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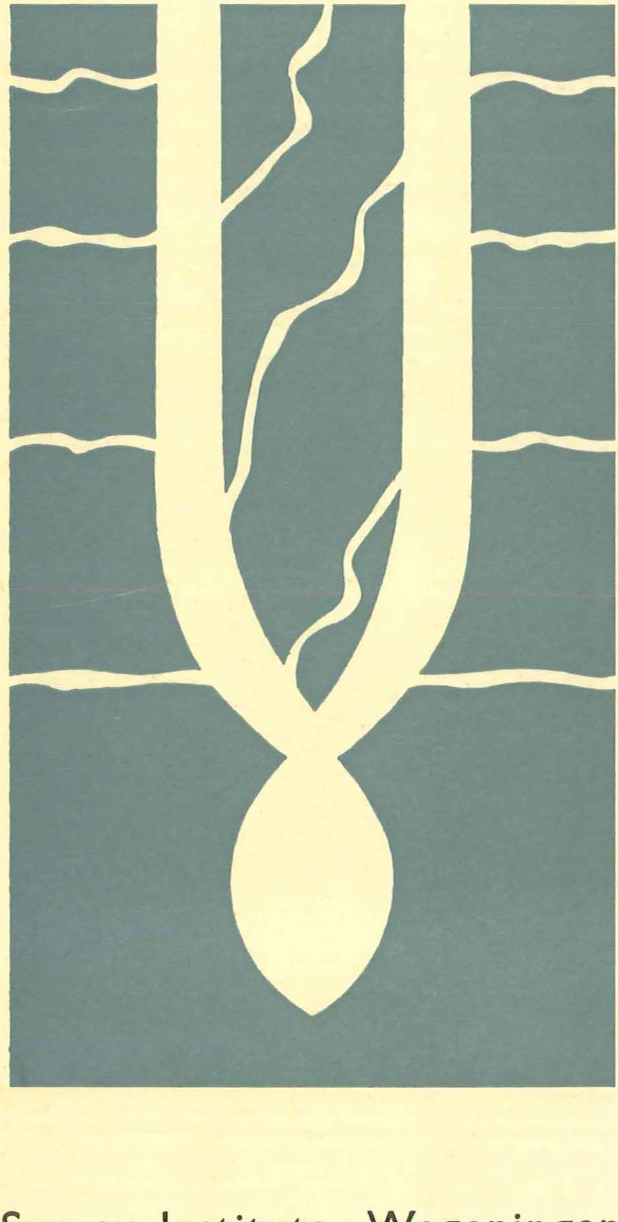
Soil Survey Papers No. 6

MICROMORPHOLOGICAL
ANALYSIS OF SOILS.
LOWER LEVELS
IN THE ORGANIZATION
OF ORGANIC SOIL
MATERIALS



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Micromorphological Analysis of Soils

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SOIL SURVEY PAPERS No. 6

Micromorphological Analysis of Soils

Lower levels in the organization of organic soil materials

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SOIL SURVEY INSTITUTE, WAGENINGEN, THE NETHERLANDS – 1973

Preface

In the years following World War II, one of the fields of study within soil micromorphology has been the organic matter. Most investigations have been almost entirely concentrated on the humus forms, i.e. the highest level of organization of soil organic matter.

The few micromorphologists who started these studies found that they had entered a real terra incognita. There was little insight into the zoological, microbiological and chemical processes, and their interrelationships, nor was much known of their effects on the micromorphology of the organic matter.

Another inexpedient factor is that a larger or smaller part of the organic matter seems to be only poorly organized.

It is therefore understandable that not until recently was a morphometric system of classification and terminology of soil organic matter developed – one more or less equivalent to Dr. Brewer's classification (1964) of the mineral constituents of soil. An attempt in this direction was made in 1969, with the publication of Dr. Barratt's work, but it can be said with all sincerity that the work presented here in Mr. Bal's doctoral thesis is the first to meet the requirements of a well-balanced classification.

Although Dr. Bal's system deals with the pure organic material and excludes organo-mineral mixtures, his work constitutes a firm contribution towards the development of a truly comprehensive morphometric system of micromorphological classification.

Dr. A. Jongerius
Secretary of the Working-Group
on Soil Micromorphology
of the ISSS

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Introduction

In most soils the organic materials (apart from present roots) are supplied from without and may be in the form of litter, organic fertilizers, or even through pollution.
In the soil they will be broken down, energy is released and plant nutrients are made available for re-cycling to the ecosystem. It is only relatively recently that it has been realized what a high proportion of total organic matter in many terrestrial ecosystems is present in the soil and litter and is decomposed there (Macfadyen, 1964).

The morphological study of organic materials in soil requires firstly an investigation into their decomposition. This is possible as the breakdown of these materials is reflected in their morphology. In the second place it is a study of their distribution in the soil. Both, decomposition and distribution of organic materials in soil, may be related to each other. Consequently, organic matter as a whole in the soil can be regarded as an individual, which in this present study will be defined as *humon.*

As the way of breakdown and distribution of organic materials in soil depends on a variety of circumstances, it is possible to distinguish a variety of different humons. This means that organic materials in soil are not a disorderly mass, on the contrary they are organized according to certain pedogenetically laws. That is why it is possible to characterize organic materials according to their morphology and spatial arrangement. This can only be done by a microscopic study of the soil in undisturbed condition. Thin sections are essential for this object.

Earlier, the organization of mineral constituents in soil was described by Brewer in his valuable work "Fabric and mineral analysis of soils" (Brewer, 1964). For a complete study of the soil it is necessary that the organic soil materials are also described.

The first step into this direction was made by Kubiena (1938, 1948, 1953) followed by Barratt (1964, 1969). However, the way in which Kubiena regarded organic matter in the soil as a whole does not contribute to a better understanding of its significance and neither does Barratt present an alternative. Neither of the two authors gave a basic description of the lower levels in the organization of organic soil materials.
At present Brewer's systematical and comprehensive system is the only one that exists, so it would be convenient that a description of the organic soil materials should, as much as possible, be adapted to that particular system. In this way a uniform system for examining and describing the soil microscopically is ensured.

The aim of the present study is to define "humon" and to describe the "organization of organic soil materials" at lower levels. Furthermore attention is paid to the interpretation of the described morphological units in relation to their genesis.

PART I

Soil
Humon and the humon-profile
The constituents of organic soil materials

CHAPTER I

Soil
Humon and the humon-profile

1.1 SOIL

This study deals with the organization of soil materials that is why soil ought to be adequately defined. Most definitions of soil do ascertain that it is a "natural body" occurring at the earth's surface and formed by alteration of mineral and/or organic materials (Joffe, 1936, 1949, pp. 10–41; Jenny, 1941, pp. 7–10; Kubiena, 1948, p. 200; Soil Survey Staff, 1960, pp. 1–2; Brewer, 1964, pp. 7–8).*

In this context the earth's surface must not be interpreted too narrowly. Any materials exposed to the influence of the soil-forming factors as atmosphere, biosphere, etc. may form soil.
For example accumulations of organic and/or mineral materials may occur in trees (Delamare Deboutteville, 1951, pp. 32–33, 195–200), in roof-gutters, etc.; these materials are also exposed to the influence of soil-forming processes. Thus it is reasonable to regard such a collection of natural bodies as soil parent material. In trees of West-Africa (Ivory Coast), Delamare Deboutteville distinguishes so-called "sols epiphytes" (epiphytes soils), and "sols suspendus" (suspended soils). These particular soils, which may be as thick as 20 cm, are characterized by a living community of which the members are characteristic for soil (Delamare Deboutteville, 1951, pp. 202–226).

Soil-forming processes may also take place in weathering artificial bodies made by man e.g. old buildings, monuments, etc. (De Beaufort et al., 1970). As a result of these weathering processes a

* Soil forming processes in organic materials are described by e.g. Pons (1960), Van Heuveln et al. (1960), Van Heuveln (1962), Jongerius et al. (1962 a, b), Puffe et al. (1963), Frercks et al. (1964).

thin layer, composed of altered materials, may be formed which can be regarded as being soil.*

Soil-forming processes may also occur in materials saturated with water, or even covered by a layer of water. Examples of animal activities in these particular materials are given by Kubiena (1953, p. 40), Van Straaten (1954), Doeksen et al (1963), Krause (1964), Slager et al., (1970) and Andriesse et al. (1972).

Thus soil is not only formed at the immediate surface of the earth, but also in caves, under a "not too thick" water-layer, in trees, on buildings, etc.

According to Jenny (1941, p. 3) characteristic for all soils is that they are "anisotropic," that is, the sequence of soil-properties differs profoundly along a line extending from the surface of the soil toward the centre of the earth from that along lines parallel to the surface. In general this is true, but not for soils on weathering stones, e.g. in walls of buildings. In this particular case the line along which the properties differ profoundly may even, more or less, be a horizontal one. More exactly the line along which the properties differ profoundly runs from the surface of the soil toward unaltered materials, which are not part of the soil. Mostly this line is toward the centre of the earth.

Soil may thus, be defined as:

> "*Soil* is the collection of natural bodies formed by alteration of mineral and/or organic (sedimentary and/or sedentary and/or igneous and/or artificial) bodies due to exposure at the earth's surface and having an anisotropic arrangement of properties along an axis normal to the soil's surface"

It is necessary to make some remarks, concerning this concept of soil, i.e.:

- Alteration has a broad meaning ranging from a mere change in arrangement of the bodies (e.g. in an unconsolidated sediment) up to and including their complete chemical alteration (Fig. 1).

* Regarding materials formed by weathering of artificial bodies as soil, does not contradict with the demand of soil materials being "natural bodies". Because weathering of the artificial bodies is a natural process; consequently, the weathering-products are natural bodies.

– To include organic soils (formed in autochthonic organic bodies as some peats), alteration of "sedentary" bodies was mentioned. According to La Forge (in: Glossary of Geology and Related Sciences, 1962, p. 259) sedentary means: "In sedimentation, *formed in place without transportation,* by the disintegration of the underlying rock or *by the accumulation of organic materials;* said of some soils, etc."
  The word sedentary was coined from the Latin word *sedentarius* derived from *sedens;* present participle of *sedere* = to sit; it may be used as: remaining in one locality; not migratory: said of birds, etc. (Webster's new world dictionary, 1972).
  In this way sedentary peats can be distinguished from sedimentary peats.
– The particular anisotropic arrangement of properties along an axis normal to the soil surface (representing horizons) does not imply that soil properties are absolutely isotropic along lines parallel with the soil's surface.
  However, anisotropy in this latter direction is of quite a different nature and often observable microscopically only (Fig. 1).
– According to this concept the lower boundary of the soil is at that point of the axis mentioned, where the "soil-bodies" meet unaltered bodies. These particular unaltered bodies may be the source from which the soil-bodies have been formed, but they need not necessarily to be genetically related with the soil-bodies lying upon them (Fig. 1).

1.2 HUMON

The present study deals in particular with organic soil materials. If one in studying the organic materials puts as most important their breakdown, then they can be regarded as forming together an entity in soil.

To be able studying such an entity it must be clearly defined. As the decomposition-processes are soil-forming processes they are dependent on soil-forming factors (Bal, 1970, pp. 33–34).*

* Soil-forming processes are processes operating in soil; the soil constituents themselves are the reagents. Soil-forming factors, on the contrary, do cause the soil-forming processes. Soil-forming factors may exist outside the soil (e.g. climate); they are discussed by Jenny (1941).

This implies that in different soils the breakdown of organic materials will proceed differently.* Thus, by the decomposition-processes operating in organic soil materials these materials form together a "natural, genetic entity" existing in soil.

As by the decomposition-processes the morphology of the organic soil materials is changed it is possible to describe the organic entity morphologically. Even the way in which the organic soil materials are broken down is morphologically reflected. That is why different organic entities can morphologically be distinguished. Often a particular organic constituent is not broken down completely at the same spot in the soil. By translocation (in one or another way)** of the organic constituent a next stage in its decomposition will take place elsewhere in the soil. Thus, the organic constituents, in a different stage of breakdown, are spatially arranged in the soil, forming together a "three-dimensional individual". The appearance of this individual in the soil depends to a great extent on the (physical and chemical) qualities of the organic constituents, the way of breakdown of the organic materials, and the way in which the organic materials are translocated.

Thus the breakdown-processes operating in organic soil materials produce a "natural, three-dimensional, genetic individual", which can morphologically be described and characterized.

Soil can then be regarded as being built up of a mineral and/or an organic entity. Often they merge into each other in the soil and then may be composed of an own part and a combined part of the soil. The own part of the first-mentioned entity is generally a C-horizon which is almost free of organic materials.
The own part of the second one is generally built up of mineral-free O-horizons. The combined part is an A-horizon and possibly B-horizon. In some cases one of the mentioned entities may even comprise the whole soil as discussed on pages 5–7.

* Under terrestrial conditions the decomposition of organic soil materials progresses with depth, whilst in peats the decomposition of organic materials may decrease with greater depth.

** Translocation of organic materials in soil may occur in different ways as e.g. by animals, which ingest the materials and defaecate them elsewhere; in solution or suspension in water going down through the soil; by churning; turning of a particular horizon into another horizon deeper in the soil by disappearance of the underlying horizon (e.g. in course of time the F-horizon in a "Moder Humus Form" will turn into the H-horizon lying beneath it. Bal, 1970; Babel, 1972).

In literature the name "Humus-form" has been suggested for the ecological system, comprising the upper part of the soil (L + F + H (+ A)), which is characterized by the presence of organic materials and living organisms; these organisms are active in the breakdown of the organic materials (Müller, 1887, pp. 7, 55, 65–66; Kubiena, 1948, p. 203; 1953, pp. 26–27, 37–50; 1955 b, p. 73).*

The indication "Humus-type" has also been used (Hartmann, 1952; 1965, pp. 8–9) and would be suitable as it is related with "soil-type" (Barratt, 1964).
"Humus-profile" was suggested by Babel (1971). Babel's conception of humus-profile shows a strong similarity to that of humus-form according to Kubiena.

The mere presence of organic materials is not enough for that part of the soil to be regarded as humus-form (Müller, 1887, p. 10). In fact one subdivides the soil into "humus-form" (= the upper part of the soil) and "soil minus humus-form" (= the lower part of the soil) (Müller, 1887, pp. 10, 60) as also a subdivision of the soil into "solum" and "soil minus solum" (Soil Survey Staff, 1960, p. 30; Brewer, 1964, p. 9) is possible.
However, it is difficult to determine which part of the soil is living. For this reason this concept has a certain disadvantage from a soil scientific point of view.

Apart from this disadvantage there are also some other objec-

* Kubiena (1955 b, p. 73) described the concept of humus-form, based on Müller's ideas, as follows:
"Humus-form" is not a chemical concept and therefore does not mean merely a particular organic substance or a group of organic substances. It is not confined to the so-called "humus-substances", nor even to the "organic matter" of the soil since it comprises also the in-organic matter and the way in which the organic and inorganic constituents are mixed or combined with one another. In addition to this, the "humus-form" is bound up with the formation of a typical humus-profile and with a typical "soil-life" produced by typical microbial and macrobial biotic communities and their activities. The "humus-form" is thus a concept of a formation in nature: that is to say, a complex consisting of the biotic community plus its biotope. It is a concept of a formation in nature like that of the soil as a whole, of which the "humus-form" is a part. In terms of the usual profile nomenclature it comprises more or less the "living" A-horizon plus the L-layer on its surface, although no humus-form could be thought of without the connexion with the remaining parts of the soil and the interrelation between life and dynamics of both."

tions to the use of the name as well as the concept of "humus-form", "humus-type" and "humus-profile".
These are the five following:

1. A disagreement in literature on the concepts of humus-form and humus-type (Barratt, 1964; Bal, 1970). They are used both in an identical and contradictory sense:

1.1. *humus-form* as an entity (Kubiena, 1948, 1953, 1955) as opposed to humus-form as a horizon within that entity (Ramann, 1911, pp. 171–177, 192–195).

1.2. *humus-type* as an entity (Hartmann, 1952, 1965, pp. 8–9) as opposed to humus-type as a horizon within that entity (Jongerius and Schelling, 1960).

2. The concepts of humus-form, humus-type and humus-profile are restricted to the decomposition of organic matter in the earth's crust under natural vegetation. However, the decomposition of organic materials does also occur elsewhere as e.g. in cultivated soils, and even in trees (Delamare Deboutteville, 1951, pp. 32–33, 195–202), roof-gutters, and the walls of old buildings. It is therefore necessary that the decomposition of organic matter in agricultural soils, etc. is also incorporated within the same concept.
   This imperfection in the present concepts of humus-form, etc. was already mentioned by Kubiena (1955 a), Jongerius and Schelling (1960) and Barratt (1964, 1967). Nevertheless Jongerius et al. and Barratt tried to adapt these concepts, although in a somewhat modified form, to cultivated land and grassland.

3. The humus-form comprises only the L-layer, the F-, and H-horizons and in some cases the A-horizons (Müller, 1887; Kubiena, 1948, 1953, 1955; Barratt, 1964); it does not contain all visually observable organic materials of the whole of the soil. Nevertheless, there may be a very definite genetic relation between the L-layer, F- and H-horizons and the organic materials occurring at a greater depth in the soil e.g. in podzols. The whole decomposition of the organic materials progressing with depth is the result of genetic processes influenced by soil-forming factors. Through the decomposition a certain pattern is formed characterized by horizonation (Bal, 1970, pp. 33–34).

If one wants to study the entire soil, the complete decomposition pattern must therefore be described (Jongerius and Schelling, 1960; Barratt, 1964; Bal, 1970). That is why Bal (1970) introduced the concept of humus-profile, in which all present organic materials get attention.

4. The word "humus" occurs in all mentioned names.
   Linguistic "humus-form" means "the form of the humus", or "the form in which humus is present". However the concept of humus-form also means included mineral materials (see page 9) and as inorganic materials have nothing to do with humus, it is clear that the name humus-form contradicts with its concept. Also linguistic "humus-type" means "the type of humus" and "humus-profile" means "the profile of humus".
   Using these names one must define "humus". Keeping in mind the concepts of humus-form, etc. as a natural entity, existing in the soil, it must be obvious from that definition that humus must be a "natural, three-dimensional, genetic individual". None of the existing definitions do answer this demand.
   Moreover, in this definition of humus all organic materials, from plant-litter to substances with a low molecular weight, should be taken into account. Only one definition meets this requirement and this is the one provided by Scheffer and Ulrich (1960). There are, however, many other definitions of humus. The emphasis of these definitions is mainly determined by the manner in which the researcher studies the organic matter in the soil.
   Laatsch's definition (1957) is morphological whilst Kubiena's definition (1938, 1948) is pedo-ecological.*
   Kononova's definition (1961) is (bio-)chemical whilst Gel'tser's (1944) has a functional basis and is less common in the literature.**
5. Humus-form does not strictly describe the organic materials in soil, although the name "humus-form" does suggest this. It even

* Kubiena's definition has a disadvantage in that it depends on certain conditions whether specific organic material is, or is not humus. Fir-needles in a "Grobmoder" are difficult to decompose and so they accumulate (Bal, 1970); therefore they are humus. In soils where the decomposition opportunities are more favourable the fir-needles will not accumulate (Wittich, 1963) and are therefore not humus.

** The various quoted definitions of humus have been listed in the Appendix.

includes present mineral materials (see page 9). In soil, organic materials are often mixed with mineral materials. This mixture may even be very intimite. In defining the organic materials in soil as an entity one could either include the associated mineral materials (as in humus-form), or only regard the organic materials.

Including the associated mineral materials is in fact equivalent to considering that part of the soil in which organic matter is present. There are, however, reasons which make it preferable to take into account only the organic materials, viz.:

- Organic matter is the source of carbon and nitrogen, and often also for a range of plant nutrients.
- The velocity with which the decomposition of organic materials proceeds is, in general, appreciably greater than that of the weathering of mineral materials.
- The decomposition of organic materials is especially done by organisms, which consume and use them for their metabolism. Although the weathering of mineral materials may proceed in an analogous way (Jacks, 1965) it is questionable if this is necessarily always the case.
- Considering the organic materials only may be useful, e.g. for organo-chemical studies and for studying pollution of soil with organic materials.

These are the reasons why the entity is regarded as being composed of only organic materials. Thus, this way of consideration is different from existing ones, in which the mineral constituents are included.

In the light of the above-mentioned objections a new name, in which the required meaning can be given, is the only solution. The author proposes the name *humon* for this purpose. It is an artificial name, but it does indicate its relation to humus. A humon is, analogous to the concept of "soil individual" (Soil Survey Staff, 1960, pp. 2–5), a natural, three-dimensional body, composed only of organic materials. Because it should be desirable to describe the total decomposition of organic matter, that is including its mineralization, the lower boundary of the humon should be fixed to where the last remains of organic matter are mineralized.

However, this produces some practical difficulties, i.e.:

1. A certain amount of organic material (e.g. in the form of organic acids) will, under certain circumstances, disappear from the soil (e.g. with the groundwater) without it being mineralized. This would imply that the lower boundary of the humon would be situated outside the soil, which would be unrealistic. It is therefore necessary and sensible to fix the lower boundary of the humon not deeper than the lower boundary of the soil.
2. It is possible to identify a very small percentage of organic matter (e.g. in the form of organic acids) chemically, but this is not always the case visually, not even microscopically. The fact that the decomposition of organic matter, as an entity, can be more easily described visually than chemically appears to be the reason for fixing the boundaries where the organic matter changes from being microscopically observable to being no longer observable or absent.*

   Consequently one must be aware of the possibility that part of the organic matter is, for practical reason, not included in the definition of humon. Consequently the lower boundary of the humon is situated at the lowest level in the soil below which organic matter cannot be macroscopically nor microscopically observed, or is absent. When organic matter can be visually observed throughout the whole of the soil (e.g. in very thick peat) the lower boundary of the humon coincides with the lower boundary of the soil. It will therefore never be deeper than the soil.**

If we extend our definition of humon to include cultivated land, then the upper boundary is no longer always identical with the

* With microscopically observable are meant magnifications up to 200 : 1. For ordinary studies of thin sections a magnification of 200 : 1 is rather high. However, by improvement of the techniques of studying the organic materials (e.g. electron scanning microscopy with magnifications up to 40,000 : 1) it may be possible that very low quantities of organic materials are made visible. The same might be possible by using different techniques (e.g. fluorescent – and phase contrast microscopy). In other words: organic materials present in the soil deeper than the lower boundary of the humon might be made visible in future. As a result of that the lower boundary of the humon may in future be fixed deeper in the soil than it is done in this study.

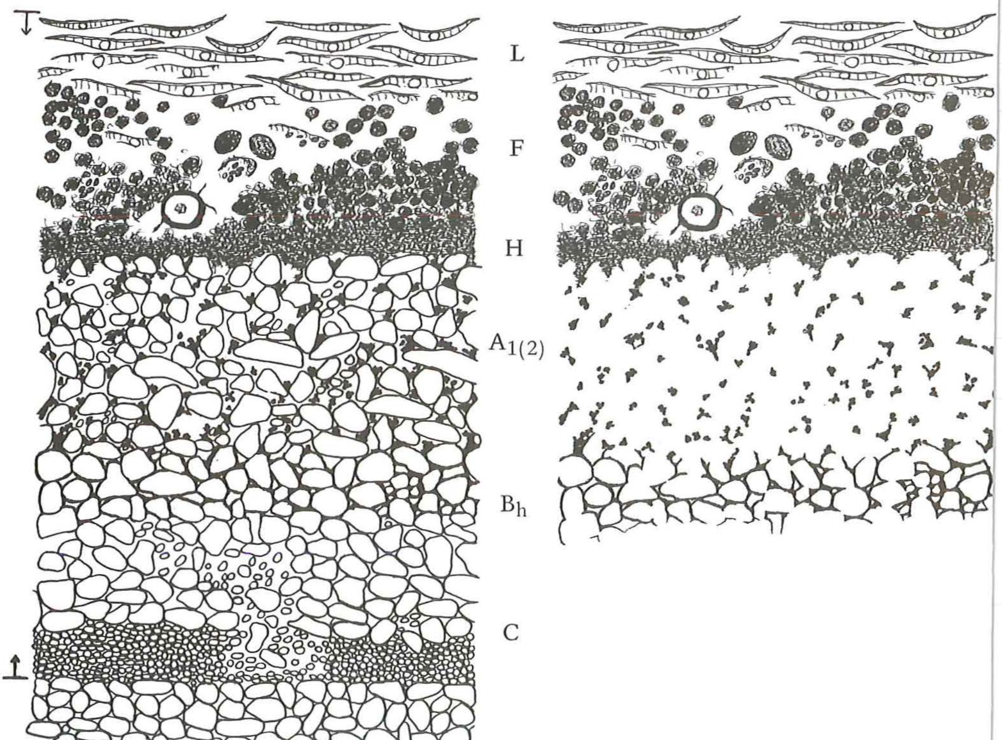
** If organic materials from a peat have illuviated into a mineral subsoil, as described by Van Heuveln et al. (1960, pp. 201–202), these particular materials are, of course, part of the humon of which the other part is the peat mentioned.

L-layer. We find that in some cases the upper boundary is an L-layer (e.g. mulch), whereas in other cases it is identical with the bare surface of the ploughed land. The upper boundary of the humon will generally coincide with the upper boundary of the soil.

Consequently the upper boundary of the humon is the highest level in the soil, above which organic matter cannot be macroscopically nor microscopically observed, or is absent.

A humon is laterally bordered by other humons, or by "non-humons" as e.g. a soil free of organic matter.

Summarizing one can submit that the humon is regarded as being composed of organic materials only. The upper and lower boundaries of a humon are determined by the organic materials being macroscopically and/or microscopically observable and the



Soil *Humon*

Fig. 1 Example of a (podzolic) soil and its humon.

lower boundary of the soil. The lateral boundaries are determined by other humons and/or non-humons.
A humon is a "natural, three-dimensional, genetic individual" existing in soil and can, at the same time, be regarded as analogous to "soil individual".
In cases where the soil exclusively (or almost compeltely) consists of organic materials (e.g. some peat soils and some mountain soils) the humon is equivalent to the soil.
Humon can thus be defined as follows:

> "*Humon* is the collection of macroscopically and/or microscopically (magnifications up to 200 : 1) observable organic bodies in soil which are characterized by a specific morphology and spatial arrangement; it is a "natural, three-dimensional, genetic, organic individual" existing in soil"

1.3 HUMON-PROFILE

The humon is analogous to the soil in that pedogenetic processes have produced horizonation: the "humon-profile".
The soil profile (Joffe, 1949 and the SSSA, 1965) is a vertical section having only two dimensions, i.e.: one normal to the soil surface, and the other parallel with the soil surface.* The profile is a vertical section through all horizons present in the soil, or humon respectively.
Humon-profile can thus be defined as follows:

> "*Humon-profile* is the vertical section of a humon in which consecutive, exposed horizons represent the resultant and mode of decomposition of organic materials"

The labelling of the horizons in the humon-profile must have a genetic bearing, as is the case with the horizon labelling of the soil

* Joffe (1949, p. 8) formulated soil profile as follows: "The genetically related exposed horizons of a vertical cut in the soil body, taken as a unit comprise what is known as the soil profile". According to the SSSA (1965, p. 342) soil profile is: "A vertical section of the soil through all its horizons and extending into the parent material".

profile. A suggestion for this cannot, as yet, be given. A starting point could be the research done by: Hesselmann (1926); Romell and Heiberg (1931); Kubiena (1948, 1953); Hoover and Lunt (1952); Ehwald (1956); Van Heuveln, Jongerius and Pons (1960); Jongerius and Schelling (1960); Jongerius and Pons (1962); Puffe and Grosse-Brauckmann (1963); Grosse-Brauckmann and Puffe (1964); Frercks and Puffe (1964); Zachariae (1963, 1964, 1965); Barratt (1964, 1967, 1968, 1969); Van der Drift (1964); Bal (1970); Babel (1971, 1972).

In a previous paper the author (Bal, 1970) described, very detailed, two different humons.

CHAPTER II

The constituents of organic soil materials

Brewer (1964, pp. 10–13) distinguishes as constituents of soil materials "skeleton grains" and "plasma", i.e.:

"Skeleton grains of a soil material are individual grains which are relatively stable and not readily translocated, concentrated or reorganized by soil-forming processes, they include mineral grains and resistant siliceous and organic bodies larger than colloidal size."

"Plasma of a soil material is that part which is capable of being or has been moved, reorganized, and/or concentrated by the processes of soil formation. It includes all the material, mineral or organic, of colloidal size and relatively soluble material which is not bound up in the skeleton grains."

The most important aspect of Brewer's descriptions is the difference in stability of the soil constituents, and the (with this agreeing difference in) capability of the constituents of being moved, reorganized and/or concentrated by processes of soil-formation.

The soil materials are also divided into large-sized (skeleton grains) and small-sized (plasma) constituents; the limit between those groups was fixed at 2 μm (Brewer, 1964, p. 303).

It is quite clear that the concepts have a genetic bearing, which in itself is of great value. However, it is to be regretted that the constituents as such have not been defined morphologically. This is in particular true for components larger than 2 μm, because the limit between "stable" and "unstable" is not exactly defined. In a thin section the decision whether a particular constituent is stable, or unstable, may be a matter of interpretation. One should have some knowledge about stability. It is well-known that chemical stability (i.e. the rate of weathering) of minerals depends in the first place on the mineral's solubility, which in its turn is dependent on environmental conditions and on the mineral's crystal structure (Loughnan, 1969, pp. 27–61). In the second place chemical stability is influenced by the mineral's size (Loughnan, loc. cit.). Thus very small minerals, or fragments of minerals (e.g. quartz) may, because of their crystal structure, be much more resistant to chemical weathering than large-sized minerals. This should imply that the very small, chemically resistant mineral is a skeleton grain. But, although a very small mineral may chemically be very resistant it may at the same time, by its very small size, be readily translocated. In consequence of this translocation the very small mineral changes the organization of the spatial arrangement of constituents that is why it is physically relatively unstable. In other words, this implies that all very small-sized constituents are relatively unstable.

The size-limit between plasma and skeleton grains may be discussed as physical stability is not only a function of the absolute size of the constituents. The difference in capability of being moved between two constituents can often be ascribed to the *relative* size. This implies that the smallest particles present are relatively unstable. For example, in a mixture of coarse sand and silt, the silt, in suspension can be translocated deeper into the soil (e.g. Wright and Foss, 1968; Altemüller, 1973; Mücher, 1973). There are indications (although these may be faint) that also small (skeleton grain-sized) organic particles (much has been studied on pollen) can be translocated through the soil by water movement (Müller, 1887, pp. 61–63; Mothes et al., 1937; Jongerius, 1957, pp. 73–76; 1970; Havinga, 1962, pp. 48–50, 62–63; Munaut, 1967, pp. 138–140; Bal, 1970; Walch et al., 1970).

This translocation is a requisite for being plasma. Nevertheless, it is not advisable to regard silt as being plasma, as the appreciable unstability is characteristic for particles not larger than some microns.

Although arbitrary, it is not unreasonable that Brewer (1964, p. 303) fixed the size-boundary between skeleton grains and plasma at 2 μm.

Also Barratt (1969) divides the soil material into skeleton and plasma. She makes, with respect to the organic soil material, a distinction between organic material which is slightly decomposed and material which is in an advanced stage of decomposition. In this way she introduces the class "humiskel" (organic residues that are essentially undecomposed or chemically preserved), and the class "humicol" (strongly decomposed organic residues of colloidal size). It is not quite clear whether Barratt uses as distinguishing parameter the presence of tissue-structure or not. One must ask oneself where exactly does Barratt fix the boundary between the two classes?

According to her definition organic skeleton grain-sized particles do not belong to the class humicol, because they are too large for being colloids. Nevertheless, Barratt describes material consisting of a mixture of such organic particles and organic plasma as being humicol. As an example she classifies some organic excrements as humicol. However, (even small) excrements often consist to a large extent of organic, skeleton grain-sized, particles (Van der Drift, 1950; Handley, 1954, p. 63; Schuster, 1956; Dunger, 1958; Priesner, 1961; Szabó et al., 1967; Bal, 1970), see Fig. 2, 3, 33, 37, 79, 80 and 81. Only occasionally excrements really consist of "organic materials of colloidal size" (e.g. large quantities of excrements of snails, Fig. 4, 5, and 6). Barratt actually indicates this in figure 1E given by her, showing that in the humicol "plant fragments" are present.

According to the present author, Barratt's use of the definition of humicol is not correct. This definition states that this class consists entirely of material of colloidal size. In practice, however, mixtures of organic plasma and organic, skeleton grain-sized, particles are classified as humicol. One is making, as it were, the same mistake if one would classify a "porphyroskelic related distribution" (Brewer, 1964, pp. 320–321) as an "argillicol" (argillaceous colloid) which is Barratt's terminology. In this case one neglects the presence of mineral skeleton grains.

2.1 ORGANIC SOIL CONSTITUENTS

What are the constituents of organic soil materials?
As already was stated in the INTRODUCTION, a morphological study of soil organic matter is in fact a study of its breakdown. The question raised can be answered by studying the decomposition which progresses according to the scheme given in Fig. 7.

