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PERIODICITY OF CRYSTALLIZATION PROCESSES IN KARST CAVES

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One of the most important problems in the study of the processes of mineral genesis is determining the causes of periodicity of crystallization phenomena and the dependence, closely connected with this, of the texture of mineral aggregates on the conditions of their growth. The significance of these problems is confirmed by endless discussions on the scope of the terms "stage", "phase" and "paragenesis" and on the nature of so-called collomorphic structures in the theory of ore formation. However, in this field, a resolution to the problem comes up against ambiguity in the interpretation of crystallization conditions and a range of other questions still far from being solved. Research into hypergene processes, particularly the processes of crystallization in karst caves, opens up much better opportunities in this respect.

Nowadays, karst caves have begun to draw the attention of many researchers, both in this country and abroad. Nevertheless, in the voluminous speleological literature, it has not been possible to find works investigating general rules governing the sequence of crystallization and the causes of the appearance of various types of mineral aggregates. The present literature is mostly dedicated to examination of their morphology or the study of rhythmic alternation of zones of stalactite and stalagmite growth to determine the absolute age of the caves. (Prinz, 1908; Churakov, 1911; Allison, 1923; Trombe, 1943; Corbell, 1947; Snyder, 1951; Vitasec, 1951). Many authors doubt the trustworthiness of such appraisals. Apparently, the first attempt to reach a solution to these closely connected problems was made by the author (Stepanov, 1966). There is now new data which allows us to go deeper into these concepts.

Basic terms used in the work

The existing terminology for mineral aggregates in caves is not yet unified, which makes the results of any investigations difficult to use. Terms usually reflect only the outer appearance of one or another aggregate and, as a rule, lack a genetic content. Often the same term is applied to aggregates of different genesis. This circumstance has shown the need for a strict rationalization of the terms used in the present work.[15]

Stalactite - stalagmite kora. This concept includes all the crystallization products grown during the crystallization period from freely seeping (gravitational) solutions - drips, planar laminar streams on the walls, roof and floor of cave cavities in subaerial conditions, i.e. above the horizontal level of constant cave pools. All mineral aggregates of this type are characterized by a strong influence of gravitation on their form. The term "stalactite-stalagmite kora" joins the forms that are similar by their genesis - stalactites, stalagmites, stalagnates (Kunsky, 1950) – draperies and wall crusts (stalactite kora) and on the cave floor (stalagmite kora).[16]

The term was first proposed by Fersman and Shcherbakov (1925). It includes the following terms: "kapelniki" (Krieger, 1955), "dripstone formation" (Dawkins, 1874), "stagmalit" (Kunsky, 1950) and "flowstone formation" (Warwick, 1953).

According to their relative crystallization time, and also to their characteristic structure, porosity and density, aggregates of this type need to be divided into two independent groups - the stalactite-stalagmite kora of ordinary calcite and the stalactite-stalagmite kora built of a light porous calcareous tufa. For the latter aggregates, Kunsky (1950) has suggested the term "travertine". However this should not be adopted, taking into account the generally accepted geological sense of the term "travertine" which is used for the products of crystallization in subthermal and hot springs independent of their structure.

The tufa kora is characterized by the same textures of the aggregates as for usual ones. The distinctions are expressed by the more massive tufa stalagmites and tufa stalactites. Gours (crystallization dams of cave pools) are mainly composed of tufa, as are the majority of cave pisolites.

Corallites. The author suggests including in this concept all the crystallization products from capillary (adsorption) water films on the surface of underground cavities. Such films have a condensation origin or appear because of the slow spread of water due to very weak trickling. It is characteristic to find corallites in the places where there are favorable conditions for supporting the maximum humidity necessary for the continuous existence of capillary water films (niches, dead ends in cave passages, places with a low air circulation).

The shape of a corallite aggregate does not depend on its position during growth on either the ceiling, walls and floor of caves, or on curtains, stalactites, and stalagmites. Especially characteristic is the position of corallites on protuberances, edges of rubble and other juts of the uneven surface of cave walls or on previous mineral aggregates. Such a distribution of corallites in a cave and the independence of their shape on the direction of gravity distinguishes these mineral aggregates from all others. Corallites differ from helictites by their shape and by their lack of an inner capillary channel. Because of their dependence on crystallization conditions (influence of the underlying substrate, speed of growth etc.), corallites can have various shapes. Corallites, whose

15 The terminology problem has been partially resolved by the publication of the second edition of Cave Minerals of the World (Hill and Forti, 1997). However, even here in this book the same term can be applied to aggregates of different genesis.

