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New advancements, applications, and prospects for micromorphology of soils

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It is a special pleasure for us, inspite of all difficulties, to be able to meet at this relatively early date. We have to thank Poland and the personal initiative of Professor Dr. Stanisław Kowaliński who have taken over the organization and the direction of a new International Working-Meeting of Soil Micromorphology on Polish territory.

This meeting is of special advantage to our branch of science. Permit me to express, in the name of all the participants, our heartiest thanks to the competent authorities and persons as well as to our highly esteemed colleague, Prof. Dr. S. Kowaliński. Poland is a new country to many of our participating colleagues. Therefore, for many of us it may be an exciting experience to be able to look at Rendzinas in the country of origin of Rendzina research, as well as to specifically see other Polish soils. It is most favorable for us that Prof. Dr. S. Kowaliński has not only inherited the enthusiasm of his teachers and predecessors for soil science, but also that he became a passionate soil micromorphologist. Here in Poland he established micromorphological investigation and in Wrocław he built a modern research division. Therefore, the best preliminary conditions exist for our convention. Moreover, Poland is a country which in general has much to give, such as its beautiful landscapes, its old culture and its folklore. I am convinced that we will take with us unforgettable impressions of our residence and our excursions here. There is another thing that we shall have to gain from our meeting. In our preceeding meetings the participation of our Russian colleagues has never before been as large as it is here. Of all those countries which are able to refer to a special development in micromorphology, Russia is very much in the foreground because of the large number of publications on micromorphology. Therefore, the possibility of close contact with the Russian micromorphological research is especially valuable to us. That is to be similarly taken for Czechoslovakia where in the last few years Soil Micromorphology has also been strongly developed.

NEW RESULTS OF MICROMORPHOLOGICAL METHODS

Since our last working meeting in Arnhem, Soil Micromorphology has considerably gained in interests. This is expressed by the creation of new working centers in all parts of the world. Including the formerly established working centers, there are now about one hundred. To me personally, about sixty are known. Its development is also characterized by a considerable advancement in new methods and techniques made possible now by the service of new tools. The determination of many organic and inorganic constituents formerly difficult to determine in thin sections have now become possible. I especially want to refer here to the results of our colleagues Dr. H.–J. Altemüller and Dr. U. Babel. Great advancements are achieved in the domain of microscopic soil biology. As it has been possible for us up to now to see mycelia, diatoms, and filamentous algae, so also has Dr. H.–J. Banse of Völkenrode succeeded in perfecting a dyeing method which makes it possible to make bacteria visible in a thin section. By this the most necessary possibilities for micromorphological research are nearly reached, if we see the principal task of micromorphology in determining the composition of the fabric elements in connection with their particular morphology, in investigating their association, genesis and transformation as a function of the environmental conditions, dynamics and biology of the soil. I think we must not forget to mention the great possibilities given by the direct microscopy of the living and undisturbed soil *in situ*. Also in this respect, new and fascinating insights into the microscopic soil life could be obtained. Dr. G. Zachariae (Freiburg i. Br.) could, among other achievements, very convincingly demonstrate that there exist close interrelations between the life of the soil organisms and the microclimate in the interior of the soil cavities. Particular investigations with the help of special apparatuses have made it possible for him to state that the soil life under certain conditions is able to create its own favorable microclimate.

Extraordinary possibilities for our research are given to us by the new Scanning Electron Microscope which was constructed in Cambridge. I remember very much the great impression of the first pictures produced by this instrument occasionally a lecture of Dr. T. R. Gray of Liverpool two years ago at Rutgers University in New Brunswick on his own investigations. With this microscope one obtains three-dimensional pictures in which even single bacteria can be seen on the surface of a sand grain in the soil. We shall be by this unique instrument in the position to perform complete fabric analyses and direct microbiological investigations in very unusual dimensions only accessible to electron microscopy. We always shall have to begin with our light microscopes and our conventional microscopic investigation as we always had and shall have to begin our work with the macroscopic profile morphology. However, beyond our micromorphology the Scanning Electron Microscopy will open the doors to an additional, entirely unknown realm of research and essentially increase our knowledge about the finest details of the construction as well as of the ultramicroscopic dynamics and biology of the soil.

