SOME CONSIDERATIONS ON QUANTITATIVE SOIL MICROMORPHOLOGY

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I. INTRODUCTION.

During the first twenty-five years of its existence, soil micromorphology was essentially a qualitative method for soil studies. Quantitative determinations on soil thin sections were very rare, and mostly restricted to soil porosity. This can be explained partly by the strong genetical approach of most soil micromorphologists in that period, and partly by the abscence of suitable techniques. Moreover, quantification had not then become fashionable in science, as it seems to have become now.

Since the early sixties an increasing, although still relatively small amount of papers on quantitative micromorphology have been published. Most of them concern volume determinations (such as volumes occupied by pores, clay-coatings, sandgrains etc.), but also other characteristics have been expressed quantitatively, such as size distributions, surfaces, orientations, etc. The publication of "Die mikromorphometrische Bodenanalyse", now ten years ago, under the editorship of W.L. KUBIENA, can be considered as a landmark in the history of soil micromorphology. Following it the term "micromorphometry" became general used to indicate the field of quantitative micromorphology.

The objetive of this paper is to discuss the possibilities and problems of quantitative determinations on soil thin sections, especially with regard to the solid phase of the soil.

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II. VOLUME DETERMINATIONS.

Already in 1848 DELESSE stated that the volume percent occupied by a given constituent in a material corresponds to the area percentage occupied by that constituent on a surface (if the distribution is homogeneous and at random). This means that in principe area percentages measured on thin sections can be considered to represent volume percentages in the sample.

In soil micromorphology the first volume analyses were mainly concerned with the pore-space, for several reasons : (i) they are easy to recognize in thin sections (e. g. the addition of stains or fluorescent dyes to the impregnating material makes it easy to recognize them, even on micrographs); (ii) there are several techniques to count them on drawings, micrographs etc. (see amongs others KUBIENA 1967); (iii) their determination could have immediate practical applications, and data could be correlated with physical properties of the soil. It may be mentioned that pores were also the first (and practically the only) fabric elements studied by electro-optical methods (e. g. A. JONGERIUS et al., 1974).

Except for some technical problems, and the universal question of the representative nature of samples and data, no specific problems arise with regard to the micromorphometry of pore spaces. This cannot be said of the quantitative determinations of the solid soil components.

The reliability and even the possibility of their quantification often depends upon several qualitative aspects, the most important initial one being their recognition as a separate fabric element. This fact, amongst others, is likely to explain the late application of micromorphometric methods to the solid phase of the soil. Under the influence of Kubiëna's work, most micromorphologists followed a morpho-genetic approach in their studies. Gradually however, as the works of Brewer, particularly that of 1964, became popular and his classification and terminology used, a morpho-analytic approach appeared. His terminology made it possible to give each feature (or at least many of them) a name, i.e. an identity, and this is a prerequisite for their quantification.

Other reasons for the late application of micromorphometry to soil constituent other than pores are that such determinations have essentially a purely scientific character (pedogenetical studies) and need to be done under the microscope by a well trained person, the identification of many features often requiring a degree of interpretation. This is also the reason why such quantifications can practically not be automatized as it is the case for pores.

Techniques used for surface measurements on soil thin sections are adopted from other sciences, especially from petrography. Most popular are the point counting methods; line countings on thin sections (e.g. with the aid of a continuous line integration stage or an integration ocular of Leitz) are used only exceptionally. Point counting eyepieces (e.g. after Blaschke (Leitz), Merz (Wild), Weibel (Wild) or Henning (Zeiss) or the eyescan of Swift) have the advantage of being less dependent on the magnification and the size of the thin section than the automatic point counters (Swift & Son; Eltinor 4 of Rathenower Optische Werke). The latter can be used only for relative small thin sections, but have the big advantage of facilitating a much quicker and less laborious counting than with eyepieces. Moreover, the feature to be determined is always situated in the centre of the field of view, and the stage can be rotated, where it is necessary for the determination of mineral substances under crossed polarizers. The use of circular polarized light (PAPE, 1974) may often facilitate point counting, because no extinction of the minerals takes place (except when their optical axis is pa ralel to that of the microscope). The application of automatic point counting in soil micromorphology was described by ESWARAN 1968.

Although methods for quantitative analyses in micromorphology are the same as in petrography, the problems are different. Let us first look to the difference in aproach of the petrographer and the micromorphologist. The former wants to know the modus of his rock sample in order to classify it. The important thing is thus the amount of each constituent present. The micromorphologist however is not interested only in the amounts and considers this parameter only as a step towards the quantification of processes, such as clay illuviation, crystal neoformations, reorganizations etc.