16 Expressed more simply, the stalactite-stalagmite kora comprizes all the stalactites, stalagmites, draperies, and flowstone growing together in the same place and at the same time. See also the Editorial note.

growth originates from solution supplied by slow trickling, may produce very unusual transitional forms to usual stalactites and stalagmites (Figure 1). The most common ones are corallites resembling lichens and fungi. Warwick (1953) describes them as fungoidal forms (from "fungus") and "botrioidal stalactites". Such aggregates were first described by Dawkins (Dawkins, 1874; Warwick, 1953). Apparently, for similar forms Balch (1948) first proposed the name "coralline formation" and explained their growth due to water sprayed by falling drops. Warwick also used the term "coralline formation" for coral-like aggregates of crystals from cave pools, i.e. for forms completely different in genesis.

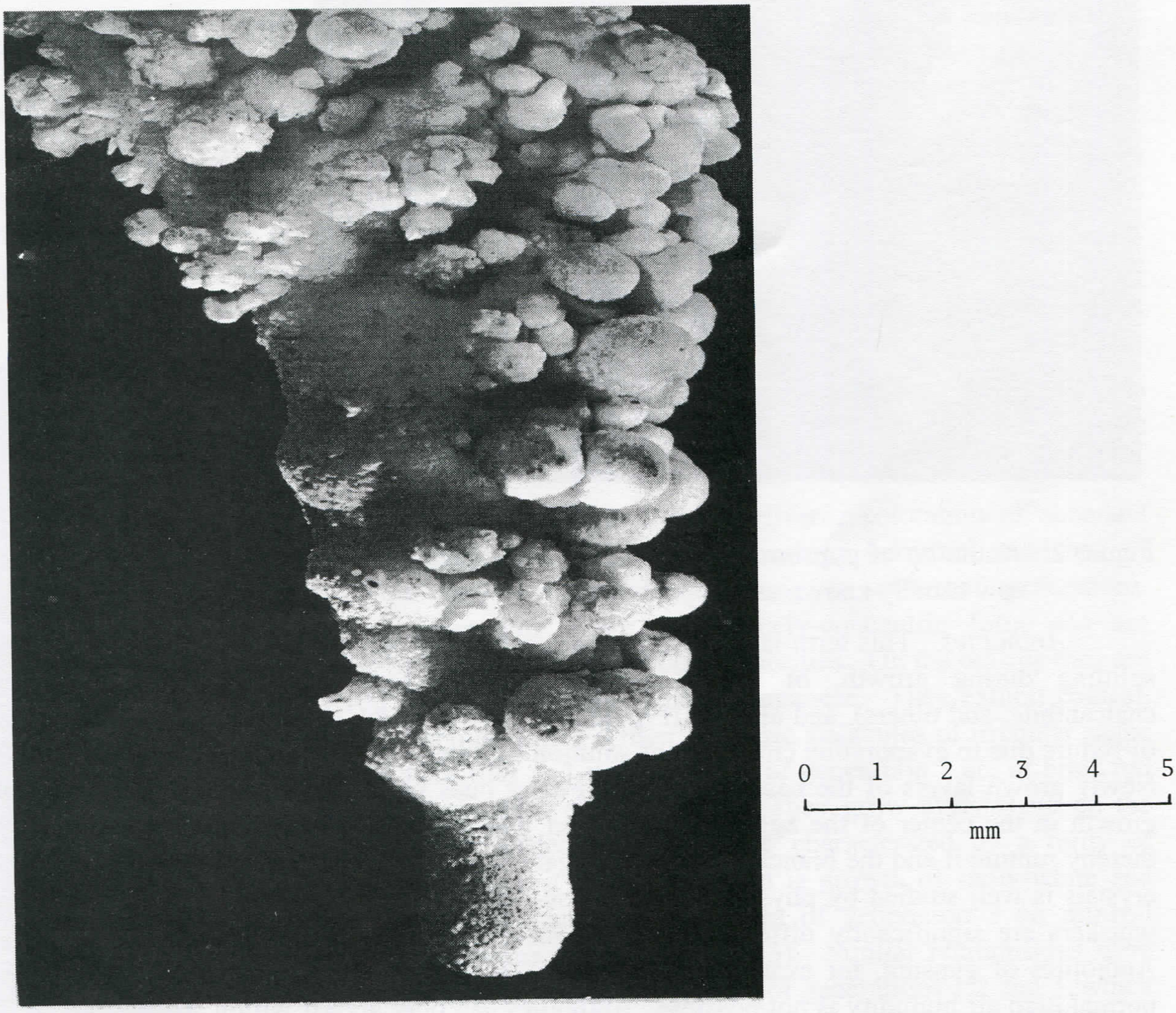

Figure 1. Corallite stalactites, Ouzundja Cave.