MICROMORPHOLOGY AND SOIL FERTILITY

The field of micromorphometry, the quantitative micromorphologic analysis has gained from the introduction of new techniques by Drs: Altemüller, Babel, Beckmann, Borchert, Geÿger, Jongerius and others. They serve in the first place agricultural, forestrial and technical soil science. In the beginning limited to quantitative determinations of space content and aggregate formation, new properties have been included in the meantime, like the relation of aggregate and cavity forms, the content of animal droppings, of undecomposed plant residues, of the rounding degree of aggregates (of glauconite), of quantitative mineralogical analysis, of the degree of weathering and others. However, micromorphometric analysis has not an end in itself. It is a part of the micromorphological investigation and has its purpose to get hold of determinable quantities of characters, the knowledge of which is of special importance. It is the essence of micromorphological soil investigation not being limited to the determination of single properties but serving to the knowledge of the entity formed by the synthesis of the single characters. It is a unique possibility in soil investigation to investigate the characters in the natural connection. This possibility can be regarded as of great importance for practical soil science. We are conscious today that the knowledge of the quantities of available nutrients in the soil, like nitrogen, phosphoric acid, potassium, as such is not giving us complete security about the effect of the application of fertilizers based only upon investigations in this respect. The effect of the given doses of fertilizers depends also on a number of other factors which are in addition to the climatic factors also factors of the soil. Investigations on soil fertility of the last decennium have been greatly occupied with the accessory factors of the effect of fertilizers [7]. In extreme cases this becomes evident in a conspicuous manner also without the necessity of closer investigations. Certain Solonetz varieties even with the best provision by plant nutrients may show complete absence of plant growth as a result of their abnormal, dense, unstable structure. We cannot say that we can get knowledge of all accessory factors influencing soil fertility by thin section analysis or microscopic soil investigation in general. But by simple fabric analysis the following characters, which can be recognized in their assemblage, may be listed:

— the grain size relation,
— the open space content,
— the aggregate content,

— the degree of densification (in particular horizons, in the subsoil or in general),

— the stability of the structure (by the aggregate and cavity forms, or by the general tendency of silting up),

— the presence of water stagnation (characters indicating gley, pseudogley formation or anmooric humus forms),

— contemporary lack of humidity (dry-humus forms, humus deficiency, tendency to dust formation by alternating dryness or hardening of clayey soils by drought),

— degree of decomposition of the plant residues,

— degree of humification,

— type of biology (classified by the humus form and its biological value, activity of bacteria, preponderate fungus growth, activity of earthworms, enchytreae or arthopodes),

— intensity of biology,

— nutrient reserves in the soil minerals (ratio between the nutrient yielding minerals and the sterile minerals),

— degree of weathering,

— form of calcium carbonate (if finely distributed or if coarse grained clastic calcite or if completely missing).

This list of accessory factors of soil fertility could be continued although some of the characters are not important for every soil but refer to particular soil types. A certain number of properties allow a quantitative determination by photometrical methods. Which possibilities are given in addition to obtain some expression for the quantity or the intensity of a property or characters?

In every particular soil area or climatical district there will only be the necessity to obtain sufficient knowledge about a particular number of accessory soil factors out of the great variety of possible general information. But still even the rest of characters might be quite numerous. Like in plant sociology and other natural sciences, if quantitative determinations would be too difficult or too timeconsuming, the method of giving estimation values for the accessory factors will be quite useful. A method based on a five-scaled estimation system has been introduced to micromorphologic analysis of thin sections by Dr U. Babel [1]. It could be easily applied also for the estimation of the biological effectivity of soils in agriculture and forestry. The advantage of it is given by the possibility not only to obtain information on single factors, but on a complex of factors. This is important because in nature never a single factor affects a phenomenon but always a group of factors closely interrelated to each other. This fact has been particularly demonstrated by Albert Einstein. After him this cooperation of a group of factors is designated as the "field effect" (Feldwirkung). A "field" in modern physics means after Einstein the totality of contemporaneously existing facts which only can be understood by their interrelation with each other.