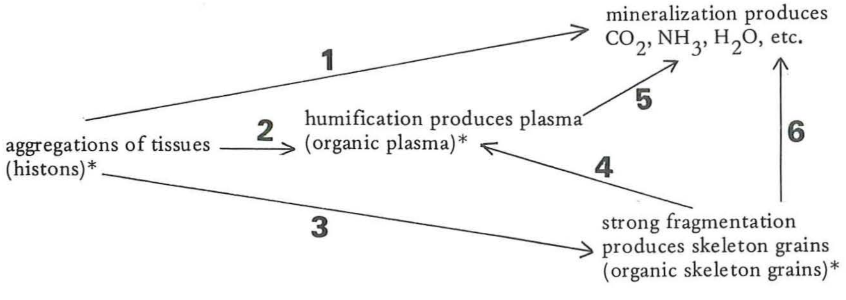


Fig. 7. Scheme of the decomposition of "Aggregations of tissues"

Broadly speaking aggregations of tissues (chiefly plant tissues e.g. dead leaves, roots, branches, etc.) are fragmented, especially by the soil fauna (process 3 in the scheme).
During and after fragmentation part of the material is (bio-) chemically broken down into substances, part of which are incorporated into the bodies of micro-organisms or transformed into substances which are characterized by a quite different molecular structure, the so-called "organic new-formations" as e.g. humic acids (process 2 in the scheme).

The decompostition according to 2 (and 4) and 3 in the scheme produces morphologically clearly different products, so that one can distinguish "aggregations of tissues", skeleton grains and plasma. As aggregations of tissues are composed of a variety of single tissues not the aggregations of tissues are the organic constituents, but the composing "single tissues".

Of course dead animals are also composed of tissues, which may be fragmented or transformed into plasma.

* Histons, organic skeleton grains and organic plasma will be discussed in separate paragraphs.

In the above described decomposition process the following organic constituents may be readily dintinguished:
1. Tissues
2. Organic skeleton grains
3. Organic plasma

To these a fourth can be added, related to micro organisms. Very small members of them ($< 2\,\mu m$) as e.g. dead bacteria are of course part of the plasma. But larger fungal hyphae cannot be regarded as belonging to one of the constituents mentioned. It is proposed to consider them as being a separate organic constituent.

The organic constituents will be discussed in separate paragraphs following below.

2.1.1 Tissues

In biology distinction is made between (single) "tissue" and "system of tissues". By tissue is meant: "An aggregation of cells, usually of similar structure, which perform the same or related functions" (Fuller and Tippo, 1949, p. 974; Koningsberger and Reinders, 1957, p. 37). System of tissues is "An aggregation of different tissues forming a larger organic unit or entity" (Koningsberger and Reinders, 1957, p. 37). In this paragraph the concept of single tissue will be defined.

In plant anatomy tissues are classified according to structure, origin and function. None of these classifications can be strictly applied since they are often mixed up (Koningsberger and Reinders, 1957, p. 45).

In addition, from a pedological point of view, these tissues cannot be regarded simply as an aggregation of plant-cells grown together as anatomically different units. Tissues can also be regarded as a combination of various materials and that is why dissimilar tissues will decay differently (Handley, 1954; Babel, 1972) into products of a varying nature. Therefore it would be useful to distinguish the plant-tissues according to their chemical composition. The composition of the cell-wall must be taken into consideration. This is in particular true as some tissues may be composed of only cell-walls (e.g. sklerenchyma). If the cells have any contents, then these are mostly plasma, or may be skeleton grains. It is, however, hardly possible to describe this chemical constitution in a general way, because it may vary considerably. (But, apart from that one must also realize that this chemical constitution will change during the decomposition of the plant).

The variation in chemical composition is mainly caused by the different composition of the secondary, and not of the primary cell-wall. It appears that the composition of the primary cell-wall is, on average, 1/3 cellulose and 1/3 (sometimes 2/3) hemicellulose. The remainder consists of pectin, proteins and lipids (values expressed in weight % of the dry cell-wall (Roelofsen, 1959, pp. 127–128)).

The chemical composition of the secondary wall shows a much wider range of variability than that of the primary wall. The cellulose content of the secondary wall may vary between 1–97%, the lignin content between 0–30%, the hemicellulose content between 1–50% and the pectin content between 0.5–45%; the amount of soluble polysaccharides varies between 0–50%, the mannan content between 0–60%, xylan between 0–40%, substances with lipid character between 1–60%, etc. (Roelofsen, 1959, p. 195).

Structural and/or chemical differences within a particular substance present another difficulty in describing tissues in a general way, e.g. those very clearly existing in cellulose and lignin (Roelofsen, 1959, pp. 2–40 and 76–86; Flaig, 1969). That is why different types of lignin will decay differently (Flaig, 1969).

Thus in considering the relative differences in decomposition-rate of the above mentioned components it is not enough to know their chemistry, but also their construction and possible link to other components. With respect to the structure of the cell-walls it is of great value to study them with the aid of a scanning electron microscope (Meylan, 1972; Troughton et al., 1972).
This means that in studying the decomposition of the various components it is in fact inadmissible to mention the incomplete name of the particular component (e.g. cellulose or lignin) only. It is necessary to use names indicating chemistry as well as construction. Nevertheless, according to the literature it often appears that pectin and hemicelluloses, contrary to lignin, are broken down very easily. This is apparent from studies by Wieringa (1954,

1955) on pectin and by Babel (1964 a) on lignin. The most resistant to decomposition would be lignin (Grosskopf, 1928; Rehorst, 1929, p. 233; Kononova, 1961, pp. 139–150; Meyer, 1962; Babel, 1964 a; Flaig, 1969).

According to Rehorst (1929, p. 226) and Babel (1964 a) cellulose may also difficultly be broken down. In this respect Babel observed that cell-walls which are exclusively built up of cellulose (in mesophyl) are not easily broken down and remain unaltered for a long time. This was possibly confirmed by investigations carried out by Grosse-Brauckmann et al. (1964). They have been able to show that quite often cellulose could be found in apparently completely humified plant remains. Lignin and cellulose appear to be present also in excrements (Fig. 80; Van der Drift, 1950, p. 156; Handley, 1954, p. 63). Lignin appeared to be present even in 16 months old excrements of Phtiracaridae (Oribatid mites) (Schuster, 1956).

Walls of growing cells (i.e. primary cell-walls) contain less cellulose and more hemicellulose and pectin than those of full-grown cells of similar origin; growing cells never contain lignin (Roelofsen, 1959, p. 1). Thus it is obvious that the first tissues to disappear are the meristematic, e.g. cambium. Meristematic tissues are more difficult to observe in thin sections anyway because primary cell-walls have a water-content varying between 60–63% by weight (Roelofsen, 1959, p. 127). This is much higher than in the thickened secondary cell-walls. Meristematic tissues will thus shrink strongly upon drying. Bonner (1935) observed that such cell-walls can shrink to about 1/3 their original thickness when dessicated (Roelofsen, 1959, p. 127).*

But, that it is hardly possible to set up a scale of absolute resistance to decomposition of the various components may be demonstrated by investigations carried out by Babel (1972). Here from it appeared that in some cases lignin and cellulose decomposed simultaneously (loc. cit., p. 77), whilst in other cases cellulose is even more resistant to decomposition than lignin (loc. cit., pp. 93 and 103).

Almost always very resistant to decomposition are cutin and suberin (see e.g. Babel, 1972, pp. 94 and 103).

* To avoid such shriveling one can dry the soil-sample by freezing instead of drying in open air. This is in particular true for samples from wet soils.

A study of the decomposition of plant remains would be made easier if names of tissues (as used in plant anatomy) were related to the chemical and structural composition of these tissues, or in other words to their rate of decomposition. Kononova (1961, pp. 139–150) observed that in lucerne roots the tissues being firstly decomposed are the living ones namely starch-containing medullary rays, cambium, phloem and parenchyma of the primary cortex. Babel (1964 a) observed that in beech leaves these are collenchym and phloem.* But, in spite of these observations it is unfortunately impossible to generalize them in terms like: medullary rays are always easily to decompose. This is because they may be parenchymatic with thin cell-walls, but they may also be composed of so-called "sklereids" (cells with very thick, lignified walls, e.g. in the phloem of beech). Thus there is no definite relationship existing between the names of tissues and their decomposition. This means that for this purpose the names of tissues (used in plant anatomy) cannot simply be adopted. For this it is necessary to introduce names which are based on chemistry and construction of the cell-walls. Unfortunately adequate names cannot be given as yet as much investigation must still be done on this subject. Because of a lack of adequate names the anatomical ones must be used accompanied, as far as possible, by a description of the constitution of the cell-walls. It often appears that difficult to breakdown are the non-living tissues with thick, lignified secondary cell-walls such as xylem and sklerenchyma (Kononova, 1961, pp. 139–150; Meyer, 1962; Babel, 1964 a).

It is quite possible that the lignified cell-walls are not only harder to decompose because of the presence of lignin (their chemistry), but they are also physically more resistant because of their firmer structure (their construction). Thus strongly lignified tissues will not be easily distorted and for this reason they can often be observed in thin sections.

In spite of the observations on the xylem's resistance these may not be generalized. It is relatively because xylem in oak (especially

* It must be pointed out here that phloem and xylem are not single tissues, but aggregations of tissues. Xylem may for a great part be composed of vascular elements with thick, lignified walls. As they are aggregations of tissues it is obvious that not only "different xylems" will decay differently, but that also internally differences in decomposition-rate exist.

if it is present in the centre of the trunk, so-called "heartwood") is difficultly, whilst, that in willow and alder is relatively easily to decompose (see footnote on page 24).

Epidermis is also relatively hard to decompose (Grosse-Brauckmann et al., 1964), due to the presence of cutin. It is often observed that the parenchyma disappears first from the leaves. Not only through microbiological activity, but also because members of the soil fauna consume the mesophyl, but not the epidermis (Zachariae, 1965; Bal, 1970).

It is likely that suberinized plant parts are also relatively hard to decompose due to the presence of suberin (see p. 53).

Summarizing it can be concluded that for microscopical study of tissues in soil four aspects are of importance, i.e.: the morphology, the physical constitution, the chemical composition, and the arrangement of existing cells. Single tissue can thus be defined as follows:

> "*Tissue* is a natural aggregation of cells (grown together in a plant, or animal body), which is characterized by a specific morphology, physical constitution, chemical composition, and arrangement of these cells.
> These variable characteristics cause the relative differences in decomposition of different tissues"

Animal tissues were not discussed, as only few comparable studies of the decomposition of animal remains have been made. It is thought that the soft protinaceous materials of soil animals are rapidly decayed leaving chitinous exoskeletons, hairs, etc. Nevertheless, the definition of tissues concerns also animal tissues.
In thin sections chitinous exoskeletons, or remains of them, may indeed be observed. They often have colours varying from reddish brown (5YR 4/8) to orange (5YR 6/8) to brown (7.5YR 4/6). Colours according to Revised Standard Soil Color Charts (1967).

2.1.2 Organic skeleton grains

According to process 3 in Fig. 7 aggregations of tissues (as e.g. leaves, branches, roots, etc.) are fragmented. In principle these fragments might be regarded as a separate group of constituents. However, it may be wondered if it is appropriate to regard large fragments (e.g. from a branch) as different from complete aggregations of tissues as branches, etc. A large fragment may even be so large in size that soil animals can live within it; moreover these animals fragmentate the large fragment intensively into very small particles. Altough these very small fragments may still be aggregations of tissues they are, by their size, so different from large fragments that it is proposed to regard them not as aggregations of tissues, but as a separate group of soil constituents, i.e.: "organic skeleton grains" (briefly o-skeleton grains).

In chapter 3 aggregations of tissues will be classified as "histons". To indicate that organic skeleton grains are in fact aggregations of tissues one could name them "histonidia" (plural form of histonidion) meaning small histons.

Organic skeleton grains are spatially quite differently arranged from aggregations of tissues. This is because skeleton grains are mostly formed by the soil fauna and therefore they mostly occur in excrements and bodies derived from excrements. As most organic particles occurring in excrements are smaller than about 2 mm, most organic skeleton grains are smaller than that particular size.

Organic skeleton grains may, however, be as large as 1 cm. The author measured that some organic skeleton grains in excrements of earthworms (Lumbricus rubellus *and* Lumbricus terrestris) *measured 3 mm, whilst in excrements of the snail* Trichia hispida *some organic skeleton grains may even be 1 cm. Priesner (1961) noted that the fly-larva* (Tipula maxima) *may also produce organic skeleton grains of up to 3 mm.*

The fact that skeleton grains are mostly smaller than 2 mm does not imply that all organic bodies in soil smaller than this particular size are organic skeleton grains. For example a very small root with a diameter smaller than 2 mm is a real aggregation of tissues; it is not a skeleton grain. Moreover this root will have a certain length, which may be larger than 2 mm.

In thin sections it may be difficult to decide whether a particle smaller than 2 mm is an organic skeleton grain or not. This is in particular true for individual fragments which, spatially, are arranged more or less separated from other soil units. If one considers the genesis of organic skeleton grains it should be concluded that an isolated spatial arrangement is rather impossible. Organic skeleton grains will occur grouped as e.g. in excrements. If they do not it can be deduced from their spatial arrangement that they must be organic skeleton grains, e.g. in the A_2-horizon of a humus podzol. Moreover it is in thin sections quite possible that the isolated arranged organic body in fact is a coupe of an aggregation of tissues.
These considerations are the reasons why such an isolated arranged organic body smaller than 2 mm (in thin section) is often regarded as an aggregation of tissues.

Previously the author (Bal, 1970) suggested organic skeleton grains were "primary particles", having in view small fragments of plant tissues formed by the soil fauna, which masticate and ingest the aggregations of tissues. For this fragmentation the reader is referred to Van der Drift (1950), Schuster (1956), Dunger (1958), Priesner (1961), and Bal (1970). Most important for the fragmentation should be mastication (Priesner, 1961). Although most organic skeleton grains will be formed by fragmentation of plant debris through the soil fauna, the concept of primary particles as equivalent to organic skeleton grains appears to be too narrow.

1. Although most fragmentation of plant tissues in soil will be done by the soil fauna, small fragments of plant tissues are also present in excrements of animals living above the soil e.g. phytophage caterpillars, birds, etc. Since the excrements of these animals are found in the soil it is reasonable to include their composing organic particles in the concept of organic skeleton grains.
2. Although most organic skeleton grains will be vegetable, a small amount of them will be of animal origin.
3. Although most fragmentation of aggregations of tissues will be done by animals, it is conceivable that a certain amount of small (skeleton grain-sized) organic particles is formed by other processes, e.g. biochemical, physico-chemical, and/or physical ones.

In some soils a coarse fragmentation can occur in this way, without forming organic skeleton grains however (Bal, 1970). But, it may be possible that in soils in which animals are almost absent or their activities are reduced in some way, organic skeleton grains are only formed by non-zoogenic processes. It is thought that in these soils the organic skeleton grains will also be present in groups, e.g. in the lower part of the organic horizons on the mineral soil.

4. Since spores, pollen grains and fragmented fungal hyphae are small skeleton grain-sized organic particles, it is proposed to regard them also as organic skeleton grains.

These are the reasons to include in the concept of organic skeleton grains not only plant tissue fragments formed by the soil fauna, but also comparable organic particles formed in a different way.
A definition of organic skeleton grains can thus be formulated as follows:

> "*Organic skeleton grains* of a soil material are individual organic grains which are relatively stable and not readily translocated, concentrated or reorganized by soil-forming processes; they include fragments of aggregations of tissues, spores, pollen grains, and fragments of fungal hyphae; they are larger than 2 μm and commonly smaller than 2 mm"

Since organic skeleton grains, except the spores and pollen grains, represent in fact a stage in the decomposition of aggregations of tissues, they vary greatly in size and quality depending on:

1. the types of tissues from which they have been derived (Priesner, 1961; Bal, 1970).
2. the process responsible for their formation, e.g. the animal species (Dunger, 1958; Priesner, 1961; Bal, 1970). Also the animal's stage of development (growth) may influence the size of the organic skeleton grains.

The author observed that of the earthworm Lumbricus rubellus *the adults fragmented poplar leaves into particles varying from*

approximately 140 × 140 – 1400 × 1400 µm, sometimes even up to 3000 × 1000 µm. The juveniles of the same earthworm made fragments of 230 × 230 – 900 × 450 µm. The adults as well as the juveniles made only few particles smaller than 100 µm.
Adults of the milliped Polydesmus inconstans *fragmented poplar leaves into particles varying from 90 × 90 – 120 × 120 µm; after having consumed alder wood the fragments were 210 × 100 µm. The juveniles of this milliped fragmented the poplar leaves into particles varying from 40 × 40 – 70 × 70 µm.*

3. the age of the skeleton grains.

An exact classification based on size is rather difficult because there is no agreement as yet on what size parameters to use. One could decide to make a classification based on the process of formation, or the behaviour in soil of skeleton grains of different size.
Unfortunately our knowledge of the relationship between animal species, type of food and the size of the organic skeleton grains made by the animals is too limited as is our knowledge of a possible difference in behaviour of the organic skeleton grains.

Through the lack of knowledge an arbitrary size classification of organic skeleton grains is proposed, which is, apart from the class 2 – 20 µm, identical with the separation in size groups of mineral particles according to the Soil Survey Staff (1951, p. 207).

size in µm	*name of separate*	
2 – 20	extremely fine	fine
20 – 50	very fine	fine
50 – 100	medium fine	fine
100 – 250	moderately fine	medium
250 – 500	moderately coarse	medium
500 – 1000	medium coarse	coarse
1000 – 2000	very coarse	coarse
> 2000	extremely coarse	coarse

In thin section it is often hardly possible to measure the exact size of the organic skeleton grains due to their mode of occurrence. An exact measurement of the size of the organic skeleton grains can be made by gently disintegrating the organic material (e.g. an excrement) in water, glycerine or lacto-phenol, followed by measuring of the size under the microscope (Priesner, 1961; Bal, 1970).

Some relevant comments will now be made on the way in which organic skeleton grains (especially the ones formed from aggregations of tissues) appear in thin section.

- *The particles smaller than 20 μm resemble points or ribbons. In fact they are small groups of cells, loose cells, or even parts of cells (Fig. 8, 33 and 81).*
- *Particles of 20 – 100 μm often occur intertwined in excrements. Their appearance is often of such a nature that one expects that they still possess tissue structure. The structures are, however, often obscured (Fig. 2, 3 and 81).*
- *Particles of 100 – 250 μm. There is no doubt about their being fragments of aggregations of tissues, although the pattern of the tissue may be obscured due to the way in which the skeleton grains occur (Fig. 2, 3, 42 and 80).*
- *Organic skeleton grains larger than 250 μm are mostly clearly visible fragments of aggregations of tissues, the larger the organic skeleton grain the easier to recognize it (Fig. 18, 37, 78 and 79).*

2.1.3 Organic plasma

Part of the plasma defined by Brewer (see page 17) consists of organic constituents. It is proposed to mention all these particular organic constituents together as "organic plasma" or briefly "o-plasma". It is possible to describe organic plasma more in detail. Organic plasma is composed of two essentially different groups of materials:

A. The chemical constituents (Fig. 5 and 6) and B. Tissue particles less than 2 μm in size (Fig. 13).

ad A. *The chemical constituents*
To this group belong chemical substances inherited from plants or animals as well as substances not arranged together in materials with a vegetable or animal structure. The inherited substances are cell plasma, vegetable slime, tannins, etc. To the non-inherited ones belong substances with a high molecular weight as the "organic new-formations". However, there does not exist a clear boundary between the two groups mentioned. On colour, and on the transparency for ordinary light, these chemical constituents can be subdivided into:

1. yellow, brown, red-brown, and red coloured organic plasma (Fig. 9, 10, 73, 74, 75, 82 and 83).
2. very darkbrown and black coloured organic plasma (Fig. 9, 23, 28 and 29).
3. opaque organic plasma (Fig. 10, 22, 25, 26 and 30).

Such a classification is logical as these groups are easily to distinguish from each other. Moreover, they may occur differently. Light coloured organic plasma occurs in terrestrial humons in all places where tissues are (bio-) chemically decomposed and may occur, after being translocated, in cutans. Moreover, light coloured organic plasma may have the appearance of a gel, part of which might be attributed to the presence of bacterial slime.

Darkbrown and black organic plasma are, in contradistinction to opaque organic plasma, still more or less transparent in transmitted light. In terrestrial humons it occurs in organic materials of which the decomposition has already considerably proceeded, or in particular tissues of decomposing small roots (page 53).

Opaque organic plasma occurs in terrestrial humons often as spots, which may be small remains of xylem or sclerotia (Fig. 10 and 22), or in sclerotia of particular fungi (Fig. 25, 26 and 30).
According to Jongerius and Pons (1962a, b) the organic plasma in the illuvial B-horizon of peat soils is also of an opaque nature.

The chemical differences between the three groups are still not known. However, in humus chemistry it is well-known that "immature" humic acids (the so-called "precursors") and fulvic acids are light coloured. There are indications, indeed, that the

light coloured organic plasma in *decomposing tissues* consists of immature humic acids (Nehring, 1955; Kononova, 1961, pp. 139–152; Babel, 1964 a). With progressive oxidation the colour would become darker (Flaig et al., 1963).
In thin sections one can observe a blackening of light coloured plasma with progressing decomposition of tissues. In these cases the black plasma then often occurs as a cloudy, colloidal mass (Fig. 9).
On the other hand very dark black and real opaque o-plasma do not appear like a colloidal mass (Fig. 10 and 28). Moreover, this very dark and opaque o-plasma may form directly (without having been light coloured) by "melanosis" (for melanosis see pages 42 and 53).

Light and dark coloured o-plasma are easily oxidized with NaOCl (see p. 33). Opaque o-plasma is only to oxidize after treating for many hours only (experiments of Dr. Babel, personal information).

From the above it is thought that the distinction of o-plasma based on colour differences may at the same time to some degree represent a distinction on chemical nature.

Of course "chemical individual, organic substances of low molecular weight" are also part of the o-plasma. It is obvious that they are present in decomposing tissues. They occur not only in decomposing tissues, since they are often soluble in water they can easily be translocated deeper into the soil.

ad. B. *Tissue-particles smaller than 2 μm*
Most of these particles will consist of cellwall fragments. As opposed to the skeleton grains these small particles can be moved, reorganized, and/or concentrated relatively easily by processes of soil formation. This is the reason to classify them as organic plasma and not as organic skeleton grains. The small tissue constituents can often be distinguished from the chemical ones by a "point like" appearance of the former.

Through the differences in physical, physico-chemical, and chemical characteristics between plasma and skeleton grains the former is much easier than the latter to be moved, reorganized, and/or concentrated by processes of soil formation.

A definition of organic plasma can thus be formulated:

"*Organic plasma* is that part of the organic soil material which is capable of being or has been moved, reorganized, and/or concentrated by processes of soil formation.
It includes all organic material of colloidal size smaller than 2 μm, and relatively soluble organic material, which is not bound up in the skeleton grains or tissues. The colloid-sized material is composed of high molecular weight constituents and of very small fragments of tissue"

Organic plasma may easily be examined with a microscope. This is especially true for purely organic soil materials, in which its presence can be established by removing it with a diluted solution of sodiumhypochlorite NaOCl (Handley, 1954, p. 63; Babel, 1964 b, 1965 a), or with 0.1n.NaOH or KOH (Bal, 1970). Organic plasma occurs not only in a pure state, but also mixed with diffusely divided iron complexes (hydroxides). These pure and mixed forms are not always easily distinguishable from each other. In this respect it is advisable to study the materials also with reflected light in which ironhydroxides often have brown-orange colours.

The presence of diffusely divided iron complexes (hydroxides) is detected by treatment with $K_4Fe(CN)_6$ and HCl (Babel, 1964 b), or with the aid of an electron microprobe analysis (Hill et al., 1971; Veen and Maaskant, 1971).

In order to demonstrate the presence of light and dark coloured organic plasma and diffusely divided iron complexes (hydroxides) one takes a thin section without a cover slip. When (non-opaque) organic plasma is oxidized for 90 minutes with the aid of a 1 : 4 solution (approximately 2.5%) of sodium-hypochlorite (NaOCl) a discolouration of the soil material is caused. The presence of organic plasma may also be demonstrated by removing it, from some isolated organic material taken from the soil, with the aid of a diluted solution of NaOH or KOH. Under the microscope it can be observed that removal causes a discolouration of the organic material.

To prove the existence of diffusely divided iron complexes *(hydroxides) Prussion blue is used. A 5% solution of potassium ferro cyanide $K_4Fe(CN)_6$ is brought in contact with the non-covered thin section for 5 minutes; this is followed up by the treatment with 1n. hydrochloric acid HCl for 1/2 minute. Upon adding the hydrochloric acid the places in the thin section where diffuse iron complexes (hydroxides) are present are coloured blue.*

Organic plasma may be difficult to observe when it occurs finely divided in the s-matrix e.g. in a clay-humus complex. However, according to Brewer (1964, p. 303) and Brewer and Sleeman (1969), its presence may be suspected by the particular colour and reduced double-refraction of the (mineral) plasma.

To study o-plasma microscopically a lot of study has to be done on its chemistry. Moreover improvement of techniques is necessary (e.g. use of electron scanning microscope with magnifications up to 40,000 : 1 and phase contrast microscopy).

2.1.4 Fungal Hyphae

In thin sections fungal hyphae are usually dark coloured (Fig. 27, 28 and 29). However, fungi in thin sections are not always easily to detect as pointed out on page 83.

Fungal hyphae can penetrate organic bodies in soil (e.g. aggregations of tissues, excrements, etc.), but they may also be present "suspended" between mineral skeleton grains.

PART II

Organization in organic soil materials

Brewer (1964, p. 134) distinguished as "units of organization" that is "the organization of soil materials into different units", peds, pedological features, and s-matrices. To these the present author proposes to add the unit *histons*.

Attention will be paid to several pedological features (in particular some organic ones). Moreover it is proposed to subdivide the s-matrix into *o-matrix* and *i-matrix*.

CHAPTER III

Histon

3.1 HISTON

By histon is meant a "natural aggregation of tissues" such as a leaf, branch, root, etc. or its remains if these are not organic skeleton grains.*

The name "histon" was derived from the Greek word *Histos,* meaning tissue. The concept of histon is introduced because it is logical to put together all "aggregations of tissues" into one unit of organization.

Histons are commonly larger than, and are thus distinguished from, organic skeleton grains. Mostly histons are larger than 2 mm, however, there is no exact size-limit between histons and organic skeleton grains. The difference between them is lying in a difference in size and/or spatial arrangement (this was discussed on p. 27).

A histon may be strongly intertwined or matted by fungi or parts of it may be transformed into o-plasma or excrements. Such phenomena in histons may be regarded as being pedological features. However, o-plasma may also be present within a histon without forming a pedological feature (see pp. 43–44).

A definition of histon can thus be formulated as follows:

> "*Histon* is a natural aggregation of different tissues (grown together in a plant or animal body) such as a leaf, branch, root, seed, fruit, etc. or the remains of that if these are larger than 2 mm. Present organic plasma is

* Histon in pedology should not be confused with histon (histone) in organic, and biochemistry. In chemistry by histon (histone) is meant any group of simple proteins that yield amino-acids on hydrolysis, as the globin of haemoglobin (Webster's new world dictionary, 1972).

part of the histon unless it has been formed into a pedological feature. Pedological features can occur within histons"

3.2 CLASSIFICATION OF HISTONS

Histons can be classified according to their origin, shape, size, internal fabric, and arrangement.

origin — All names of histons have the suffix *hist* derived from histon. Some of the most frequently occurring histons in the humon are the following:

- *foliohist* — A histon derived from a leaf. The name is coined from the Latin word "folium" (= leaf) and histon. (Fig. 14, 15, 23, and 73)
- *brancohist* — A histon derived from a branch. The name is coined from the Latin word "branca" (= branch) and histon.
- *radicohist* — A histon derived from a root. The name is coined from the Latin word "radix" (= root) and histon. (Fig. 28 and 72)
- *histonoids* — In thin sections aggregations of tissues smaller than 2 mm can occur of which it is thought that they are no skeleton grains, but a coupe of a histon. One gets this impression by their way of occurrence (see p. 27). It is proposed to name these particular histons "histonoids".

shape — For the shape of histons terms like lamellar, cylindrical, etc. will do.

size — There is no adequate classification of size of histons as yet. A division can be made between macro- and micro-histons. The boundary between these two groups can be fixed at that size below

	which it is necessary to use microscopic methods to study the histon as an entity. Tentatively this boundary is fixed where the histon's diameter is approximately 0.5 mm.
internal fabric	This is discussed in chapter V called "O-Matrix". One aspect may however be mentioned. A histon may be completely intact, but parts of it may also have disappeared. This degree of absence of parts of the histon may be described in terms of weakly, moderately, and strongly damaged (Fig. 15, 28 and 77).
arrangement	For arrangements of histons often Brewer's terminology can be used (Brewer, 1964, pp. 168–170).

Note

In Biological Sciences (Gray, 1967, p. 347) the concepts Necron *and* Humus necron *are distinguished.*
By necron is meant: "living material which has died but which has not yet decomposed; applied particularly to plant forms".
By humus-necron is meant: "partially decomposed vegetable matter not yet humus, but in a condition in which the origin from stems or leaves, etc. can still be determined".
The concepts of necron and humus necron are in fact almost identical to the one of histon. Nevertheless they were not adopted because of their restriction to vegetable matter. Moreover, in using these concepts one is obliged to define "humus" and what is meant by "partially decomposed".

CHAPTER IV

Pedological Features

Brewer (1964, p. 142) defined pedological features: "Recognizable units within a soil material which are distinguishable from the enclosing material for any reason, such as origin (deposition as an entity), differences in concentration of some fraction of the plasma, or differences in arrangement of the constituents (fabric)."

Brewer meant to indicate with pedological features, phenomena in soil which may occur as striking ones, hence their name. They attract attention by being different from the surrounding soil material. Some examples of pedological features are excrements and sesquioxidic glaebules.

But, neither excrements nor sesquioxidic glaebules are always "recognizable units within a soil material".

A soil horizon may even be completely built up of excrements or of glaebules. To maintain the definition according to Brewer one could decide to consider a particular body as pedological feature only if it is a "recognizable unit within a soil material". Consequently in a horizon completely composed of excrements these excrements might not be considered as pedological feature, but as a soil material which is characterized by a particular fabric of its s-matrix. This s-matrix could then be named e.g. if excrements are welded together: "welded fabric". In other words one should ignore the presence of excrements, but that is unrealistic and senseless of course.

However, this difficulty in Brewer's definition can be avoided by pointing out that by pedological features are meant: "bodies, which always, or often, occur in soil as striking phenomena".

Pedological features can thus be redefined as follows:

> "*Pedological features* are bodies, which often occur as recognizable units within a soil material. In such cases

> they are distinguishable from the enclosing material for any reason, such as origin (deposition as an entity), differences in degree of accumulation of some fraction of the plasma, or differences in arrangement of the constituents (fabric)"

Before dealing with organic pedological features two soil-forming processes, namely "melanosis" and "accumulation" respectively will be introduced and discussed. This is necessary as several organic pedological features may be formed by them.

4.1 MELANOSIS

Accumulations of very dark brown, or black to opaque, organic plasma can occur in organic bodies (e.g. histons). They possibly coincide with the presence of micro-organisms, which are sometimes visible in thin section. These micro-organisms produce (may be after autolysis) the dark-coloured o-plasma.*
The author proposes to name this process of dark-colouring *melanosis* (Fig. 28).**
Features in soil, formed by melanosis, can be distinguished as "melanotic" (e.g. melanotic glaebules).

4.2 ACCUMULATION

Such an accumulation of dark-coloured o-plasma (as discussed in

* Scheffer et al. (1960, p. 173) indicate that the black-coloured material produced by *Azotobacter chroococcum* and *Aspergillus niger* were earlier recognized as melanin. The content of the dark, non-crystalizable huminoid, coloured material in the mycelium could account for 54% of the weight of the mycelium. True melanin is produced by the action of the enzym tyrosinase on tyrosine (Scheffer et al., 1960, p. 110; Griffin, 1972, p. 122).

** The Greek word "melanosis" is derived from *melas* (= black) and *osis* (= forming substantive of process) and means dark-colouring (The concise Oxford Dictionary, 1964). According to Maiwald (1931, p. 131) and Griffin (1972, pp. 122–123) the term melanization (= melanosis) is, in microbiology, not only used for the formation of melanin. It is frequently used in a looser sense in connection with the action of a number of polyphenol oxidases on substituted phenols (e.g. Lindeberg, 1955). In medical science melanosis is known as a dark discolouration of the skin or organs caused by an extravasation of blood or pigmentation. "Melanoma", for example, is a black pigmented swelling in the skin caused by fungi.

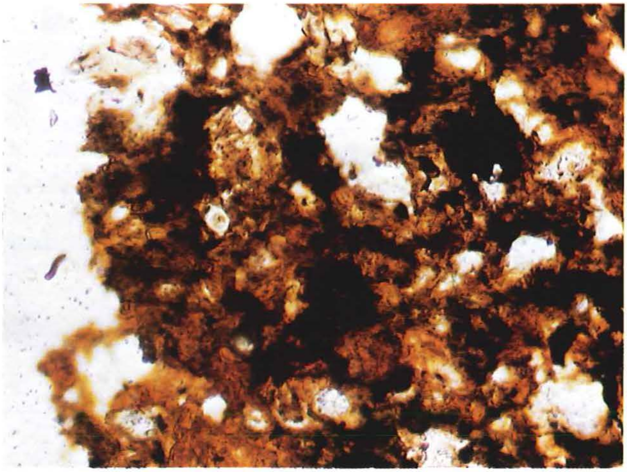


Fig. 9 Soil material composed of organic skeleton grains and a high amount of organic plasma of which the related distribution pattern can be described as o-porphyroskelic (high plasma). Note that the main colour is caused by the presence of yellowish brown organic plasma, but that also black coloured o-plasma has been formed which occurs as a cloudy, colloidal mass over the soil material (especially approximately in the centre of the figure). The small and rather sharp bounded, opaque feature on the right side of the figure may be a remnant of a sclerotium. Thin section in plain light. 220x.