As far as it was possible to find out, the first use of the term "corallite" was by Serban *et al.* (1961) for "stalagmite formations of dendritic form, looking like coral bushes and developing by the action of capillarity". Such corallites are more rare than fungoidal forms. Some authors have used the terms "limestone flowers" and "anthodite" for such aggregates. Corallites of the above-mentioned types mostly have a concentric composition, like stalactites. However, there are often seen gradual transitions to macro-crystalline aggregates which can sometimes be traced in the same specimen from the origin of growth of the aggregate to the periphery. Finally, there can be found corallites built entirely of macro-crystalline calcite. Calcite crystals in such corallites are usually poorly crystallized and have rounded coral-like shapes, though occasionally branching aggregates of well formed crystals can be seen. For macro-crystalline varieties of corallites, Serban *et al.* proposed the apt term "crystallictite" and correctly indicated their growth in capillary water films.

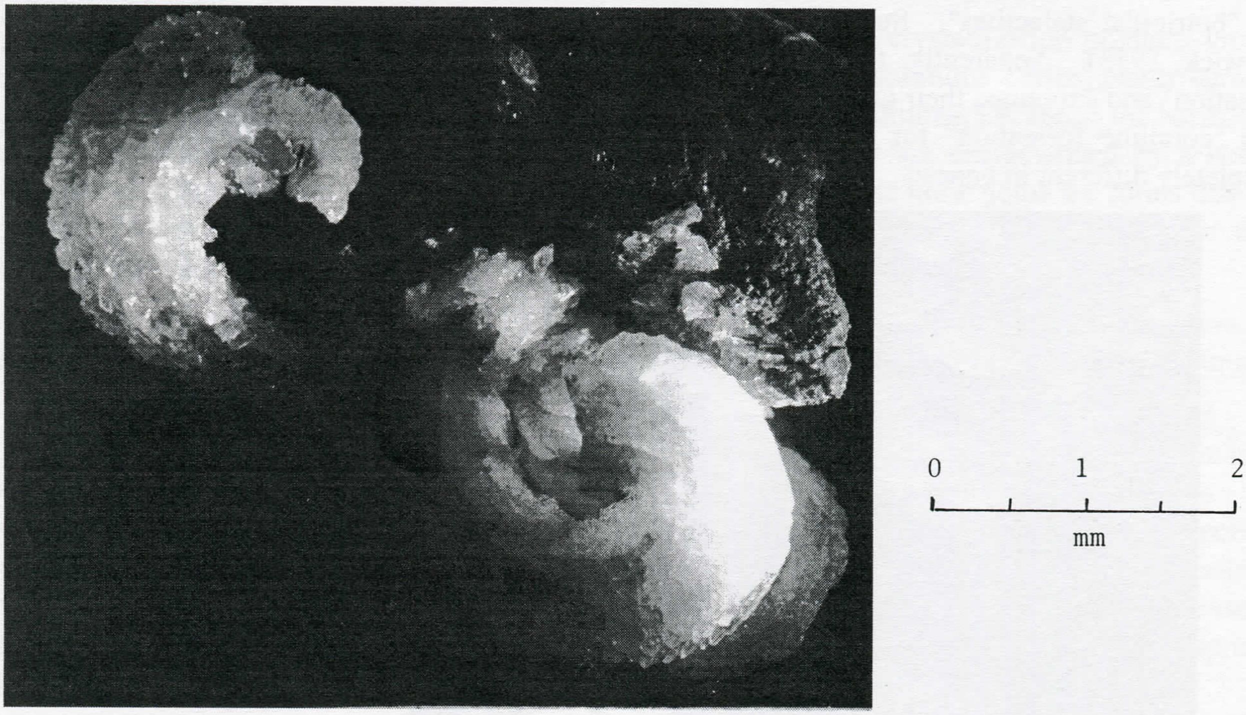

Figure 2. Antholite of gypsum, Karlyukskaya Cave, Turkmenia. [Translator's Note: this cave is now usually known as Cupp-Coutunn.]

