A. JONGERIUS (Editor)

SOIL MICROMORPHOLOGY

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Proceedings of the second international working-meeting on soil micromorphology

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EDITORIAL

At the conclusion of the editorial work, I wish to thank all the members of the Dutch Soil Survey Institute who were concerned with the preparatory work for this book. Without the enthusiastic assistance of the type room, drawing office and photography section, the editor could not have completed the work in time.

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Without their financial assistance, it would have been impossible to publish all the presented papers in their unabridged forms.

INTRODUCTION

In the early part of the thirties, Prof. Dr. W.L. Kubiena introduced microscopic and stereo-scopic investigations of undisturbed soil, and thus a totally new and, for the further development of soil science, very important research conception was born.

The work of Professor Kubiena has richly borne fruit. His enthusiasm and his very many publications have induced many people to practice soil micromorphology. Particularly after about 1950, the importance of this branch of soil science increased rapidly and hence the need for contact among the various workers. This resulted in the First Working-Meeting on Soil Micromorphology, held in 1958 in Braunschweig–Völkenrode (Germany) and organized by Prof. Dr. H. Frese and Dr. H.-J. Altemüller, both of the Institut für Bodenbearbeitung der FAL.

Every since, soil micromorphology has made progress in many respects. The number of micromorphologists has increased, new fields of investigation have been entered, old ones extended, new methods developed, etc. Therefore, at the request of Professors Kubiena and Frese and Dr. Altemüller, a Second International Working-Meeting on Soil Micromorphology was organized, this time in Arnhem, The Netherlands. Professor Kubiena presided at the meeting.

The papers presented at the second Meeting are collected in this book. As was the case with the contributions to the first Meeting, these papers cover many facets of micromorphologic research.

The first group of papers concerns micromorphologic investigation of decomposition of organic matter and humus formation as well as microscopic biology. Since 1958, these topics have made great strides.

The second group consists of many papers dealing with the "classical" topics of soil formation and soil classification. It is gratifying to see that so many soils from nearly all over the world were discussed. It is obvious that with the aid of micromorphology, insight into the said topics can be extended considerably.

The third group consists of papers dealing with micromorphologic results in the field of paleopedology.

As to methods, preparation techniques and micromorphometrics were accentuated in 1958. Several papers in this book show that especially concerning the latter topic, considerable progress has been made since then. Amongst others, it is now possible to characterize soil structure very exactly with the aid of micromorphometry. Other remarkable developments are the application of phase contrast microscopy to thin section investigations and the progress in colour photography.

Regarding the possibility of the application of micromorphology to that part of soil science which is directed at agricultural practice, gratifying developments have begun, as appears from some of the papers. The same can be said of non-agricultural soil science, viz. soil mechanics.

The participation in the Meeting, both concerning the number of nationalities represented and the number of participants, was greater than in 1958. This is also apparent from the number of papers. The published papers of 1958 amount to 28, and now to 46; in 1958, the authors represented eight nationalities, and now thirteen. This is partly a result of the contributions of colleagues from Australia, Canada and New Zealand, and partly because of the growing number of European countries where micromorphology is practised.

We may repeat that micromorphology and its applications have been strongly developed during recent years; nevertheless we can state that this is just the beginning. Without a doubt, soil micromorphology has a great future.

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We owe this fortuitous working-meeting to a series of favourable circumstances. One of these arose from the fact that the town from which this meeting is being directed disposes of two independent research departments of micromorphology. Wageningen has become a center of micromorphological research which is able to give much stimulation to the visitor, be it in regard to equipment, new techniques or particular research projects. This is due to the ability of a man who disposes of a particular talent for organization and who has kept all of us vigorously involved in preparing the meeting. He has given valuable new impulses for the collaboration of the different working branches. The research department established by Dr. A. Jongerius is one of the best-equipped at present. However, its particular importance is due to the fact that it belongs to the Dutch Soil Survey Institute, directed by Dr. F.W.G. Pijls. It is therefore devoted to a particular specialization, a purpose guided by continuous practical requirements. It is able to satisfy these requirements, as can be seen by its rapid growth, by the esteem it is held in, and by the popularity which micromorphology has gained in The Netherlands during the last decade. The department of Micromorphology of Ir. S. Slager belongs to the Institute of the former Professor Dr. C.H. Edelman of the State Agricultural University of Wageningen, whose early death has been a very great loss to all of us.
Dr. Edelman as a scientist has seen his goal to be to help man and therefore he always gave preference to that which increased productivity, diminished need and raised prosperity. It has been a great and noble goal. We may ask today what might has caused him, in this connection, to see micromorphology as a tool to attain it. We know that his main interest has been research of soil structure and, in collaboration with S. Slager, the application of particular methods to field soils. Why is it that he and so many other soil scientists working in the most varied branches, have increased more and more their interest to micromorphologic research within the last decade? Is it the mere application of the microscope as a working tool? Is it the mere application of microscopic techniques? Or is it more than that, and if it is, will it bring about new results and new possibilities of research for soil science? Would soil science develop in the same way without soil micromorphology? Would it attain the same standard of knowledge if micromorphology had never appeared? These are the questions which I shall try to treat and answer in the following article.