The concept of the field effect valids also for soil science. The search after its rules is a particular task of soil micromorphology because it enables, as we said, to investigate a number of factors, properties and facts in their natural connection. Also the effect of a potassium fertilizer does not depend only on the content of available potassium in the soil but also on the space content, the kind of structure, its stability, the water economy, the humus formation, the biological activity, and on other characters of the soil. However, this field of accessory factors is not the same with every soil. It shows characteristic differences. To make these differences comparable, the establishment of particular tables, like those of U. Babel would be advisable. In these tables the accessory factors ordered after their importance, under addition of the estimation values of their intensity or quantity, should be listed. It would be advisable to use also here a five-scaled estimation system.

Investigations with the application of the field principle and micromorphological methods will be in addition applicable for the determination of the suitability of a soil for a particular crop. It would be an advantage for soil advisory service in the tropics — to put out a particular example — to complete our concepts of the best banana-, cocoa-, coffee-, oil palm-, coconut-tree- and teak-soils after the new viewpoints. It has been of particular interest to myself to recognize the advantages of the field principle (in opposite to the testing of single properties) occasionally the investigation of certain soils upon the development of plant diseases in the tropics, particularly the Panama disease (produced by *Fusarium oxysporum forma cubense*) in banana plantations (W. Kubiëna, E. Geÿger, 1967). Also here we could recognize that the field of factors is changing in the different regions and that with some factors a kind of substitution is possible.

Now I would like to point at another field of practical application: to the problem of the recuperation of certain soils of the tropics and subtropics which have become completely unfertile. These soils had been originally humid soils of Braunlehm character. They belong now to regions which have undergone a climatic change which caused also dryness in the soils. But the decisive influence in regard to their sterility has been primarily brought about by destructive soil treatment, by unfavorable crops, excessive and uncontrolled pasturing, destruction of the protective woods, disadvantageous changes in the general water supply and others. By all this the increase of waste-land has become so disastrous that it leads to a great part to a general impoverishment of districts and whole countries. These districts and countries coincide to a great deal with the regions of extreme malnutrition of mankind. The recuperation of the fertility of these soils therefore represents an important measure in the fight against hunger and inadequate nutrition in the world. The raising of the crops of a country produced by her own soils is for the fight against hunger much more important than any help by importation of food from abroad. Also all expectation on an increase of plant production by new bred highly effective plant varieties is without profit as long as in the correspondent development countries the soil area is primarily composed of waste-land entirely unsuitable for any kind of cultivation.

What kind of methods are available to us to make these sterile soils of the subtropic and tropics with alternative humidity again applicable for agriculture? Dr. A. Primavesi, professor of soils of the University of Santa Maria, Brasil, has worked out particular measures for this purpose which he has tested for years in special field experiments in the big waste-land area on the east margin of the semi-dry tropics of Brasil. He could obtain by his endeavourments not only the complete recuperation of the waste-land soils but reached even record crops of wheat on them.

The methods of Primavesi do not follow a fixed scheme but are always adapted to the character of the soil. Therefore his treatments vary from soil to soil and are following their effects which are under continuous control. The primary goal of his treatments is to obtain a stable, well aerated sponge fabric, a revival of the biological activity of the soil and by this an assuring and economizing of the available rains which gives also the possibility to make the best profit of the given mineral fertilizers and vegetable manuring.

We see that the control of the recuperation measures is quite a similar procedure as the searching for the accessory factors of soil fertility by thin section analysis. Therefore no other method will be more suitable to help in the recuperation of the depleted soils than micromorphologic investigation by determining the estimation values of the decisive soil characters. During a stay as a guest professor at the soils institute of Santa Maria it has been possible to me, to investigate thin sections of the tested soils of A. Primavesi, before and after the treatment. It has given me the confirmation that the application for the recuperation of depleted soils may be regarded as one of the most profitable tasks of micromorphologic soil analysis.