Not only is the approach different but also the material. A rock is mostly composed of randomly distributed rather pure and sharp bounded constituent (minerals), but this is seldom the case for soil materials on the scale of the thin section : specific distribution patterns, often related to a macro scale (e.g. ped-cutans) make thin sections rather heterogeneous ; many fabric elements are complex bodies (e.g. soil nodules and concretions) with often gradual boundaries (e.g. diffuse nodules, neocutans).

The first problem requiring investigation is the extent to which micromorphological units can be determined quantitatively. The second problem is the interpretation of the results obtained. In the following paragraphs these problems are discussed with the help of a few simple and common examples.

Example 1.

Micrograph no. 1 shows a soil material with lenticular gypsum crystals in the pores. The volume percent of the gypsum can be determined quantitatively (e.g. with point counting) without problems. The interpretation of this value is also quite simple : it is clear that it represents the amount of gypsum present in that soil material (if the determination has been done on a representative sample and in a statistically acceptable way). When this volume percentage is converted to weight percentages (taking into account the density of the soil material and of the gypsum), the result obtained corresponds quite well with data from chemical analyses.

Example 2.

Micrograph no. 2. shows a soil material characterized by the presence of strongly oriented fine-clay cutans covering the walls of the pores. A quantitative determination of this feature can easily be done, but the interpretation of the results is less evident than in the first example, since fine clay is not restricted to these cutans but occurs also in the groundmass. Thus the data obtained do not represent the total amount of fine clay in that soil material but only the amount of fine clay showing the morphological characteristics of illuviation. Illuviated clay that has lost these morphological characteristics is thus not included, nor is inherited or new-formed fine clay. If the counting unit is defined and restricted in this way, it can be used unambiguously in soil genetical studies. In many cases there is even a reasonable relation ship between the quantity of fine-clay cutans and papules (i.e. here fragmented cutans) present and the increase in fine clay observed by granulometric analyses.

Example 3.

Micrograph no. 3 shows a section in an argillic horizon in which the pores are covered by agricutans composed of clay (fine and coarse), organic matter and some silt, Quantitative determinations of this feature usually presents no problems (in that it has sharp boundaries and sufficient contrast). The interpretation of the data is less self-evident as the agricutans cannot be correlated directly with any physical or chemical property of the soil material (e. g. grain size distribution, organic matter content, increase in clay or organic matter content).

Therefore it is only of relative value for the activity of a process.

Example 4.

Micrograph no. 4 shows a neocutan of iron oxihydrates (neoferran), i. e. an impregnation of the groundmass with iron compounds. This feature has diffuse boundaries and the iron concentration increases towards the pore walls. In such a case there are certain problems in quantification such as : (i) where is the limit of the feature? (ii) are the included sand grains to be considered as belongin to the feature or to the groundmass ? Even if we give a pragmatic solution to these questions, the interpretation of the values obtained remains difficult : the concentration of iron-oxihydrates is not known, and more difficult still, is not constant. The same problem could be illustrated with diffuse nodules of iron-oxihydrates, manganese, microcalcite etc.

Volume measurements of these features, and their interpretation is thus impossible because of the absence of sharp limits, the unknown and variable concentration of the characteristic constituent and its heterogeneous distribution, and the fact that the feature and the groundmass are not mutually exclusive, i. e. both have some constituents in common (e. g. sand grains, clay mass). In such cases less laborious measurements (e. g. determination of the mean diameter of the nodules, or their frequency) or a reasonable estimation may be sufficiently significant.

Example 5.

Micrograph no. 5 shows, in cross section, a pedotubule filled with aggregates of the same composition as the surrounding matrix (ortho-aggrotubule according to BREWER 1964). The volume occupied by the pedotubules as an entity (hatched zone) can be considered as a measure of the intensity of the biological activity in that horizon. Data obtained by point-counting of the coarse and fine material in the tubule and in the groundmass will correspond more or less to the sand and the clay content of the soil sample determined in the laboratory. The area occupied by pores in the feature and in the groundmass is a measure of the porosity, corresponding to physical measurements. All these determinations can thus be meaningful. However, a count using following units : coarse material, fine material and pores in the groundmass (plasma and skeleton grains and voids in the s-matrix), and the pedotubules (pedological features) as a whole (hatched zone) gives values which have no physical or chemical meaning, because the counted units belong to different levels of organization and are not mutually exclusive. A solution for such a case is to make two different sets of measurements each restricted to one level of organization, e.g. pedotubules versus groundmass, and another comprising coarse and fine material, voids and features such as clay coatings. Moreover the size difference between the pedotubules (several mm) and the other constituents (some tens or hundreds of µm) requires separate counts for technical and statistical reasons.

