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A critical review of hypotheses on the origin of vermiculations

by

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INTRODUCTION

Previous authors have proposed many hypotheses to explain the processes which lead to the formation of clay and mud vermiculations. However their theories, so fundamentally different from each other, seem to be inconsistent with the substantial homogeneity of these unique speleothems.
We have tried clearify the subject by comparing the information gathered from a literature survey with the results of field observations and laboratory experiments carried out over several years. We have found that phenomena observed in many different places and circumstances by previous authors and ourselves can be summarized in a single organic theory, which is consistent with all of the available evidence.

THE MAIN CHARACTERISTICS OF VERMICULATIONS

Definition - Vermiculations are thin, irregular and discontinuous deposits of incoherent materials commonly found on the walls of caves and external surfaces and are a few centimetres in extent. This definition differs considerably from previous ones which stated that vermiculations are confined to clayey or muddy deposits and only to be found on calcareous substrata.
In comparing the opinions of previous writers with our own field observations we consider that the previous definitions were too restrictive. As will be seen below in paragraphs 2 and 4, these speleothems are widespread under a variety of different conditions.

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The occurrence of vermiculations. They are reported from very diverse environments as can be seen from Table 1.

TABLE 1 - Some examples of vermiculation in Karstic areas.

Cave	Location	Climatic conditions: Temperature	Climatic conditions: Humidity	Other conditions	Reference
Sanctuary of Frasassi	Near the very large entrance	Quite unstable	Unstable	—	Perna, 1959
Grotta Grande del Vento	Large chambers	Fairly unstable	Nearly stable	Strong seasonal airflow	Perna, 1959
Pont Niv 2206 LoVa	Narrow passages	Stable	Stable & very high	—	Perna, 1959
Zelbio 2037 LoCo	At the point where the passage suddently narrows	Stable	Unstable	Strong seasonal airflow	Bini, 1970 & Bini, 1973
Grotta Masera 2213 LoCo	Between 1st & 2nd sump	Stable	Stable	Temporary flooding	Unpublished data
Grand Aven Canjuers, France	Temporarily flooded passages	Stable	Stable	Temporary flooding	Pommier & Garnier, 1955
Grotta del Fo' di Barni 2292 LoCo	Small cave with no air flow	Fairly stable, warm	Fairly stable	—	Unpublished data
Abisso di Val Laghetto 1600 LoCo	Deep vertical cave with permanent ice formations	Stable, very cold	Fairly stable	Strong seasonal airflow	Unpublished data
Grotte di Castellana	Artificial passage from the cave to the lifts	Unstable	Unstable	Strong seasonal airflow	Anelli & Graniti, 1967
Grotte di Bossea	—	Unstable	Unstable	Strong seasonal airflow	Cigna, 1961

Cave	Location	Climatic conditions		Other conditions	Reference
		Temperature	Humidity		
Postojna Caves Yugoslavia	1. Grotta dei Nomi antichi	Unstable	Unstable	Strong seasonal airflow	Waldner, 1936
	2. Artificial gallery between the Black Chamber and Piuca Pot	Unstable	Unstable	strong seasonal airflow	de Joly, 1934
Buco della Volpe 2210 LoCo	Ubiquitous	Stable, warm	Stable	—	Unpublished data
Buco del Frate 1 LoBs	In Guano Chamber	Unstable	Unstable	—	Unpublished data
Grotta di Valcellina	Near upper entrance	Unstable	Unstable	Strong seasonal airflow	Mosetti, 1954

TABLE 2 - Vermiculations at sites other than Karstic areas

Site	Location	Climatic conditions		Other conditions	Reference
		Temperature	Humidity		
Antro delle Gallerie 2001 LoVa	Initial passage of the pre-Roman mine cut in porphyry	Stable	Stable	—	Unpublished data
Naples	Caves in volcanic tuffs	?	?	—	Parenzan, 1951
	Open air	Unstable	Unstable	—	Perna, 1959 & Unpublished data
Milan	Cellar	Stable	Stable	—	Unpublished data
Paris	Cellars of the Natural History Museum	Stable	Stable	—	Renault, 1963a

TABLE 3 - Substrata of vermiculations other than limestone

Site	Substrata	Reference
?	Concrete	Perna, 1959
Naples	Volcanic rocks	Parenzan, 1961
Zelbio	Mud	Bini, 1975
Buco della Volpe 2210 LoCo	Rubber (electric cables)	Unpublished data
Tana del Pirola 3011 LoSo	Moonmilk	Bini *et al.*, 1971
Grotta del Fò di Barni 2292 LoCo	Moonmilk	Unpublished data
Antro delle gallerie 2001 LoVa	Porphyry	Unpublished data
Tana del Pirola	Schist	Bini *et al.*, 1971
Milan	Window-panes	Unpublished data
Milan	Concrete floor	Unpublished data
Milan	Cellars	G. Cappa (personal communication)

Vermiculations have also been found, though with differing degrees of abundance and appearance, both in non-limestone caves (see Table 2) and on non-calcareous substrata (see Table 3). In our experience they can be found in nearly any cave if looked for very carefully.

The Distribution of Vermiculations

Their location is apparently random; this concept will be developed later. Vermiculations have been observed on the roofs, walls and floors of caves and on any other surfaces with them (e.g. Buco della Volpe - 2210 Lo Co. - See table 3).