Our main task will always remain the increase of plant production for the benefit of mankind. To meet all its requirements much preparatory work must be done. I would like therefore particularly welcome the endeavors of Dr. R. Brewer, Canberra, in the field of descriptive micromorphology which have the goal to lay hold as far as possible on the great multiplicity of microscopic forms in the soil. At the time of our last working meeting, Dr. Brewer's book devoted to this subject had not been published. It appeared in the meantime [2]. It will not be easy to everybody to make oneself familiar with his extensive nomenclature only by his book. Dr. Brewer is ready to make it possible for every interested colleague to acquire a series of about 150 colored slides of fabric details with the corresponding descriptions. It is intended to show these slides in the exhibition of our working meeting.

OUTLOOKS FOR GENERAL PEDOLOGY

Soil micromorphology not only found interest and application in applied soil science but also in other natural sciences such as Pleistocene geology, geobotany, geozoology and soil zoology. It attained particular application in geography so that a number of geographic institutes now have their own independent section for soil micromorphology with complete optical equipment, cutting and grinding machinery, research and technical assistants. Increasing demand of the natural sciences to use general pedology, particularly soil micromorphology, as auxiliary sciences is obliging us not only to work out new possibilities for practical agriculture, forestry and technical soil science, but also to develop new pedological bases of research for the natural sciences. Also in this direction new routes have been opened and new results have been brought forth since our last meeting.

By soil micromorphology a particular working field has been developed which properly speaking has not yet obtained a particular name, nor has it been made apparent nor given a proper definition and delimitation. Though general pedology disposed of genetical systems of soil systematics, of a more or less developed soil geography, of doctrines of soil development and soil evolution, of a paleopedology, of branches of soil microbiology and soil zoology directly engaged in problems of soil genesis, but not of an organized unit of research which is able to unite particular parts of these branches to a special working field without making just a simple conglomerate of them. I refer to this particular working field here with special accentuation because it uses and needs emphatically the principles and working methods of soil micromorphology and would hardly been able to develop successfully without them.

This new working field could be named *geopedology*. This name takes pattern from similar designations in other related sciences. Thus geochemistry is engaged in the investigation of the chemical composition of the earth globe, of the rules of the distribution of the chemical elements upon it, migration and their mode to unite to definite chemical compounds. In a similar way, geobotany and geozoology serve the investigation of the plants and animals in regard to their global distribution, historical development, migration and socialization. We know that soils have a particular distribution and historical development on the globe, which are in close connection with the conditions and the life development of their locations. However, we know that with this the possibilities of soil composition, distribution and genesis are by no means exhausted. These additional possibilities have somewhat complicated soil investigation in our days and have made its results less secure for many critics. However, they have intensified investigations of micromorphology considerably.

Unlike the moon which has largely preserved its form probably through long periods, the face of our earth is subject to continuous alterations. If we only take into account the effect of our rains, we get to the fact that each day about eight millions of tons of solids are removed and carried away into the oceans. We know that by this gradually the high mountains disappear and whole landscapes become leveled and deep valleys carved out. However, we know that much less the solid rocks but much more the erodable soil cover, continuously renewed by weathering, is carried away and transported into the oceans. But this material of the many former soil covers did not get lost. It became first of all deposited in the old or contemporary shelf areas, but it also can be found in the bottom of the lakes or on the river terraces, even in ponds and pools. Far greater masses of former soils are deposited in the oceans than that which covers the surfaces of the continents today.

However, we know also that the oceans show continuous alteration. Their boundaries change and in the course of earth history wide areas of them are free again and converted into dry land. Their surfaces are then not occupied by soils formed *in situ* but by great masses of sediments of former soils, mostly formed under the influence of entirely different conditions as the contemporary soils of their regions. The same can be observed in areas of dried-out lakes, ponds, pools and rivers.