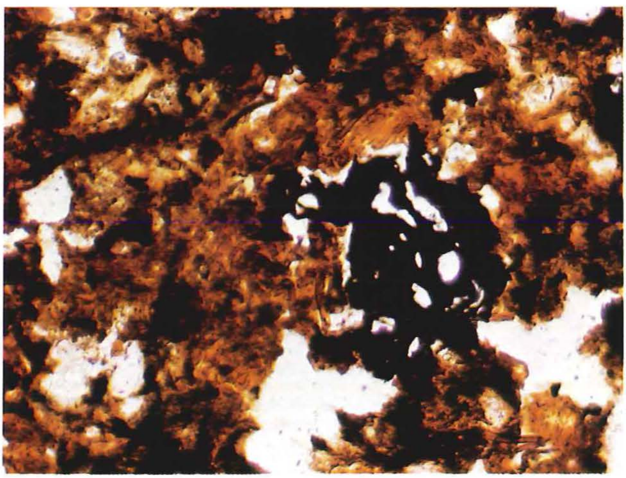


Fig. 10 Can be described as Fig. 9. Note the melanon which is the opaque pedological feature. The opaque character of this pedological feature can be ascribed to the presence of opaque organic plasma. Thin section in plain light. 220 x.

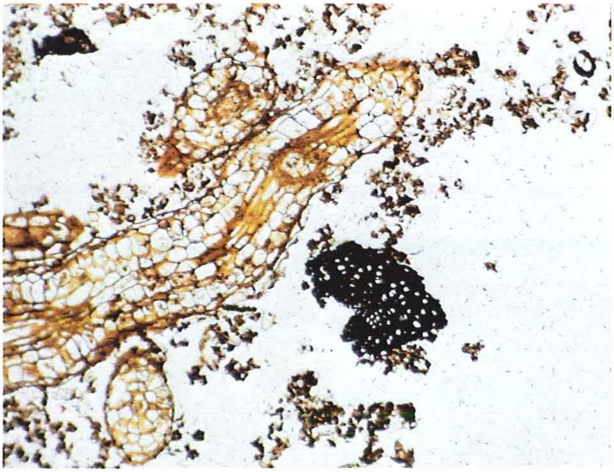


Fig. 22 Melanon formed by an accumulation of opaque organic plasma in xylem. Note the longitudinal and cross sections of some small radicohists. Thin section in plain light. 36 x.

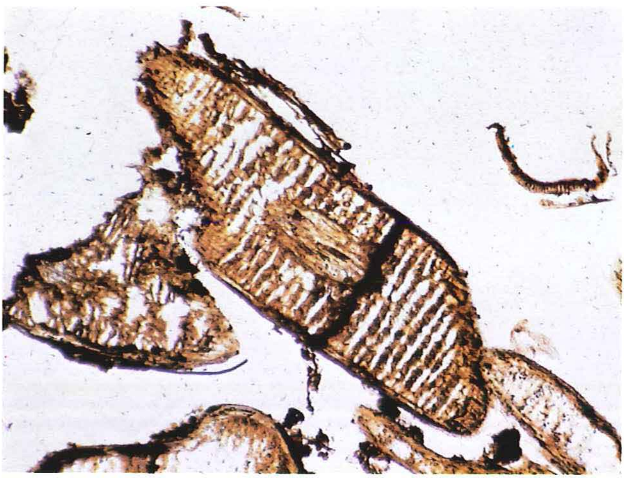


Fig. 23 Elongated melanon in a foliohist. The melanon is an α-accumulation of black organic plasma. Thin section in plain light. 36 x.

the preceding paragraph) is generated during pedogenesis. It is, as it were, formed from nothing or in other words it has been "generated". There are, however, several accumulations which have been formed by transportation of existing constituents. These genetically different accumulations must be distinguished from each other. It is proposed to name them α- and β-accumulations respectively, which can be formulated as follows:

"*α-accumulation* is an accumulation of a constituent, or constituents formed by generation"

"*β-accumulation* is an accumulation formed by transportation of one, or more existing constituents"

α-accumulations are not only formed by decomposition of organic bodies. In practice they may also be formed by weathering of minerals resulting in the formation of clay minerals and iron oxides (examples described by Mermut and Pape, 1971). Another example of an α-accumulation are excrements generated by animals after they have ingested histons.

Examples of β-accumulations are: illuviation and diffusion cutans, and several glaebules. These β-accumulations may be subdivided according to the way of transportation, e.g. diffusion or illuviation in suspension as was done for cutans by Brewer (1964, p. 224).

Complex accumulations are formed by generation as well as transportation; they are indicated as $\alpha\beta$-accumulations.

What kinds of pedological features concerning organic materials can be distinguished?

It needs no explanation that organic excrements and organic cutans around mineral skeleton grains satisfy the definition of pedological features. But, in fixing other organic pedological features some difficulties may arise. For example in decomposing tissues light coloured o-plasma may be present as a thin layer at the cellwalls, or it may fill up the cell lumena throughout the tissues, or it may even cover the tissues to a great extent (Fig. 73, 74 and 75). Other soil materials as e.g. organic excrements may be composed of organic skeleton grains and different quantities of

o-plasma (whether this is light- or dark-coloured) throughout the soil material.
It is beyond dispute that these forms in which the o-plasma occur may be α-accumulations or perhaps $\alpha\beta$-accumulations. If the o-plasma occurs as a thin layer at the cellwalls or at the surface of the o-skeleton grains one could consider this layer as a pedological feature, e.g. a kind of cutan. But when the cell lumena or the spaces between the o-skeleton grains have been filled up with o-plasma this latter does not form pedological features.

Apart from the fact that it is often difficult to distinguish organic cutans around o-skeleton grains one may wonder if it is significant to distinguish them at the present state of knowledge. The same may be wondered on the "organic cutans" at the cellwalls in tissues. That is why it is proposed to consider o-plasma occurring throughout organic soil materials as part of the matrix of these materials.

However, accumulations of o-plasma can occur in such a way that they form recognizable units within the soil material or in other words in such a way that they are easily distinguishable from the enclosing material (for example when within a histon dark coloured or opaque o-plasma is locally formed). In these cases the accumulations of o-plasma are distinguished as pedological features. Organic pedological features can occur as:

cutans, subcutanic features, glaebules, fungons, and excrements including some pedotubules.

These pedological features will be dealt with in two subchapters, i.e. IV.I (cutans, subcutanic features, organic glaebules, and fungons), and IV.II (excrements and some pedotubules). This subdivision in subchapters is only made because relatively much attention will be paid to excrements.

CHAPTER IV.I

Cutans · Subcutanic features · Organic glaebules · Fungons

4.1.1 CUTANS

According to Brewer (1964, p. 206) a cutan is: "A modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or in situ modification of the plasma; cutans can be composed of any of the component substances of the soil material".

The same author (page 208) classifies cutans in several ways. One of them is the mineralogical nature of the cutanic material. However, as there exist organic, as well as mineral cutans, it is proposed first of all to make a distinction on their nature into: mineral, organo-mineral, and organic cutans. Moreover it is proposed to make a distinction of cutans according to their composing constituents into: plasmans, skeletans, and plasmans-skeletans.

plasman	is composed of plasma
skeletan	is composed of skeleton grains
plasman-skeletan	is composed of a mixture of plasma and skeleton grains.

The plasmans-skeletans can, in their turn, be subdivided into: plasmic skeletans if the amount of plasma is relatively low and skelic plasmans if the amount of plasma is relatively high.

On their mineralogical, or chemical nature some examples of plasmans are: argillans, ferrans, mangans, and humicans. The first three mentioned are described by Brewer (1964, pp. 211–218). The humicans will be discussed under the organic cutans.

A particular type of cutan is the *matran,* which in composition is identical, or almost identical, with the composition of the s-matrix of e.g. peds and/or apedal soil materials (Fig. 16).
Matrans are thought to be formed by rather drastic conditions.

This may especially be clear in the case of matrans which are formed by "mass transportation" from an overlying horizon (resembling "agricutans" described by Jongerius, 1970 and Brammer, 1971). Also the "matri-ferri-argillans" described by Van Schuylenborgh et al. (1970) might be recognized as matrans. Because of the drastic conditions by which matrans are thought to be formed they cannot be classified (on the process of formation) as "illuviation", "diffusion" and "stress" cutans as can be done for other cutans as described by Brewer (1964, p. 224).
According to the present author the genetic classification for pedotubules proposed by Brewer (1964, p. 256) can be adopted for matrans as follows:

orthomatrans	The cutanic material has been derived from the soil material of the horizon in which they occur.
metamatrans	The cutanic material has been derived from the soil material of another horizon from that in which they occur, usually an overlying horizon.
paramatrans	The cutanic material is quite unlike that of the soil materials of any of the horizons in the soil.

Cutans can also be designated according to their being organic or inorganic (see page 56), and at the same time according to their composing constituents. For example a cutan composed of organic skeleton grains is called an "o-skeletan", whilst a cutan composed of inorganic skeleton grains is called an "i-skeletan".*

Organic cutans
These are cutans, which are completely, or almost completely, composed of organic constituents and are therefore named *organans* (Bal, 1970). There are organans, which consist entirely of organic plasma, e.g. in the B_{2h}-horizon of a humuspodzol in pure quartz sand; or in other words these cutans are o-plasmans.

According to McKeague (1967) an o-plasman may dissolve almost completely in diluted NaOH or 0.1 mol. $Na_4P_2O_7$ at a pH of approximately 10; this was reaffirmed by the present author. This proves that this particular organan consists almost completely

* The prefix "o" or "i" is meant to indicate the material's being organic or inorganic.

of humic substances; that is why it is proposed to name this type of cutan, on its chemical nature, a *humican* (Fig. 83).

Excrements can be enveloped by dark coloured organans; may be these are humicans (Fig. 17 and 18).
In this respect the author wants to bring to notice the so-called *peritrophic membrane.* This particular membrane may be formed by several soil animals around the excrements in their intestines to protect these latter (Mason and Gilbert, 1954). Unfortunately it has never been seen with ordinary light, but it is not impossible that it will with the aid of certain techniques. If this will be true then it is proposed to call this particular cutan a *membran.*
However, there are indications that this peritrophic membrane can be oxidized by which its colour changes to black. For by decomposition of this membrane there will undoubtedly NH_3 be released and autoxidation may occur (see paragraph subcutanic features). Thus a dark coloured organan surrounding an excrement (i.e. excrement organan) may betray an earlier present membran.

Moreover one may add then to the groups of cutans, distinguished by Brewer (1964, pp. 224–226) on the basis of interpretation of the process of formation, a new group named *wrapping cutans.* In this group it is thought also to include cutans formed by animals, which plaster channels with their excrements.
A definition of these cutans can thus be formulated as follows:

> "*Wrapping cutans* are formed through actively wrapping up or plastering a soil material with the cutanic material by organisms"

Thus a membran is a "wrapping organan".

Organo-mineral cutans
These are cutans, which consist of a mixture of organic and mineral constituents. In the names of these cutans the name of the dominating constituent is prefixed by the name of the other composing constituents. For example a cutan which is composed of a mixture of dominantly clay minerals and a minor amount of organic constituents is called an "organo-argillan" (as described by Brewer, 1964, p. 214). A cutan, which is composed of a mixture of dominantly organic skeleton grains and a minor amount of mineral constituents

is named a "minero-o-skeletan".

There are cutans, which are completely composed of faecal material. On their being faecal it is proposed to call them *scatans* (derived from the Greek word *skato* meaning excrement). Scatans are especially formed by earthworms, which plaster their tunnels with their excrements (Fig. 19 and 20).* Jongerius (1970, p. 316) mentioned these "vermicutans".
A particular scatan is described on page 73.

4.1.2 SUBCUTANIC FEATURES

According to Brewer (1964, p. 293) a subcutanic feature is: "A pedological feature (recognized by a difference in texture, structure, or fabric as compared with the enclosing s-matrix) that has a consistent relationship with natural surfaces in the soil material, but does not occur immediately at the surfaces." Of organic subcutanic features are known the neo-organans, which are a type of neo-cutans. A neo-organan is a zone in the s-matrix immediately adjoining natural surfaces, with which it is associated. Relative to the rest of the s-matrix it is characterized by a higher content of one or more organic constituents, or it is characterized by a different arrangement of present organic constituents (Fig. 46). Several types of neo-organans can be distinguished, i.e.: neo-plasmans, neo-skeletans and neo-matrans.

Excrements may be characterized by the presence of neo-humicans, of which the origin is not yet fully explained. Humic acids (organic plasma) may be formed in the intestines of the soil fauna (Franz et al., 1948; Laatsch, 1948; Dunger, 1958; Kurcheva, 1960).
Thus it might be possible that neo-humicans are formed inside the animal, but it is far more likely that their origin lies in the fresh excrements. Because, humic acids may be formed by autoxidation through a weak alkaline reaction and the formation of NH_3, with our without after autolysis of micro-organisms (Scheffer et al., 1949; Flaig, 1950; Küster, 1952; Kononova, 1961, p. 154). Such reactions were measured in fresh excrements by Van der Drift and Witkamp (1959). It is reasonable to suggest that the

* It is clear that these cutans are at the same time "wrapping cutans".

autoxidation takes place at the periphery of the excrement, and this could explain the presence of a neo-humican (It is not quite impossible that an excrement neo-humican in fact betrays the presence of a kind of, as it were, "embedded" peritrophic membrane).

The author can only partly agree with the suggestion that neo-humicans originate (as α-accumulation) in older excrements. In fact, if black colouration occurs in such excrements it can often be seen that this takes place throughout the excrement (Hartmann, 1951, p. 51; 1965, p. 33 and plate IV; Jongerius and Pons, 1962; Bal, 1970). In such a case humic acids could possibly form through autoxidation after the autolysis of present micro-organisms (Scheffer et al., 1949; Küster, 1952), as well as with the aid of phenol-oxydase originating from micro-organisms in a non-alkaline environment (Küster, 1955; Kononova, 1961, p. 155; Flaig et al., 1963).

A *neo o-matran* is a zone in the s-matrix immediately adjoining the natural surfaces, with which it is associated. It is characterized by a higher content of o-matrix.*

Stress neo-organan Brewer distinguishes cutans in several ways. One of them is based on interpretation of the process of formation (Brewer, 1964, p. 224). In this latter way are, amongst others, distinguished *stress cutans* which are: "in situ modifications of the plasma due to differential forces such as shearing; they are not true coatings. Most stress cutans are simple types".

From this definition it is clear that stress cutans are not cutans (as Brewer already ascertained), in fact they are neo-cutans. That is why the present author proposes to classify stress-features as neo-cutans.

Moreover it appears that the definition of stress cutans, according to Brewer, is not comprehensive enough. Only plasma would be modified in its arrangement. However, in excrements it may happen that organic skeleton grains, adjoining the surface, are arranged parallel with this latter. This is because the excrement is pushed through the animal's intestines (Fig. 21 and 37).

These are the reasons why a new concept of stress-features must be formulated, i.e.:

* o-matrix consits of organic skeleton grains plus organic plasma. It will be discussed in chapter V.

> "*Stress neo-cutans* are in situ modifications in the arrangement of plasma and/or skeleton grains due to differential forces such as shearing"

The above-described feature in excrements may thus be classified as *stress neo o-skeletan.*

4.1.3 ORGANIC GLAEBULES

According to Brewer (1964, pp. 259–260) a glaebule is: "A three-dimensional unit within the s-matrix of the soil material, and usually approximately prolate to equant in shape; its morphology (especially size, shape, and/or internal fabric) is incompatible with its present occurrence being within a single void in the present soil material. It is recognized as a unit either because of a greater concentration of some constituent and/or a difference in fabric compared with the enclosing soil material, or because it has a distinct boundary with the enclosing soil material."

According to the present author there are several organic glaebules, e.g. α- and *β-anthracons* and *melanons.*

The name anthracon was derived from the Greek word *anthrax* which means coal, but also charcoal. To distinguish charcoal from coal these are designated as α-anthracon and β-anthracon respectively.

Not organic glaebules, but occurring in soil are fragments of brick. As these were not described by Brewer they are introduced in this study as *plinthons.*

α-Anthracons have been derived from histons, which changed into charcoal.
Although the tissue-structure may still be visible in them (Fig. 24), their chemistry is quite different from the histons from which they were formed. That is the reason to regard charcoal as glaebule instead of histon.

β-Anthracons are fragments of coal.
According to Brewer (1964, p. 266) nodules are:

"Glaebules with an undifferentiated internal fabric; in this context undifferentiated fabric includes recognizable rock and soil fabrics." This means that β-anthracons can be classified as nodules.

Melanons These glaebules are formed by melanosis of histons, or remains of histons, or melanized soil materials, which may be unrecognizable remains of sclerotia. If part of a histon is melanized, only this is the melanon (Fig. 10, 22 and 23).

Plinthons are bricks or fragments of bricks in soil.
The name was coined from the Greek word *plinthos* which means brick.

According to Brewer (1964, pp. 140–146) pedological features (and thus also glaebules) can be divided into two broad classes, i.e. "orthic" ones (are formed in situ), and "inherited" ones (relicts of the parent rock and parent material or of underlying materials). According to this division anthracons are only glaebules if they are part of the parent material. However, charcoal as well as coal may be brought in soil by forest-fire and/or man (e.g. with manure). The same may be true for fragments of brick. This means that if charcoal, coal or brick is brought in soil by man then these materials should not be considered as glaebules. The present author thinks that this is unrealistic, or in other words the concept of the inherited pedological features is not comprehensive enough.

Thus it appears that included bodies may have been brought in soil in another way, as e.g. by man. The concept of these particular pedological features can thus be better defined as follows:

> "*Inherited pedological features* are relicts of parent rock and parent material or of underlying materials, or they have been added to the soil in some other way (e.g. by man)"

Defined in this way anthracons and plinthons are inherited pedological features. Melanons may be orthic, as well as inherited, mostly they are orthic pedological features.

4.1.4 FUNGONS

Fungi may be present in soil in different forms, i.e. hyphae, sclerotia and spores. They may be regarded as pedological features and are proposed to be named fungons, which can be defined as follows:

> "*Fungon* is a sclerotium, or an accumulation of fungal hyphae and/or spores in a soil material"

Sclerotia are globular, resting fungal bodies; often they are melanotic (Fig. 30). The ones observed in soil are mostly of species of Cenococcum (IJzerman, 1924; Mikola et al., 1962).
In fact sclerotia might also be regarded as glaebules, but as they are fungal they are regarded as being fungons.
Fragments of sclerotia also occur in soil; they are proposed to be named *sclerotia splinters* (Fig. 25 and 26).

Fungons formed by accumulation of hyphae are named *hyphons,* coined from hyphae and fungon. They may be divided into two groups (α- and β-hyphons) based on the arrangement of present hyphae. In the first group the hyphae are irregularly arranged whilst in the second group the arrangement of them is regular. The regular arrangement is often characteristic for hyphons present in histons. In these cases it is caused by the fact that the hyphae penetrate the cell-walls instead of growing into the cell lumen. Thus it is determined by the internal fabric and chemical composition of present tissues (Bal, 1970). The two groups can be formulated as follows:

> "*α-hyphon* is a fungon characterized by irregular arrangement of present hyphae" (Fig. 27)

> "*β-hyphon* is a fungon characterized by regular arrangement of present hyphae" (Fig. 29)

Several β-hyphons may be distinguished on the way of arrangement of present hyphae (internal fabric), for example concentric, or a complicated arrangement of hyphae in different directions.
Unfortunately a satisfactory description of different internal

arrangements of hyphae cannot be given as yet. An interesting form of β-hyphon can be present in small radicohists derived from roots with a "primary anatomical structure".* In this particular case the cortex of the dead root is so strongly attacked by fungi that it changes into a hyphon. As the fungi produce black coloured o-plasma, the cortex is coloured black, which means that the hyphon is a melanotic one. The stele (all tissues situated inside the cortex) is not penetrated by the fungi on the contrary it shrinks and disappears completely, so that the melanotic hyphon remains (Fig. 28, 29 and 64).

After a certain period of time all tissues of the rootlett (including the cortex) have been decomposed. In other words only the fungal hyphae as well as the black coloured o-plasma are still present. Even the black o-plasma may disappear so that ultimately only the fungal hyphae remain. Obviously these fungal hyphae are very resistant.**

As soon as the root has formed a periderm the melanotic hyphon is not formed, as the cortex dies and is shed, and the particular fungi are incapable to attack the periderm (Fig. 28).*** The resistance of periderm was also observed in peat soils by Grosse-Brauckmann et al. (1964).

Fungons formed by accumulations of spores are named *spore fungons.*

* These roots are built up of outer-tissues (called together "cortex") and tissues inside of them (called together "stele") (Koningsberger and Reinders, 1957, p. 89).

** According to Meyer (1964) these fungal hyphae in the root's cortex are of the fungus *Cenococcum graniforme* (Sow.) Ferd. et Winge. Cenococcum is not only a typical mycorrhizal fungus, but it is also capable of existing saprophytically. It is a symbiotic partner of nearly all the trees in the forests of the boreal and temperate zones. Moreover this fungus is very resistant against drought. Thus after the root has died Cenococcum consumes the cortex. It does not consume the stele and it is not capable to attack suberinized parts of the plant (as the periderm is).
According to several investigators (see Griffin, 1972, pp. 124–126) the resistance of hyphae to lysis by enzymes is directly influenced by the dark fungal pigments ("melanins").

*** Periderm consists of cork-cells in which the middle-lamel is lignified; next to this there is another layer of suberin. Against the latter there may be in some cases other lignified layers present (Koningsberger and Reinders, 1957, pp. 80–81). The high content of lignin and suberin causes their resistance to decomposition.

CHAPTER IV.II

Excrements

Prior to discussing excrements a definition of these is given:

> "*Excrements* are solid excreta derived from the intestines of the fauna; they consist of non-resorbed components of earlier consumed materials. In addition the excrements contain other materials that are added to the already mentioned components by the animals themselves in their intestines, such as intestine-epithelia-cells, secretions, enzymes, etc."

As members of the soil-fauna (e.g. earthworms) can consume organic, as well as mineral soil materials, their excrements can be organic, organo-mineral, as well as mineral. The discussion of excrements refers to organic, as well as to mineral ones. Although this definition is correct it is strongly genetic. Morphologically excrements may be considered as pedological features. A morphological definition of excrements may be formulated as follows:

> "An *excrement* is a three-dimensional pedological feature, which is spheroidal, ellipsoidal, cylindrical, thread-like, platy or shapeless. It consists of skeleton grains and/or plasma (mineral and/or organic), and is internally often densely packed (loose packing is less frequent and may be very characteristic). Its boundaries are distinct or diffuse. It may occur (as a separate individual, or as member of a group of like individuals) at the soil surface, in voids of any type, as well as embedded in the s-matrix of soil material of different kind, or many like or unlike excrements together may even built up a complete soil horizon"

The word "excrements" is deliberately used since in literature coprogenic particles are often confused with excrements. The incorrect usage of the term coprogenic was already discussed in an earlier paper and the term zoogenic particles was suggested instead (Bal, 1970). This latter part is correct and yet, no fully satisfactory, because particles formed by burrowing activities of animals, such as in mole-hills, are also zoogenic. Particles should be named according to the process by which they are formed. The correct term for excrements should therefore be "enterogenic entities" or "enterogenic particles", which literally means: "entities originating from the intestines". The word enterogenic is derived from the Greek word *enteron* which means intestine.

Excrements are morphologically described on:
- Characteristics of individual excrements namely: the composition of their s-matrix; their shape, size, internal fabric, and smoothness; occurrence of cutanic and subcutanic features.
- Their distribution patterns.

4.2.1 CHARACTERISTICS OF INDIVIDUAL EXCREMENTS

4.2.1.1 Composition of the s-matrix of excrements

By s-matrix is meant the present constituents (see Chapter V). In soil classifications distinction is made between organic and mineral soil materials, based on the content of organic and mineral matter as expressed as weight percentages (e.g. Soil Survey Staff, 1960, p. 25). There are, however, no visually obtained parameters for indicating the difference between mineral and organic soil materials. If desired an optical or electro-optical measurement of volume content (Jongerius, 1963; Jongerius et al., 1972; Bal, 1970) could be done. Distinction can be made between organic, organo-mineral and mineral excrements (Fig. 42, 53, 35 and 49 respectively).

In literature (Slager et al., 1970) the designation "matric faecal pellets" is used to describe excrements having a s-matrix similar to that of the soil material of the horizon in which they occur. The present author proposes to describe excrements as "matric" when they have a s-matrix which is similar, or almost similar to that of the soil material from which they were derived. In this way clear changes in the composition of the s-matrix (by masticating and/or ingestion of the material by the animals) are taken into consideration. In general the mineral materials will not be changed very much by the animals. However, the (s-matrix of) organic materials may be changed considerably, e.g. when histons are changed into excrements. That is why excrements derived from histons are not matric.

When such interpretations can be made excrements can be classified into two broad genetic groups which are respectively: *matric* and *amatric* excrements.

Excrements can also be classified on derivation in another way, namely taking into consideration their derivation and occurrence. The composition of their s-matrix need not necessarily to be similar to the material from which the excrements have been derived.

For example organic excrements within a histon may be formed by animals living within this histon (Fig. 33 and 54) whilst in other cases the animals defaecate elsewhere as earthworms may defaecate mineral material within brancohists (dead branches) on the soil surface or in another horizon (Fig. 61).

Considered in this way excrements can be classified into three broad genetic groups which in fact may be similar to those of pedotubules according to Brewer (1964, p. 256).

ortho-excrements	have been derived from the soil material in which they occur (Fig. 33, 47 a and 54).
meta-excrements	have not been derived from the soil material in which they occur (Fig. 57, 58 and 61).
para-excrements	are composed of material which is quite unlike that of the soil materials of any of the horizons in the soil.

By soil material is meant the unit of study (see page 68) which may be e.g. a histon, but also a horizon. It is clear that this classification of excrements may often coincide with the one of pedotubules. However, in the case of e.g. a single excrement embedded in a particular soil material (Fig. 57) it is not classified as a pedotubule.

4.2.1.2 Shape of excrements · Modexi

The water-content of excrements may, during defaecation, vary greatly. If the water-content is high, the excrements leave the animal's intestines as a fluid mass as is done by some earthworm-species (Lee, 1967; Bal, 1970). In these cases the excrements are shapeless. Very often, however, this water-content is much less and then the excrements are shaped, three-dimensional entities (individuals). That is why modelled, and non-modelled excrements are distinguished. However, the border between modelled and shapeless may be vague (see page 70). The shape of excrements is formed by the animal's intestines and sphincter. That is why the excrement's shape is very often cylindrical. But, that it sometimes may be rather complicated is to be seen in Fig. 38. In this figure the cylindrical excrement has lengthwise and crosswise grooves.

Up till now excrements in soil were called "faecal pellets" (Brewer, 1964, pp. 299–301). Regarding their size (which will be discussed on pp. 62–66) it is hardly possible to maintain the name faecal pellets, as this name suggests that the object is small. It is also hardly possible to call a threadlike excrement as a pellet, as this indication means a small object with roughly a spherical shape. That is why the present author proposes to name modelled excrements *modexi,* which can be defined as follows:

> "*Modexi* are excrements, which have left the animal's intestines as shaped, three-dimensional individuals"

The name modex (i.e. the singular of modexi) was coined from the words *mod*elled and *ex*crement.*

* Coined from Greek these particular excrements may be indicated as *typocopra* (plural form of *typocoprum*). *Typos* = shape; *Kopros* = dung, excrement.
Another possibility is to name them *scatotypes* (= plural form of *scatotype*). The Greek word *skato* = excrement.
However, the word *modex* is much more easy in practice than *typocoprum* and *scatotype.*

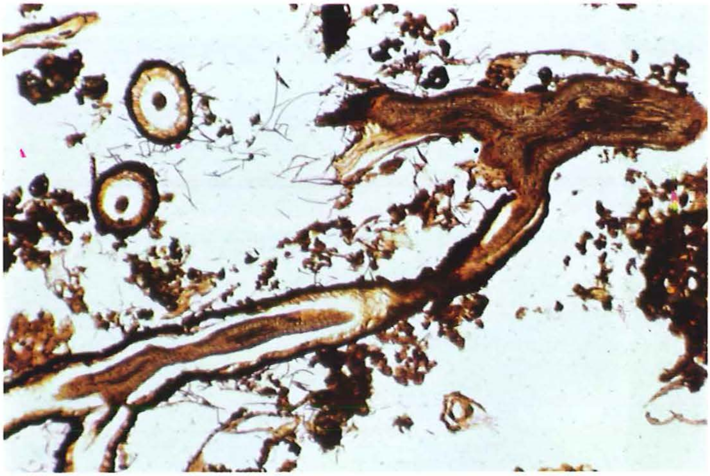


Fig. 28 Longitudinal section of a non-damaged to strongly damaged small radicohist. Moreover two cross sections of small radicohists. Note the α-accumulation of black coloured o-plasma formed by fungi which can be classified as a "melanotic β-hyphon". The thin, dark coloured threads are fungal hyphae; they are in particular visible protruding from the radicohist in cross section. The part of the radicohist which is characterized by the presence of periderm (in the uppermost part of the radicohist in longitudinal section) cannot be attacked by the fungi. That is why in that particular part of the radicohist the melanotic hyphon is absent. Thin section in plain light. 36 x.

Fig. 29 Melanotic β-hyphon in strongly damaged small radicohists. Note the regular arrangement of the fungal hyphae in the hyphon. Thin section in plain light. 88 x.

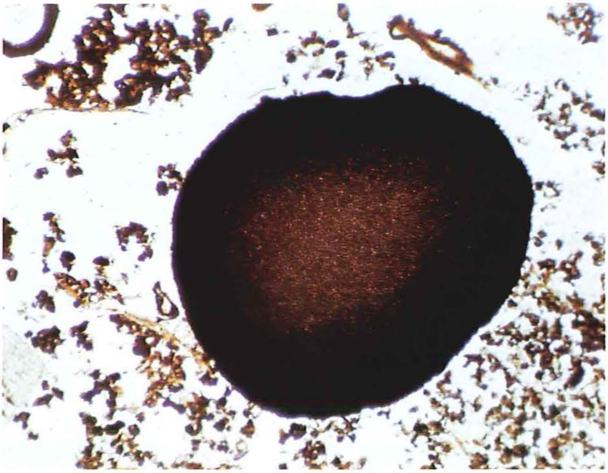


Fig. 30 Sclerotium. Note the presence of opaque organic plasma, in particular in the wall of the sclerotium. This wall is more resistant to decomposition than the sclerotium's centre which will be related to the amount of opaque organic plasma. That is why sclerotia splinters are often fragments of the wall of the sclerotia (Fig. 25). Thin section in plain light. 36 x.

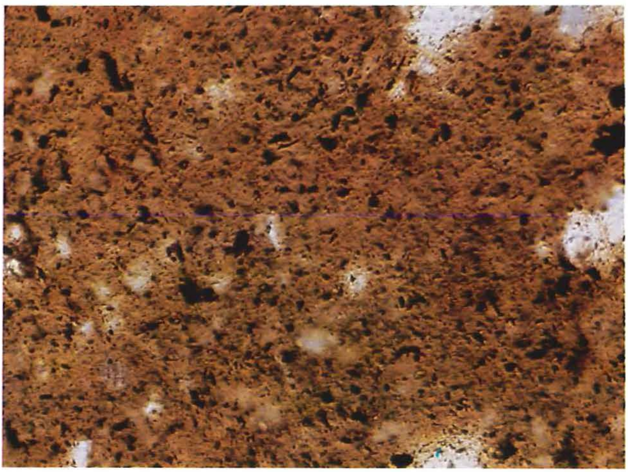


Fig. 31 Sporadic basic distribution pattern of extremely fine, organic skeleton grains. The organic skeleton grains are the dark coloured spots in the s-matrix; the latter consists principally of mineral materials. The dark spots $< 2\ \mu m$ are coarse, organic plasma grains. Thin section in plain light. 220 x.

In a group of modexi the individuals may have been welded together yet they are still regarded as modexi if the individuals are still recognizable. Of course only the shape of modexi is to describe. Five groups are distinguished, i.e.: 1. spherical; 2. ellipsoidal; 3. cylindrical; 4. platy; 5. threadlike.

Apart from these main forms, the so-called "transformed shapes" are separated.

1. *spherical* — All forms in this group have a spheroidal habit and all names end with *sphere.* Within this group two subgroups are distinguished:

1.1 *sphere* — Its cross-section is a circle (Fig. 32).

1.2 *amoebosphere* — Its cross-section is a circle with dents and bulges. The name is coined from "amoeba" because of its resemblence to this organism.

2. *Ellipsoidal* — All forms of this group are eggshaped, and all names in this group end with "oid". Within this group three subgroups are distinguished:

2.1 *ellipsoid* — The longitudinal section is a symmetrical ellipse (Fig. 33).

2.2 *spermoid* — The longitudinal section is principally a symmetrical ellipse of which one extremity is drawn into a thread. This thread was probably caused during the defaecation through closing of the animal's sphincter. If this is the case, then the thread forms the closing end of the modex, which could be interesting to know because it is then possible to reconstruct the way in which the modex is pushed through the intestines. It could be of probable significance for the explanation of e.g. certain cutans around the modex and the fabric of these cutans (page 68). The name is constructed from "spermatozoid", because of its resemblence to one, and ellipsoid.

2.3 *conoid* — The longitudinal section is an asymmetrical ellipse, of which one end is broader than the other. In other words: the modex has the shape of a cone, hence its name.

3. *Cylindrical* — All forms in this group are related to the cylindrical form and names in this group end with "cylinder". Within this group three subgroups are distinguished:

3.1 *cylinder* — The longitudinal section is a rectangle. Within this subgroup two types can be distinguished:

3.1.1 *long cylinder.* The longitudinal section is a slim cylinder of which the length is more than 2 x the width (Fig. 34).