Usually they do not show a close relationship to surface peculiarities such as shape, micro-fissures, rock inclusions, etc., e.g. in the Abisso di Val Laghetto 1600 LoCo cited above, we found dry vermiculations crossing fissures up to 2 mm at right angles, with no distortion. This is not the general rule since many vermiculations follow fractures and grooves, especially where such irregularities facilitate the initial formation of deposits which subsequently evolve into vermiculations.

In some cases spot-like vermiculations prevail over other forms on the roof, e.g. Hölloch, Switzerland; Tana del Pirola - 3011 Lo So (Bini *et al.*, 1971), but such a location cannot be considered to be typical.

The material forming vermiculations

Any material, not only clay and mud, can be a suitable constituent for vermiculations, provided that certain physical conditions are satisfied. Percolating heterogeneous substances such as alumina and iron oxides as suitable (Parenzan, 1961) and many other non-calcareous fillings have been detected by X-ray diffraction analysis in the Tana del Pirola cave - 3011 Lo So (Bini *et al.*, 1971). Vermiculations were found made of candle-black on the walls and roof inside the San Michele Sanctuary in the Gargano Peninsula of Italy before recent restoration (G. Cappa & T. Samoré - personal communication) and Warwick (1959) reported similar examples made from torch - black in Poole's Cavern, Buxton, England. All of these materials are fundamentally incoherent, but they agglomerate under the particular conditions prevailing in the hypogean environment.

We have received confirmation from another Italian caving group that they have found many types of organic and mineral substances composing vermiculations which they have examined. [1]

The dimensions of vermiculations

Vermiculations range in size from less than 1 mm up to 10 mm in thickness and from 1-2 mm to tens of mms in width and length so that there is quite a range to their dimensions as observed in nature.

[1] A preliminary study was published while this work was coming under revision: BERTOLANI, M., ROSSI, A., GARUTI, G., 1977: The speleologic complex «Grotta Grande del Vento - Grotta del Fiume» in the Frasassi canyon (Ancona, Italy). *Act. VI Congr. Internat. Spéléol. Olomouc 1973*, T. 1:357-366.

The morphology of vermiculations

An interesting morphological classification has been published by Parenzan (1961) and illustrated in Fig. 1:

Maculazioni argillo-limose (Silty clay, spot-like vermiculations)	1. **Macule puntiformi** (pimple-like spots)
	2. **Macule plachiformi** (plate-like spots)
	3. **Macule bollose** (bubble-like spots)
	4. **Macule irregolari, elissoidiche o allungate** (irregular, ellipsoidal or elongated spots)
Vermicolazioni argillo-limose	5. **Vermicolazioni grosse - «Pelli di leopardo»** (Large vermiculations - «Leopard's spots)
	6. **Vermicolazioni lineari, allungate semplici** o anastomosizzate - «Pelle di tigre» (Linear, elongated, single or anastomising vermiculations - «tiger-skin»)
	7. **Vermicolazioni a geroglifici** (Hieroglyphic vermiculations)
	8. **Vermicolazioni dentritiche** (Dentritic vermiculations)

This classification, which is merely descriptive, is integrated with observations on the «halo» (Warwick, 1959); many vermiculations are surrounded by a clear «halo» whose extension ranges from a few mm to about a centimetre (Fig. 3). This «halo» is usually visible and is only absent in a few cases; therefore the morphological description is conveniently combined with the specification «with halo» or «without halo». The implications of the different shapes of vermiculations and haloes on genetical and evolutionary processes are discussed below.

Active and fossil vermiculations

Not all of the vermiculations are still growing. Many of them are quite dry or even fossilized; this is the case of those which are covered by a calcite layer (Parenzan, 1963; Anelli & Graniti, 1967; Samoré, 1972; Bini, 1975). They can also develop in some periods of the year and completely stop at other times. The modifications induced by speleological activities on air flow and humidity