Antholites. This term is proposed by the author for parallel-fibred aggregates, twisting and splitting during growth, of readily soluble minerals (gypsum, saltpetre, halite, epsomite, chalcanthite, and others), and also ice (Figure 2). Growth of the aggregate occurs only at the point of fixture due to evaporation (freezing) of solution supplied via the capillaries of a porous substrate. Newly grown layers of the base move the previous ones up. Usually, because of more intensive growth in the center of the aggregate compared with the periphery, mechanical forces appearing thereby rupture it and the branches of the aggregate bend outwards. The growth mechanism of such crystals is well studied by physicists - that of so-called whiskers (filamentary crystals). However whiskers are significantly different, having a more perfect crystal structure and a smaller size. Antholites of gypsum, for example, attain 30 cm in height. Growth of antholites in caves with normal high air humidity is not possible. Antholites can only appear within rare periods of dryness in caves and with soluble materials available in the capillary waters. As a consequence of this mechanism of growth, the influence of gravity is not manifested in their shape.[17]

The main features of crystallization succession.

The general method of study of age correlations between the mineral aggregates of caves is assumed to be the macroscopic observation of the succession in which they overgrow the substrate. Effective results are given by the study of polished samples cut perpendicular to the plane of growth. First of all, this draws attention to a steady succession of overgrowth among stalactites and stalagmites of different color and shape or different stage of wind erosion of their surface. The succession of overgrowth of aggregates with different colors is sustained everywhere where the

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[17] We should note that for long antholites, gravitation does become important though its effect is destructive.

coloring of a stalactite - stalagmite kora is caused by a mechanical addition of clay. Earlier generations, as a rule, contain a greater quantity of impurities of a coarse fraction. This rule can be broken when organic matter significantly influences the coloring of calcite (Anakopiska Abyss, Caucasus).

The often observed overgrowth of tufa stalagmites on tufa cascades and the overgrowth of usual stalagmites on tufa ones reliably follows. All these varieties strongly differ by the shape and structure of their surface. It is constantly observed, growth of corallites on a stalagmite kora or the overgrowth of corallites by a stalagmite kora of the second generation. The multiplicity of such observations and their consistent character, kept for all visits to caves, testifies to the validity of this principle.

The succession of crystallization of mineral aggregates in particular caves.

The author has investigated about 13 karst shafts and both horizontal and inclined caves in Crimea, Caucasus, and Turkmenia, as well as many karst landslide breccias in the Oka and Moskva river basins on the Russian plain. Ouzundja Cave and Uralskaya karst shaft, both located in the northern part of the Central karst plateau of Crimea (Ivanov, 1963), and Anakopiiskaya Cave in Abkhasia were the most thoroughly studied.

Ouzundja Cave (Kruber, 1915) comprizes an extensive horizontal system of very narrow vertical and steeply inclined cavities, related to a system of tectonic disturbances in the limestone.

Characteristic for this cave is the diverse coloration of abundant stalactites. A consistency in age relationships between stalactites of different colors indicates that they belong to different generations. Stalactites of generation 1 are of a finely-concentric form and are characterized by a larger content of clay impurities. On the outside they are often covered with a black film of bog manganese. They exhibit conical, cylindrical and tubular forms. Often eccentric stalactites of irregular shape are seen. The stalactites and stalactite kora of generation 2 are of brick red color due to a slight dash of terra rossa. They grow everywhere on the earlier aggregates of generation 1 and are characterized by a rarity of eccentric forms. The most evidently traced is growth of snow white and cream-colored stalactites and stalactite kora of generation 3 on mineral aggregates of generations 1 and 2 (Figure 3). Similar relationships were observed between the more rare stalagmites of generations 1,2 and 3, which differ from the stalactites by having the same form. The differences between stalactites and stalagmites of different generations are easily found in their cross-sections.