3.1.2 *short cylinder.* The longitudinal section is a short squat cylinder of which the length is less than 2 x the width.

3.2 *bacillo-cylinder* — The longitudinal cross-section is a cylinder of which the ends are rounded off. The name is constructed from *bacillus,* because of its likeness to one, and cylinder. Within this subgroup two types can be distinguished:

3.2.1 *long bacillocylinder.* The longitudinal cross-section is a slim cylinder with rounded off ends, of which the length is more than 2 x the width (Fig. 35, 42, 44, 48, 67 and 68).

3.2.2 *short bacillocylinder.* The longitudinal cross-section is a short squat cylinder, with rounded off ends, of which the length is less than 2 x the width.

3.3 *clono-cylinder* — The longitudinal cross-section is a cylinder. In addition, the cross-wise section of the cylinder is partly contracted in one or more places (Fig. 36).

These contractions are made by the animal, probably because the latter contracts its sphinctermuscle one or more times during defaecation. The name is constructed from the Greek word *kloneo* (= to wobble) and cylinder.

One could, if necessary, introduce as types "long" and "short".

The cylindrical modexi can be drawn out to an extremity. Such forms are indicated by putting the word "sperm" in front, e.g. sperm-clonocylinder, spermbacillocylinder (Fig. 37 and 80; see also Schaller, 1962, p. 22, Abb. 16 a).

All cylindrical shapes can be curved as well as straight. From observations on active animals in situ the author comes to the conclusion that these curved shapes may form directly after defaecation. Since the fresh faecal material has a plastic consistency, it will easily twist. If the object on which it is deposited is smaller than the modex, the latter will reshape around it. In this respect the curved forms are of derived nature and cannot be classified as natural forms. However, if observed modexi are curved, this can be noted as e.g. curved bacillocylinder.

4. *Platy* — Only rectangular plates with a length of 1.5 to 2 × the width are known. The plates may or may not have a middle groove in the length-wise direction. If it has a middle groove then the modex will be called "aulacoplaty" (coined from the Greek word *aulax* meaning groove and platy). The presence of such a middle groove is typical for excrements of large Isopoda (Fig. 39; and see Schaller, 1962, p. 22, Abb. 16 b).

5. *Mitoid* — The basic form is a thread, of which the length is much greater than the thickness. The name is coined from the Greek word *mitos* (= thread).
Two subgroups are distinguished:

5.1 *monomitic* — A simple thread which may be straight or bent. The Greek word *monos* means single.

5.2 *helicomitic* — The thread is more or less rolled up and may resemble a spiral (Fig. 40). The name is coined from the Greek words *helix* (= spiral) and *mitos*.

The mitoid excrements are characteristic for e.g. snails.

An exact determination of the shape in thin sections is only possible for the basic forms 1, 2 and 3 when a longitudinal section is available. The basic forms 4 and 5 are hardly discernable in thin sections. They can only be detected in non-impregnated samples, or in the field. A magnifying glass is in most cases sufficient for this purpose.

Transformed shape of modexi

The shape of modexi can be transformed e.g. as a result of "ageing" (see p. 83). This can be a slow process, so it is often possible to reconstruct the original shape. Such modexi can be named after their original shape with the prefix: "transformed". A clonocylinder transformed through ageing can therefore be called a "transformed clonocylinder" (Fig. 41).

The magnitude of transformation can be indicated by using the words weakly, moderately, or strongly. If the original shape cannot be reconstructed then it will be sufficient to use the term: "transformed modexi".

4.2.1.3 Size of excrements

Excrements are considered which vary greatly in size from some micrometres to approximately 20 cm. They can be divided into micro- and macro-excrements just as peds can be divided into micro- and macro-peds as done by several authors (Nikiforoff, 1941; Clarke, 1941; Frei, 1950; Gracanin, 1950; Jongerius, 1957, p. 5; Brewer, 1964, pp. 134–140). The boundary between these subtypes could be taken at that size below which it is preferable to use the microscope in studying the excrement as an entity. In other words this boundary can be taken where the excrement as an entity still can be fairly easily seen with the naked eye which might be, for example, at approximately 500 μm. But, as in temperate regions the soil-fauna produces excrements of roughly not larger than 3 mm, and this size is not too large to be observable in this section, it is preferred to fix the size-boundary between micro- and macro-excrements at 3 mm.

Macro-excrements

The size, shape and arrangement of macro-excrements are properties which can only be measured macroscopically. This will not be discussed here. Macro-excrements originate from large animals which may live outside as well as inside the soil, such as cattle in pastures, or animals in forests and steppes, or invertebrates in soil. Examples of macro-excrements are the cylindrical ones of 7 cm long and with a diameter of 2.9 cm produced by the earthworm *Hippopera nigeriae* known from Nigeria (Bates, 1960). The present author possesses earthworm excrements from Surinam, Brazil, Nigeria and Ivory Coast which measure up to several centimetres. Macro-excrements will undoubtedly also be produced by:

1. The 38 cm long and 13 mm thick earthworm *Lumbricus friendi* Cogn., which lives in Central Europe (Zachariae, 1967).
2. The 60 cm long and 6–10 mm thick earthworm *Pheretima tumulifaciens* Lee, living in New Guinea (Haantjens, 1965; Lee, 1967).
3. The Megascolide earthworms *(Megascolides australis)* found in Australia, which measure more than 2.5 m in length (Schaller, 1962, p. 51).
4. Members of the earthworm family Microchaetidae in South Africa, which can be as long as 7 m and as thick as 8 cm (Ljungström and Reinecke, 1969).
5. The African earthworms *Dichogaster jaculatrix* (Baylis, 1915) and *Hyperiodrilus africanus* (Madge, 1969; from: Edwards et al., 1972, pp. 120–121).
6. The giant *Notoscolex* earthworms in Burma (Gates, 1961).

Micro-excrements

These originate mainly from the invertebrate soil fauna. However, a certain amount of them is produced by caterpillars, snails, etc., which live on the vegetation on the soil's surface and whose excrements are deposited in and on the soil. The saprophage as well as the phytophage fauna (carnivors should, in principle, be included) contribute to this type of excrements. The saprophages are the greatest producers since they consume the dead organic material.

Of all excrements the micro-ones are by far the most important. They may form a considerable part of the humon.

What size parameters should be used to classify modexi?

Barratt (1969, tabel 1) gives a classification, which is identical to the "particle-size classification of sand and silt" according to the Soil Survey Staff (1951, p. 207), to which she only added a class "extremely fine".

It is suggested that a size classification of modexi should be better based on derivation as the size of modexi depends to a certain degree on the animal's size. Nevertheless it is difficult to relate exactly the modex' size to the animal's, or to that of specific groups of animals. Moreover the excrement-size may also depend on the stage of growth of the animal and, to a certain extent, even on the type of food consumed by the animal (Bal, 1970). Young animals may produce smaller excrements than adults. Good examples of this were described on Oribatid mites by Zachariae (1965) and Bal (1970).
The present author measured that juveniles of the milliped *Polydesmus inconstans* Latzel produced modexi (cylinders) of 175–250 μm, whilst adults produced long cylinders of 600–900 μm.

As the relations between excrement-size and animal's size and quality of consumed food are poorly known, it is up till now only possible to make an arbitrary size-classification like the one Barratt used, however, adding a few more classes.

size in microns	*name of separate*		
< 20	extremely fine	fine	micro-excrements
20 – 50	very fine		
50 – 100	medium fine		
100 – 250	moderately fine	medium	
250 – 500	moderately coarse		
500 – 1000	medium coarse	coarse	
1000 – 2000	very coarse		
2000 – 3000	extremely coarse		
> 3000			macro-excrements

Excrements of species of Oribatid mites, Enchytraeidae, small Collembola, and smallest species of Diptera-larvae are smaller than

250 μm, very often smaller than 100 μm. Sometimes their size is not more than a few micrometres (e.g. spheroidal excrements of *Enchytraeus buchholzi* Vejdovskij).

Excrements of species of Isopoda, Diplopoda, Lepidoptera-larvae, and larger Diptera-larvae are often between 250–1000 μm in size. Moreover the ones of small earthworm species, or juveniles of larger earthworm species are also often of these size-classes.

Excrements of larger species of Isopoda, Diplopoda as well as of Diptera and Lepidoptera-larvae, and small and large earthworm species are often 1000 – 2000 μm and even up to 3000 μm.

How to measure the size of modexi?
With regard to this parameter it is important to decide whether to measure the size of the excrement in wet, moist, or dry condition. That is because excrements may shrink considerably by drying especially when they are organic and wet. The author ascertained that the length of particular moist excrements was 1.5 X as large as the length of these excrements when they were dry.
As soil materials must be dried before it is possible to make a thin section of them (Jongerius et al., 1963, 1973) the size of dried excrements is measured.

Drying in open air will not cause a change in size only. It is not quite impossible that it also causes some changes in shape. To avoid these changes in size and (possibly) shape it would be better to dry the samples not in the open air, but by freezing. This particular technique will be described by Jongerius et al. (1973).

With regard to the size of modexi it is also important to decide along which axis of the excrement the size must be measured. Barratt (1969) speaks of "mean width of faecal pellets". It is assumed that this means the section of the pellets in thin section. However, in thin sections the orientations of the modexi are always at random and so is their section. Thus, the measured size is irrelevant.
In fact the width as well as the length should be noted. However, most modexi are spherical, ellipsoidal or cylindrical. As the ratio between length and width is approximately fixed by the shape

there should be no objection to using the length as a measure for size.* A difficulty in such a determination of size-classes (which also presents itself for determination of shape) is that the longitudinal section of a modex must be present. However, as already mentioned before, the orientations of modexi are always at random and therefore one must be able to reconstruct the shape of the excrement, but one may expect that also the optimal orientation is to be observed. With some experience and background knowledge one should be able to determine size-classes in thin sections. The range within each class is large enough to allow for such estimations.

An exact measurement of size and shape can only be obtained of non-impregnated modexi, e.g. by breeding the animals and gathering their excrements (Bal, 1970).

4.2.1.4 Internal fabric of excrements

The s-matrix of excrements may consist of a mixture of organic and mineral materials. However, because the organic ones may be composed of organic skeleton grains with a clearly visible tissue-structure the s-matrix cannot, in these cases, be described after Brewer as he excludes "recognizable undecomposed organic remains" from his system (Brewer, 1964, p. 12). That is why spatial arrangements of organic materials with respect to mineral materials is at present difficult to describe. Nevertheless the spatial arrangement of organic constituents can be described in a way proposed by the present author (see chapter V).

For descriptions of voids occurring within excrements reference is made to Brewer (1964, pp. 179–204). The dimensions of voids in closely packed excrements may be so minute that they are often hardly observable with usual magnifications. However, other excrements have easily observable voids. A special kind is the

* The size of platy modexi (established in non-impregnated samples) can in fact only be determined by measuring the length, the width, as well as the height of the modexi.

"central void", which can be present in modexi (Fig. 42).* Probably this central void is a gass-bell formed in the animal's intestine.

4.2.1.5 Smoothness of modexi

This has to do with the minute details of the arrangement of plasma and skeleton grains (of the s-matrix) of the modex' surface. Three forms of smoothness are distinguished. These are:

meta surface	The surface of the modex appears morphologically to be significantly smoother than would result from the normal random packing of plasma and skeleton grains as this is present within the modex. Or in other words the arrangement of plasma and/or skeleton grains of the surface has changed e.g. by stress (Fig. 21 and 37).
ortho surface	The arrangement of plasma and skeleton grains appears morphologically to be equal throughout the modex (Fig. 35, 42 and 80).
protuberant surface	Skeleton grains are clearly visible protruding from the modex. Often these protruding skeleton grains are organic. The author observed this particular type of surface on excrements of Tipulidae larvae after they had ingested leaves from the tree *Frangula alnus* Mill.

Note: The concept of smoothness, as well as the indications meta and ortho for particular forms of smoothness are similar to those for walls of voids according to Brewer (1964, p. 185). The form protuberant is introduced in the present study.

* Brewer (1964, pp. 260–261) has described the internal fabric of glaebules. In this internal fabric void-patterns are included. One of them is "central void" meaning: there is a single, large, central void.
According to the present author this particular "central void" can be adopted for excrements.

4.2.1.6. Cutanic and subcutanic features at/in excrements

Excrements may be characterized by cutanic and subcutanic features. Some of these are formed by the passage through the animal's intestines. During this passage there is an interaction between the intestines and the consumed material e.g. stress features or the formation of a peritrophic membrane. In this way several organans and neo-organans can be formed (see 4.1.1 and 4.1.2).

Interaction (stress?) may also be deduced from observations made by Slager et al. (1970). These authors described the presence of a birefringent rim within mineral excrements parallel to the surface and adjacent to it whilst the excrements' s-matrix is characterized by an argillasepic plasmic fabric.

4.2.2 DISTRIBUTION PATTERNS OF MODEXI

4.2.2.1 Basic distribution patterns of modexi

According to Brewer (1964, p. 160) basic distribution pattern is the distribution pattern of like individuals with regard to each other. Known basic distribution patterns, in which modexi may be arranged are: random, clustered, tubulic, concentric, and stringed.

It is also necessary to ascertain whether the intermodexical space has been occupied by voids or by other soil materials. This phenomenon will be discussed in the subparagraph "Embedded modexi".

A. *Random basic distribution patterns*

According to Brewer (1964, p. 168) a random basic distribution pattern is characterized by a randomly distribution of like individuals throughout the soil material, so that there is no recognizable specific pattern of distribution. In this definition by "soil material" is meant the unit of study in which the characteristics being studied are relatively constant (Brewer, 1964, p. 10).

According to the present author it is necessary to make a subdivision within this basic distribution pattern of modexi. This subdivision is based on:

1. the size of the intermodexical space (= the distances between individual modexi).
2. the modexi being single, or welded. By single modexi is understood that they occur as discrete entities whilst welded modexi are coagulated.

In this manner three sub-patterns are distinguished, i.e.:

1. *Single, sporadic modexi*	The intermodexical space is relatively large throughout the soil material (Fig. 43). This basic distribution pattern is, for convenience sake, reported as *"sporadic modexi"*.
2. *Single, heaped modexi*	The intermodexical space is relatively small throughout the soil material (Fig. 44 and 45). This basic distribution pattern is, for convenience sake, reported as *"heaped modexi"*.
3. *Welded, heaped modexi*	Like modexi are welded together throughout the soil material. This basic distribution pattern is, for convenience sake, reported as *"welded modexi"*.

The degree of welding of the modexi may be characterized by the void-distribution pattern, caused by the welding. Mostly these voids are mammillated vughs in the terminology according to Brewer (1964, pp. 189–191). But, as a matter of fact, the degree of welding should be included in the name of the basic distribution pattern. This may be indicated as weakly, moderately, and strongly welded.

3.1 *weakly welded modexi*	Only parts of like, distinct modexi are welded together to such a degree that voids are present between the individuals (Fig. 48 and 49).
3.2 *strongly welded modexi*	Like modexi are welded together to such a degree that the individuals can hardly be seen. The modexi are recognizable due to the particular internal fabric of the soil material

and/or to the presence of cutans or neo-cutans, which occur as thin lines in the soil material indicating the contours of individual modexi, and/or the presence of the contours of the modexi as such (Fig. 46, 47 a and 82). Mammillated vughs, as a result of the distribution of the modexi, are absent or almost absent.

Some A_1-horizons, in which many earthworms are active, may almost completely be characterized by this particular basic distribution pattern (Fig. 47 a).

In some cases the modexi are so strongly welded that they may only be recognized by the particular arrangement of the soil consituents. For example these constituents may be arranged in groups of "curved lines" throughout the soil material. This arrangement is especially clearly observable when the present o-plasma occurs accumulated in these lines, possibly representing neo-organans (Fig. 47 b). The modexi may be so extremely welded (whether this is caused by the animal pressing its excrements against one another or by "ageing", see paragraph 4.2.5.1) that one might come to the decision to regard the soil material not as an accumulation of modexi, but as a soil material which is characterized by a particular fabric of its s-matrix. This fabric might be named *striofabric* because of the striated orientation pattern and/or parallelism of the constituents. The author is fully aware of the possible objection about considering curved lines composed of accumulations of o-plasma as part of the s-matrix. Because these particular accumulations may in fact be former neo-organans which are pedological features. The same difficulty was felt by Jongerius (1970) when he described deformed argillans as "masepic fabric" after they have been part of the s-matrix caused by churning and are not recognizable as "papules" (masepic fabric and papules are designations according to Brewer, 1964, pp. 313–314 and 274–275 respectively).

Groups of curved lines (in consequence of the particular arrangement of soil constituents) may also be formed during defaecation of wet, shapeless excrements. During defaecation a particular "flow pattern" in the watery faecal mass may be formed and fixed by desiccation. Although this flow pattern is also composed of groups of curved lines it is different from the one which is characteristic for extremely welded modexi. Nevertheless it may also be described as a particular form of striofabric.

It will be clear that much investigation has still to be made on strio-patterns, not to distinguish different patterns only, but also on their genesis.

The "welded modexi" distribution patterns do also describe two types of microstructure of Barrat's (1969) classification according to "shape", i.e. "spongy" (occur in plasmic soil materials) and "expanded pelleted materials" (occur in humicols and humiskels). For the concept of humicol and humiskel one is referred to page 19 of the present study.
However, in the Barratt's system strongly welded modexi containing mineral skeleton grains (as shown in Fig. 46 and 47 a) cannot be described.

B. *Clustered basic distribution pattern*
According to Brewer (1964, p. 168) a clustered basic distribution pattern is characterized by the concentrated occurrence of like individuals in clusters or groups throughout the soil material.

If the cluster or group itself is the unit of study, the basic distribution within it may be described in turn (as is done in describing the random basic distribution patterns). It is possible, however, to distinguish accumulations of modexi as entities according to the internal distribution of its modexi as: 1. *group,* in which the modexi are single individuals and 2. *cluster,* in which the modexi are welded.

1. *Group* The modexi in the group are single individuals. The modexi in this distribution pattern may be reported as *grouped modexi* (Fig. 58).

2. *Cluster* As in this basic distribution pattern the modexi are welded, they may be reported as *clustered modexi.* On the degree of welding two sub-patterns are made, i.e.:

2.1. *Open cluster* The modexi in the cluster are weakly welded. As a result of the arrangement of the modexi voids are present between them. These voids are interconnected, mammillated vughs (void description according to Brewer, 1964, pp. 189–191) (Fig. 48, 49 and 50).

2.2. *Massive cluster* The modexi in the cluster are strongly welded. Individual modexi can only just be seen. Mammillated vughs, as a result of the distribution of the modexi, are absent or almost absent (Fig. 51, 52, 53 and 82).

Clusters can originate during defaecation (e.g. excrements of earthworms) as well as through ageing (ageing will be discussed on pp. 81–84).

C. *Tubulic basic distribution pattern*

This basic distribution pattern was not described by Brewer; it is introduced here.

> "A *tubulic basic distribution pattern* is characterized by the accumulation of like individuals in channels throughout the soil material"

Regarding the filled channel* as the unit of study the basic distribution pattern of the modexi present may be described in terms of random, clustered, etc. and the modexi being single or welded as was described under the random basic distribution pattern of modexi (Fig. 54, 55 and 56).

D. Concentric basic distribution pattern

According to Brewer (1964, p. 168) a concentric basic distribution pattern is formed when groups of like individuals occur along approximately concentric lines or surfaces, or a single approximately circular or elliptical line, or spherical or ellipsoidal surface.

In this particular basic distribution pattern like modexi may occur single as well as welded. That is why two sub-patterns may be distinguished, i.e.:

1. concentric basic distribution pattern of *single* modexi.
2. concentric basic distribution pattern of *welded* modexi.

* For the definition of channels one is referred to the first foot-note on page 73.

Of course the degree of welding may also be indicated, as is done under the random basic distribution pattern.

Modexi in this particular distribution are mostly present in channels.* They may at the same time occur in a cutanic referred distribution pattern,** e.g. in a kind of scatan (see chapter IV.I, paragraph *cutans,* p. 48). In this scatan the faecal material may consist of single, or welded modexi. Thus, in these cases this particular cutan may be called a *modexan* (Fig. 19, 20 and 56). In detailed descriptions the distribution of the modexi within the modexan may be described, e.g. random, or normal, or parallel, or inclined with reference to the channel's surface.

E. Stringed basic distribution pattern

This basic distribution pattern was not described by Brewer; it is introduced here.

> "In a *stringed basic distribution pattern* like individuals are arranged along a single line, forming as it were a string"

Modexi arranged in a stringed basic distribution pattern lie often longitudinally and almost in a direct line. Moreover, the modexi are weakly welded at their extremities forming a string (Fig. 80). Stringed basic distribution of modexi is always already present during defaecation and is produced for example by earthworms and Enchytraeidae. Mostly this distribution pattern can only be observed in the field.

F. Embedded modexi

The space between the modexi may be occupied by other soil materials or in other words the modexi are embedded. In these cases the name of the distribution pattern is prefixed by the designation *embedded.* For example *embedded, sporadic ellipsoids* (Fig. 57) and *embedded, grouped ellipsoids* (Fig. 58).

To ascertain whether the modexi are embedded or not is not

* Channels are particular voids, which commonly have smoothed walls, regular conformation, and a relatively uniform cross-sectional size and shape over significant proportions of their length (Brewer, 1964, p. 193).

** Referred distribution pattern is the distribution pattern of like individuals with regard to a specific reference feature (Brewer, 1964, p. 160). Cutanic referred distribution pattern means that like individuals are associated with natural surfaces in the soil materials (Brewer, 1964, p. 169). For the concepts of the referred distribution patterns normal, parallel, and inclined, one is referred to Brewer (1964, p. 169).

merely a morphological parameter. It may be an important genetic information. Modexi might be embedded by rather drastic conditions as e.g. being translocated, being buried or being consumed by an animal but not digested.

4.2.2.2 Related distribution patterns of modexi

According to Brewer (1964, p. 161) related distribution pattern is the distribution of like individuals with regard to the distribution of groups of individuals of a different kind. There are F- and H-horizons, which almost completely consist of unlike modexi (Bal, 1970). Also some pedotubules may contain unlike modexi if present excrements are for example consumed by Enchytraeidae and transformed into their smaller excrements. Unfortunately it is at present impossible to describe exactly distribution patterns of unlike modexi in relation to each other.

If the abovementioned excrements of Enchytraeidae are present in a tubulic basic distribution they may be regarded as being pedotubules in a host pedotubule.

Of course the unlike modexi may occur in different basic distribution patterns and for this reason a range of different related distribution patterns is possible.
But to distinguish all these different patterns may be too detailed. However, they are all characterized by the fact that unlike modexi are associated with each other. That is why these are named *hetero – modexical,* which can be defined as follows:

> "*Hetero – modexical* related distribution pattern is the distribution pattern of like modexi with regard to the distribution of groups of modexi of a different kind" (Fig. 59, 60 and 41)

Details in this particular distribution pattern can be given by describing the basic distribution patterns of the different modexi present. Moreover, in this detailed description an estimation of the quantities of different modexi can be included.

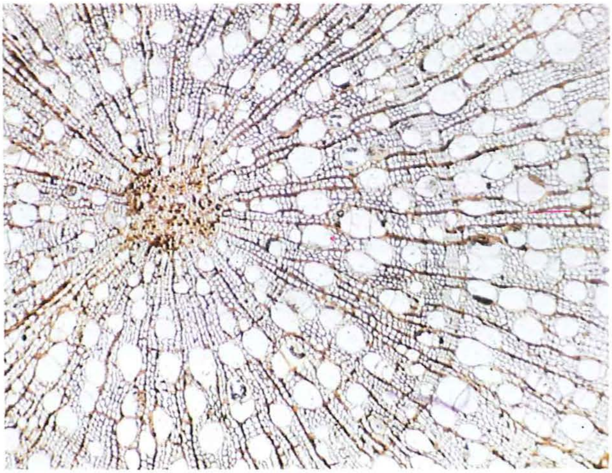


Fig. 72 Cross section of a radicohist characterized by a "histonic" internal arrangement. (In fact it is also characterized by a "coniatic" internal arrangement along separated, thin radial zones, which can be seen as slightly, yellowish coloured radial lines. In plant anatomy the tissue as a whole is named xylem; the thin, yellowish coloured lines are the medullary rays in the xylem). Thin section in plain light. 36 x.

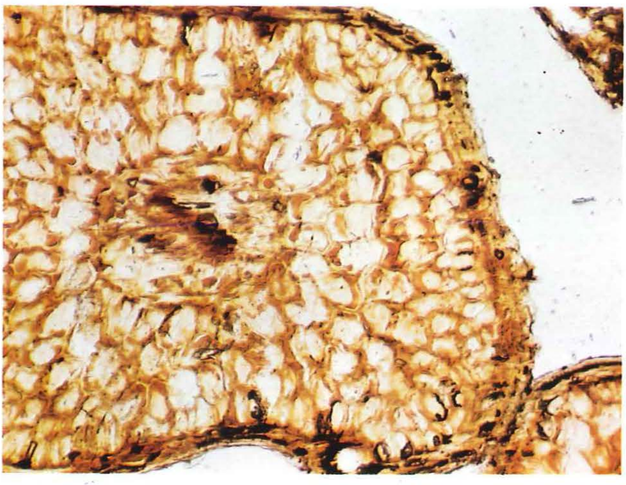


Fig. 73 Cross section of a foliohist characterized by "coniatic" internal arrangement of tissue with reference to yellowish-brown, organic plasma. Thin section in plain light. 88 x.

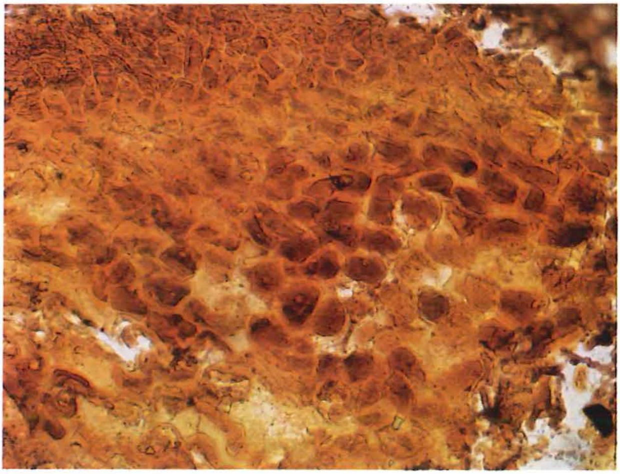


Fig. 74 "Phellemic" arrangement of tissue with reference to yellowish-brown, organic plasma. Note that some of the present cells are merged in the o-plasma. With progressing decomposition this arrangement will be transformed into pleistoplasmatic. Thin section in plain light. 220 x.

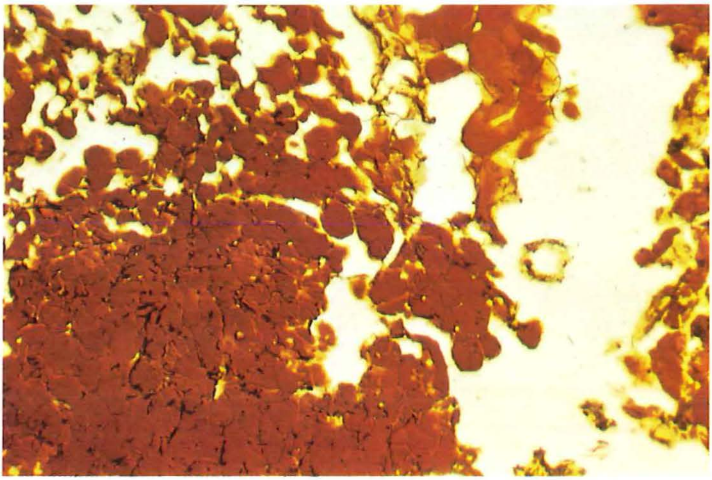


Fig. 75 "Pleistoplasmatic" arrangement of tissue with reference to red coloured organic plasma. (In this case it was formed from phellemic). Thin section in plain light. 88 x.

4.2.3 CLASSIFICATION OF MODEXI

Modexi are studied according to their different characteristics in the following order of succession:

shape
size
mineral, organo-mineral, or organic
basic distribution (whether embedded or not)
related distribution
ortho, meta, or para
(matric or amatric)

In the final report on the observed phenomena their encoding is written in a different order of succession:

related distribution
basic distrubution (whether embebbed or not)
ortho, meta, or para
size
mineral, organo-mineral, or organic
(matric or amatric)
shape

The modexi being matric or amatric was put within parentheses because it is not always necessary to report this parameter as mineral excrements are often matric whilst organic excrements are often amatric.

Some examples of classification are given; one of these in Fig. 33.

1. Classification of modexi up to and including their basic distribution pattern, and
2. up to and including their related distribution pattern.

1. *Classification of modexi up to and including their basic distribution pattern*

1.1. Let us suppose that in the soil material organic modexi are present. These modexi are 70 μm in size (= fine), are ellipsoidal, and have been formed there from present foliohists. Moreover, these modexi occur in a clustered basic distribution pattern. These modexi are classified as follows: clustered distribution of ortho, fine, organic, amatric ellipsoids.

In this classification one may include the internal fabric of the clusters, i.e. the modexi being single or welded, as well as the degree of welding. In the case that these particular modexi are weakly to moderately welded in an open cluster, the classification will be as follows:

open clusters of ortho, fine, organic, amatric ellipsoids.

1.2. In the case that organo-mineral modexi (of 1000 μm (= coarse) in size, having a bacillocylindrical shape and derived from material of the A-horizon) occur accumulated in tubules (with an internal "heaped" basic distribution pattern) in the C-horizon, these modexi are classified as (in which the internal distribution within the tubule is written within parentheses):

tubulic distribution of meta, (heaped), coarse, organo-mineral, matric bacillocylinders.

2. Classification of modexi up to and including their related distribution pattern

The soil material may be composed of modexi, which occur in a hetero-modexical related distribution pattern. There are soil materials which are composed of fine, organic spheres and medium, organic clonocylinders, and two different types of ellipsoids, i.e. fine, organic ellipsoids and coarse, organic ellipsoids. These modexi are classified as follows:

hetero-modexical distribution of fine, organic spheres; medium, organic clonocylinders; fine, organic ellipsoids and coarse, organic ellipsoids.

In this classification may be included the basic distribution patterns of the different modexi, as well as an estimation of the quantities of the different modexi, e.g.:

hetero-modexical distribution of ± 50% of strongly welded, fine, organic spheres; ± 30% of grouped to moderately clustered, medium, organic clonocylinders; ± 20% of grouped, fine, organic ellipsoids, and some sporadic, coarse, organic, moderately transformed ellipsoids.

4.2.4 PEDOTUBULES CONCERNING EXCREMENTS (SCATOTUBULES)

According to Brewer (1964, p. 236) a pedotubule is: "A pedological feature consisting of soil material (skeleton grains or skeleton grains plus plasma, as distinct from concentrations of fractions of the plasma) and having a tubular external form, either single tubes or branching systems of tubes; its external boundaries are relatively sharp. Tubular form, in this context, means that the feature as a unit, or its impression in the enclosing soil material, has a relatively uniform cross-sectional size and shape, most commonly circular or elliptical; that is the impression of the pedotubule conforms to the definition of channels."

Pedotubules can be grouped according to their basic fabric into a number of classes. Two of these are the so-called "striotubules" and "aggrotubules", which are respectively:

"Striotubules are pedotubules composed of skeleton grains and plasma that are not organized into recognizable aggregates but exhibit a basic fabric with a directional arrangement related to the external form. The directional arrangement is semi-ellipsoidal with the walls of the pedotubule approximately tangential to the semi-ellipsoid" (Brewer, 1964, p. 241).

"Aggrotubules are pedotubules composed of skeleton grains and plasma which occur essentially as recognizable aggregates within which there is no directional arrangement with regard to the external form; individual skeleton grains may also occur; the basic fabric approaches agglomeroplasmic fabric in some cases" (Brewer, 1964, p. 239).

Next to a morphological classification of pedotubules a genetic classification must be set up on the basis of interpretation of the morphology of pedotubules. In such a classification one can decide to name the pedotubule after the animal that formed it, but it is also possible to name the tubule after its composing materials. In this way the present author proposes to name pedotubules which are composed of excrements *scatotubules* (the Greek word *skato* means excrement). The faecal material may occur as recognizable modexi, but also as shapeless excrements.

In the author's opinion several striotubules and aggrotubules are at the same time scatotubules. Scato-striotubules may be formed e.g. through earthworms that fill their tunnels with their excrements forming "striofabric" as was described on page 70 (Fig. 61 and 47 b).

Scatotubules composed of modexi are proposed to be named *modexotubules.* These are often aggrotubules, but modexotubules which are composed of skeleton grains only are not aggrotubules by definition. However, in the author's opinion modexotubules composed of skeleton grains only must also be regarded as aggrotubules. This is possible when a slight change in Brewer's definition is introduced, i.e.:

> "*Aggrotubules* are pedotubules composed of skeleton grains and/or plasma which occur principally as recognizable aggregates within which there is no directional arrangement with regard to the external form; the basic fabric approaches agglomeroplasmic fabric in some cases"

Accepting this modified definition of aggrotubules the definition of modexotubules can be formulated as follows:

> "*Modexotubules* are aggrotubules in which the recognizable aggregates are modexi which may be arranged in any basic distribution pattern"

Based on the basic distribution patterns of the modexi and on their presence within or without a channel, three variations have been recognized within modexotubules.