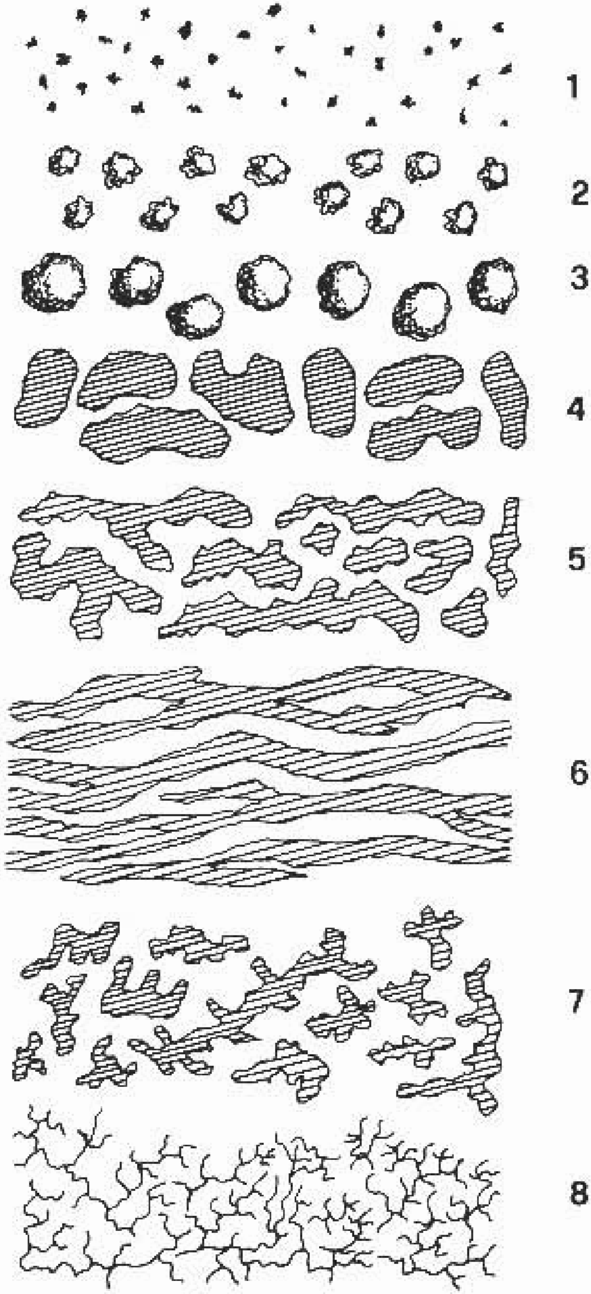

FIG. 1 - Morphology of the vermiculations (after Parenzan), the numbers refer to the classification used in the text.

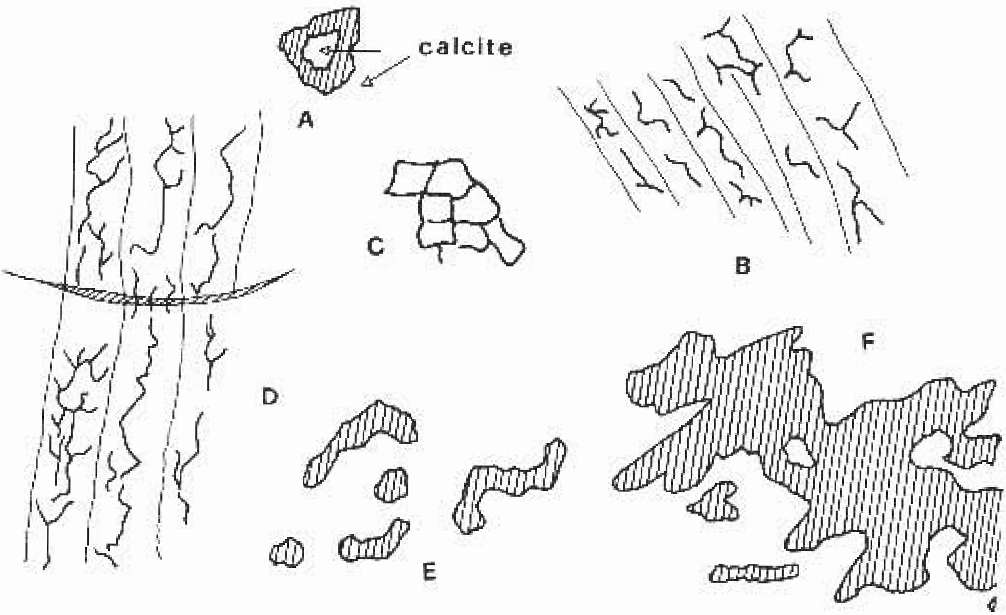

FIG. 2 - Shapes of the vermiculations in the Grotta Zelbio (after Bini):
A. Fossil spot-like vermiculations made by patches of calcite an their haloes.
B. Type II vermiculations over grooves.
C. Type II, reticular vermiculations over microfractures.
D. Type II vermiculations over grooves.
E.-F. Type I vermiculations.

can also cause substantial changes in their growth, e.g. Grotta Zelbio, 2037 Lo Co (Bini, 1970).

THE GENESIS OF VERMICULATIONS: SOME CONSIDERATIONS CONCERNING THE MAIN THEORIES

Many authors have attempted to explain the origin of vermiculations; the main theories proposed in the literature are:

fossil fillings
chemico-genetical deposition
biological formation
mechanical deposition from moving water or air
clay-layer drying processes (Montoriol Pous hypothesis)

FIG. 3 - Type II vermiculations near the first narrow passage in Grotta Zelbio - 2037 Lo Co. The coin is 25 mm in diameter (Photo T. Samorè).

Owing to the great heterogeneity in the appearance of vermiculations, these theories were developed in quite different directions.

Renault (1959) has suggested that vermiculations could develop from the remains of **former fossil infillings**, but this hypothesis cannot be confirmed by either the observations of other authors or by the latest observations of the present writers. It is not possible, for instance, to explain in this way the vermiculations found in the caves cut in volcanic tuffs in Naples (Parenzan, 1961) which have never been filled up after their original excavation several centuries ago; or in the case of those formed in the electric cables recently laid in the cave Buco della Volpe - 2210 Lo CO (Fig. 4).

The **chemico-genetical hypothesis** has been supported by many authors: the most recent views aiming at confinig it, as we shall see later, to the role of feeding the substances which are involved in some of the growth processes of vermiculations.