When interpretating volume measurements of pedotubules (or other pedoturbations) it should borne in mind also that in a soil with high biological activity existing tubules (or other features) are frequently destroyed (i. e. embodied in the groundmass) during the process of formation of new ones. The amount of morphologically recognizable pedotubules will be limited thus to an optimum value. Some large tubules may include smaller (more recent) ones. Since an expression of the intensity of the soil pedoturbation by the soil fauna is needed, it is logical to count these zones twice (it is clear that they have been perturbated twice). The sum of perturbation zones (pedotubules) and the groundmass will thus exceed 100%.

Summarizing the discussion on the previous examples, it can be stated that, in order to obtain results that are appropriate for sound interpretation, the units counted should conform to following criteria : they must.

- belong to a same level of organization,
- have sharp boundaries,
- be homogeneous (at the scale of observation),
- be mutually exclusive.

The implication of this is that some features can never be counted, and others only in a restricted number of combinations. Features formed by a concentration of relative pure constituents (e.g. clay-cutans, gypsum chambers, vivianite crystals) can be generally quantified easier than those derived from a reorganization or impregnation of the groundmass (e.g. pedotubules, rusty mottles). The above formulated rules are very simple and seem self-evident, but the number of mistakes made by students, and even by scientists with respect to them is rather surprising. Indeed, under the influence of the present morpho-analytical aproach, many students are inclined to use morphological units or groups of units as counting units, e.g. clay cutans, iron nodules (whether diffuse or not), and even neostrians etc.

As a last remark concerning volume measurements it is important to stress that not all pedologically important microfabrics can be expressed quantitatively in volume percentages, e.g. related distributions, birefringence patterns (plasmic fabrics), degree of orientation etc. For some of them other parameters can however be measured (see below).

III. Length measurements and frequency countings.

Length-measurements are executed directly under the microscope with a micrometer eyepiece, on photographs with a measuring rule, or by a special apparatus such as the TGZ 3 of Zeiss. Electro optical instruments can also be used in many cases. Such measurements may provide data on the evolution of the grain sizes in a soil, e. g. the increase in size of neoformations such as gypsum crystals or calcite or iron nodules, and the decrease in size of weathering minerals (cf. BENAYAS, 1967).

Perimeter measurements can be made on photographs with the aid of a curvimeter (cf. GEYGER & BECKMANN, 1967) or with the electro-optical methods. Perimeters measured on thin sections correspond to surfaces in the soil body, and have been used to calculate the lobation ratio of pores (BECKMANN, 1962).

Length and circumference measurements in soil thin sections are faced with two major problems : the diffuse outline of some features and the fact that dimensions measured on thin sections may very between the real size and zero. A sand grain for instance will only exceptionally be cut according to its longest diameter, more frequently somewhat higher or lower. Relationship between grain sizes measured in thin sections and determined by sieving have been discussed by FRIEDMAN 1958.

Frequency counts, e. g. the number of grains or nodules per square centimeter, per field of view with a given magnification etc. are easy to carry out and provide sufficient data in most cases to allow a comparision between different soil materials without laborious volume measurements.

IV. Quantitative study of orientations.

Whereas in petrography, especially with respect to metamorphic-bodies, the quantitative study of the orienta tion of rock constituents is one of the main fabric analyses, such determinations are rather exceptional in soil micromorphology.

Orientations of soil components are essentially three dimensional features. In thin sections they can be measured in a plane (i. e. in two dimensions) or in the space (i. e. in three dimensions). The former measurements are rather simple to execute, using a graduated rotating stage of the petrographic microscope, or simply with a protractor on photographs. This can be done for elongated grains, pores, or features such as birefringent streaks, (HILL, 1970, MAGALDI, 1974), elongated nodules etc. The data are represented on cumulative-length rose diagrams, but their interpretation is mostly rather complicated and doubtful, since the angle between the plane of the section and that of the object is not usually known, e. g. a fissure with an inclination of 45 º will appear under 45 º in a vertical section parallel to the inclination, but under 0º in a vertical section normal to it. So for randomly oriented features having all a same inclination, all possible values between 0º and the real inclination will be found. Since only directions can be measured, the upper half of cumulative-length rose diagram is, in fact, sufficient, the lower half being symmetrial to it.

Orientations in three dimensions are much more difficult to measure. This can only be done on petrographic size thin sections with the aid of a universal stage. The orientation of the optical axis of the elongated minerals is determined and plotted on a stereographic projection (BARTON, 1973, KORINA & FAUSTOVA, 1964).