Variety 1: The modexotubule is composed of rather large amounts of modexi and is present in a channel of approximately the same diameter. The modexi occur mostly in one or another random basic distribution pattern, e.g. single, heaped ellipsoids (Fig. 54). This particular modexotubule is formed by animals as they make channels by ingesting the soil material and fill them up with their excrements. The occurrence of these particular modexotubules is especially characteristic for densely packed soil material as a ped, or apedal soil materials, or a histon.

Variety 2: The modexotubule is composed of rather small amounts of modexi and is present in a channel of approximately the same diameter. The modexi occur more or less in a concentric basic distribution pattern adhering to the channel's wall and occurring around a central channel. If the amount of modexi is low this variety grades into modexans, i.e. cutans composed of modexi.

Variety 3: The modexotubule can be composed of different amounts of modexi and can be present in an existing void of any type (which has a much larger cross-sectional size than the tubule), or on the surface of the soil, or embedded in highly vughy soil materials. The modexi are arranged in a concentric basic distribution pattern around a central channel; within these concentric surfaces the modexi are welded (Fig. 62–66).

Varieties 2 and 3 are formed because soil animals (especially earthworms and Enchytraeidae) put their excrements around themselves making a tunnel (possibly to protect themselves against desiccation) (Fig. 67 and 68).

4.2.5 EXCREMENTS IN THEIR RELATION TO THE GENESIS OF THE HUMON (SOIL)

Excrements are of value to interprete genetic processes operating in soil. Although they may be characterized by a particular shape (modexi), this is not always typical for the particular animal from which they originate. This is quite obvious from the small number of existing shapes relative to the large number of animal species.

Thus, for a genetic interpretation it will be imperative to take into consideration not only the shape, but also the size, internal fabric, and distribution patterns of the excrements. Some knowledge of the soil fauna is essential. For example, if one is acquainted with the feeding habits and excrement-types of the various members of the soil fauna, it is possible (in particular with the aid of a micromorphological analysis) not only to determine the role of these members in the decomposition-sequence of organic matter (fragmentation of histons, mixing of organic and inorganic and translocation of soil materials: *redistribution* and *homogenization*), but also to locate in the soil accurately the various stages of decomposition of organic matter. Examples are given by Zachariae (1963, 1964, 1965, 1967); Van der Drift (1964); Szabó et al. (1967) and Bal (1970). In this respect the investigations on peat soils carried out by Puffe and Grosse-Brauckmann (1963), Grosse-Brauckmann and Puffe (1964), Frercks and Puffe (1964) should also be mentioned. However, a micromorphological analysis on its own can never give complete insight into all faunal activities in the breakdown of organic matter, such as the chemical transformations undergone by organic materials in the animal's intestines. However, these latter have already been frequently studied in another way (Franz and Leitenberger, 1948; Van der Drift, 1950; Schuster, 1956; Dunger, 1958, 1963; Brüsewitz, 1959; Kurcheva, 1960; Priesner, 1961; Bocock, 1963; Ghilarov, 1963; and others).

In studying soil genesis it is not enough to know the activities of the animals only, it is also necessary to study the decomposition of the excrements in their turn. Only scant attention has been given to these particular processes (Schuster, 1956; Van der Drift and Witkamp, 1959; and Szabó et al., 1964).

That is why decomposition of excrements (as far as this is reflected morphologically) will be discussed here. Principally this decomposition may occur in two different ways, viz.:

1. By the consumption of excrements by the coprophage members of the soil fauna.
2. By the decomposition of excrements by other processes. The decomposition by these processes is called *ageing* (Bal, 1970). Ageing may be characterized by significant changes in shape,

distribution, and internal fabric of the excrements.

In the following ageing will be discussed in detail.

4.2.5.1 Ageing of excrements

In the broadest sense ageing can be understood as the changes of the excrements by microbiological, chemical and physical processes. The results of those processes can be determined by a study of the relevant characteristics. From the chemical point of view the final stage could be fixed at that phase of ageing when the organic faecal material is completely mineralized, or transformed into "organic new formations". In other words the end is fixed at that phase in the breakdown-process where the original material is essentially changed, or even disappears.

However, this particular reasoning can only be applied to the organic constituents in the excrements. In other words ageing of mineral excrements is not to be described in this way.

From a microbiological point of view this end should be fixed at that stage when there is no more microbiological activity. Although the number of microorganisms involved in ageing excrements decreases as ageing proceeds (Van der Drift and Witkamp, 1959; Szabó et al., 1964) it appears unlikely that a stage might be reached after which micro-organisms no longer take part in further decomposition. So we could probably make the end point identical with the chemical, which is, however, not quite satisfactory.

However, all these processes have their effect on the morphology of the excrements, or in other words on their physical constitution. Thus ageing can also microscopically be observed and described. From his microscopical studies of humons the author (Bal, 1970) defined ageing as being:

"The morphological changes that occur in the excrements solely as a result of micro-biological, physical, and chemical processes, until the excrements disintegrate."

From this point of view the author (Bal, 1970) fixed the end of ageing at the disintegration of the excrements. This is obvious because from morphological (physical) viewpoint it is difficult to speak of excrements, and especially of modexi, after they have disintegrated. After this the modex has changed into differently organized soil material. However, there are soils in which the modexi completely lose their individual character through ageing and are absorbed into the s-matrix without being disintegrated. This may be the case e.g. with organic modexi of Oribatid mites when they amalgamate into a "massive cluster" and after that forming a massive entity in which it is almost impossible to recognize individual modexi. The same can happen to mineral modexi of earthworms (Fig. 69). Earthworm excrements in an "open cluster" on the soil surface amalgamate through ageing to form a "massive cluster" and after that form a mammillated to rounded blocky ped (these are the characteristic small peds on the surface of several soils).

Thus, in these cases, after a period of time, we cannot really speak of modexi anymore, in spite of the fact that they did not disintegrate. So ageing can better be defined in such a way that it does not have to end with disintegrating of the excrements. A revised definition of ageing can thus be formulated as follows:

> "*Ageing* is expressed by the morphological changes (shape and/or internal fabric and/or distribution pattern), which the excrements undergo solely as a result of microbiological, chemical and physical processes. Ageing starts immediately after the excrements have left the animal's intestines and ends with their being no more recognizable, neither as single nor as welded individuals; that is because the excrements disintegrate, or form a massive entity, or merge together with some other soil material (e.g. a ped, or apedal soil material)"

The denomination *ageing* for these phenomena was knowingly done because in natural sciences it is understood as *irreversible changes in course of time.* The morphologically (physically) determined stage, at which soil material is no longer excrement, appears to be satisfactory. Therefore it is acceptable to fix the end of ageing of excrements using morphological criteria.

In fact ageing is the name for changes occurring in the excrements in course of time. The length of this period may be very different. As ageing begins directly after defaecation it occurs in all soils. But, in soils which are characterized by an intensive biological activity (e.g. mull), it is quite possible that ageing terminates prematurely because the excrements are consumed. Ageing is therefore an important and typical phenomenon in soils low in biological activity. In these ageing can proceed in different ways. Two examples of ageing of organic modexi are described by the author (Bal, 1970):

1. In the modexi the organic skeleton grains remain visible over a period of time. Eventually the modexi disintegrate into these clearly distinguishable organic skeleton grains or clusters of them (Fig. 70). This can happen either suddenly or gradually. In some cases fungi play an important part in this, but in other cases no fungi can be seen in the thin section. However, according to Szabó et al. (1964) fungi can be present, even when they escape detection.
2. The modexi (with an internal *granular* related distribution pattern)* keep their individual character for a very long time. Eventually they become gel-like in appearance because organic plasma is formed (thus the internal related distribution pattern changes to *o-porphyroskelic* or *pleistoplasmatic*).* At this stage in the ageing there are two possible ways in which it can proceed depending on the type of modexi:
   2.1 The shape of the modexi is transformed, but they retain their individual character. After this the organic skeleton grains gradually separate thereby the modexi lose their original shape completely and turn to *strongly transformed* (a clear transformation of shape and internal fabric, Fig. 41 and 71).
   2.2 The modexi weld together forming an "open cluster" eventually forming an aggregate in which the separate individuals can hardly be distinguished, i.e.: "massive cluster" (Fig. 82). This is a good example of the transformation of fabric.

* For the concepts of the mentioned distribution patterns one is referred to chapter V.

In the literature, morphological descriptions of transformations of modexi can be found, and which are now recognized as ageing. Examples are given by Jongerius et al. (1962 a, b); Zachariae (1964, 1965); Van der Drift (1964); and Babel (1968).

CHAPTER V

O-Matrix

5.1 S–MATRIX · I–MATRIX · O–MATRIX

The concept of o-matrix is related to that of s-matrix defined by Brewer (1964, pp. 147–148). According to Brewer, the s-matrix consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations. "Recognizable undecomposed organic remains" are excluded from the s-matrix (Brewer, 1964, p. 12).

However, in the present study (Introduction and Chapter I) it was pointed out that all soil materials sould be described including "recognizable undecomposed organic remains" as they are also part of the soil. Accepting the concept of soil, given in the present study, the concept of s-matrix according to Brewer is not satisfactory as all constituents are not involved in the definition.

In redefining the s-matrix it may have advantages to divide this into a matrix consisting of organic constituents and a matrix consisting of inorganic ones, called respectively o-matrix and i-matrix (the "o" refers to organic, the "i" to inorganic). Before doing so it must be realized that in the s-matrix present voids are included. In soil materials, which consist of mineral and organic constituents it is often impossible to associate the voids present exclusively with the inorganic or exclusively with the organic constituents as they are mostly associated with both. That is why in the concept of i-matrix as well as in the concept of o-matrix the voids must be ignored. If they would be included in both concepts their adding up would lead to a doubling of the voids in the s-matrix. However, this can be avoided by defining the division-matrices as being composed of only solid particles and to exclude voids from them. Definitions of the different matrices can thus be formulated as follows:

"*i-matrix* of a soil material is the mineral material within this unit of study being simplest (primary) peds, or composing apedal soil materials (in which pedological features occur), or pedological features. It consists of mineral plasma and/or mineral skeleton grains"

"*o-matrix* of a soil material is the organic material within this unit of study being histons, or simplest (primary) peds, or composing apedal soil materials (in which pedological features occur), or pedological features. It consists of tissues and/or organic plasma and/or fungal hyphae, or of organic skeleton grains and/or organic plasma and/or fungal hyphae"

"*s-matrix* of a soil material is the i-matrix plus o-matrix within this unit of study. Moreover present voids are included, but only if they do not occur in pedological features other than plasma separations"

5.2 INTERNAL SPATIAL ARRANGEMENTS OF O-MATRICES

In this paragraph the way in which particles constituting o-matrices, are spatially arranged will be discussed. This is almost the same as what is understood by "fabric". Brewer (1964, p. 131) defined soil fabric as "The physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids".

As the concept of o-matrix concerns only its solid particles it is impossible to describe its fabric. But it is possible to describe only the spatial arrangement of these solid particles. This is the "internal arrangement". To describe the spatial arrangement Brewer (1964, pp. 159–173) introduced "distribution" and "orientation" patterns. Unfortunately Brewer's terminology is not sufficient to describe completely the distribution patterns of organic soil materials. For describing these latter the present author proposes a new terminology. But it should be made clear that the details to be observed depend on the magnifinication used. A particular arrangement observed at low magnification may make way for an arrangement of different type at high magnification. Thus in noting down the arrangement it is necessary to mention the magnification used. The arrangements described by the present author are observed with magnifications of up to 200 : 1.

The internal arrangement of o-matrices is closely related to the manner and stage of decomposition of the organic matter. Only internal arrangements concerning tissues, organic skeleton grains and o-plasma will be discussed. Some arrangements of fungal hyphae were discussed in chapter IV, p. 38. Two main types of internal arrangements of o-matrices are recognized:
– Arrangements of tissues with reference to o-plasma.
– Arrangements of organic skeleton grains and organic plasma.

5.2.1 Arrangements of tissues with reference to organic plasma

These arrangements occur in histons, or in pedological features present in or derived from the histons (e.g. melanons and α-anthracons), or in particular sclerotia fungons.

Basic and related distribution patterns* of tissues will not be discussed here, as a satisfactory distinction of different tissues does not exist as yet (see chapter II, paragraph 2.1.1). That is why in the related distribution patterns of tissues with respect to o-plasma only the presence of these constituents is taken into consideration. The type of tissue and plasma is not.

1. Only tissue is present, there is no plasma.
   1.1 *histonic* — The o-matrix is mainly composed of intact, or apparently intact tissues. Plasma is not present, neither in the cell lumena nor in the cellwalls (Fig. 72).

2. The tissues are plastered on and/or impregnated with and/or covered by organic plasma. Four subforms can be distinguished:
   2.1 *coniatic* — The cellwalls of the tissue are plastered on by and may be also coloured by and/or impregnated with organic plasma. Some plasma may be present in the cell lumen. The cellwalls of the tissue can be deformed to such an extent

* For the concept of basic and related distribution see Chapter IV, pp. 68 and 74.

that originally opposite cellwalls now touch each other (collapsing of the cell), or they may have been broken (Fig. 73). The name coniatic is coined from the Greek word *konia* (= to plaster).

2.2 *plasmonesic* Parts of the tissue are covered by organic plasma. Some tissue-cells are completely immersed in the gel-like substance. Other parts of the o-matrix are in fact coniatic. This arrangement was described earlier by Babel (1964 a, b; 1965 a, b) and Bal (1970); however they did not introduce a name for it. The name plasmonesic is coined from the word "plasma" and the Greek word *nesos* (= island). One can visualize this as one or more islands of plasma in the tissue.

2.3 *phellemic* Is characteristic for o-matrices in which present tissues have often thick cellwalls as e.g. the suberinized in phellem. The cell lumena mostly contain brown o-plasma, which in phellem probably consists of derivatives of tannins (Koningsberger and Reinders, 1957, p. 84; Grosse-Brauckmann and Puffe, 1964). Individual cells can separate from the tissue and/or may be merged in the o-plasma (Fig. 74 and 76).

As this arrangement is in particular characteristic for phellem the name phellemic was coined from the name of this particular tissue (the Greek word *phellos* = cork).

2.4 *pleistoplasmatic* The tissue is barely visible. The organic soil material consists almost entirely of organic plasma which may have the appearance of a gel (Fig. 75 and 77).

The name pleistoplasmatic is coined from the Greek word *pleistos* (= most) and plasma, meaning the plasma dominating over the tissue.

For more detailed investigations one might add to the name of the related distribution a description of the present tissues according to their type as well as to the structure of their cellwalls. Reference should be made to the discussion on tissues in chapter II, paragraph 2.1.1.

Detailed studies on the decomposition of tissues have been already carried out at an early date by Grosskopf (1928). Investigations on anatomic changes during humification in fir needles led Grosskopf to his observations on the formation of dark humic material in places where the cellulose walls of the parenchymatic tissues were broken down.

In such investigations it is possible to study the progressive decomposition of the cellwalls. In this respect the decomposition of lignin is of specific interest since through this process most humic acids are thought to be formed (Grosskopf, 1928; Flaig, 1955, 1958, 1966, p. 392, 1969; Flaig et al., 1954, 1963; Hurst et al., 1967; Oglesby et al., 1967; and others see: Welte, 1952; Bremner, 1954; Springer, 1955; Scheffer and Ulrich, 1960; Kononova, 1961; Martin et al., 1971).

Babel (1964 a) observed that the secondary thickening of the cellwall in the sklerenchyma of beech leaves in a raw humus would be the first to breakdown. Firstly by disengaging from the middle-lamel, then it becomes lodged like a ring in the cell lumen. The middle-lamel never breaks down in this early stage of decomposition, but will keep its form. In xylem, in some cases, the middle-lamel may be the first to break down, but here, too, it is commonly the secondary wall thickening which is the first to decompose. However, the latter does not disengage itself from the middle-lamel, but becomes granular instead. This decomposition of the secondary wall thickening in xylem as well as in sklerenchyma is accompanied by a colour change to yellow or to yellow-brown. According to Babel (loc. cit.) these yellow products are "new-formations", thus they are organic plasma (possibly in a coniatic related distribution pattern).

Kononova (1961, pp. 148 and 152) and Martin et al. (1971) suggest that these "humic substances" could also form without lignin. The first mentioned author concluded this from the analyses of organic new-formations in humified leaves as well as from the anatomy of the decomposing tissues. This conclusion may be corroborated by Meier's observations made in his study of the "Brown rot" disease in birch-wood (Meier, 1955). Schuffelen and Bolt (1950) and Laatsch et al. (1951) even experimentally demonstrated the formation of humic acids from cellulose without lignin being involved.

5.2.2 Arrangements of organic skeleton grains and organic plasma

These arrangements occur especially in organic pedological features, but they can also occur in e.g. peds and apedal soil materials. Discussed are:
- "Basic distribution patterns" of organic skeleton grains.
- "Related distribution patterns" of organic skeleton grains with respect to organic plasma.

5.2.2.1 Basic distribution patterns of organic skeleton grains

In describing basic distribution patterns one must in principle describe the distribution of like individuals in relation to each other. Basic distribution pattern of skeleton grains as such means nothing as these grains can vary in size from 2 μm up to >2 mm. Consequently describing basic distribution patterns of skeleton grains is in fact only possible if beforehand the notion of like grains is defined. One could decide to regard skeleton grains as like individuals if they are approximately of the same size using the size-classes proposed in chapter II, p. 29. However, it is not known as yet in what detail the distribution patterns of skeleton grains in relation to each other must be described.

As the difference in morphology as well as in behaviour between skeleton grains and plasma are evident, it is obvious to describe their distribution patterns in relation to each other. If skeleton grains would be regarded as being composed of groups of like individuals an enormous scale of distribution patterns presents itself. It is questionable whether this is necessary at the present stage of knowledge. Seen from this viewpoint it may be justified to reduce skeleton grains to the same denominator (as in fact is

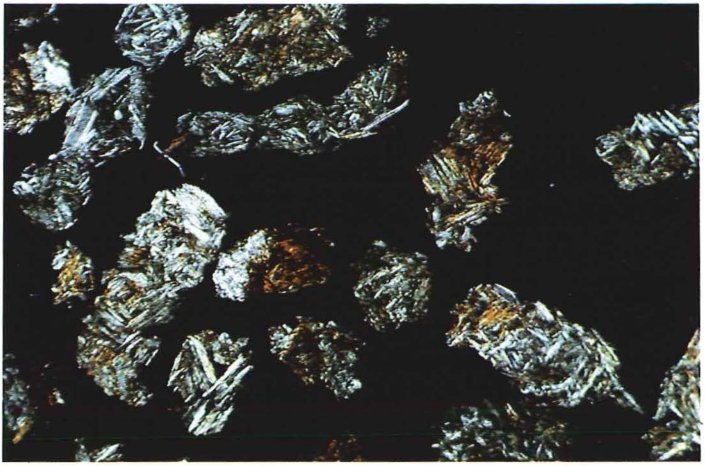


Fig. 80 Excrements of the earthworm *Dendrobaena rubida* after it had ingested xylem of a brancohist. Excrements formed from xylem are often little uniform in their shape. The main form is cylindrical varying from bacillocylinder and sperm-bacillocylinder to clonocylinder. The bacillocylinders even occur in a "stringed" basic distribution pattern is this figure.

Note that:
1. the organic skeleton grains are clearly recognizable fragments of "aggregations of tissues" in which cellulose is clearly present (streaks of birefringement).
2. the pattern of the arrangement of o-skeleton grains with respect to o-plasma is "granular".
3. the form of smoothness of these modexi is ortho.

Thin section under crossed polarizers. 36 x.

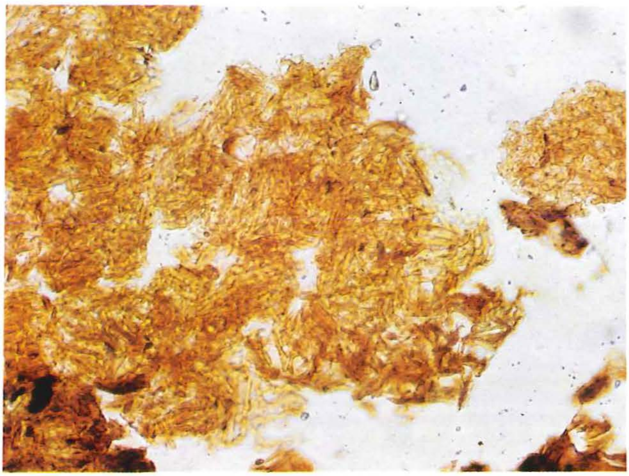


Fig. 81 Moderately welded, fine to medium, organic cylindrical modexi. The fine, organic skeleton grains, which have clearly recognizable plant tissue structure, occur in a "granular" related distribution pattern with reference to o-plasma. Thin section in plain light. 220 x.

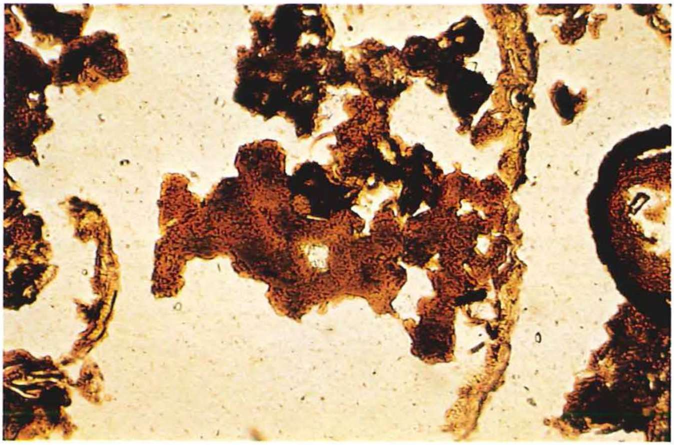


Fig. 82 "Massive cluster" of strongly welded, organic ellipsoids (in the centre of the figure). The related distribution pattern of organic skeleton grains with respect to organic plasma is pleistoplasmatic. Note that the o-plasma is brown. Thin section in plain light. 118 x.

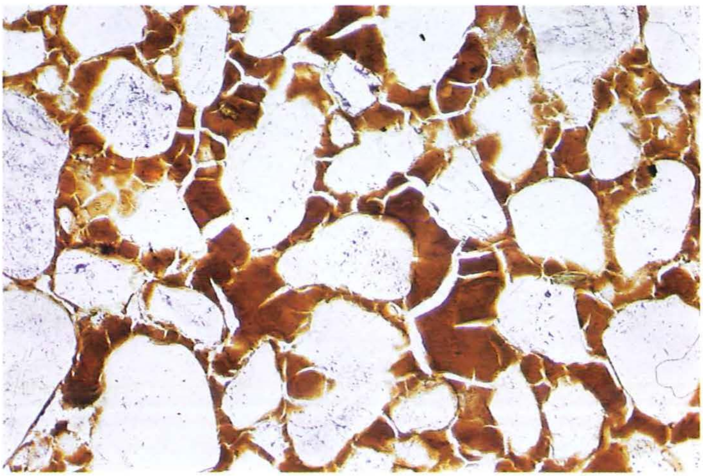


Fig. 83 Porphyroskelic (grading into intertextic) fabric. The mineral skeleton grains are almost entirely embedded in brown organic plasma. In fact this fabric is an extremely formation of "illuviation humicans". Note the cracks in the o-plasma which have been formed by desiccation. The related distribution pattern of o-plasma with reference to

done with plasma components), or in other words although it may scientifically be not quite correct, all skeleton grains are, for convenience sake, regarded as being like individuals when describing their distribution pattern.

One exception was made, i.e. the porphyroid basic distribution pattern (page 92) as this is a striking one.

However, to meet more or less this imperfection it is possible to add to the name of the distribution pattern the size of the skeleton grains (see page 29).

It is quite possible that Brewer (1964, p. 170) followed the same line of reasoning when he described distribution of skeleton grains (not subdivided into groups) in relation to plasma.

Regarded in the above-described way, organic skeleton grains mostly occur in a random basic distribution pattern, although they may also occur clustered. For the concept of random and clustered basic distribution pattern one is referred to page 68 and 71 respectively.

A. *Random basic distribution patterns of organic skeleton grains*
According to the present author it is necessary to subdivide the random basic distribution patterns into two types. These are distinguished from each other by the size of the interskeletal space (= distance between skeleton grains) into:

1. *Densosoroskelic* basic distribution pattern. This basic distribution pattern is characterized by the densely packed occurrence of the organic skeleton grains. This packing may be so closely that voids, belonging to the s-matrix, cannot always be observed with magnifications up to 200 : 1 (Fig. 18, 32, 33, 36 and 42).
The name densosoroskelic is coined from the two Greek words *densos* (= dense) and *soros* (= to pile), and skeleton grains (skelic).
Sometimes the way in which the skeleton

grains are packed together can be recorded in subtypes, for example:

1.1 *symplectic* — The organic skeleton grains are entwined forming a dense mass. Larger skeleton grains, which are easily flexible are often arranged in this pattern (Fig. 32 and 36). The name is coined from the Greek words *sym* (= together) and *plek* (= to twist).

1.2 *porphyroid* — Larger organic skeleton grains occur embedded in a dense mass consisting of smaller ones. This distribution pattern may be characteristic of organic excrements of earthworms as they ingest histons as well as excrements from other soil animals, which make small organic skeleton grains. The name of this distribution pattern is chosen because of the resemblance of this pattern to the porphyroskelic related distribution pattern of plasma and skeleton grains as described by Brewer (1964, p. 170).

2. *Adensosoroskelic* basic distribution pattern. This basic distribution pattern is characterized by the relative large interskeletal space or in other words the space between the skeleton grains is clearly visible with low magnifications. It is obvious that in the adensosoroskelic distribution pattern the i-matrix may occupy the interskeletal space. This type of distribution pattern can be subdivided into two subtypes, viz.:

2.1 *hyphantic* — Loose packing of (usually large, elongated) organic skeleton grains which are arranged in such a manner that they form a woven pattern (Fig. 37 and 78).

The name is coined from the Greek word *hyphantos* (= woven). This distribution pattern may be characteristic of excrements of Tipulidae larvae, the Diplopod *Glomerus conspera* Koch and it may occur in excrements of Lumbricidae.

2.2 *sporadic* — The spatial arrangement of the organic skeleton grains is such that they have either no or only minimal contact with each other (Fig. 31 and 79).
The name is coined from the Greek word *sporaden* (= sporadic). This particular distribution pattern may be formed e.g. by churning and biological homogenization.

B. *Clustered basic distribution pattern*
Clusters of organic skeleton grains are spatially arranged throughout the soil material.

Fungal form — If a large part of the organic skeleton grains consists of fragmented fungal hyphae, to the name indicating the basic distribution pattern is added (fungal form).

5.2.2.2 Related distribution patterns of organic skeleton grains with reference to organic plasma

At present three patterns are distinguished, which are related to the amount of organic plasma, i.e.:

1. *granular*
   According to Brewer (1964, p. 170) "granular" expresses a related distribution which is characterized by the absence of plasma, or all the plasma occurs as pedological features.
   For the o-matrix, granular means that organic plasma is absent, or is present in small quantities against the cellwalls in the organic skeleton grains, as a result of which the grains become

slightly coloured. The tissue-structure in the organic skeleton grains remains clearly visible (Fig. 33, 37, 80 and 81).

2. *o-porphyroskelic*
   This related distribution clearly exhibits a relationship with the porphyroskelic related distribution pattern described by Brewer (1964, p. 170). To avoid confusion in the terminology the name of this related distribution of the o-matrix is prefixed by an "o". In this related distribution pattern organic plasma surrounds, and lies between, the organic skeleton grains. The organic skeleton grains are, however, still more or less recognizable in the o-matrix.
   If the content of plasma is low then "low plasma" is added to o-porphyroskelic. If the content of plasma is high then "high plasma" is added (Fig. 9 and 10). If the organic skeleton grains are very small, the o-matrix resembles a jigsaw puzzle. In this case the related distribution may be named "o-porphyroskelic (puzzle-like)".

3. *pleistoplasmatic*
   Organic skeleton grains are absent or, when present, can hardly be seen. This phenomenon is caused by the fact that organic plasma of the o-matrix becomes so dominant that the organic skeleton grains are either not or only partially observable. For this reason the o-matrix may have a gel-like appearance (Fig. 82 and 83).
   The name pleistoplasmatic was coined from the Greek word *pleistos* (= most) and plasma, indicating that the plasma is dominating over the skeleton grains.

Some explicative remarks pertaining to the distribution patterns are perhaps relevant here:

a. It is repeated here that to the name of the distribution pattern may be added the size of the skeleton grains (as distinguished on page 29); e.g. "coarse granular" meaning a granular related distribution pattern concerning skeleton grains larger than 500 μm.

b. There is a correlation between the related distribution patterns and the decomposition stage of plant debris, i.e.:
   1. The granular, histonic, coniatic and particular types of phellemic related distributions may represent an initial stage in the decomposition process. The histon and organic skeleton grains have clearly recognizable tissue in which cellulose and lignin are often still present (Fig. 72, 73, 76, 78, 80 and 81). However, although anatomical changes may apparently be absent the tissues may have changed much in their chemistry. Wittich (1939) showed a loss of 33.6% of the dry matter.
   2. The o-porphyroskelic, plasmonesic and particular types of phellemic related distributions represent an intermediate decomposition stage of plant debris. The presence of organic plasma may obstruct the observation of the tissue. After removal of the organic plasma (as described on page 33), it is probably still observable (Fig. 74).
   3. The o-porphyroskelic (high plasma or puzzle-like) and the pleistoplasmatic related distributions represent an advanced stage of decomposition of plant debris (Fig. 9, 10, 75, 82 and 83).

      The organic skeleton grains and tissues are morphologically and chemically greatly altered and for the greater part changed into organic plasma. Vegetative structures are, if present, only recognizable after the removal of the organic plasma. In some cases cellulose will then be recognizable (Handley, 1954, p. 63; Grosse-Brauckmann and Puffe, 1964; photographs 1 and 3 in Babel's publication, 1964 b).

c. Subforms can be separated on the nature of the organic plasma. The yellow, brown, and red-brown ones form one group. The black-coloured o-plasma, and the opaque o-plasma form also two separate groups.

   For an understanding of separation into these subforms one is referred to the pages 30–32.

d. The colour of the matrix may largely depend on the amount, but especially on the nature of the organic plasma.

Postscript

Organic and mineral soil materials in ONE *morphological classification – system?*

As soil may be composed of inorganic as well as of organic materials, both have to be taken into account in its study. This means that in soil science a system is needed in which both are described.

Brewer (1964) describes the mineral soil materials, and although he (loc. cit., p. 12) made a provision for organic materials in his system, he made the restriction that this could only hold for the "humified organic matter". He stated that "Recognizable undecomposed organic remains are not considered; these materials have characteristics so different from the mineral constituents that they require a different method of treatment not within the scope of fabric and mineral analysis."

However, this same author did not give a clear definition of "humified" and "undecomposed". Therefore it is impossible to decide (using Brewer's system) whether particular organic materials are humified or undecomposed. Two examples may illustrate this difficulty, i.e.:

1. Do we have to consider a "histon" (composed of tissues), in which organic plasma is present as a thin layer at the surface of the cellwalls, as undecomposed or humified? It is thought to be undecomposed according to Brewer and therefore he left it out of discussion. On the other hand, however, in this histon plasma is present and consequently falls within Brewer's system. The question rising is how to decribe the presence of the plasma without mentioning the tissues?
2. Are organic skeleton grains (as introduced in the present study) to be considered as humified or undecomposed? This is important to decide as A-horizons can be an intimate mixture of organic and mineral skeleton grains (e.g. in excrements). As

organic skeleton grains are small particles of tissue (structure often clearly visible) it is not quite clear whether they are humified according to Brewer. One might get the impression that Brewer regards the organic skeleton grains as humified matter. This is because organic modexi (faecal pellets) were classified by Brewer as pedological feature (Brewer, 1964, pp. 299–300). But, in the examples of excrements given by Brewer (1964, fig. 96 and 97) tissue structures are not clearly visible. It is, however, wondered whether modexi composed of clearly recognizable fragments of tissues (e.g. Fig. 37 and 80 in the present study) may in fact find a place in Brewer's system?

The two foregoing examples illustrate the need of an exact definition of "humified" and "undecomposed" that Brewer should have given.

However, it may be wondered why "undecomposed organic remains" could not go together with decomposed organic remains and mineral constituents in one system? Although we can allow for optical differences between undecomposed organic remains and mineral constituents, there are still no essential disparities for size, shape and arrangement between these two soil materials. Moreover, organic plasma has optical characteristics quite different from mineral plasma, but nevertheless it is included in Brewer's system.

Brewer (1964, p. 12) has already put forward a parallel between mineral and organic soil materials, i.e.: decomposition of mineral skeleton grains into mineral plasma, and decomposition of organic soil material (read "organic skeleton grains" and "histons") into organic plasma.

In conclusion it can be stated that in describing exactly related distribution patterns of soil materials, it is necessary to mention the presence of other soil materials including "undecomposed organic remains".

With reference to the above-mentioned the present author is of the opinion that all soil materials, organic as well as mineral, can and even have to be included in *one* system. With the aid of such a system the soil can be studied and described completely. To make progress in soil science this particular system is indispensable and must be developed. To attain this aim the next step is describing the distribution patterns of organic constituents in relation to the mineral ones. This is possible as the principles of the classification of both are the same.

Morphological system of describing soil materials useful for soil - classification only?