NATURE OF MICROMORPHOLOGIC RESEARCH

Which is the principle of micromorphology? We should not be too afraid to use the designation morphology. This term, created by J.W. von Goethe, designates the science of the form and of natural formations in general, including the causes and laws of their genesis. But where in soil science (apart from profile morphology) have properties, laws or genesis of form ever been in question? For my students I used to apply a particular analogy in order to make the morphologic principle of research understood: soils in their multiplicity, their variability of dynamics and biology, are comparable to watch works of very different constructions. We are able to investigate a watch in very different ways. We can put it into a mortar and pound it to a very fine powder. The chemical analysis of this powder gives us complete information on the nature and quantity of the different metals used for the construction of the whole, and perhaps also on the nature of the stones which fill out the pivot bearings. Of course this analysis cannot tell us anything about the existence of the numerous small driving wheels and checking wheels, the kind and number of springs, screws, fuses, pivots, chain links, levers, small metal wires, bridge elements, etc. of which the works of a watch are composed. For this purpose a mechanical analysis would be necessary which would sort all these isolated components (and not only according to size), and investigate them either in groups or individually. It is easy to understand that by this analysis it will not be easy to conclude from the nature of these isolated components the function of each of them or from this the function of the whole, or to establish a hypothesis of the connection of the individual elements in the whole. A third mode of analysis of such a watch would investigate its works without destruction, endeavour to examine every part in its place and determine the nature of their connection. This would be necessary to conclude their function from a better basis. There still exists a fourth possibility for analysis, and that is to investigate the works in a state of motion and to examine their elements, their position and their role in the course of action and counteraction.

The principle of the last two modes of analysis represents that of micropedology, i.e. the pinciple of undisturbedness and the principle of functional investigation, in part by direct observation of function. The soil is also an object which is in a state of constant change and whose interior is in constant motion. The fact that the investigation of the soil by these principles at the same time represents microscopic research is necessarily caused by the facts that the individual elements of the soil only become visible under the microscope, and that the deciding events take place in microscopic dimensions.

Is the comparison with watch works a correct one, or does it rather complicate the matter? It is a very simplified comparison, for the soil is much more than watch works; it is a whole world which differs from ours only because it is one of much smaller dimensions. We would not know more of our own world if we could only see it from the distance of the stratosphere. The soil is an organized space of life like our own living space, a "living system", as S.A. Waksman puts it. In spite of this, our picture of the watch works allows us to show the essence of the morphologic principle.

Morphology refers not only to the inanimated world as in the case of geomorphology, but also to the animated and living world. The term had originally been created by Goethe in the sense of morphology and morphogenesis in the development of organisms. Only later did it obtain the wider, present meaning. In soils the organic part, in its final effects, cannot be separated from the inorganic one. How far this interlacing of the inorganic and the organic takes place, and how important it is for practical soil science, could only be fully shown by micromorphology. I shall therefore particularly come back to this subject later on. Micromorphologic research because of its name, can easily be taken for one whose mission is only to describe forms and structures, and whose final goal is completely absorbed in the establishment of a kind of histology of the soil or a doctrine of structure. To be sure, micromorphology deals with soil structure to a great extent, and it owes many valuable results to this fact. However, a glance at the great multiplicity of subjects encompassed by our working-meeting shows that it is by no means completely absorbed in it. It encompasses nearly all branches of soil research, from soil microbiology, soil zoology, humus chemistry and soil weathering to soil mineralogy and soil micromorphometry. The connection between them is easily understood if we think of our comparison with the watch works. We are not contented with the mere investigation of the composition of the works, but also want to know their function and the role of every element in the operation of the whole. For micromorphological research the soil not only represents a composition of constructural elements, but also a composition of organisms, and finally a composition of biological, chemical and physical processes. This manifold but always characteristic framework of the most different components, phenomena and events, which only in its particular combination forms the entity of a soil, this organized multiplicity to investigate, is our mission, each in his own specialization.