Such analyses were made mostly for soil mechanics purposes (LAFEBER, 1964).

Measurements of the intensity of interference colors in a clay mass can give numerical values representing the relative degree of orientation of the particles (MOR

GENSTERN & TCHALENKO, 1967). Although this method is theoretically applicable to soil materials, so many additional factors interfere that up to now no satisfactory results have been obtained (STOOPS & ESWARAN, 1973). Interfering factors are chiefly the colour of the clay, thickness of the section, mineralogical composition of the clay (e. g. the amount of amorphous material present) and the inclination of the oriented clay domains with respect to the plane of the section.

V. Discussion.

A trend to quantify the observed features and processes can be recognized in all earth sciences, and soil micromorphology does not escape from this evolution. From the examples quoted above it is clear that not all micromorphological features are suited to quantification in thin sections. In the cases where it is theoretically possible one needs to investigate first the extent to which a determination makes sense and produces data that could not be obtained more easily from physical or chemical analyses.

E. g. the quantitative determination of total gypsum, calcite etc. in soil thin sections is not particularly useful, since the same result can be obtained more easily and more precisely by chemical analyses. When primary and secondary gupsum, or calcite is present, a micromorphometric determination of both types may be very important for pedogenetic studies, and cannot be obtained by chemical analyses, which determine only the total amount of Ca-sulphate or-carbonate present.

Some features can only be determined by micromorphometric methods, e. g. the intensity of pedoturbation by soil animals.

A discussion of the statistical value of the data obtained by measurements on thin sections is beyond the scope of this paper. It must be emphasized however that in most cases the results must be treated extremely care fully, and many problems may arise, e.g. due to the fact that some features are localized at the border of peds of such sizes that thin sections never can be statistically representative. Also the strong vertical anisotropy of many soil horizons (e.g. the Ao) may hinder statistical valuable determinations.

Only volume measurements on relative pure and ho mogeneous compounds (crystals, clayskins p.p.) yield absolute data allowing pedochemical calculations. Volume determinations on other units (agricutans, pedotubules) only permit a relative comparison between different soil materials. Length, and frequency determinations are simpler than volume measurements but can be used only to compare rather related materials (e.g. in one profile; in different profiles on the same parent material, etc).

It must be emphasized that many important micromor phological observations are related to exceptional features and fabrics, for which quantification is of no statisti cal value, and is moreover superfluous : their presence or absence is significant in themselves, i.e. their quali tative aspect is more important than their quantitative aspect. Moreover, it must be emphasized also that in soil micromorphological studies exceptional features, having no real statistical value, are frequently more in formative than the mean composition of the soil material; this is even more true for SEM-studies.

It is evident that in many cases micromorphometric results are not more convincing than a good quantitative description. Micromorphometric analyses are certainly not superfluous, but should be used judiciously.

The author is fully conscious of the fact that the subject is not treated exhaustively. If this paper however may lead to a more thorough discussion of the subject in future, its principal aim is fully reached.