It is of importance to note that at the present time great masses of sediments of former soils form a great contrast in their characteristics to the soils which nowadays are formed from fresh parent rocks. Whereas in our temporate climates as soil *in situ*, primarily Braunerde, Podsols and Chernozems, are formed, soil sediments of previous geological periods, especially when older than of Pleistocene age, show mostly the character of tropical to subtropical Braunlehm or Rotlehm with or without infusions of laterization of pseudogleyization, at which these infusions may show considerable variation.

Can this contrast exactly be defined? Is it possible to recognize the character of the former soils in their sediments? The investigations of a great number of micromorphologists have shown that the character remained surprisingly well preserved in the microscopic elementary fabric of the sediments, also if the destruction of the soils as such had been considerable. These results are of *great importance for paleopedology* because by their aid the former soil covers can be reconstructed in cases when no remnants of soils are present *in situ*. They have *importance for general pedology* because they elucidate obscurities in the genesis of these soil covers and facilitate their exact denomination. They have *importance for practical soil science* because these areas are mostly at the same time areas of intensive farming. They have *importance for se-*

dimentary petrography since the knowledge of the manifold micromorphology of these sediments and its conformity with the microscopic fabric of definite soils, the possibility of an extensive geopedologic exploitation of the statements open a new working field also for sedimentology. They give also a new basis for a more detailed classification and denomination of the sediments and sedimentary rocks.

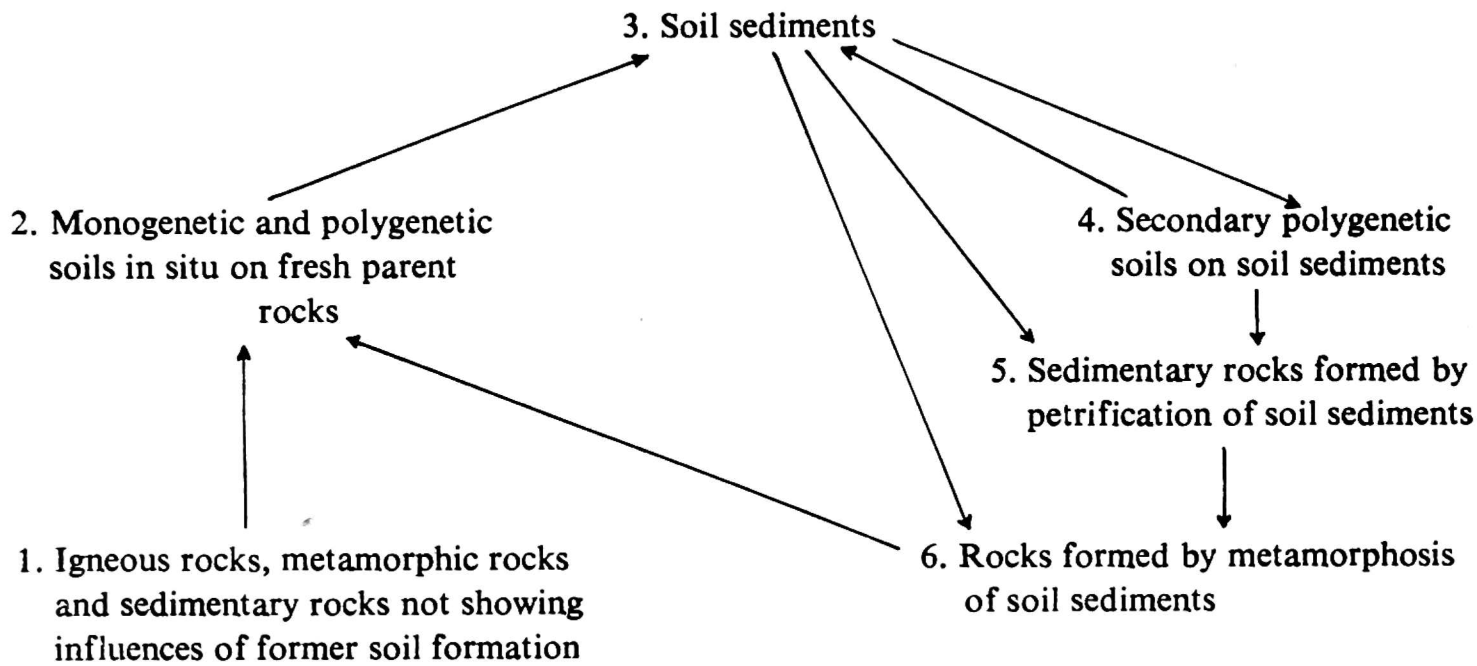
However, the soil sediments show in their new habitats not only the characters which they have obtained during the time of their orignal development as soils but they also show more or less the influences of the recent environmental conditions. By these influences, in addition to the former characters, new ones come into being. The influences of the conditions of the present habitats may be so important that the newly formed characters preponderate greatly over the inherited ones. But they can also be so unimportant that only inferior changes may occur in the micromorphology. In both cases the results allow almost always to reconstruct the different polygenetic phases and their effective environmental conditions.