It has been suggested that vermiculations are generated by decalcification of the rock wall *in situ* (Renault, 1953), by percolating water, but this hypothesis

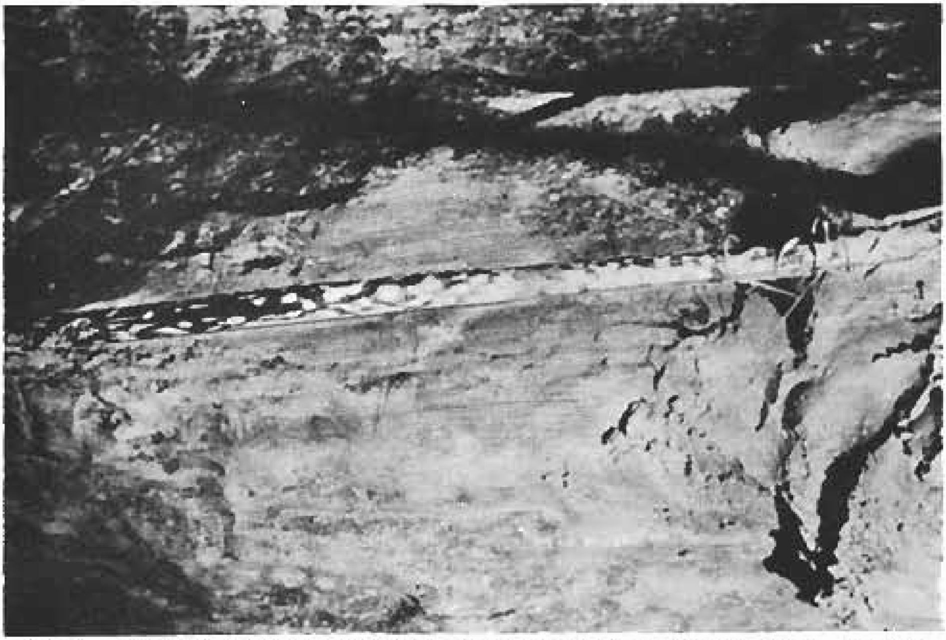

FIG. 4 - Type II vermiculations growing over an electric cable in Buco della Volpe - 2210 Lo CO (Photo. G. Cappa)

has neither been supported by the observations of Parenzan (1961), nor by the author's observations (vermiculations on non-calcareous substrata), nor by Choppy (1955 - vermiculations over concretions), nor by Perna (1959).

The corrosion due to condensation of droplets (Renault, 1959), while certainly existing (Andrieux, 1970) is not likely to be very effective in most cases.

Some authors have correlated vermiculations with the presence of sulphurated water (Marchetti, 1950) or sulphur dioxide (Mosetti, 1954) produced by guano deposits: but these situations are relatively rare. Elsewhere identical formations can be observed where these special conditions do not occur (Perna, 1959). Therefore this relationship is also likely to be applicable only in a limited number of special locations.

The **biological process**, proposed by Anelli and Graniti (1967) following some observations made in the Castellana Caves, Bari, is based on the assumption that micro-organisms, particularly *Mucor racemosus* Fres. a fungus, can develop selectively on cave walls. In this way they are thought to promote the aggregation of organic and mineral particles, while the «halo» represents the area where acids and other substances secreted by them, inhibit the growth of surrounding colonies. Since this hypothesis does not fit all types of vermiculations and since we noted that the authors had not carried out any biological control on the shapeless clay deposits of their caves it was important to test this factor.

For this purpose we carried out the following experiment in the Grotta Zelbio Cave - 2037 Lo Co. Five stations were chosen in the first 70 m of the cave where the passages are characterised by a strong seasonal air flow and where several groups of vermiculations had been noticed (Bini, 1970 & 1975). We took samples, using sterile swabs from the vermiculations, from the adjacent shapeless clay deposits and from the clay of the floor, polluted by human transit. These samples were transferred into Petrie dishes containing glucose-peptone agar and incubated in a cave-like environment (temperature c.15°C, without light).

In all three series of samples the same bacterial colonies were found and no fungus species except in those taken from the polluted floor, in which mycelia developed together with the same bacterial colonies as were found in the other two sample groups. We have concluded that no substantial difference can be found, from the biological point of view, between the vermiculation material and the shapeless clay. The results found by Anelli and Graniti should be ascribed to the high degree of pollution of Castellana Caves which have been open as show caves for many years.

Based upon the above evidence, the authors consider that the concept of the selective influence of the growth of colonies of mycelia or bacteria should be discarded. However, it is possible that such mycelia developing over vermiculations (Parenzan, 1961) may have some stabilising effect upon these surficial accumulations.

The **hypothesis invoking the transport of material by moving water or air** (Pommier & Garnier, 1955; Parenzan, 1961) is certainly a valid explanation of the source and collection of materials but provides no contribution to the interpretation of the peculiar processes of their aggregation in the form of vermiculations. Pommier & Garnier (1955) ascribed the genesis of vermiculations to the deposition of clay when cave passages were temporarily flooded, but as we have already noticed many of these deposits have never been flooded. Such formation can take place only when the water-level at the end of the flood period drops quickly as demonstrated in the laboratory by Renault (1963b) and not during the rising stage at the beginning of the flood, as was pointed out by the authors mentioned. However, a quick fall in the water-level is quite unusual inside caves. Normally the water surface lowers slowly and the influence of surface tension would prevent the clay from depositing in vermiculations, instead it would form a continuous layer. This subject will be examined again below because any deposition of this kind should be considered as a particular case of the processes that will be treated in one of the following sections.

Renault (1959) introducing the concept of **air-flow deposition** noticed that aeolian deposition requires a climate drier than that normally experienced in temperate latitudes. This is certainly true in the case of thick loess deposits, but there is no reason to consider it essential where very small quantities of material are concerned. In any climate, winds will carry a certain amount of organic and mineral particles, though the quantity could change as a function of humidity and other physical factors. Those cavers who wear spectacles know this from direct experience, since even gentle air flow in caves is able to carry a certain amount of dust which adheres to lenses under humid conditions. Cigna (1961) has calculated the amount of dust involved from a mathematical point of view.