Fig. 1

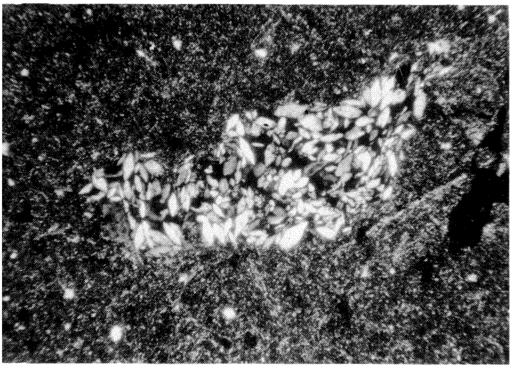

Fig. 2

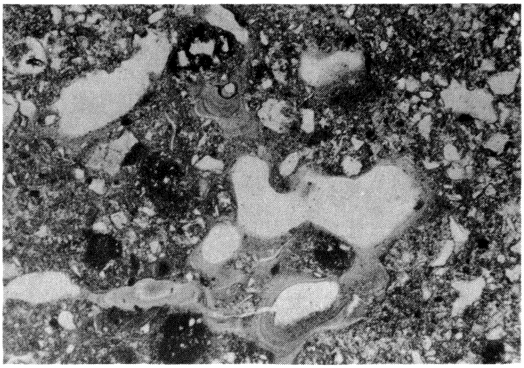

Fig. 3

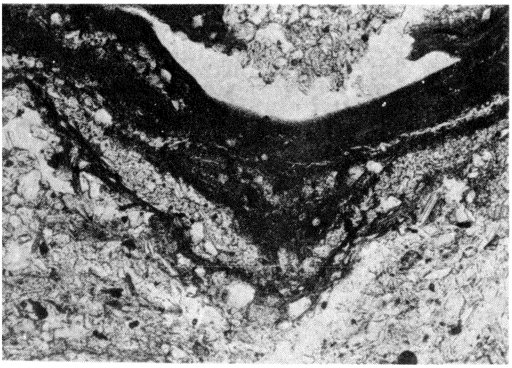

Fig. 4-A

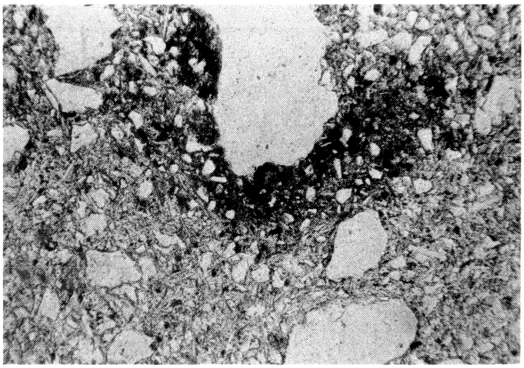

Fig. 4-B

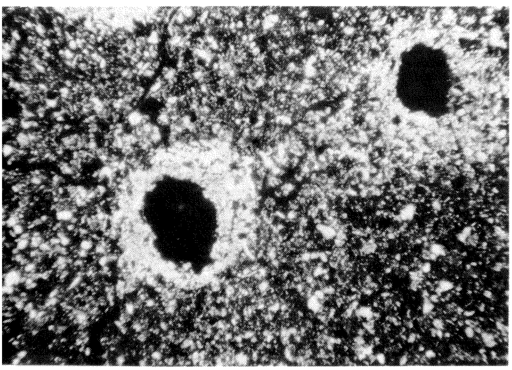

Fig. 5

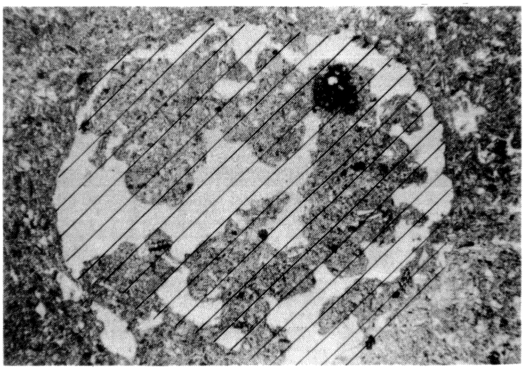

Fig. 1 : Lenticular gypsum crystals in a pore. Crossed polarizers. 55 x.

Fig. 2 :Coatings of fine clay (ferri-argillans) covering the wall of pores. Plain light, 100 x.

Fig. 3 : Coating of clay, organic matter and silt (agricutan) deposited in a pore. Plain light, 100 x.

Fig. 4 a:Diffuse impregnation of the soil matrix with iron oxihydrate along a channel (neoferran). Plain light, 100 x.

Fig. 4b: Calcite crystallites in soil material around channels (neocalcitans). Crossed polarizers, 55 x.

Fig. 5 : Cross-section of channel, containing soil pellets (ortho-aggrotubule). Plain light, 55 x.

SUMMARY

Quantitative soil micromorphology, also called -micromorphometry, only become well known amongst soil scientists some ten years ago. Most micromorphometric analyses are concerned with soil porosity, because pores are relatively easy to identify and to measure, and the obtained results can have an immediate practial application.

Measurements on the different compounds of the soil's solid phase are less frequent because they cannot be automatized so easily and can be done only by a rather experienced micromorphologist. Problems of quantitative determinations in soil thin sections, especially with regard to the solid phase of the soil, are treated in this paper.

Area percentages measured on thin sections correspond in principe to volume percentages in the threedimen

sional soil material. Not all morphological units can be considered however as counting units without more. Some requirements should be fulfiled in order to obtain data that are appropriate for sound interpretation: the counting units should (i) belong to a same level of organisation, (ii) have sharp boundaries, (iii) be homogeneous (at the scale of observation) and (iv) be mutually exclusive.

Measurements of lengths and frequencies of constituents are less laborious to do and can replace in some cases the area determinations, especially when the latter are not possible for the above stated reasons. Orientations can be measured on thin sections rather easily, but care should be taken when interpreting these two-dimensional features in the three-dimensional soil body.

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