The present author is convinced that the proposed system of describing the soil is not only suitable for classification of soil materials and ultimately of soils, but also for other purposes as studying:

– *soil genesis*	Many genetic processes are reflected in the soil's morphology, e.g. transformation of histons in excrements by the soil fauna, welding and disintegration of these excrements by ageing followed by translocation forming particular cutans (organans) at greater depth. Cutans are also very informative in studying soil genesis (Brewer, 1964, pp. 224–226).
– *the chemistry of organic soil materials*	Detailed description of these materials provides useful background in selecting samples for chemical analyses. Perhaps it will be possible in future to make microanalyses in thin section. A start into this direction was already made by Kononova (1961, p. 139) in microtomesections and by Babel (1964 b) in thin sections.
– *the physics of soil materials*	It is possible to correlate the microscopical properties of these materials and their physical characteristics, e.g. stability or water-holding capacity (Bal, 1970, fig. 2).
– *the soil eco-system*	Describing and characterizing the world of small soil organisms and their ecology.

APPENDIX

Different definitions of humus and humification

HUMUS

Over a period of time the word humus has been given very different meanings as shown in the definitions below. These can be divided into morphological ones and into definitions, which stress the breakdown of organic materials. There are also definitions which are based on the pedo-ecology or on the (bio-) chemistry of the organic materials. Humus may also be defined on the function which is its most characteristic one in the opinion of a particular author. Finally there are definitions which are mixtures of the above mentioned ones.

Morphological:

Laatsch, 1957, p. 114	Humus is that part of the organic matter in soil in which tissue structures can no longer be recognized macro- or microscopically.
SSSA, 1965, p. 337 (definition 2)	Humus includes the F and H layers in undisturbed forest soils.

(Bio-) Chemical:

Kononova, 1961, p. 163	Humus consists of microbiologically synthesized substances of high-molecular-weight in or on the soil. It is identical with humic substances (= new formations),

i.e.: fulvic acids, hymatomelanic acids, humic acids, and humins (loc. cit., pp. 49–51).

Chemical-morphological:

Maiwald, 1931, p. 117

Humus is that part of the organic soil materials, which has been broken down to such an extent that original plant- and/or animal tissue structures cannot be observed macroscopically or microscopically. It has the characteristics of the dark coloured "end-products" formed by decomposition of organic soil materials.

Breakdown of organic materials:

Scheffer and Ulrich, 1960, p. 1

One understands by humus the dead plant or animal substances present in or on the soil; these are subjected to a progressive decomposition, transformation and synthetic process instigated and continued by biochemical processes.

Gray, 1967, p. 261

Humus is the decomposing organic matter in the soil.

Pedo-ecological:

In these definitions the resistance of organic materials to decomposition is regarded as the main criterion of humus.

Kubiena, 1938, pp. 224–225
1948, p. 203

Humus comprises all organic matter in the soil which, under the prevailing decomposition conditions in the biological locality, appears to be difficult to affect, and therefore becomes piled up in a characteristic manner.

Morphological-ecological:

Encyclopedia of Science and Technology, 1971, volume 6, p. 581

Humus is the amorphous, ordinarily dark-coloured, colloidal matter in soil, representing a complex of the fractions of organic matter of plant, animal, and microbial origin that are most resistant to decomposition.

SSSA, 1965, p. 337 (definition 1)

Humus is that more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually it is dark coloured.

Functional:

Gel'tser, 1944

Humus is that fraction of the organic soil colloids which possesses the capacity of combining with the mineral part of the soil to form organo-mineral aggregates. In other words: humus is the stuff which creates a soil structure, and any organic material that does not take part in structure formation is excluded from the definition of humus.

Thus Gel'tser regards all the

organic material which does not participate in the structure-formation as not being humus. According to her, humus should be considered as being mainly autolysis products of bacteria. These materials belong, to a great extent, to the humic acids.

The list of definitions of humus in different (modern) languages published by Jacks et al. (1960, p. 108) is noteworthy.

United Kingdom:	Humus is the amorphous (colloidal) organic matter of soil.
U.S.A.:	Humus is the organic complex of the soil which is more or less resistant to microbial decomposition.
Netherlands:	All organic matter in the soil subject to decomposition, transformation, and neoformation.

In the present author's opinion it is hardly possible to give a definition of humus which is accepted by a particular country. For example the so-called Dutch definition (almost identical to that of Scheffer and Ulrich, 1960) is not sound as many people in the Netherlands (including soil scientists) regard humus as amorphous organic matter in the soil as it is defined in the Dutch Dictionary written by Kruyskamp (1961):

"Humus is the dark matter in the soil which originates from rotting and decaying plants and other organic materials"

HUMIFICATION

The different concepts of humification mostly follow from the different meanings given to humus. Most logically are those which state that humus is formed by humification (Laatsch, 1957; Kononova, 1961; SSSA, 1965; Gray, 1967). However, the definition of humification given by a certain author may contradict the definition of humus according to this same author (e.g. Gray, 1967). According to others humic acids are formed by humification (Scheffer and Welte, 1949). This definition is sound if these authors regard humus as being identical with humic acids (e.g. Kononova, 1961).

According to some definitions humification has nothing to do with humus, e.g. Dutch Dictionary (Kruyskamp, 1961).

Some definitions of humification are:

Laatsch, 1957, p. 114	Humification or humusformation means decomposition of plant-, and animal tissue structures and formation of amorphous organic matter.
Kononova, 1961, p. 163	Humification is the process by which humus is formed in the following way: – tissues are decomposed into chemically simpler, individual substances, and – these decomposition products are synthesized into substances of high-molecular-weight, i.e. humic substances (humic substances = humus, see page 101 of this study).
SSSA, 1965, p. 337	Humification is the process involved in the decomposition of organic matter and leading to the formation of humus.

Gray, 1967, p. 261	Humification is the process by which plant detritus is turned into humus.
Scheffer and Welte, 1949	Humification is the process by which humic acids are formed.
Kruyskamp, 1961	Humification is identical with peatformation.

Summary

Soil is a natural body at the earth's surface formed by interaction of a range of biological, physical and chemical processes; it consists of mineral and/or organic components. Thus, it is obvious that it can be studied according to the relevant characteristics. But, as these processes are reflected in the morphology of the soil materials, and thus also in the soil's as a whole this natural body can also morphologically be investigated, as is done in the present study. In this respect morphological parameters are: shape, size, distribution, and colour.

Before starting this study it is necessary to define soil. Although it should be preferable to have a concept of soil which is acceptable for all people interested in it, whether they are civil engineer, agriculturist, or pedologist this is unfortunately impossible. Such a concept would be too general. That is why several concepts of soil exist adapted to the way of considering soil. In this study it is defined as it is acceptable for the pedologist and to a great extent also for the soil-biologist.

As physical, chemical and biological processes can only progress according to certain laws it is, as a matter of fact, needless to say that these laws are also reflected in the soil's morphology. That is: the soil components are not a disorderly mass, on the contrary they are organized according to certain laws. This can already be detected macroscopically, but much more data are obtained when the soil is studied microscopically, especially on soil in undisturbed condition (i.e. *micromorphology*) with the aid of thin sections.

Much investigation on this very subject was already done by Brewer (1964) especially on the organization of mineral matter. Only few micromorphological studies were made on organic soil materials, although these latter are very important in soil genesis

and fertility. A comprehensive, logical system of describing the organization of organic soil materials is still needed. In this study the author proposes a system of classification of organic materials in soils taking due consideration of genetic processes. In this system much attention is paid to organic and inorganic excrements present in soil. These particular soil units were only briefly discussed by Brewer (1964, pp. 299–301). Just as soil must be defined before studying it so must organic matter. In the author's view all organic materials in soil are part of a "natural, three-dimensional, genetic entity", which he named: *humon.* That is why a range of different humons can be distinguished. In order to study the organization in the humon the author describes its constituents, and the way in which these are organized into so-called *units of organization.* In consequence he is able to formulate the lower levels in the organization of organic soil materials, which are not merely a sterile description, but based on genetic considerations as far as possible.

Introduction of a new method of study is often accompanied by introduction of new concepts (with adapted names), or by redefining existing concepts; this is also the case in the present study. To get a view of these particular concepts the present study is supplied with a "Glossary of terms".

The ultimate aim of micromorphological studies on soil is to detect the complete organization of this body, that is of all its composing components: mineral and organic. That is why the author tried to adapt the way of describing the organization of organic materials as much as possible to that of the mineral components according to the system of Brewer (1964). It is logical that this is possible to a great extent as mineral and organic matter in soil are in fact subject to the same processes. Summarizing this means that now two systems are available for describing the organization of mineral and organic materials in soil respectively. Both systems are based on the same principles, so that it is possible to study the organization of both materials in relation to each other.

Finally it is briefly remarked that micromorphological studies on organization of soil materials are not only useful for classification-purposes, but also for studies on genesis, chemistry and physics of the soil and also for studying it as an ecosystem.

Samenvatting

De bodem is een natuurlijk lichaam aan de aardoppervlakte gevormd door een reeks van biologische, fysische en chemische processen en bestaande uit minerale en/of organische bestanddelen. Bestudering hiervan is mogelijk aan de daarop betrekking hebbende karakteristieken.

Aangezien deze processen weerspiegeld zijn in de morfologie van het bodemmateriaal, en dus ook in de bodem als geheel, is het eveneens mogelijk deze natuurlijke eenheid morfologisch te onderzoeken, zoals is verricht in deze studie. Hierbij moet worden vermeld dat morfologische parameters zijn: vorm, grootte, distributie en kleur.

Alvorens met deze studie te beginnen is het echter noodzakelijk het begrip bodem te definieren. Hierbij zou het belangrijk zijn tot een dusdanige definitie te komen, dat ook andere in de bodem geinteresseerden zoals bouwkundigen en landbouwkundigen deze kunnen accepteren. Helaas behoort een dergelijke uniforme omschrijving niet tot de mogelijkheden aangezien een dergelijk concept te algemeen zou zijn. Dit is de reden waarom er zovele definities van de bodem bestaan afgestemd op de wijze waarop de bodem wordt beschouwd. In dit proefschrift is de bodem zo gedefinieerd dat zij door de bodemkundige kan worden geaccepteerd en grotendeels door de bodem-bioloog.

Aangezien fysische, chemische en biologische processen aan bepaalde wetten gebonden zijn, behoeft het geen betoog, dat deze wetten in de morfologie van de bodem zijn weerspiegeld. Of anders uitgedrukt: de bodemcomponenten vormen tezamen geen ongeorganiseerd geheel, doch vertonen duidelijk hun gebondenheid aan de eerdergenoemde wetmatigheden. Dit is reeds macroscopisch te zien, doch nog veel meer gegevens worden ons deel wanneer de bodem, en dan speciaal die in ongestoorde toestand, microscopisch wordt bestudeerd aan de hand van dunne doorsneden hiervan (i.e. *micromorfologie*). Aan dit onderwerp werden door Brewer (1964) reeds vele onderzoekingen gewijd, waarbij het minerale deel speciale aandacht verkreeg. Aan het organische deel daarentegen, werden veel minder onderzoekingen verricht, alhoewel dit deel een belangrijk aandeel levert in de bodemgenese en -vruchtbaarheid. Er bestaat daardoor nog steeds behoefte aan een uitgebreid logisch systeem, waarin die organisatie van de organische bodembestanddelen beschreven wordt.

In dit proefschrift presenteert de schrijver een classificatiesysteem voor het organische deel van de bodem gebaseerd op haar genetische achtergronden. In dit systeem is veel plaats ingeruimd voor de organische en anorganische excrementen die in de bodem aanwezig zijn. Deze materie kreeg van Brewer slechts zeer weinig aandacht (Brewer, 1964, pag. 299–301).

Evenals de bodem, alvorens deze te kunnen bestuderen, gedefinieerd moet worden dient dit ook voor de organische stof te geschieden. In de opvatting van de schrijver vormen alle organische bestanddelen tezamen een "natuurlijke, driedimensionale, genetische eenheid", die hij de naam geeft van *humon*. Op deze wijze is het mogelijk diverse humons te onderscheiden. Teneinde de organisatie in het humon te kunnen onderzoeken beschrijft de auteur haar elementaire bestanddelen en de wijze waarop deze zijn gegroepeerd in zogenoemde *organisatie-eenheden*. Hierdoor werd het hem mogelijk de lagere niveaux in de organisatie van organische bodemmaterialen te beschrijven, dus niet zo maar een steriele beschrijving maar zoveel mogelijk naar de wijze waarop zij gevormd werden.

Een nieuwe onderzoeksmethode gaat dikwijls vergezeld van nieuwe begrippen met daaraan aangepaste benamingen, of van het aanbrengen van kleine wijzigingen in reeds bestaande begrippen, zoals dat ook in dit proefschrift tot uiting komt. Deze werden overzichtelijk samengebracht in een verklarende woordenlijst welke achterin het proefschrift werd opgenomen.

Het uiteindelijke doel van micromorfologisch onderzoek aan de bodem is te komen tot een volledig inzicht in de organisatie van dit lichaam en haar samenstellende componenten zowel mineraal als organisch. Dit is de reden, dat de auteur heeft getracht de beschrijving van de organisatie van de organische materialen zoveel

mogelijk aan te passen aan de wijze waarop Brewer (1964) dit voor de minerale componenten heeft gedaan.
Aangezien zowel de minerale als de organische bestanddelen in de bodem in feite aan dezelfde processen onderhevig zijn, is het logisch, dat deze aanpassing zeer ver doorgevoerd kan worden.

Samenvattend kan worden gesteld, dat thans twee systemen beschikbaar zijn, waardoor het mogelijk is de organisatie van alle bodemcomponenten te beschrijven. Beide systemen zijn gebaseerd op dezelfde principes zodat de mogelijkheid geschapen is de relatie tussen minerale en organische componenten vast te stellen.

Tot slot volgt een korte uiteenzetting dat een micromorfologische studie niet slechts dienst kan doen voor classificatiedoeleinden van de bodem, maar ook ter bestudering van haar genese, de chemische en fysische processen daarin en eveneens ter bestudering hiervan als een ecosysteem.

Glossary

α-Accumulation	"α-Accumulation is an accumulation of a constituent, or constituents formed by generation" (p. 43).
β-Accumulation	"β-Accumulation is an accumulation formed by transportation of one or more existing constituents" (p. 43).
Ageing	"Ageing is expressed by the morphological changes (shape and/or internal fabric and/or distribution pattern), which the excrements undergo solely as a result of microbiological, chemical and physical processes. Ageing starts immediately after the excrements have left the animal's intestines and ends with their being no more recognizable, neither as single nor as welded individuals; that is because the excrements disintegrate, or form a massive entity, or merge together with some other soil material (e.g. a ped, or apedal soil material)" (p. 82).
Aggrotubules	"Aggrotubules are pedotubules composed of skeleton grains and/or plasma which occur principally as recognizable aggregates within which there is no directional arrangement with regard to the external form; the basic fabric approaches agglomeroplasmic fabric in some cases" (p. 78).

α-Anthracons	"α-Anthracons have been derived from histons, which changed into charcoal" (p. 50).
β-Anthracons	"β-Anthracons are fragments of coal" (p. 50).
Excrements (definition based on derivation)	"Excrements are solid excreta derived from the intestines of the fauna; they consist of non-resorbed components of earlier consumed materials. In addition the excrements contain other materials that are added to the already mentioned components by the animals themselves in their intestines, such as intestine-epithelia-cells, secretions, enzymes, etc." (p. 55).
An excrement (morphological definition)	"An excrement is a three-dimensional pedological feature, which is spheroidal, ellipsoidal, cylindrical, threadlike, platy or shapeless. It consists of skeleton grains and/or plasma (mineral and/or organic), and is internally often densely packed (loose packing is less frequent and may be very characteristic). Its boundaries are distinct or diffuse. It may occur (as a separate individual, or as member of a group of like individuals) at the soil surface, in voids of any type, as well as embedded in the s-matrix of soil material of different kind, or many like or unlike excrements together may even built up a complete soil horizon" (p. 55).
Fungon	"Fungon is a sclerotium, or an accumulation of fungal hyphae and/or spores in a soil material" (p. 52).

Hetero-modexical related distribution pattern	"Hetero-modexical related distribution pattern is the distribution pattern of like modexi with regard to the distribution of groups of modexi of a different kind" (p. 74).
Histon	"Histon is a natural aggregation of different tissues (grown together in a plant or animal body) such as a leaf, branch, root, seed, fruit, etc. or the remains of that if these are larger than 2 mm. Present organic plasma is part of the histon unless it has been formed into a pedological feature. Pedological features can occur within histons" (p. 37).
Humon	"Humon is the collection of macroscopically and/or microscopically (magnifications up to 200 : 1) observable organic bodies in soil which are characterized by a specific morphology and spatial arrangement; it is a "natural, three-dimensional, genetic, organic individual" existing in soil" (p. 15).
Humon-profile	"Humon-profile is the vertical section of a humon in which consecutive, exposed horizons represent the resultant and mode of decomposition of organic materials" (p. 15).
Inherited pedological features	"Inherited pedological features are relicts of parent rock and parent material or of underlying materials, or they have been added to the soil in some other way (e.g. by man)" (p. 51).

i-Matrix	"i-Matrix of a soil material is the mineral material within this unit of study being simplest (primary) peds, or composing apedal soil materials (in which pedological features occur), or pedological features. It consists of mineral plasma and/or mineral skeleton grains" (p. 86).
o-Matrix	"o-Matrix of a soil material is the organic material within this unit of study being histons, or simplest (primary) peds, or composing apedal soil materials (in which pedological features occur), or pedological features. It consists of tissues and/or organic plasma and/or fungal hyphae, or of organic skeleton grains and/or organic plasma and/or fungal hyphae" (p. 86).
s-Matrix	"s-Matrix of a soil material is the i-matrix plus o-matrix within this unit of study. Moreover present voids are included, but only if they do not occur in pedological features other than plasma separations" (p. 86).
Melanons	"These glaebules are formed by melanosis of histons, or remains of histons, or melanized soil materials, which may be unrecognizable remains of sclerotia. If part of a histon is melanized, only this is the melanon" (p. 51).
Melanosis	"Accumulation of black or opaque organic plasma in soil bodies, possibly formed by micro-organisms" (p. 42).

Modexi	"Modexi are excrements, which have left the animal's intestines as shaped, three-dimensional individuals" (p. 58).
Modexotubules	"Modexotubules are aggrotubules in which the recognizable aggregates are modexi which may be arranged in any basic distribution pattern" (p. 78).
Organic plasma	"Organic plasma is that part of the organic soil material which is capable of being or has been moved, reorganized, and/or concentrated by processes of soil formation. It includes all organic material of colloidal size smaller than 2 μm, and relatively soluble organic material, which is not bound up in the skeleton grains or tissues. The colloid-sized material is composed of high molecular weight constituents and of very small fragments of tissue" (p. 33).
Organic skeleton grains	"Organic skeleton grains of a soil material are individual organic grains which are relatively stable and not readily translocated, concentrated or reorganized by soil-forming processes; they include fragments of aggregations of tissues, spores, pollen grains, and fragments of fungal hyphae; they are larger than 2 μm and commonly smaller than 2 mm" (p. 28).
Pedological features	"Pedological features are bodies, which often occur as recognizable units within a soil material. In such cases they are distinguishable from the enclosing material for any reason,

	such as origin (deposition as an entity), differences in degree of accumulation of some fraction of the plasma, or differences in arrangement of the constituents (fabric)" (p. 41).
Plinthons	"Plinthons are bricks or fragments of bricks in soil" (p. 51).
Soil	"Soil is the collection of natural bodies formed by alteration of mineral and/or organic (sedimentary and/or sedentary and/or igneous and/or artificial) bodies due to exposure at the earth's surface and having an anisotropic arrangement of properties along an axis normal to the soil's surface" (p. 6).
Stress neo-cutans	"Stress neo-cutans are in situ modifications in the arrangement of plasma and/or skeleton grains due to differential forces such as shearing" (p. 50).
Tissue	"Tissue is a natural aggregation of cells (grown together in a plant, or animal body), which is characterized by a specific morphology, physical constitution, chemical composition, and arrangement of these cells. These variable characteristics cause the relative differences in decomposition of different tissues" (p. 25).
Wrapping cutans	"Wrapping cutans are formed through actively wrapping up or plastering a soil material with the cutanic material by organisms" (p. 47).

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Figures

The figures to which is referred in the text have been placed on the pages 137–170.
However, some have been included in the text, these are the following:

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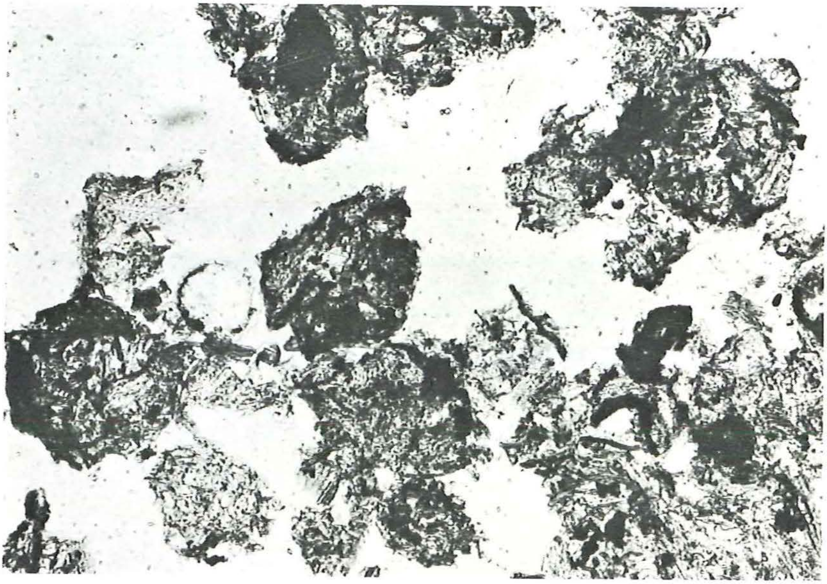


Fig. 2 Organic, spheroidal excrements of Mycetophilidae larvae. The excrements consist of plant tissue particles which are densely packed together in the excrements. Thin section in plain light. (Figure from Bal, 1970). 150 x.

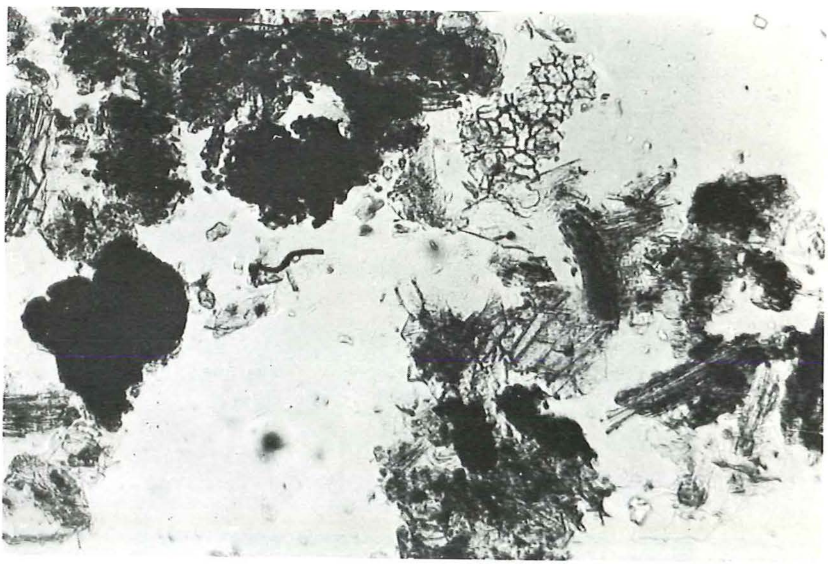


Fig. 3 When the excrements shown in Fig. 2 are disintegrated (e.g. in glycerin) they appear to be composed of plant particles (of approximately 80–160 μm) in which the tissue structures are still clearly visible. (Figure from Bal, 1970). 140 x.

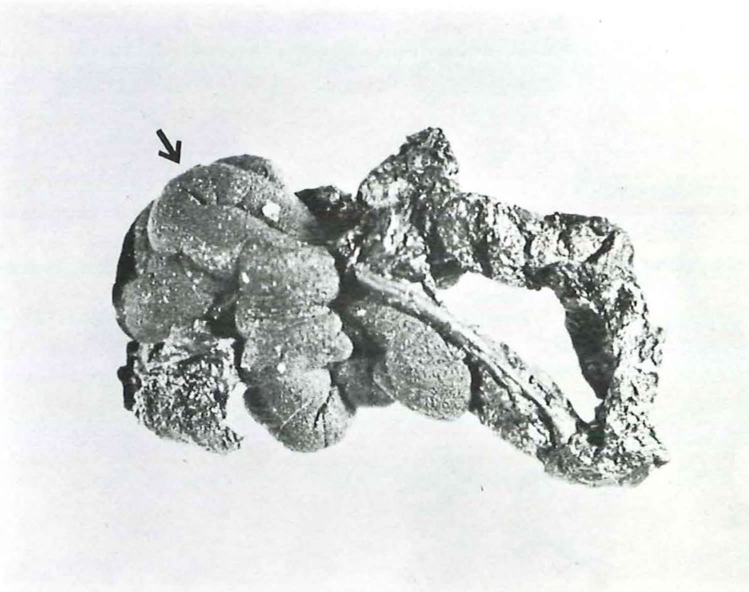


Fig. 4 Excrement of a snail part of which consists of a tough, tarry substance (in the figure indicated by an arrow), which is organic plasma. 6 x.

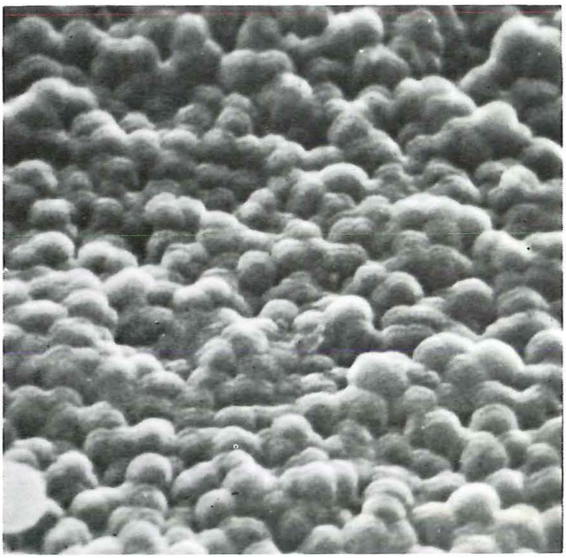


Fig. 5 Scanning electron microscope photograph of the tarry substance in excrements of snails. Note that this particular kind of organic plasma has been formed into globular units. 7780 x.

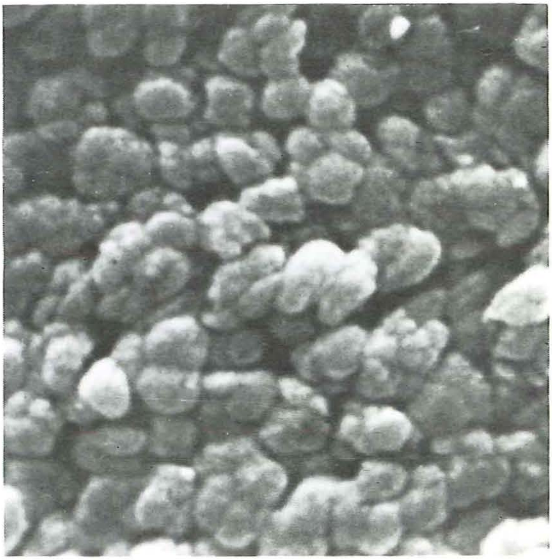


Fig. 6 Detail of Fig. 5. It is clearly observable that the globular units in fact are clusters of welded smaller, more or less globular, units. Note the present voids. 7855 x.

Fig. 8 Extremely fine, organic skeleton grains of a disintegrated excrement (in glycerin) of an Oribatid mite. Apart from cellwall fragments also some fragments of fungal hyphae are visible. 170 x.

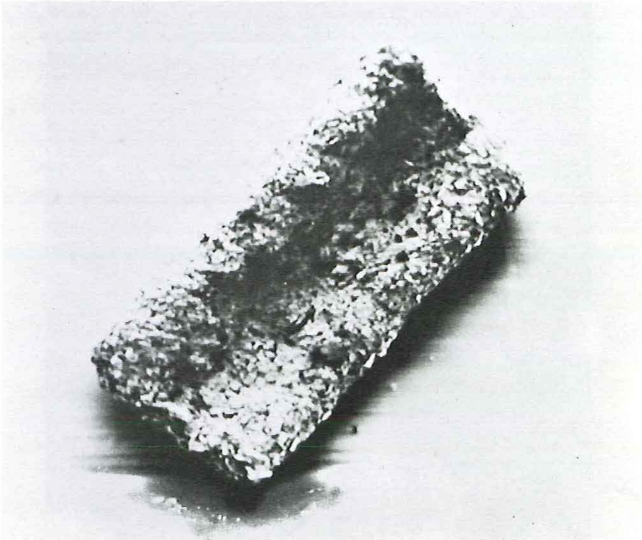


Fig. 11 Excrement of a large Isopod. Hand specimen. 50 x.

Fig. 12 Detail of the surface of the excrement in Fig. 11 (scanning electron microscope photograph). Note that the Isopod has apart from organic materials also ingested some mineral matter. The silt grain of approximately 20 μm occurs embedded in strongly fragmented plant tissues. 1030 x.

Fig. 13 Detail of Fig. 12. The extremely small particles of approximately 2 μm are remnants of cellwalls. They represent a particular group of organic plasma. 5154 x.

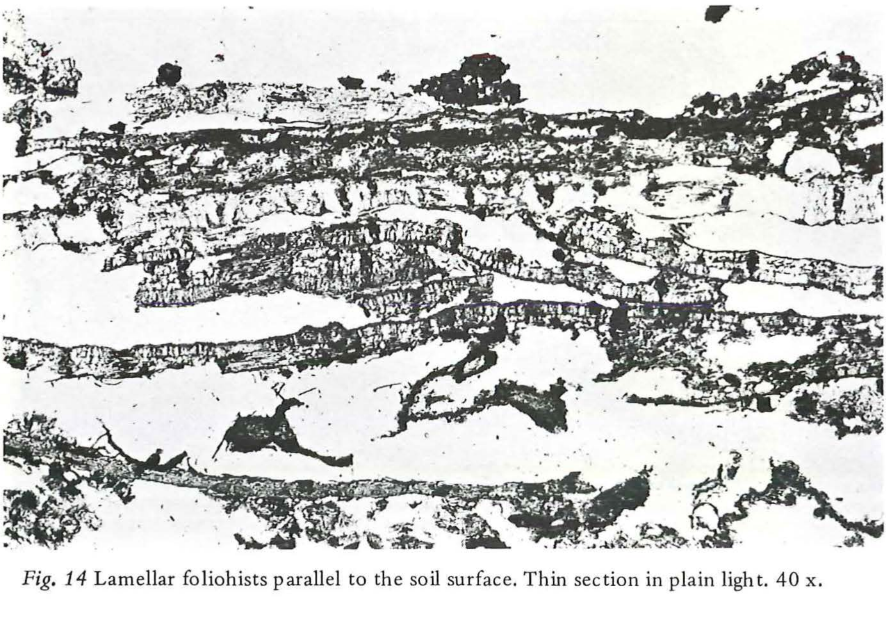


Fig. 14 Lamellar foliohists parallel to the soil surface. Thin section in plain light. 40 x.

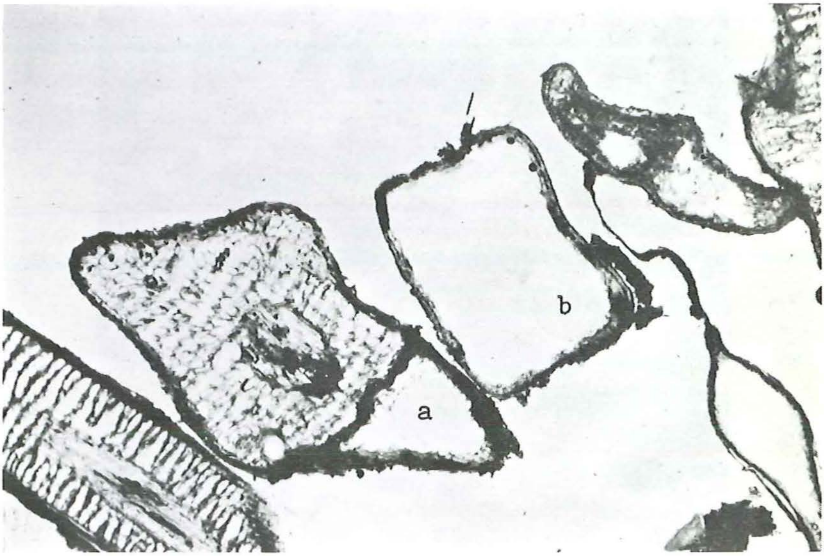


Fig. 15 Cross sections of cylindrical foliohists. In one of these an elongated melanon is present (a), a second one is strongly damaged (b). Thin section in plain light. 37 x.

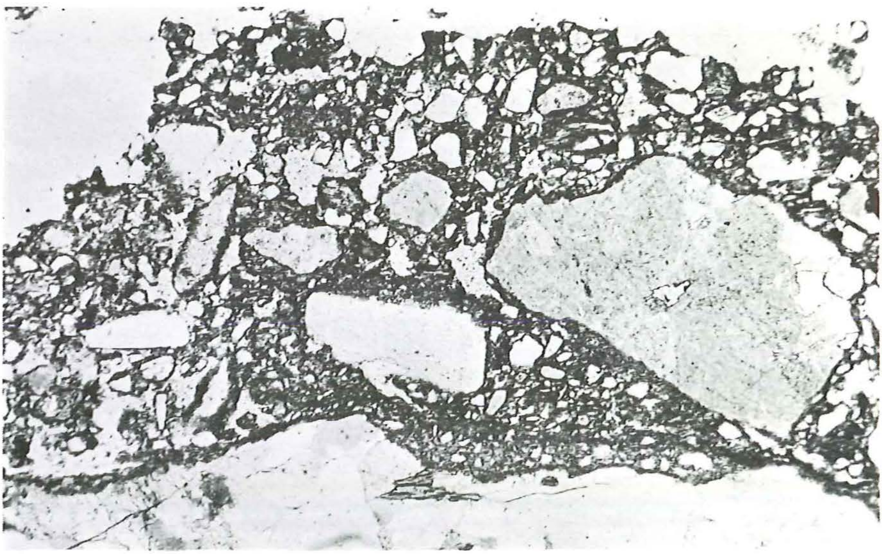


Fig. 16 Matran. Of course this cutan is at the same time a plasman-skeletan. Thin section in plain light. 40 x.