According to our observations in Grotta Zelbio - 2037 Lo Co and Pont Niv -2206 Lo Va, vermiculations have often been found associated with sudden variations in cross-section. At such points a highly localized change in condensation or evaporation (according to the season) occurs and interacts with the local clay and with the dust deposited by vortices in the air flow. Air-flow deposition is likely to take place even at the present time, nevertheless it could not be considered as a genetical process by itself because it is liable to produce deposits of any kind. Also in this case peculiar physico-chemical conditions are required to concentrate the deposited materials to form vermiculations.

We should like to mention another hypothesis, which Professor A. Boegli formulated to us verbally, regarding the Hölloch vermiculations. He considers that these vermiculations are due to the **deposition of small particles at the periphery of dried-out condensation droplets**; where these are plentiful, they might form a lattice of deposits. This hypothesis puzzles us since, as we shall see later, the particles suspended within the droplets usually precipitate at the centre of each drop (Andrieux, 1970) and not around it.

The **theory of Montoriol-Pous** (1962) is worthy of particular attention, it is based on the studies he carried out in Cueva del Requerillo in Spain. Summarising the main points of this author's hypothesis, the vermiculations develop through three different stages (Fig. 5):

Stage I - i.e. «negative vermiculations». The rock surface is covered with a continuous layer of colloidal clay which retains a certain amount of water. When evaporation occurs, the volume begins to decrease, producing a lattice of dessication craks.

Stage II - i.e. «leopard's spots». If evaporation continues, the layer of clay shrinks still further and the bare rock surface just about equals the area covered by the clay.

Stege III - i.e. «clay vermiculations». The area covered by the clay layer continues to decrease and is restricted to thin vermiculations, and their water-content is very small, approaching zero.

If the surface covered by clay is called SA *(superficies arcillosas* of Montoriol-Pous) and the bare rock surface SD *(superficies desnuda)* the follo-