THE MORPHOLOGIC PRINCIPLE

The many-sidedness of our work and the great variety in specialization of the members of our congress lead us to understand the concept of the morphologic principle. If the composition of the phenomena to be investigated is given from the beginning by nature, we can never get hold of it by some kind of synthesis but only by continuous analysis. A mineralogist not working according to the morphologic principle will state that a soil contains considerable amounts of goethite besides plenty of amorphous iron hydroxides. A mineralogist applying the morphologic principle will try to determine in which parts of the microscopic fabrics of the soil the crystal aggregates of goethite are precipitating, in which form they are deposited, in which development phases they pass to their final stages, by which macroscopic environmental conditions they are produced, or to which particular circumstances within the microscopic soil fabric they owe their formation. A soil zoologist not working according to the morphologic principle, but wishing to investigate the particular fauna of a special soil variety, will determine those forms which seem to be typical for that soil by a comparison of species lists. A soil zoologist investigating the same soil variety according to the morphologic principle will determine the animal species most typical for it by more or less direct research in the interior of the soil; he will select the most interesting animal forms according to the importance of their biological efficiency; he will follow their life customs, investigate their living spaces, their environment and food requirements, their role in the decomposition of particular plant and animal residues, in the humification of decomposition products and their binding of inorganic components of the soil.

The micromorphologist sees undisturbed entities, or at least undisturbed sections of them, in the soils. The only reality which offers everything to him is the undisturbed and living soil in nature which has been left in its corresponding environment. Several specialists see the necessity to begin their work in the interior of the soil in nature by the application of direct microscopy, and to return again to the place where they started. Frame samples are sections of pedological entities, as are thin sections and microtom sections prepared from them. It is essential for the method of the micromorphologist that he searches for the entity so that he can see it with his eyes and conceive it in its reality. Every insight into a thin section which the microscope reveals to him allows him to recognize the integrity of the fabric. He does not only see all that which is already known to him, but also that which has resisted research up to the present. The unknown and unexplored stimulates him and reminds him constantly of what is missing for an understanding of the whole. The undisturbed framework of building elements and functional efficacies of the soil therefore have a particular organizing faculty for entire soil research. It is like a register in the form of a net pattern of lines, in which the investigator may put all his results, and in which the empty spaces give notice of what remains to be cleared up by himself or his colleagues. His kind of registration, however much it can take place only in the spirit, will always be done at a predetermined point, i.e. it will be produced with full precision and not at any imprecise or hypothetically assumed spot.

Micromorphology needs a great number of particular research techniques. However, it has not only taken over techniques from other natural sciences or adapted them for its purposes from petrography, metal microscopy, plant anatomy, microbiology, microchemistry and microphysics, but it has also created numerous techniques of its own. How much this particular branch of micromorphology is still developing will be noticed in a series of particular contributions to our present meeting. But the micromorphologist does not only need particular techniques for his work, for in most cases he also finds himself in a position to apply other new ways leading to knowledge. The microscopic techniques allow him to perceive an overwhelming number of unknown details. Where should he begin with his investigation? The beginner tends to lay hold of all, to describe all he is able to distinguish. But such descriptions are tiring and will scarcely be read by anybody. It is very important for the micromorphologist to select *the essential* from an abundance of material, and to present it with particular emphasis. Essential criteria are found by continuous comparative investigations of a multiplicity of soils. It is a matter of finding the particular, unequivocally typifying criteria; this kind of research follows the *principle of differential diagnosis*.

However, this *principle of comparative investigations* must be applied for the investigation of any microscopic phenomenon for a number of soils.

It will always be a matter of the entire spectrum, consisting of different stages of development or different variations produced by environmental conditions of differing intensity. Every phenomenon presents itself in weakly pronounced, typical, and degenerated phases. They are all generally recognized easily by their well-marked and strongly differentiated micromorphology. To the micromorphologist the soil collection in most cases is not a set up for exhibition but working equipment, one of the most important details of his research department. Of similar importance is his collection of thin sections to which he can return at any time when new questions arise.

All these new techniques, implements and principles of research must lead to new results. The novelty of the results, the unusuality of the newly found characters, present their main feature; the methods of micromorphology and micropedologic biology do not replace the current macrochemical and macrophysical methods, but at the same time they themselves have become irreplaceable. Of particular interest to us is the value of the results, their role in the progress of soil science, and the possibilities they open for its further development.