The composition of the soil sediments, including a great part of their micromorphology (as the elementary fabric), is mainly the result of the former soil forming processes and have decidedly been established before deposition. However, some alterations after the deposition, which are not produced by a secondary soil formation on their surfaces, must be taken into account. They are of particular character and are in general easily recognized microscopically. They are denominated in their totality as diagenesis. Such alterations produced by diagenesis are: the solidification by densification, cementation or aging of mineral gels, the crystallization or recrystallization of fabric components, the transformation of organic layers into coal or bituminous alteration products and others. To know the micromorphologic phenomenon of the different alterations produced by diagenesis is an important task of micromorphology for geopedologic purposes. But it can be already said that in most cases diagenesis does not destroy the fabric produced by former soil formation. In some cases even conservation of it may take place.

A further alteration of soil sediments and remnants of soils may be produced by metamorphosis. Former humus layers, like coal beds, are transformed by metamorphosis into graphite strata. Graphite in crystalline schists goes mostly back to former inclusions of plant residues in ancient mineral soils. Accessory minerals, like large accumulations of magnetite, may indicate former sulphite-rich Sapropel formations. All soil sediments of the ancient oceans will be present today in the form of gneises or other crystalline rocks. Partly migmatite formations may be produced by intrusions of magma.

In general, it can be seen that geopedologically there exists a kind of rotation of which a presentation has been tried by the following table.

Scheme of the geopedologic transformation products, their distribution and genetic interrelations



On the parent materials not yet altered by former soil formation processes (1 and 6), the soils *in situ* (2) are produced (by passing through their characteristic development stages). They may be of monogenetic nature (for instance Braunerde on granite) or of polygenetic nature (for instance Braunerde on granite but developed by an earthening of relict Braunlehm residues of Tertiary age as a result of a decisive climatic change). These soils *in situ* are more or less open to soil erosion and are in the history of the earth sooner or later carried away by flowing water, by the movement of glaciers or by wind action and deposited in the form of soil sediments (3) in relief depressions, river terraces, lake bottoms or in the shelf regions of the oceans. These soil sediments can be transformed to solid sedimentary rocks (5) by diagenesis. Loose soil sediments may have as such already considerable soil character and may be regarded and used as soils. But they may give rise to entirely different soil formations if the environmental conditions, particularly in regard to climate, are changing (4). However, also they are open to soil erosion and sooner or later again their transformation into soil sediments or even, if solidified, into sedimentary rocks takes place.