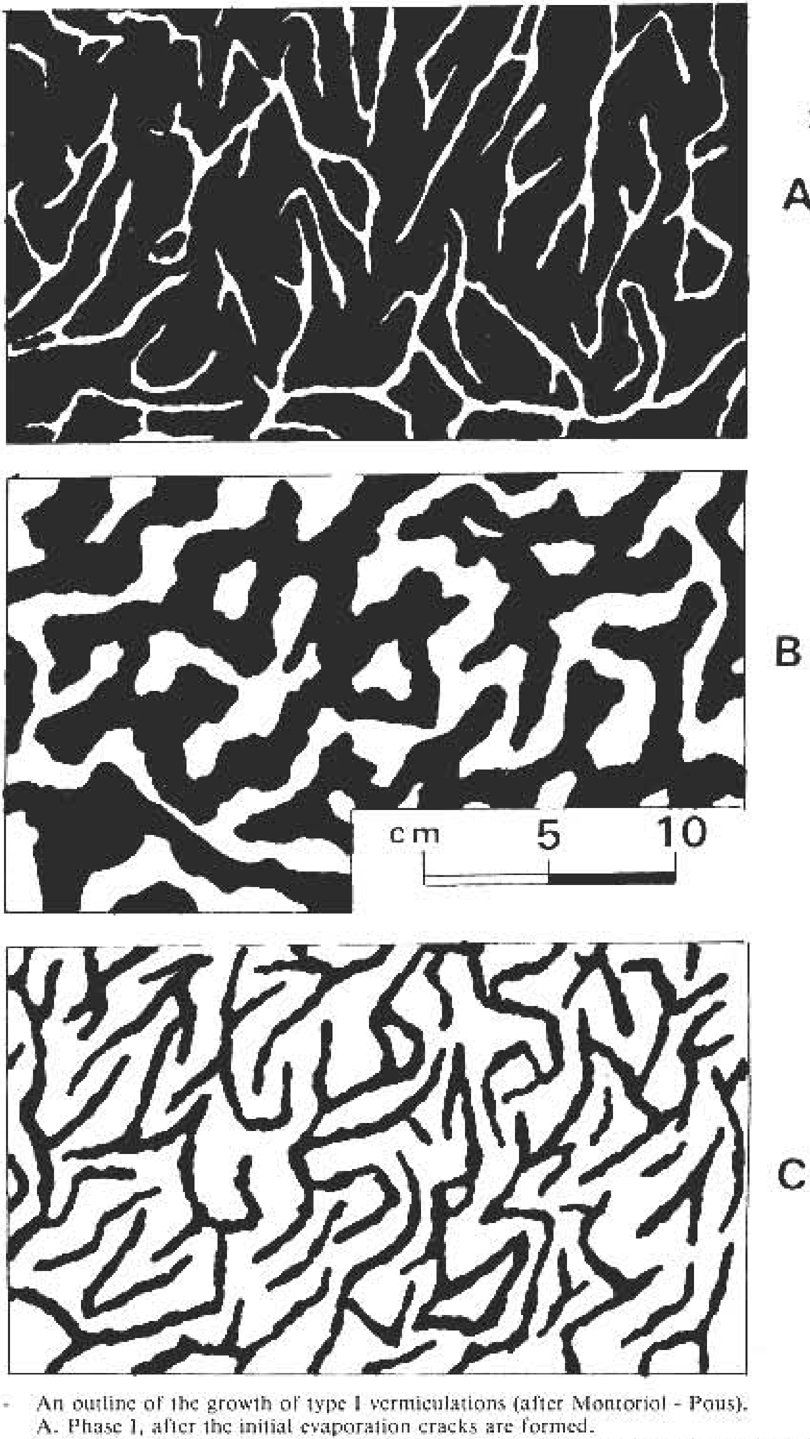

FIG. 5 - An outline of the growth of type I vermiculations (after Montoriol - Pous).
A. Phase I, after the initial evaporation cracks are formed.
B. Phase II, the drying has continued, the clay contracts and some pieces fall to the floor (leopard's spots).
C. Phase III, after evaporation is completed, clay vermiculations have formed.

wing ralationship can be established:

Negative vermiculations ——▷ Leopard's spots ——▷ Clay vermiculations
or $SA/SD > 1$ ——▷ $SA/SD \simeq 1$ ——▷ $SA/SD < 1$
——▷ (H_2O content is decreasing) ——▷

In fact the process is a particular case of a more general one, i.e. the drying out of any surface covered by a clay layer. Both inside and outside of caves, the evaporation of water causes the latter to crack (Stage I); the type of any further evolution depending upon the rate of evaporation and on the type of cray. If the drying out is fast, it leads to the formation of single cracks of polygonal soil or mud cracks. If the process develops on the roof it causes the clay to fall down in small, thin sheets. If on the other hand evaporation is slow, it may produce vermiculations (Stage II and III) (see also Renault, 1963a).
These later stages are only produced under these conditions if the clay, or other vermiculation components possess special physico-chemical or mineralogical properties such as considerable volume changes associated with the content of hydration water. Cracking leads to the formation of vermiculations if the material is incoherent, is joined to the substratum only by the surface-tension forces of a liquid film and the material lacks liquid, making it fragile and reducing it to a powder.

The Montoriol-Pous hypothesis provides no solution to the problem concerning the formation of the clearer «halo» which surrounds many, but not all, vermiculations. Nor does it explain all types of vermiculation because it assumes that before they can exist, a more-or-less thick, but continuous layer of clay must form. However this condition seems to be impossible to fulfil in many cases, e.g. over electric cables (2210 Lo Co) or in mines (2001 Lo Va; Bus del Diavul - 2203 Lo Va, etc.).

A UNITARY THEORY OF VERMICULATION GENESIS

On the basis of this general review of all hypotheses advanced to date, we shall try to produce a unitary theory capable of explaining any of the processes observed.

The materials forming vermiculations are of diverse origins, e.g. the remains from limestone decalcification, the corrosion of other, superimposed formations (chemico-genetical hypothesis), the transportation by percolating water of pre-existing deposits or the deposition by air or water flow of the waste-products of human pollution. Summarising, any fine-grained material can be a component of vermiculations.

All of these materials were initially suspended within water films adhering to the walls, roof, floor, debris or other objects. The water is derived from percolation, condensation and occasionally by flooding. Water films may be permanent or temporary, different clay deposits arising in each case.

If both water and clay (or any equivalent substance) are present in considerable quantities, a shapeless mudflow, completely saturated with water will be produced (Case I): it will be thick and coherent, because its constituents can be very sticky.

On the other hand, where the volume of water is high compared with the clay or silt content then a suspension will be produced (Case II) with almost the properties of a colloid. Such a suspension may be produced by the deposition of calcium ions upon a particle surface in a calcareous environment (Renault, 1963a), or as a consequence of surface electrical phenomena (Thompson effect, Gibbs law - Andrieux, 1970), or on account of the properties of the materials composing the suspension (Al_2O_3, $Fe_2O_3 .nH_2O$), colloidal silica (Bini *et al.*, 1971). A colloidal suspension is similary produced when water is concentrated in droplets, other conditions being the same as in the second case.

In the first case vermiculations cannot arise, at least until evaporation takes place, starting the Montoriol-Pous «negative vermiculations» process. We suggest that this process, besides the conditions outlined by Montoriol-Pous, involves a decrease in water-content and a simultaneous increase in electric charges which will accelerate the aggregation of the particles. It can be observed that these vermiculations are solid, homogeneous and never finely dendritic and are usually lacking a «halo».

In the second case agglomerates form with a tendency to increase in both height and area. This is mainly due to evaporation but deposition is also affected by other factors such as temperature, pH etc. (Renault, 1963a, b). The final result will be the formation of thin, branched vermiculations with a granular rather than a compact surface; in addition they will usually be surrounded by a clear «halo». (Fig. 3). Any groove or fracture which affects the substratum can obviously accelerate or guide this process.

The relationship between evaporation, electric charges, surface tension, water droplet and water film are complex, for further details we refer the reader to the studies by Andrieux (1970) which contain a clear exposition of the whole problem.

A high evaporation rate has been observed where the air flow is considerable and consequently one may expect to find a concentration of type II vermiculations at the entrances of caves (particularly of those which are at the warmer end of an air-flow system), on the walls adjacent to locally strong flows, or where the cross-section of the passages suddenly change their dimensions. On the contrary, type I («negative») vermiculations are normally found far from the entrances. These principles are confirmed by our own observations which indicate that a great many of the dendritic (type II) vermiculations referred to by different authors, have been found near the warmer end of air-flow systems. As a particular case, we studied the distribution and peculiar characteristics of the two types in Grotta Zelbio - 2037 Lo Co (Bini, 1975) (Fig. 2).