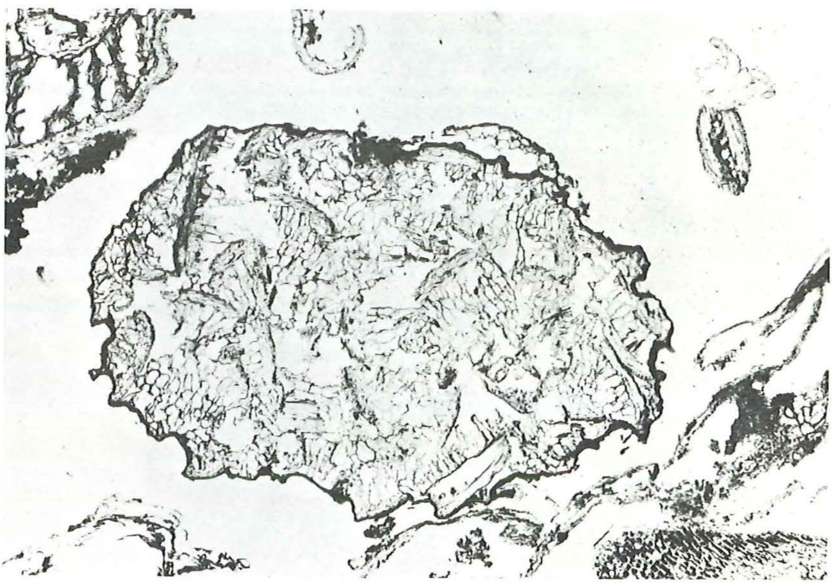


Fig. 17 Excrement organan (humican). It is possible that this black cutan occurring at the surface of the excrement is an oxidized peritrophic membrane. Thin section in plain light. (Figure from Babel, 1972). 54 x.

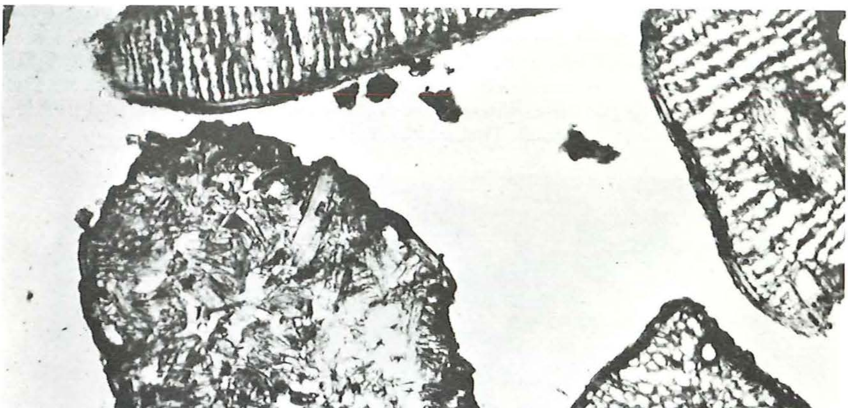


Fig. 18 Ellipsoid in which the coarse o-skeleton grains are arranged in a densosoroskelic basic distribution pattern. This excrement is characterized by an accumulation of dark coloured o-plasma at its surface. It is thought to be an organan (although neo-organan is not impossible) formed by oxidation of a peritrophic membrane. Thin section in plain light. 37 x.

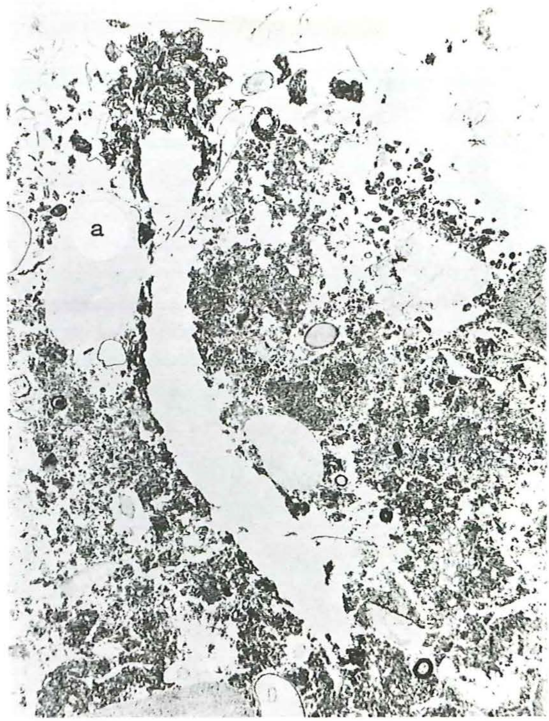


Fig. 19 Scatan (cutan composed of excrements) on the wall of a channel made by an earthworm (possibly *Lumbricus rubellus*). The scatan (which is observable as a thin, dark line especially at the left side of the channel) is merged in the cluster of bacillocylinders at the soil's surface. It is composed of bacillocylinders (which are weakly to strongly transformed by moving of the earthworm, see Fig. 20) and is strongly separated from the adjacent non-cutanic soil material. Thin section in plain light. 1.6 x.

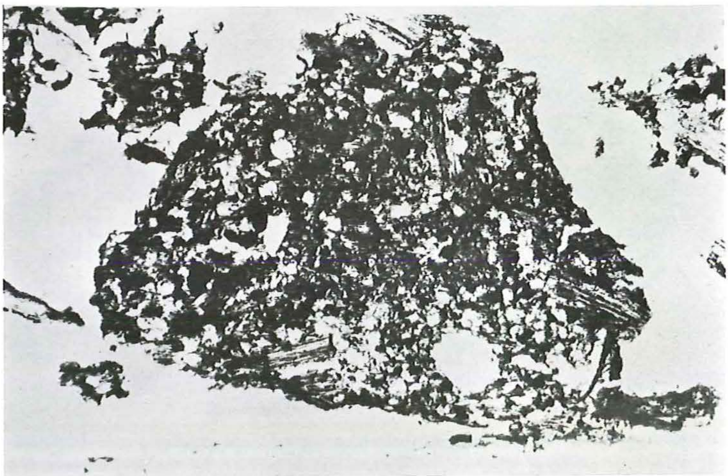


Fig. 20 Detail (a) of the scatan in Fig. 19 demonstrating an excrement. Thin section in plain light. 40 x.

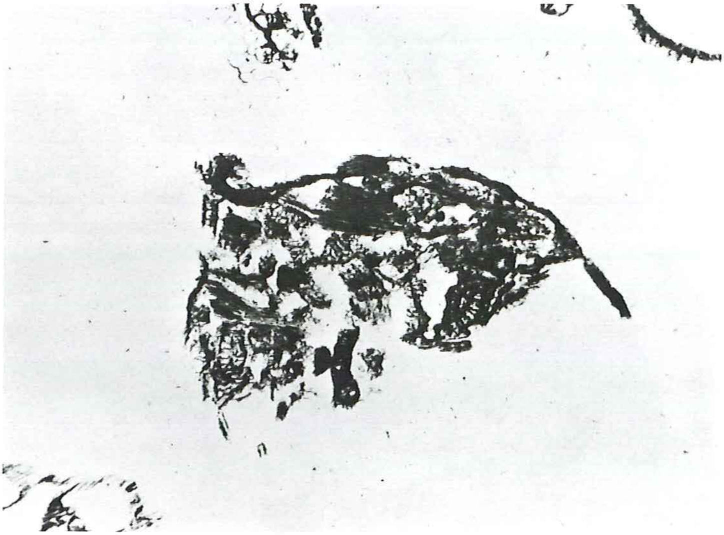


Fig. 21 Part of a spermoid (or sperm-bacillocylinder). The form of smoothness of this modex is meta surface owing to the presence of a stress neo o-skeletan. Thin section in plain light. 40 x.

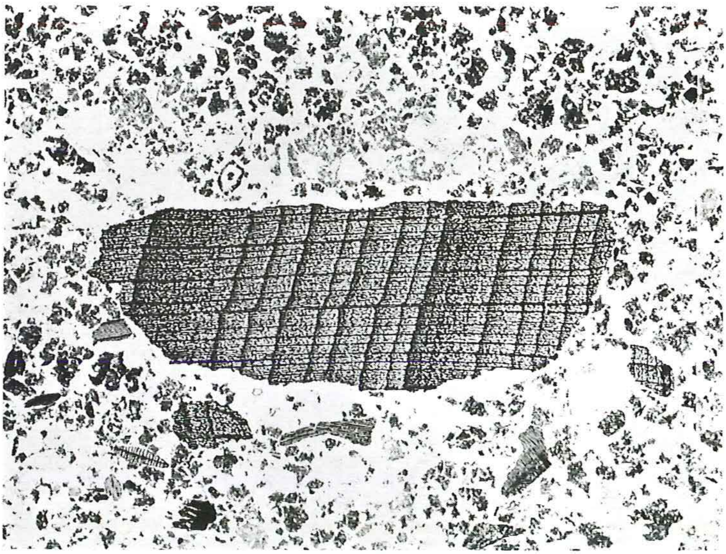


Fig. 24 α-Anthracon in which the tissue structure (xylem) of the histon from which it has been formed is still clearly visible. Some small α-anthracons are also present. Thin section in plain light. 6 x. .

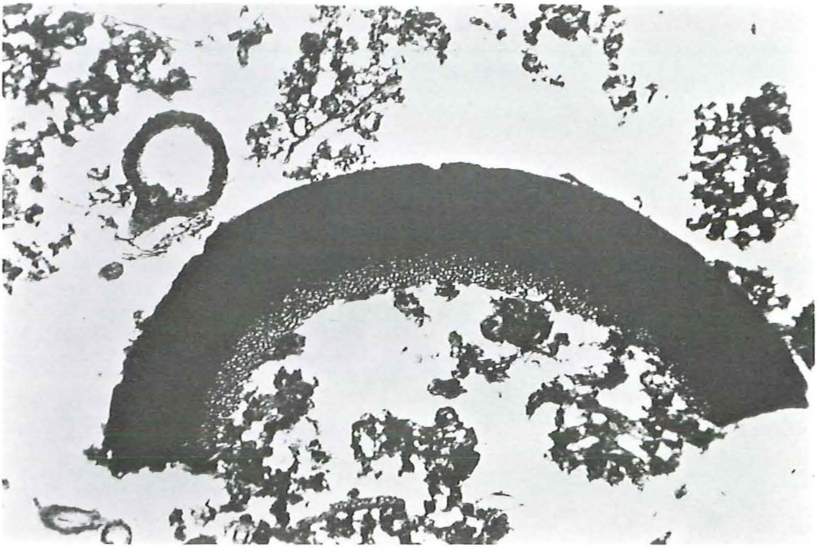


Fig. 25 Sclerotium splinter which is characterized by the presence of opaque o-plasma. This pedological feature has been formed from a globular sclerotium (type of fungon) of which only part of the wall has remained over. Thin section in plain light. 35 x.

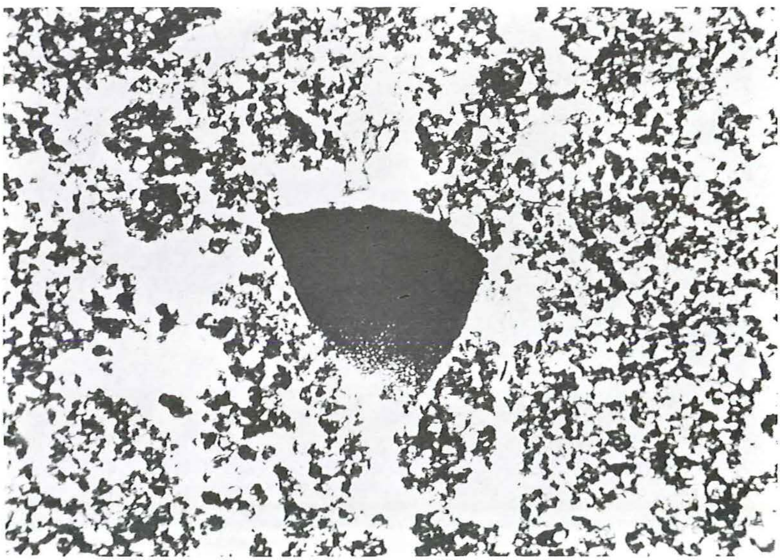


Fig. 26 Sclerotium splinter (see Fig. 25). The straight, radial edges are strikingly. Thin section in plain light. 37 x.

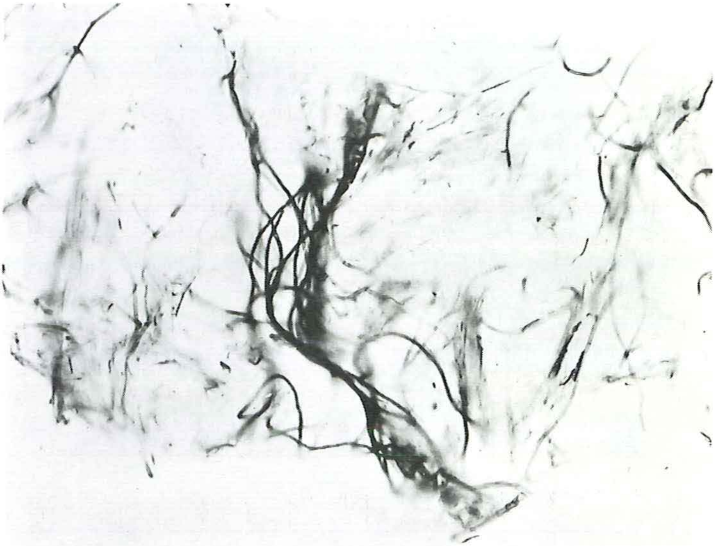


Fig. 27 Irregular arrangement of fungal hyphae in an α-hyphon. Thin section in plain light. 258 x.

Fig. 32 Organic spheres of Mycetophilidae larvae (small fly larvae). The organic skeleton grains are arranged in a symplectic basic distribution pattern. Thin section in plain light. 190 x.

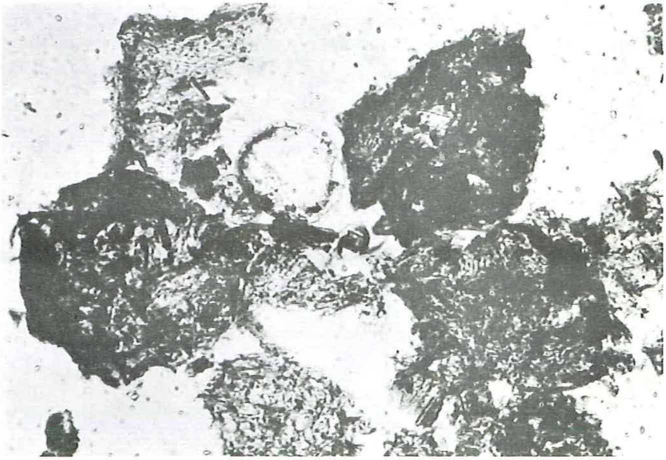
Fig. 33 Ellipsoids (modexi ellipsoidal in shape) of Phtiracaridae within a foliohist. Regarding the histon as unit of study the excrements can be described as: single, heaped, ortho, moderately fine, organic, amatric ellipsoids. Note the clearly visible organic skeleton grains (in the excrements) which occur in a densosoroskelic basic and in a granular related distribution pattern. Thin section in plain light. 82 x.

Fig. 34 Organic long cylinders of the small Isopod *Trichoniscus pusillus* Brandt. Thin section in plain light. 37 x.

Fig. 35 Mineral long bacillocylinders of the earthworm *Allolobophora chlorotica.* The form of smoothness of these modexi is "ortho surface". Thin section under crossed polarizers. 32 x.

Fig. 36 Organic clonocylinders of an Adela larva. The organic skeleton grains are arranged in a symplectic basic distribution pattern. Thin section in plain light. 57 x.

Fig. 37 Organic sperm-bacillocylinder of a Tipulid larva. The organic skeleton grains are arranged in a hyphantic basic distribution pattern, whilst the related distribution of o-skeleton grains with respect to o-plasma is granular. The form of smoothness of this modex is "meta surface" owing to the presence of a "stress neo o-skeletan". Note the (moderately fine to) moderately coarse, organic skeleton grains which are clearly visible fragments of "aggregations of tissues". Thin section in plain light. 35 x.



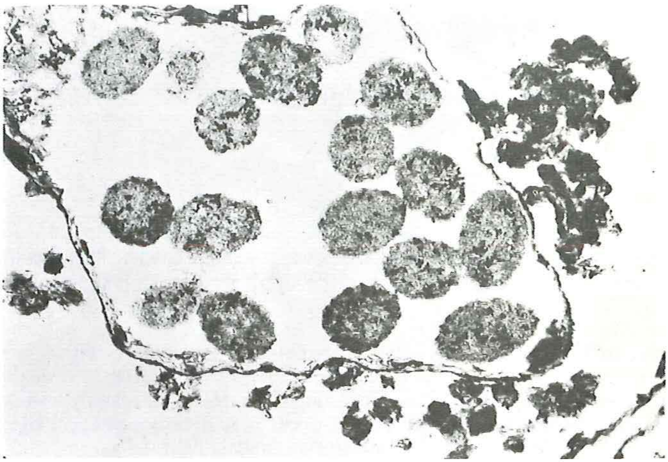
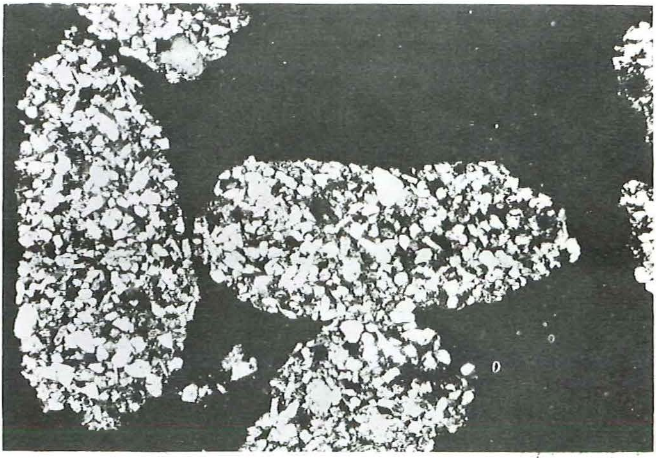
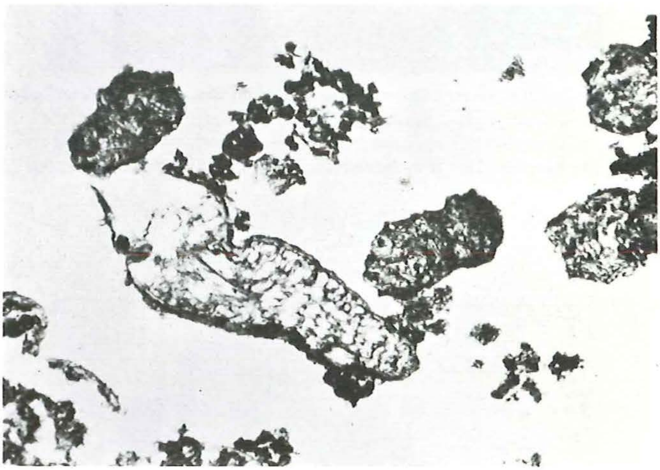


Fig. 32, 33 and 34 For the accessory captions one is referred to page 147.





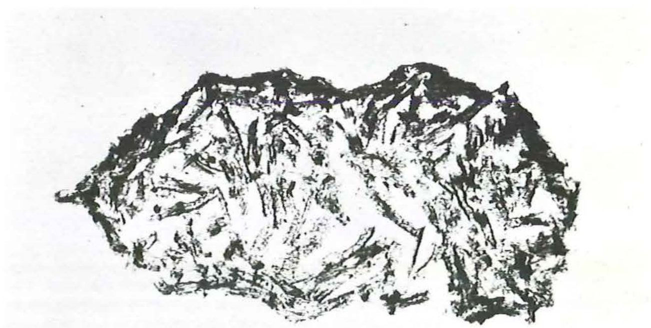


Fig. 35, 36 and 37 For the accessory captions one is referred to page 147.

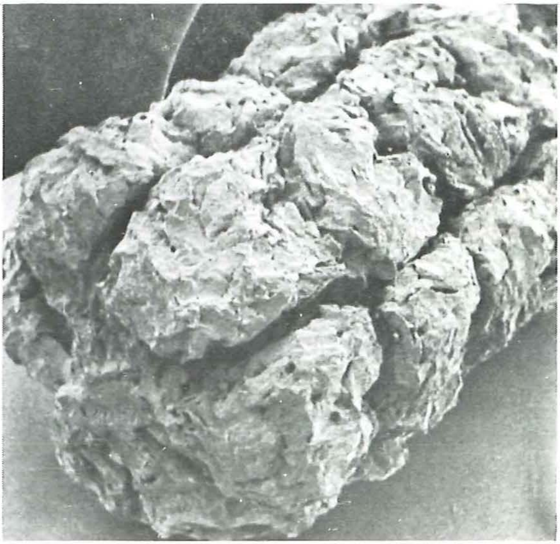


Fig. 38 Scanning electron microscope photograph of an organic, cylindrical excrement of the Lepidopteron larva *Hyloicus pinastri* L..Note the lengthwise and crosswise grooves. The excrements of this phytophague caterpillar which feeds on leaves of shrubs and trees are also part of the humon after they have left the animal and fall on the soil. 15.4 x.

Fig. 39 Aulacoplaty modex of a large Isopod. Scanning electron microscope photograph of a hand specimen. 50 x.

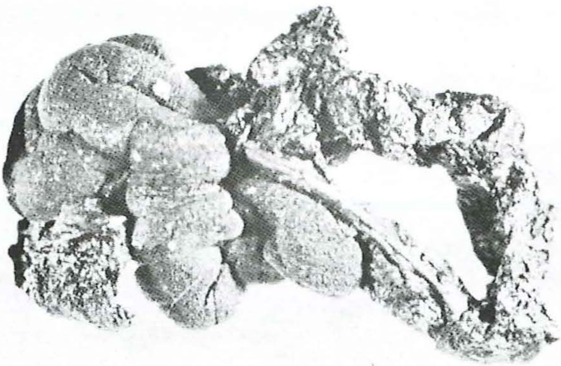


Fig. 40 Helicomitic modex of a snail. Hand specimen. (Figure from Jongerius, 1961). 6 x.

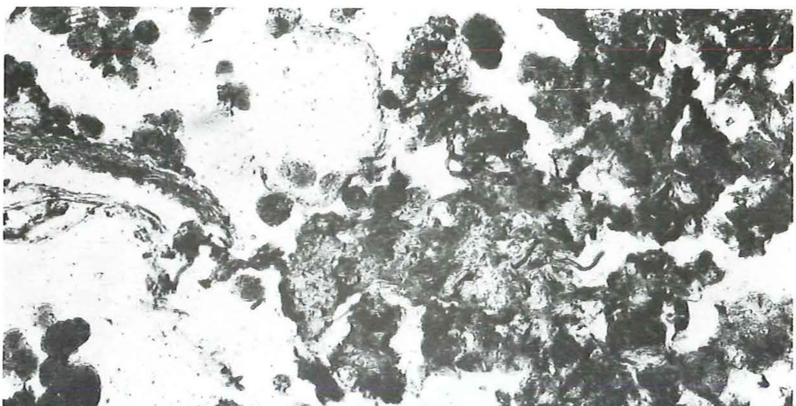


Fig. 41 Hetero-modexical related distribution pattern of ageing (organic) ellipsoids and (organic) clonocylinders. By ageing the ellipsoids become welded (left on the figure), whilst the clonocylinders lose their shape and become "strongly transformed clonocylinders" (very clearly observable in the centre of the figure). Thin section in plain light. 140 x.

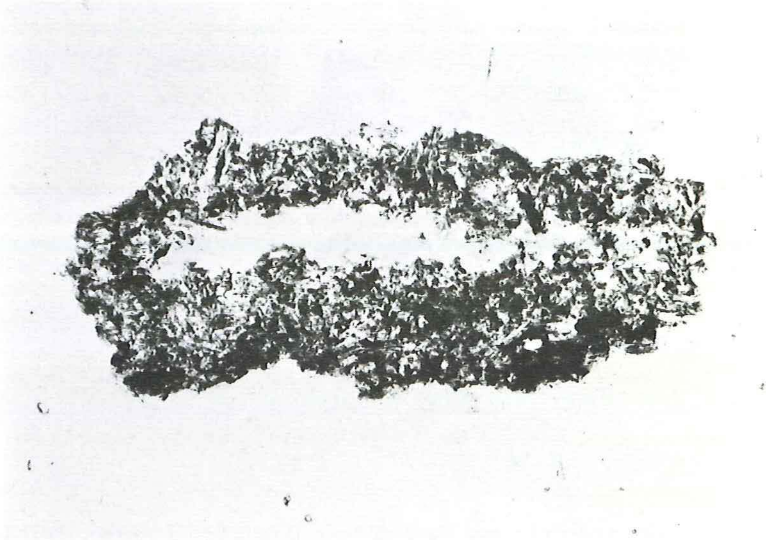


Fig. 42 Organic long bacillocylinder with a "central void" of the earthworm *Dendrobaena rubida.* The moderately fine (to moderately coarse), organic skeleton grains are arranged in a densosoroskelic basic distribution pattern. The form of smoothness of this modex is "ortho surface". Thin section in plain light. 104 x.

Fig. 43 Sporadic basic distribution pattern of fine, organic ellipsoids. Thin section in plain light. 37 x.

Fig. 44 Single, heaped basic distribution pattern of (organo-) mineral long bacillocylinders of the earthworm *Dendrobaena rubida* at the soil surface. The earthworm from which the excrements were formed is also to be seen. ± 2 x.

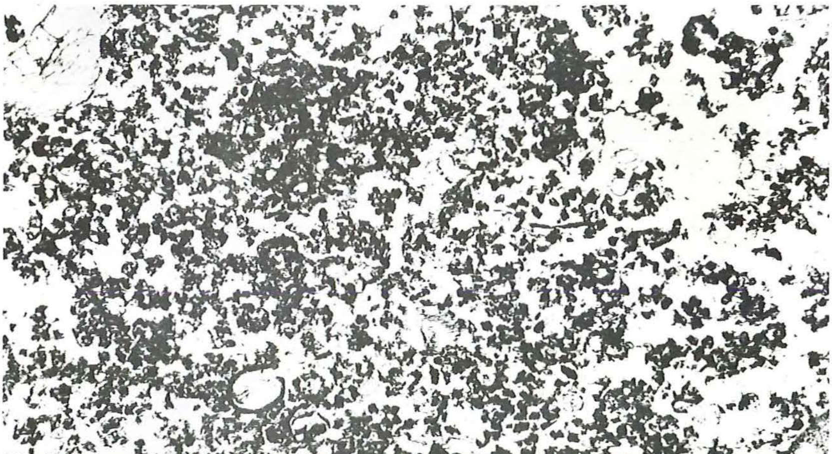


Fig. 45 Fine bacillocylinders of Enchytraeidae occurring in single, heaped (to weakly welded) basic distribution pattern. Thin section in plain light. 43 x.

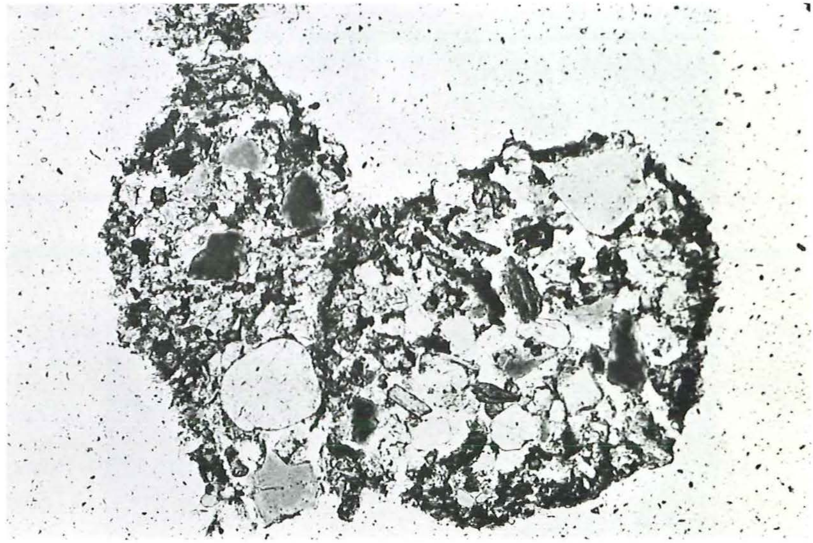


Fig. 46 Excrement neo-organan in excrements of the earthworm *Allolobophora chlorotica.* Thin section under partly crossed polarizers. 50 x.

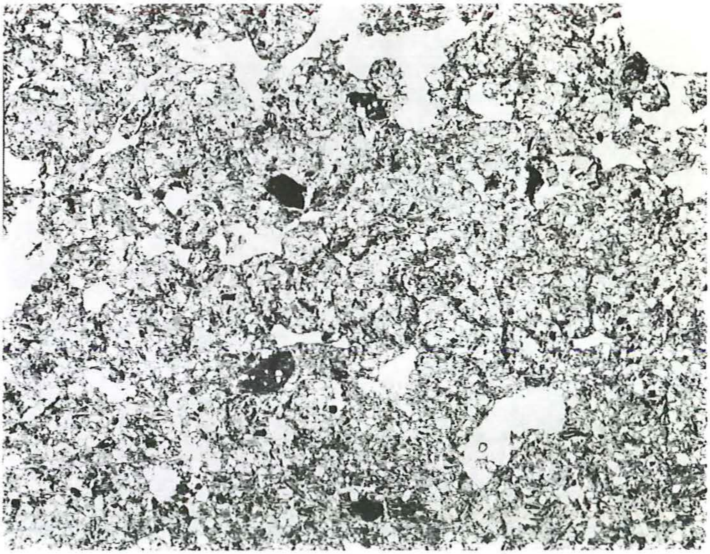


Fig. 47 a Strongly welded ortho-excrements of the earthworm *Allolobophora chlorotica.* Note that individual modexi are distinguishable only by the occurrence of neo-organans. Thin section in plain light. 6.5 x.

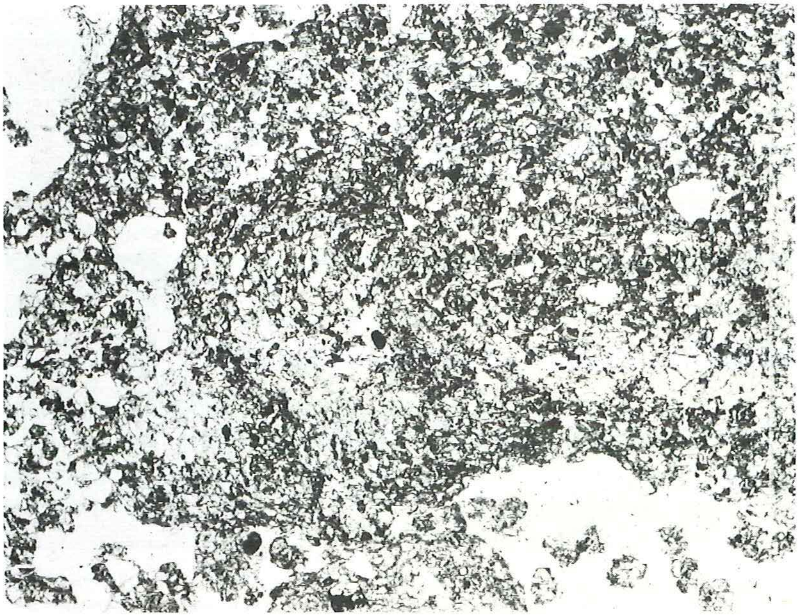


Fig. 47 b Extremely welded modexi forming "striofabric" by the presence of neo-organans occurring as dark coloured striated lines in the s-matrix. Thin section in plain light. 35 x.

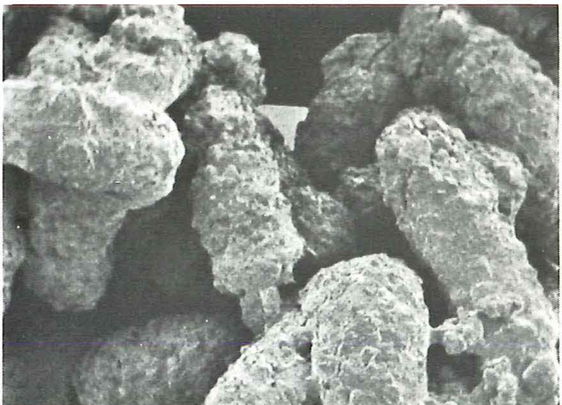


Fig. 48 Detail of an "open cluster" in which organo-mineral long bacillocylinders are weakly welded. Such clusters are often formed by earthworms on the soil surface. Electron scanning microscope photograph of a hand specimen. 15 x.