SOIL LIFE AND HUMUS RESEARCH

Beginning wit soil life and its effects on humus formation, we can already point to an important achievement: the thin section of humus formations permits like no other means the recognition of the biological efficiency of a soil or habitat in a most clear and simple way. This refers to the decomposition and humification of the organism residues, to the kind and intensity of the combination of humus substances with inorganic components, and to the biological influence on structure formation. In view of the clearness and great efficiency of these possibilities, it is surprising that humus thin sections have not yet found common application in the practical taxation of soils and habitats. Most suitable for taxation purposes is the investigation of super sections which are 10–15 times larger than normal preparations (generally 6 x 8 cm, i.e. the size of the sample frame). In most cases they allow the examination of the entire humus layer including förna, F- and H-horizon in a single preparation (vertical section). If the preparation is produced automatically by grinding machines, it does not take any particular effort to cut an impregnated frame sample at intervals of 5 mm in horizontal plates, and to prepare a separate thin section from each of them. The valuation of the intensity of biological decomposition and humification is firstly performed by the determination of the humus form. Since every humus form corresponds to a particular biology, it is an expression of the mode and intensity of decomposition and humification of the organism residues and fixation of mineral substances at the same time. Micromorphology can claim that only by its principles has it been possible to succesfully continue the development of the doctrine of humus forms, initiated in very fortunate manner by P.E. Müller. The investigation of thin sections, as well as investigations in the field of micropedologic biology, permit a much more detailed analysis and a much more exact distinction and determination of humus forms than former methods. While Müller distinguished three humus forms, at present we know of at least eighteen easily distinguishable and identifiable humus forms and varieties, as given in my last review on the subject: *The Soils of Europe*. The further completion of the taxation of soils and habitats is possible to every advisor by comparative micromorphologic analysis. They allow him to establish particular efficiency and valuation scales for the soils of his working district. By the use of morphometrical methods, a valuation by quantitative methods will also be possible in the future.

Humus research, in my opinion, has received a series of new and decisive impulses from micromorphology. As the most important ones I would like to cite the following:

(1) Micromorphologic analyses have stated that in all biologically active humus forms the soil fauna represents not only the accompanying, but *the decisive agent* of decomposition and humification. Coprogenous and non-coprogenous humus micromorphologically is nearly always easy to distinguish. The knowledge of dropping forms in general allows one to recognize the role of particular animal groups in the decomposition of organism residues. In the coprogenous part of the humus better decomposition and humification dominates by far. Valuable humus forms are inconceivable without the particular participation of the soil fauna in their genesis. The soil fauna is also entirely responsible for the mixing and combining of the organic substance with inorganic parts of the soil.

(2) Micropedology can show up in detail the dominating role of the soil fauna in humus formation. Morphologically specialized zoology is able to study the role of every decisive animal form in the transformation of organism residues. This goes so far that even the succession of different animals and their effects in decomposition can be determined. The research method has been completed particularly by G. Zachariae, who primarily applies the investigation of super sections combined with observation in situ and in vivo.

(3) The method of micropedology allows one to investigate the biology and effectiveness of soil fungi and actinomyces in situ and in vivo. It permits, within microscopic dimensions, the determination of their claims in regard to environment conditions, food requirements, their antagonistic effects and their role in the decomposition of particular organic substances and tissue elements. At the same time, it could be testified that fungi in the soil produce particular forms of growth which are different from those developing in artificial media. Mycological soil studies are essentially facilitated by micropedology, for through the aid of micromanipulation (by hand or apparatus) conidia, spores and fragments of mycelium can, without particular effort, be directly transferred from the soil space to artificial media for the preparation of pure cultures. In addition, by the microscopic analysis of thin sections the development of soil fungi and their effect on the decomposition of tissue elements can be investigated advantageously.

(4) With the aid of debris preparations and microtome sections, micromorphology allows one to examine the decomposition products and humic substances in humus forms by direct investigation, i.e. without the extraction and application of solvents. Their determination or characterization can be achieved by dye reactions, microchemical tests or micro-optical methods. Because of the preserved morphological connection, continuous comparative investigations permit one to not only determine the origin of the decomposition products, but also to follow the genetical sequence of transformations.

(5) From micromorphological investigations, it could be testified that the importance of soil fauna applies not only for their dominating role in humification, but also for their role in structure formation in the same way. Almost all aggregate formation in the soil is produced by the action of soil animals. This influence is not limited to the humus horizons, but also refers to the (B)- and B-horizons. In addition to aggregate formation, a similar influence can be stated in the space formation. The only non-biological aggregate and space types of structure-forming character can almost only be found in the form of fragment structures (produced by a decrease in volume when drying), crumbs in earthy rotlehm (by "rote Vererdung"), and aggregates and endurations produced by lateritic precipitation.