As already mentioned, the same phenomena occur in the case of condensation droplets. The «halo» which surrounds both spot-like and dendritic vermiculations is mainly due to evaporation and the neutralisation of the electric charges on colloidal particles (Andrieux, 1970).
Andrieux noticed that droplets grow and develop surrounded by a small water «collar» which is irregular in plan, due to local variations in the surface of the substratum (Fig. 6). Within each droplet a suspension is generated which is electrically charged and consequently able to reduce the surface tension of the drop itself. If evaporation occurs, the suspended solid materials aggregate at the centre of the drop, leaving a «halo» which corresponds to the «collar» surrounding the primary droplet.

In the case of dendritic vermiculations composed of coarse materials, the process is similar. When the agglomerates grow within the film of water covering the substratum, they join up with each other and precipitate out. Under these conditions as we have already seen, each particle retains a thin film of the water surrounding it which evaporates slower than the general water body. These

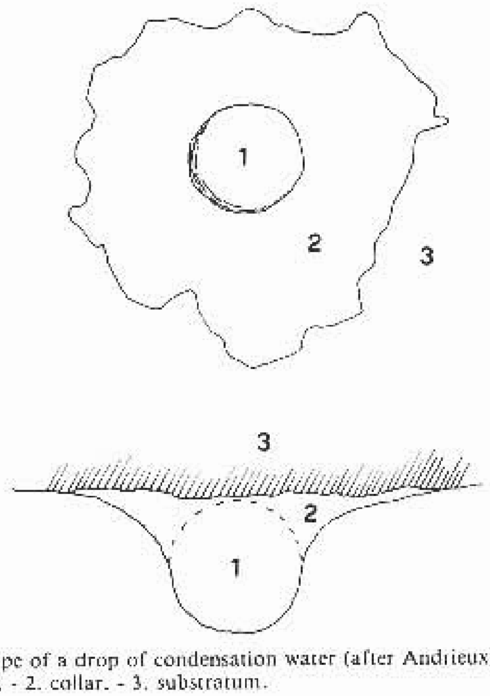

FIG. 6 - The shape of a drop of condensation water (after Andrieux).
1. drop. - 2. collar. - 3. substratum.

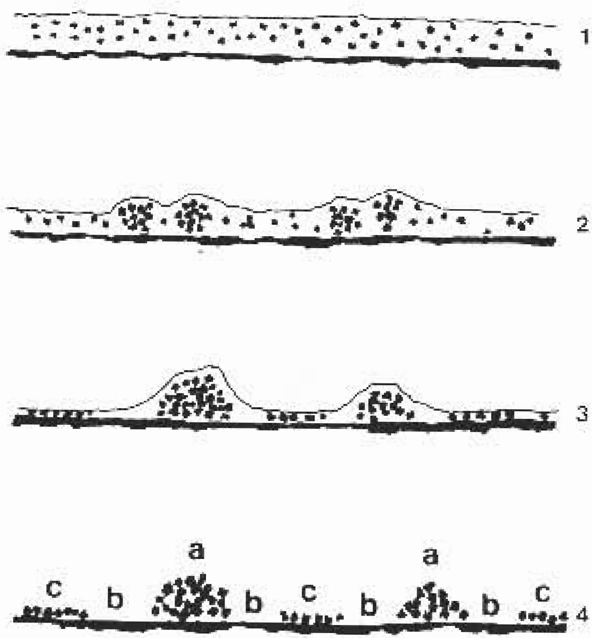

FIG. 7 - An outline of the growth of a type II vermiculation
1. - a water-film with suspended colloidal particles.
2. - the same, after it has dried and the particles have begun to join up.
3. - the aggregates precipitate together and halo has formed.
4. - after drying has continued a. - vermiculation. b. - halo, c - intervermicular clay.

«local» films are linked to the substratum by a «collar» of water whose dimensions vary as a function of the dimensions of the agglomerate. Again this «collar» forms the «halo» when the water film evaporates completely and/or the suspension is concentrated (Fig. 7). It must be pointed out that after the first drying the process may be repeated indefinitely; the new material will precipitate preferentially over the old vermiculate and will increase its size.

A peculiar kind of vermiculation has been observed and described in the Tana del Pirola - 3011 Lo So cave (Bini *et al.*, 1971). It is considered to be a particular case of type II vermiculations and deserved a detailed description. The cave in which it is found is developed in a small lens of saccharoidal limestone surrounded by schists. The inner side-passages are cut in limestone which forms the floor and the lower half of the walls, while the upper parts of the walls and the roof are composed of schist. Spot-like vermiculations lie on the roof and the upper parts of the walls (Fig. 8). They are very thick, reddish-coloured and gelatinous and lack «haloes». They were examined chemically in

FIG. 8 - Type II vermiculations in Tana del Pirola - 3011 Lo Co. Spot-like forms on the schist of the roof. The telephone counter in the centre-bottom of the photograph is 25 mm in diameter. (Photo. A. Bini).

the laboratory and the main constituents were found to be alumina and silica while calcium and magnesium oxides were found in small quantities. Using X-ray diffraction analysis, the following minerals were identified: amphibole, antigorite, calcite, epidote and quartz. The quartz was mainly present in the colloidal state.