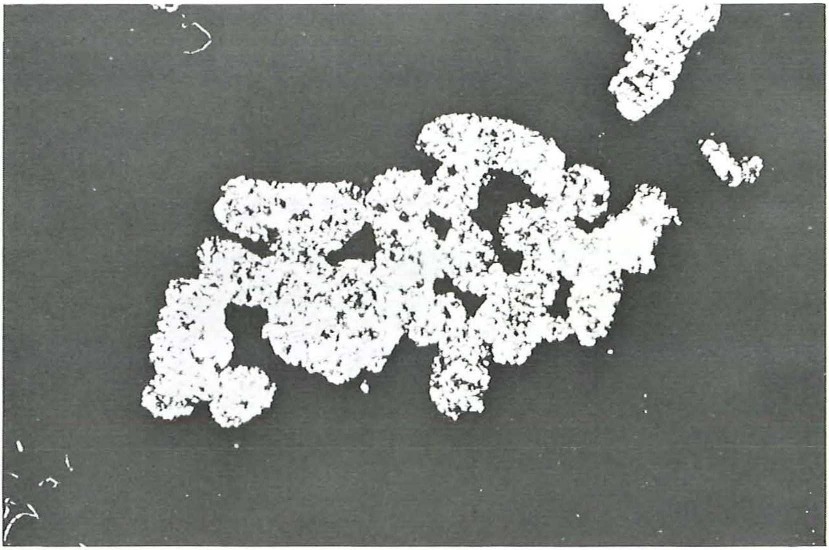


Fig. 49 "Open cluster" of weakly (to moderately) welded, mineral bacillocylinders of the earthworm *Allolobophora chlorotica.* Thin section under crossed polarizers. 9.7 x.

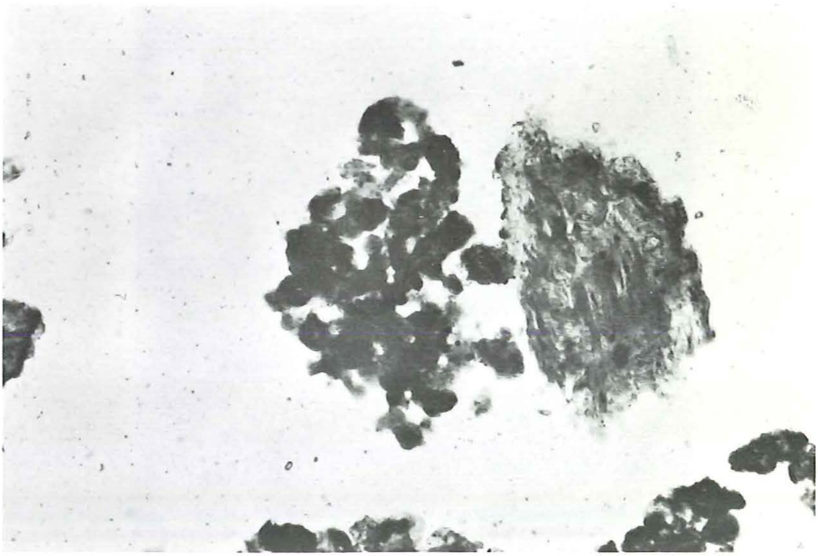


Fig. 50 "Open cluster" of moderately welded, fine, organic ellipsoids. Thin section in plain light. 144 x.

Fig. 51 "Massive clusters" of strongly welded bacillocylinders of earthworms at the soil surface. (Figure from Spectrum Dieren Encyclopedie, No. 74, Band 5, p. 1772, 1972). ± 2.5 x.

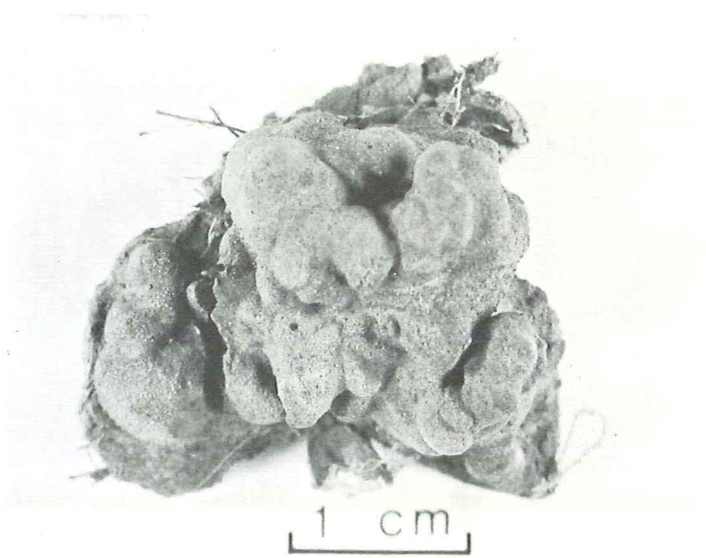


Fig. 52 "Massive cluster" (taken from the soil surface) composed of strongly to extremely welded bacillocylinders of an earthworm. Hand specimen. 2.4 x.

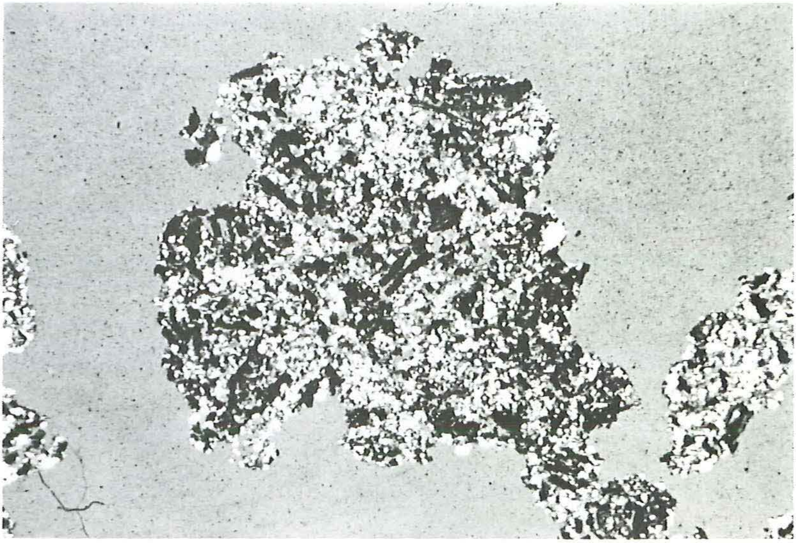


Fig. 53 "Massive cluster" of organo-mineral bacillocylinders of the earthworm *Lumbricus rubellus.* Thin section under partly crossed polarizers. 9.7 x.

Fig. 54 Tubulic basic distribution pattern of ortho, organic ellipsoids. These excrements can also be described as "modexotubules variety I" in a histon. Within the tubules the ellipsoids occur in a single, heaped basic distribution pattern. Thin section in plain light. (Figure from Van Der Drift, 1964). 31 x.

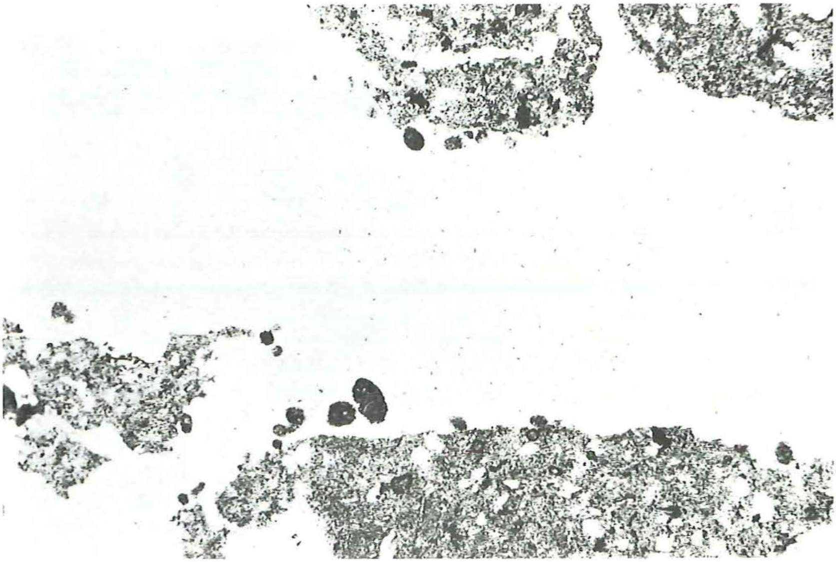


Fig. 55 Tubulic basic distribution pattern of ellipsoids adhering to the channel's wall. Within the channel these ellipsoids are arranged in a sporadic basic-, and in a cutanic referred distribution pattern. The distribution of the ellipsoids has been formed by Oribatid mites which migrate through existing channels (with a relatively large diameter) in the soil. Thin section in plain light. 40 x.

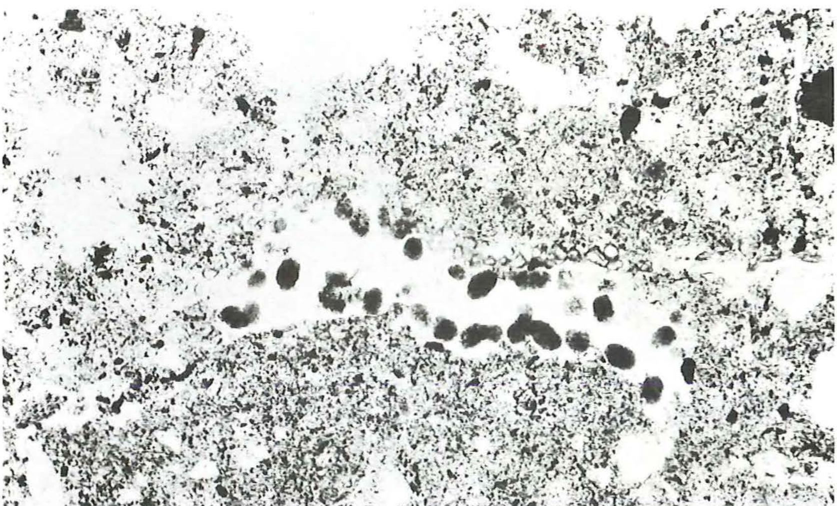


Fig. 56 Tubulic basic distribution pattern of organic ellipsoids. Within the channel the ellipsoids are arranged in a concentric basic-, and cutanic referred distribution pattern. However, the ellipsoids may also be described as present within a "modexan" (cutan composed of modexi). Thin section in plain light. 100 x.

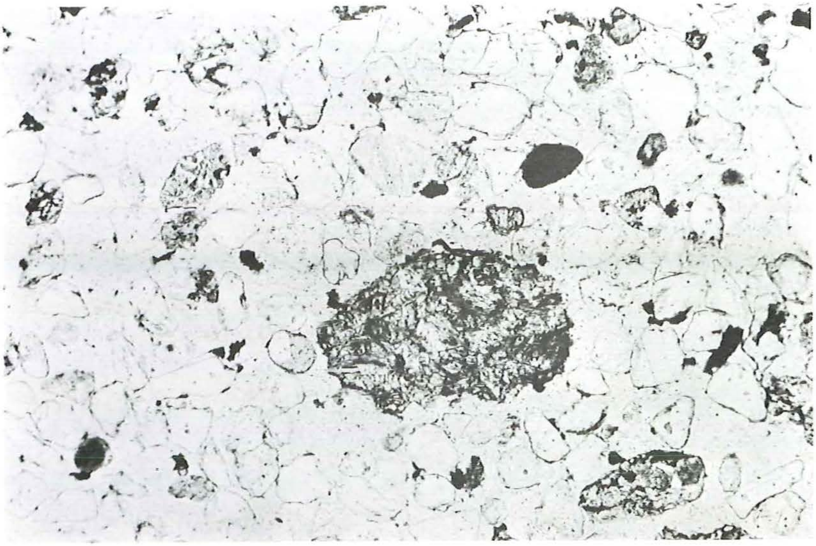


Fig. 57 Embedded, sporadic, meta, organic ellipsoid. Thin section in plain light. 38 x.

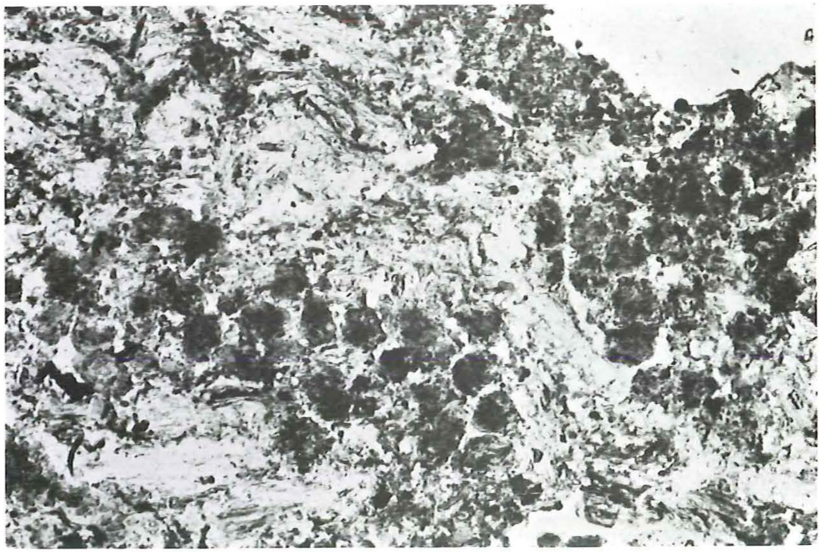


Fig. 58 Embedded, grouped, meta, organic ellipsoids. The ellipsoidal excrements of Oribatid mites are embedded in shapeless, organic excrements of the earthworm *Dendrobaena rubida.* Thin section in plain light. 158 x.

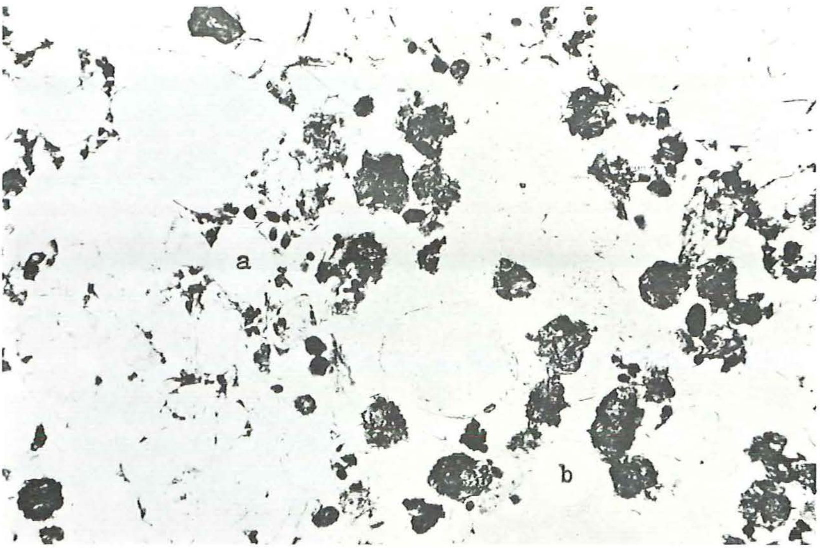


Fig. 59 Hetero-modexical related distribution pattern of two different types of ellipsoids (a and b). Thin section in plain light. 40 x.

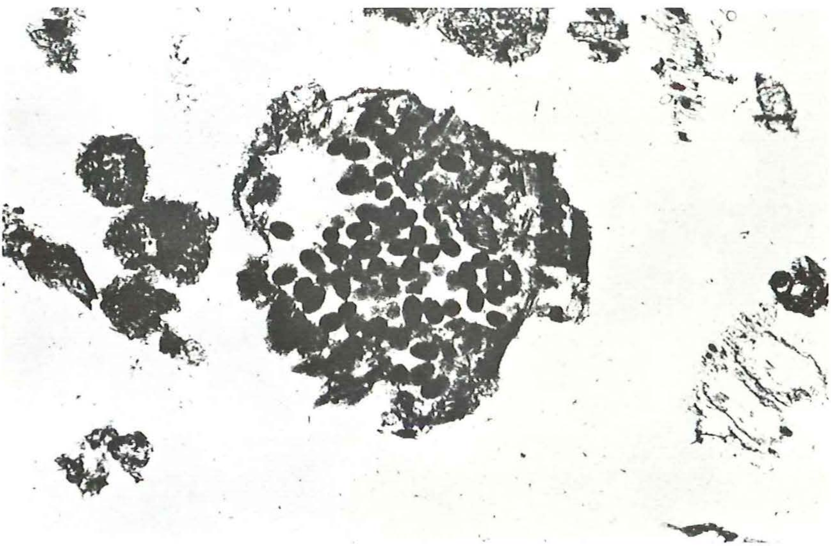


Fig. 60 Hetero-modexical related distribution pattern of two types of modexi (a large one and three smaller). Moreover, the large excrement is the "host pedological feature" for fine ellipsoids (which are the "included pedological feature"; the designations host- and included pedol. feat. after Brewer, 1964, p. 157). These fine ellipsoids have been formed by Oribatid mites which lived within and ingested the large excrement. Thin section in plain light. 44 x.

Fig. 61 Meta striotubules formed by earthworms which have defaecated in their channels. Thin section in plain light. 4.4 x.

Fig. 62 Two "modexotubules variety 3" normal to the soil surface. They consist of organo-mineral bacillocylinders and have been formed by the earthworm *Lumbricus rubellus.* The channel within the tubule continues in the soil. 0.6 x.

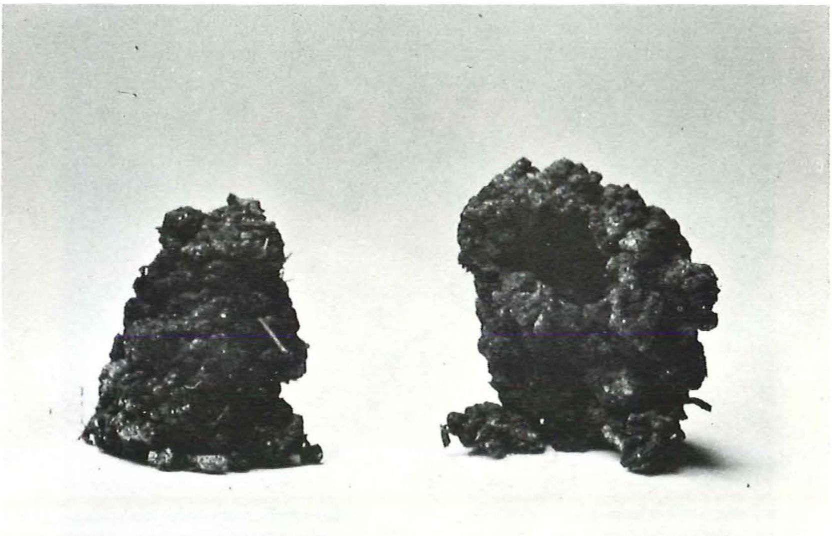


Fig. 63 The two "modexotubules var. 3" shown in Fig. 62 separated from the soil. 0.9 x.

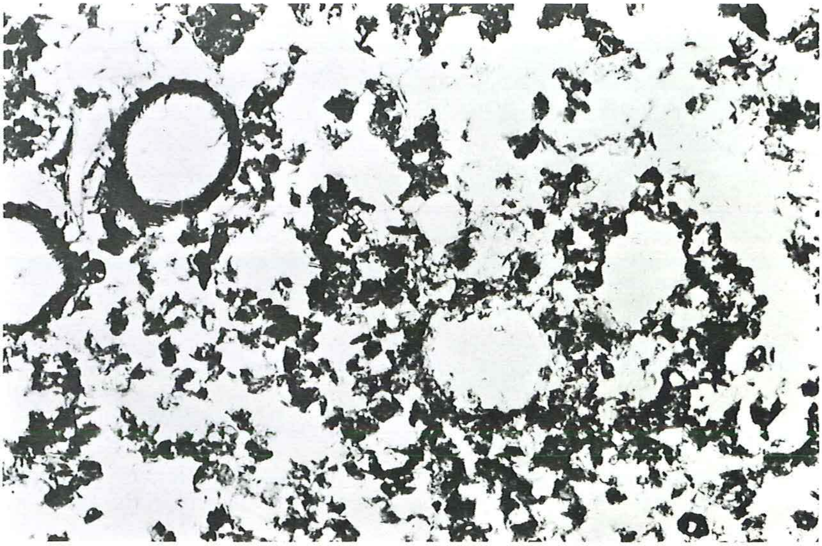


Fig. 64 On the right side of this figure (two?) "modexotubules variety 3" embedded in "single, heaped, fine bacillocylinders" of Enchytraeidae. On the left side of this figure two melanotic β-hyphons formed in small radicohists. Thin section in plain light. 98 x.

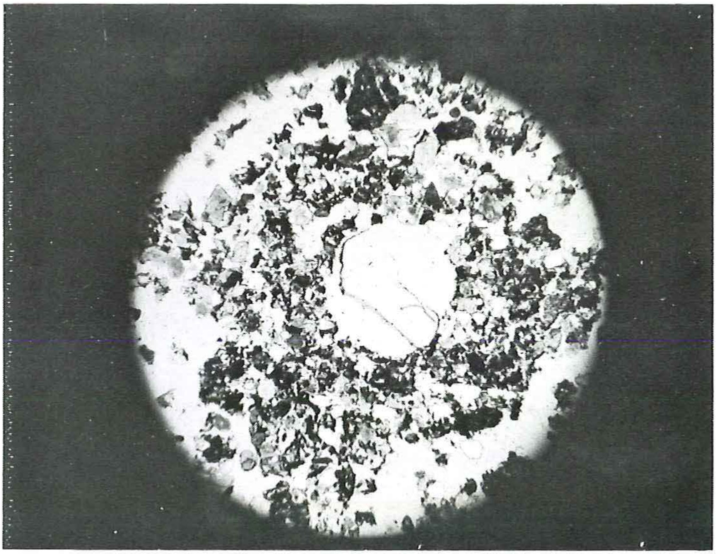


Fig. 65 "Modexotubule variety 3" composed of welded, organo-mineral bacillocylinders of an earthworm. Thin section under partly crossed polarizers. 13.7 x.

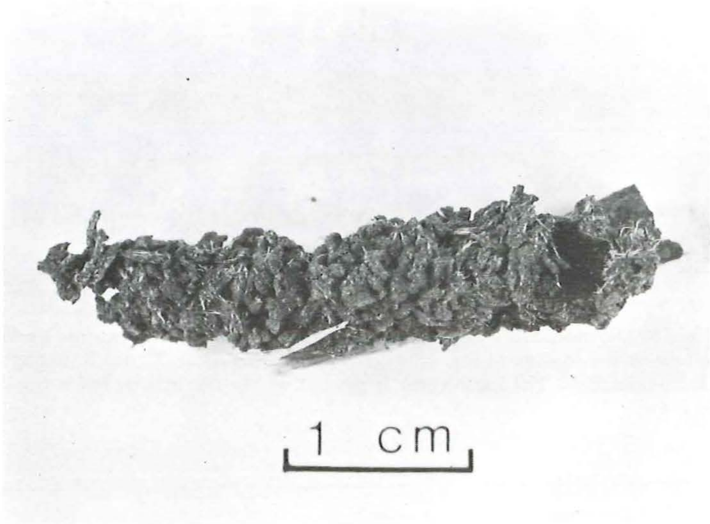


Fig. 66 "Modexotubule variety 3". The composing organic bacillocylinders of a small earthworm species are quite observable. Hand specimen. 2.5 x.

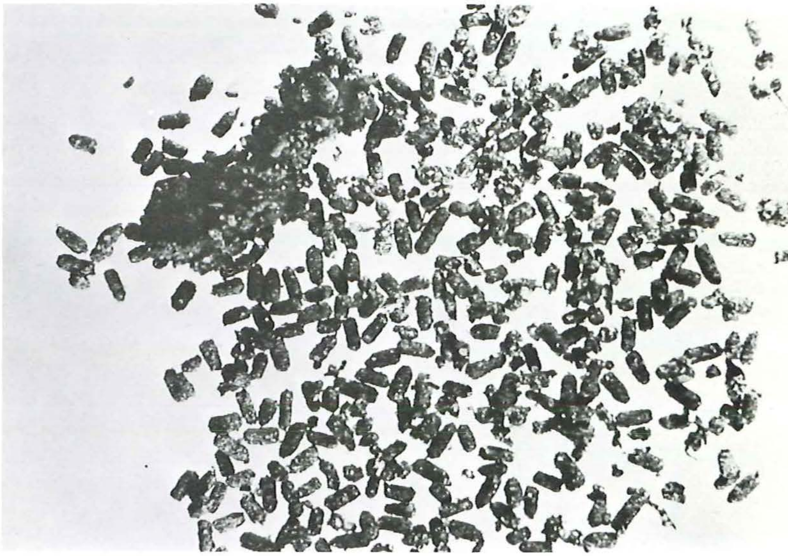


Fig. 67 and 68 Organo-mineral long bacillocylinders of the small earthworm *Dendrobaena rubida.* Left at the topside of Fig. 67 a "modexotubule variety 3" which is composed of these bacillocylinders. The earthworm is present within the tubule, but is leaving it in Fig. 68. ± 4 x.

Fig. 69 Organo-mineral excrements (bacillocylinders) of earthworms. By "ageing" the excrements will amalgamate together. After a certain period only the uneven wall of the void will betray their earlier presence. Thin section in plain light. 40 x.

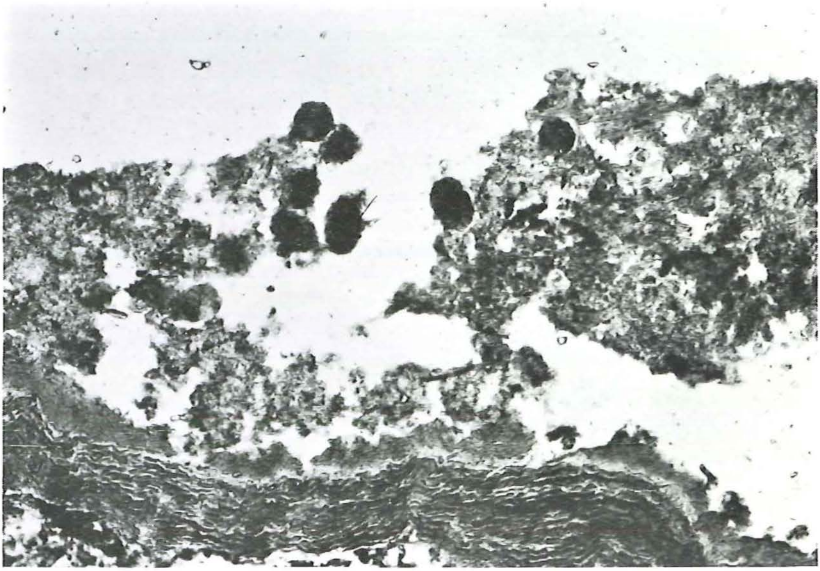


Fig. 70 "Ageing" of organic, ellipsoidal modexi. By this process the excrements have been disintegrated into their clearly visible, organic skeleton grains. At the bottomside of this figure part of a histon with a phellemic related distribution pattern. Thin section in plain light. 145 x.

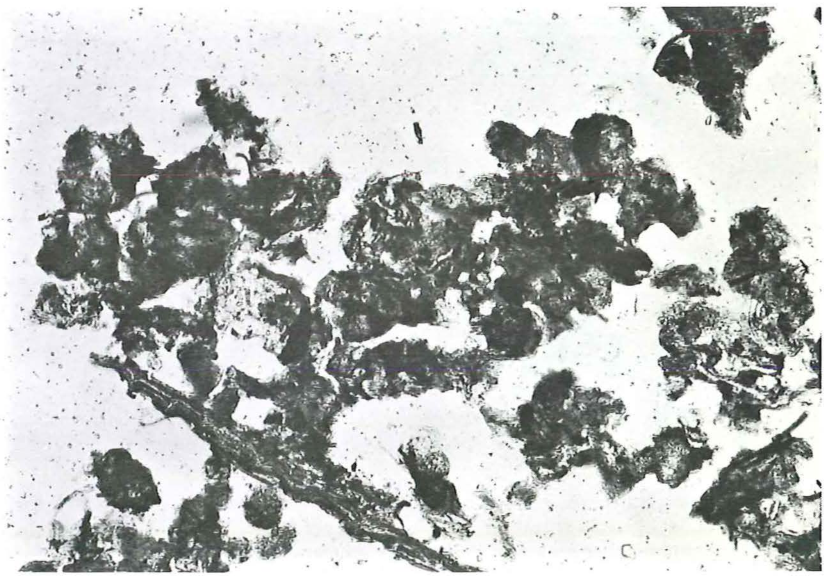


Fig. 71 Moderately to strongly transformed, organic spheres (spheroidal modexi) of small Diptera larvae. The transformation of the shape is caused by "ageing". At the final stage of this process the excrements will disintegrate. Thin section in plain light. 145 x.

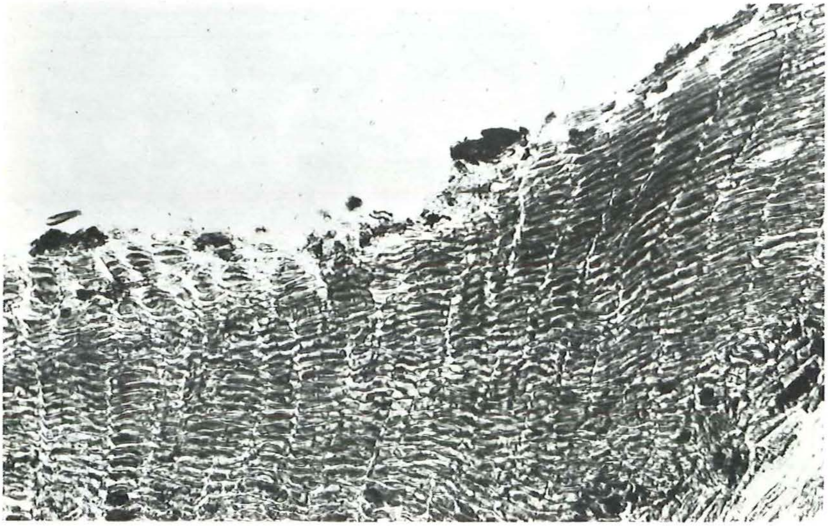


Fig. 76 "Phellemic" related distribution pattern of tissue with reference to o-plasma. This form of phellemic distribution represents an initial stage in the decomposition process. Thin section in plain light. 236 x.

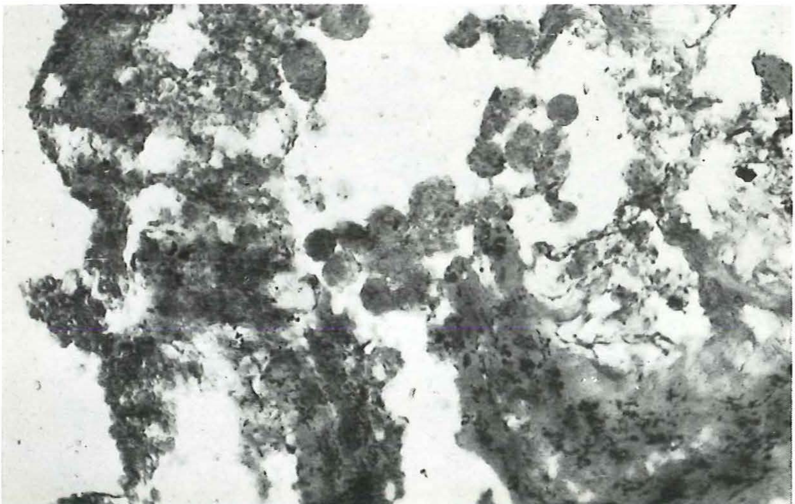


Fig. 77 Strongly damaged histon (possibly radicohist) with a pleistoplasmatic related distribution pattern. Note that this distribution pattern has been formed from phellemic related distribution pattern. Thin section in plain light. 142 x.

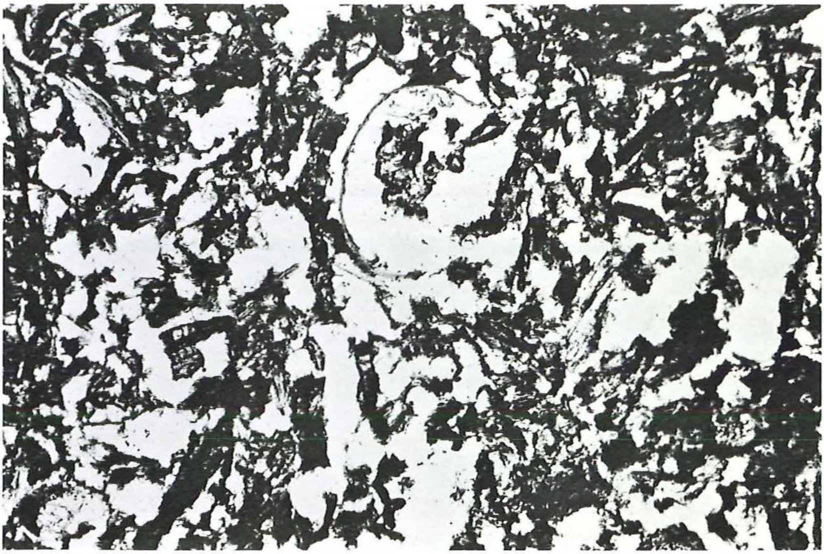


Fig. 78 Coarse, organic skeleton grains arranged in a "hyphantic" basic distribution pattern. Detail of excrement of an earthworm (possibly *Lumbricus rubellus*). Thin section in plain light. 40 x.

Fig. 79 Coarse, organic skeleton grains in a "sporadic" basic distribution pattern. Detail of an organo-mineral excrement of the earthworm *Lumbricus rubellus*. The o-skeleton grains are clearly visible fragments of "aggregations of tissues". Thin section in plain light. 38 x.

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