SOIL BIOLOGY AND SOIL TYPE[1]

Soil science has an immense amount of microbiological and pedozoological publications at its disposal. But the material available would not suffice to explain the particular biology which contributes to the genesis of particular soil types. Up to now textbooks of soils have brought either nothing or only very general notes on the characteristics which allow one to distinguish the biology of a podzol, braunerde, pseudogley, tropical braunlehm, solonchak, solonetz, smonitza, chernozem, sierozem, dystrophic, oligotrophic, eutrophic and sapropelitic anmoor from each other. We know that all these types show particularly great contrasts in their soil life, and that their humus formations have been developed to very striking products of these differences, but our biological knowledge in this respect is very limited. Since the essence of the soil consists in its being a biological system, soil science will remain incomplete without that knowledge. Soil science urgently needs the development of a particular working branch for its progress: the *special soil biology*, the biology of the soil types, sub-types and varieties. Such a particular working branch cannot confine itself to only species lists and organism numbers of soil types, because in this way nothing is yet said on the soil life itself, or on the effectiveness of the different organisms involved. But, in view of the tremendous abundance of organism forms and the high numbers of organisms in most soils, how can such research be performed? Would the life of a scientist be sufficient to conceive the biology of even one single soil profile? Could a summarizing synthesis of the biologies of the different organisms of the soil - without considering their mode of combining with each other and without knowing their mutual checking and stimulation - ever lead to a real knowledge of the entire biology of a soil?

It was necessary to develop this pessimistic picture in order to point out the particular role of a micromorphologically oriented biology of the soil, and its indispensability for modern soil science. The picture of a great abundance of phenomena, and of an overwhelming predominance of details, is the same here as in the other branches of micropedology. The mode of overcoming these difficulties, with the application of the same methods,

[1] The expression "soil type" is used in the original sense of W.W. Dokuchaev, and represents an equivalent to "great soil group".

is as possible here as there: micromorphologically oriented soil biology does not start from a species list and organism numbers, no matter how useful they otherwise might be, but from the biological investigation of the most important decisively characterizing phenomena. In what manner this becomes possible will be demonstrated in papers of both microbiological and zoological specialists in the course of this meeting. A special soil biology can only start from the micromorphology of the soil. Tracing the essential biogenic phenomena, it examines the course of their genesis by direct investigations in the interior of the undisturbed soil, and the effectiveness of the organisms decisively involved. Its goal is not a synthesis of results obtained outside the soil, but the analytical investigation of the natural entanglement of the processes. It can confine its investigation to any limit desired, since the smallest contribution of this kind will also represent a section of the real soil life and elucidate a point of its framework. In reality this kind of research has already begun. Its progress, a great deal of which depends on the general progress of soil science as an independent natural science, will be determined only by the number of microbiologists and zoologists working in this particular branch of soil biology. The specialization of their research requires that they also devote their interest to micromorphology and humus research at the same time. In this connection, it can be said that progress in the knowledge of humus forms will also depend greatly on the investigations of such morphologically specialized microbiologists and zoologists.

MICROMORPHOLOGY AND SOIL SYSTEMATICS

Systematics always represent a touchstone for the stage which a science has reached corresponding to its phase of development. In opposition to a classification, which serves particular purposes of practical application and which according to their specialization imposes intentional simplifications, systematics see as their goal the establishment and further evolution of a general system able to connect all branches of specialization, in short, all sciences dealing with soil research. My predilection for soil systematics has particularly fostered my predilection for micromorphology. The latter has given to every scheme of division, be it classification or systematics, the knwoledge of a number of very characteristics soil properties, unknown up to the present. In most cases where doubts arise as to where to order particular soil forms according to conventional properties or profile morphology, micromorphological analysis can bring the decision. In my opinion an up to now unattained perfection of insight into the inner construction of a soil has brought to all soil research the very decisive knowledge that not only every soil type, sub-type and variety, but also every one of their horizons, corresponds to a particular microscopic fabric. The pattern presented by a thin section is characteristic for a soil type in the same way as its profile. However, it does not simply represent an additional means for its characterization, it reveals entirely new aspects of the innermost essence of a soil. I am of the opinion that there exist whole groups of soils whose different forms can be unequivocally be distinguished only by the aid of micromorphology. Complete evidence in this respect exists in the case of