On the basis of the field and laboratory observations, the following process has been suggested for the origin of these peculiar vermiculations.
Water, percolating along the fissures of the overlying schists, brings in many different minerals which precipitate as a gel, retaining considerable quantities of water, owing to environmental changes on entering the cave. The deposit grows as spot-like vermiculations of a semi-liquid nature which soon thicken, becoming too heavy and consequently fall on to the floor in one piece. In this manner the floor also becomes covered with the same kind of vermiculations.

This suggested mechanism is likely to be associated with the same colloidal processes as in type II vermiculations. However, these forms are morphologically rather different owing to the peculiar characteristics of the materials carried down by water percolating through non-calcareous formations.

FIG. 9 - Type I vermiculations in Buco del Frate - 1 Lo Bs. (Photo. G. Cappa).

CONCLUSIONS

The proposed mechanisms of vermiculation growth are considered to explain in a satisfactory manner the development of any type of spot-like or dendritic vermiculations. The different shapes assumed by these features appear to be only the consequence of climatic or environmental conditions.

The fundamental structure of vermiculations is very simple and depends on few physical and chemical parameters. Any other explanation referring to some particular formation, including those cited in the literature, can be easily brought within the proposed mechanism by means of a scientific and critical analysis. It should be remembered that one of the aims of science and scientists is to formulate general laws to which one may refer particular observations. On this basis we propose the following table summarising the morphogenetical processes of vermiculation formation:

FIG. 10 - Type I vermiculations in Grotta di Frasassi (Marche). (Photo. G. Cappa).

	Type I vermiculations («negative» vermiculations of Montoriol-Pous)	Type II vermiculations («normal» vermiculations)
Kind of material forming the vermiculation	Thin material, rarely coarse aggregates	Large, distinct macroscopic aggregates often made of thin material.
Water needed for the growth of the vermiculations	Very much water initially, followed by a big reduction by evaporation	A thin layer , almost constant
Halo	Absent or scarce	Always present
Morphology: general shape	Usually large and thick	Usually thin
Shapes according to Parenzan's classification		
- spot-like	No. 2, 3, 4.	No. 1
- vermiculated	No. 5, 6	No. 7 & 8
Dimensions:		
width	Up to some cm	Up to some mm
length	Up to many cm	Up to many cm
thickness	Up to 1 cm	Up to some mm
Where they grow	Everywhere there is wet clay and meteorogical conditions able to dry it	Where humidity is nearly 100%; therefore water forms a thin film over the surface of the surface of the substratum.

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SUMMARY

Mud and clay vermiculations are irregular and discontinuous deposits of incoherent materials, almost ubiquitous, found both inside and outside of caves, overlying limestone or other materials, they are formed from many substances (clay, mud, candle-black, colloidal silica, etc) also their shape dimensions vary greatly. The following genetical hypotheses have been proposed: fossil fillings; chemico-genetical deposition; biological formation; mechanical deposition from moving water or air; clay-layer drying process (Montoriol-Pous hypothesis); physicochemical deposition from drying liquid films.
The last is proposed by the authors who, having discussed the various hypotheses, give many

examples and the results of some experiments. They distinguish two types of vermiculations:

Type I or negative vermiculations
Type II or normal vermiculations.

The genesis of type I is explained by the Montoriol-Pous hypothesis; these vermiculations are large and made of clay or other colloidal material, and are due to the gradual drying of a layer of clay or other substance.
The last stage of this drying process causes the vermiculations to form in a more or less dried state. The vermiculations of the second type are small and thin, much ramified and always with a clear «halo» around them.
Vermiculations consisting of many materials have been observed, usually as macroscopic aggregates. They are caused by the drying of a liquid film containing suspended colloidal particles. The proposed mechanism provides a good explanation of all the observed characteristics of vermiculations.

RIASSUNTO

Le vermicolazioni argillose sono depositi irregolari e discontinui di materiale incoerente; praticamente ubiquitari. Si trovano sia in grotta che all'esterno, su calcare o qualunque altro materiale; sono formate da ogni tipo di materiale (argilla, nerofumo di candele, silice colloidale, etc.). Inoltre hanno forme e dimensioni variabili. Le ipotesi genetiche sinora enunciate sono: riempimento fossile; chemiogenetica; biologica; sedimentazione da trasporto idrico ed eolico; ipotesi di Montoriol-Pous, disseccamento di strati di argilla.

Gli autori dopo aver discusso queste ipotesi, portato numerosi esempi ed eseguite alcune prove sperimentali, distinguono due tipi di vermicolazioni.
Vermicolazioni di I tipo o negative di Montoriol-Pous
Vermicolazioni di II tipo o normali,
Il primo tipo corrisponde all'ipotesi di Montoriol-Pous ed è costituito da vermicolazioni massicce composte di materiali in genere fini; sono dovute al graduale disseccamento di uno strato di argilla (o altro) molto idratato; lo stato finale di questo disseccamento sono appunto alcune «zolle» di materiale più o meno secco che costituiscono le vermicolazioni.
Il secondo tipo di vermicolazioni è costituito da vermicolazioni (o maculazioni) esili e sottili ramificate, poco spesse e fornite sempre di un marcato alone chiaro intorno. Sono costituite da ogni sorta di materiale in forma generalmente di aggregati macroscopici. Sono dovute alla precipitazione in stato di gel ed aggregazione elettrostatica per evaporazione di particelle in sospensione in un film liquido.

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