It can be said that among the geopedologic transformation forms of the Pleistocene or even of the Tertiary as well soil *in situ* as soil sediments can be found. Relicts of soil *in situ* profiles of the Tertiary have almost always lost their original A horizons, in many cases also their B horizons, so that only the character and the micromorphology of the (B)lC horizon allows the identification of the former soil character. Among the geopedological transformation products of the middle to lower Mesozoic formations *in situ* of the former terrestrial soils are completely missing so that the former soil types can almost only be reconstructed from soil sediments or corresponding sedimentary rocks. The same counts for the soils and transformation products of the Paleozoic with some particular exceptions. By the influence of the diagenesis of subaquatic and semiterrestric soils, even the humus horizons may be found in relatively well preserved conditions, as with the coal beds of the Carboniferous and the black shale formations of the Cambrian. Microscopic preparations of the humus layers of the Carboniferous allow frequently not only to recognize the plant varieties concerned but also their transformation into droppings by the activity of ancient soil animals. This opens a very promising new research field. The bituminous clay shales and shaly clays of the Cambriam correspond to subaqueous gyttja and sapropel formations. The frequent blue-gray to dark violet-colored shales are produced from former subaqueous soils of gley character.

It might be mentioned that the majority of soil sediments correspond in their micromorphology to terrestrial soils of the tropics and subtropics. Soil sediments of Braunerde fabric are very rare or entirely missing in marine sediments. The explanation of this is given by the fact that the formation of soils produced by a temperate cool to cold climate, especially one characterized by hard winter months, has been possible only with the end of the Tertiary period. The whole time of about 200 millions of years, during which the formation of higher developed terrestrial soils had been possible, was exclusively characterized by tropical to subtropical climates in which humid periods were only interrupted by temporary dry or semi-dry intermissions. The ancient cold epochs belonged to an age in which environmental conditions and life development had not been adequate enough for the formation of terrestrial soils.

The above scheme gives only a simplified overview about the geopedological transformation products and their genetic interrelations. In reality the possibilities are even more manifold than given in the table. A particular group of polygenetic soils and soil sediments are those in which various fabric types of different genesis are combined. As typical examples in this respect the varieties of the Lessive type can be mentioned (Braunlehm-Lessive, earthy Braunlehm-Lessive, Braunerde-Lessive or Parabraunerde, Rotlehm-Braunerde-Lessive, earthy Rotlehm-Lessive, Pseudogley-Lessive). But micromorphologic analysis enables one to clear up this multiplicity of forms and their genesis.

What makes micromorphologic analysis so particularly suitable for geopedological studies?

First of all it enables the investigator to comprehend a number of details of the construction and composition of the soil which cannot be recognized with other methods. It also enables one to see and investigate a number of characters simultaneously, and gives the possibility to obtain a conception of the whole by investigating the particular modes of the combination of the single elements to the entity.

Of particular importance is the ability to comprehend the micromorphogenesis of the different phenomena. By a sufficient number of investigations and with the aid of sufficiently numerous series of preparations of the same soil type not only can the characters as such be determined but also the different genetical phases of their formation and their fading away can be ascertained.

Soil genesis in general is very important for soil micromorphology. It avoids errors and facilitates knowledge and correct denomination of the phenomena. The soil is a natural formation which only in the final phases reaches a certain stability, otherwise it does not stop but is subject to continuous, though always characteristic, changes. There had been pedologists who wanted to have the soil types characterized rather by the processes dominating in them than by their properties. At any rate it has been a great merit of the Russian School of Pedology, first of all of V. V. Dokutchaev and his followers, to have decidedly pointed at the importance of soil genesis for the conception of the soil types in dependence of the leading environmental conditions. The introduction of this principle has led to the establishment of the genetical system of soils instead of the former systems based on a certain number of properties. It was the first natural system of soils which selected the most typical criteria out of the multiplicity of all characters of a soil including those of their genesis. Only by this may their mutual relationship and dependence of the systematical units and the adequate construction of the system as a whole progressing from the most simple to the most complicated and highest developed be warranted.

Since geopedology and micromorphogenesis both concern the investigation of the convertability of the soils as their subject of research, it is easily understood that only a genetical system can be applied for their purpose.

By the consideration of the genetic characters and their close dependence from the environmental factors one has the security that the established systematical units fit into their climatical, geobotanical and geozoological environments. The control of this fitting; i.e., of the coincidence of the delimitation of the soil unit in the field with the delimitations of the habitat, is an important task of soil micromorphology in the service of the natural sciences.

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