeen. He was leader of the very successful Aberdeen-Spitzbergen Expedition 1954 to investigate the relationship between permafrost and indurated layers in the soils of Scotland. He was awarded the Kubiëna Medal in 1996 and made a Fellow of the Royal Geographical Society of Scotland in 1999. One of his research students was awarded the British Society of Soil Science silver medal 1989.

He has been active for fifty-five years both in teaching and research in Soil Science mainly in the areas of pedology, including micromorphology, and soil classification. He has over 90 publications including seven books, four of which have been translated into Spanish and one into Chinese. He has also produced three interactive CDs.

His work has involved visits to numerous countries including nearly all in Europe, Russia, Australia, Argentina and the USA.

He has had research students from many countries with projects on their soils.