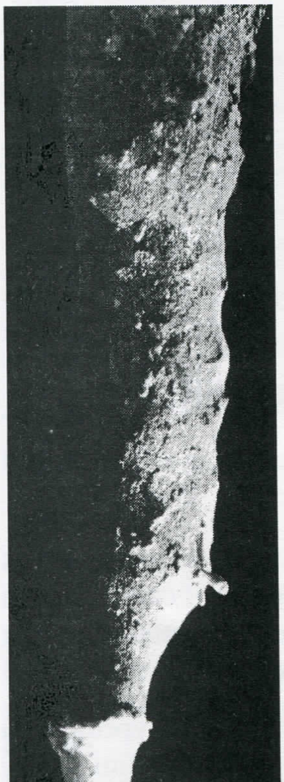
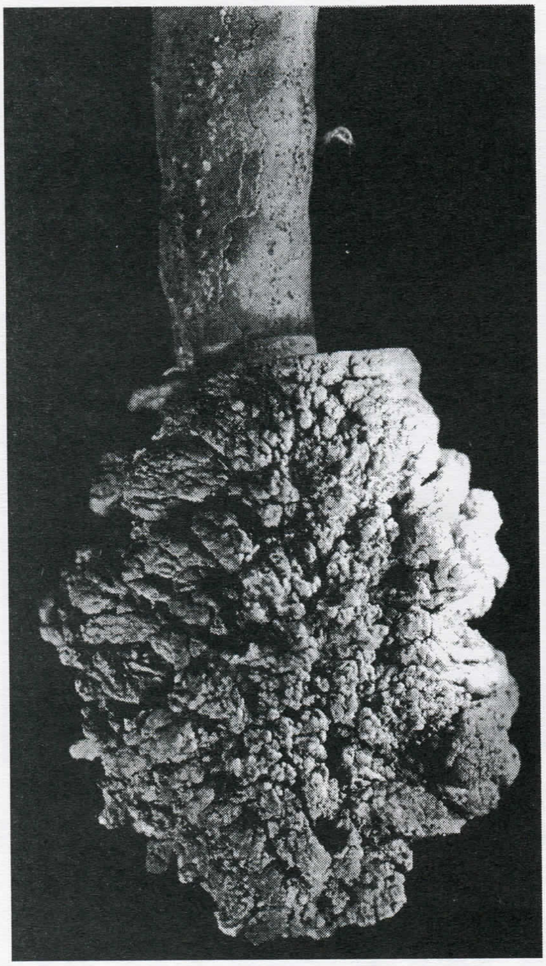


Figure 3. Stalactite of later generation (white) growing on a stalactite of generation 1, Ouzundja Cave.



During flooding by cave waters of stalactites of generation 2, there was observed on them a limestone tufa crystallization of cauliflower-like form (Figure 4).

Corallites in Ouzunja Cave are found in distant, though not all such, regions which is clear from the manner of their formation. Characteristic is a presence of corallites in partially enclosed cavities and niches. They are observed in conspicuous quantities in side branches of the old part of the cave not far from the entrance. The most widespread are fungoidal corallites of generation 1. They always grow on stalactites and stalagmites of generation 1 (Figure 5).

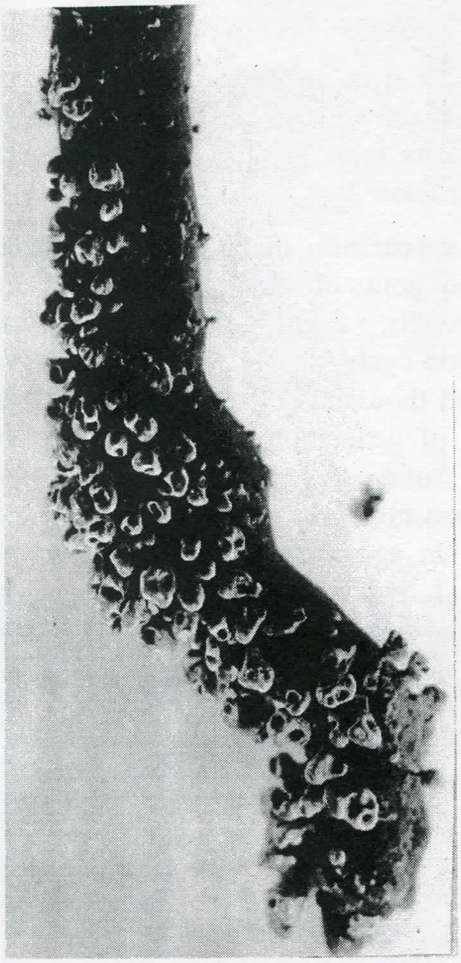
Corallites of generation 2 are found more rarely and usually are kidney-shaped. They usually overgrow the red stalactites of generation 2.
The findings cited indicate the presence of three cycles of crystallization in Ouzundja cave; also, the third cycle continues to evolve. The development of "sinter" aggregates proceeded via the scheme: 1st cycle, stalactite-stalagmite kora of generation 1 > corallites of generation 1; 2nd cycle, stalactite - stalagmite kora of generation 2 > corallites of generation 2; 3rd cycle, stalactite-stalagmite kora of generation 3. For this cave, a wide distribution of mineral aggregates of all cycles of crystallization is characteristic. More evident is a significant decrease in the amount of deposited material in later crystallization cycles, as is well shown in the karst shafts Uralskaya and Kristalnaya.

Figure 4. Overgrowth of a stalactite by limestone tufa during the period of its submersion, Ouzundja Cave.

The karst shafts Uralskaya and Kristalnaya are located in the northern part of Aypetri Yaila (Central karst plateau) in Crimea. Mineralization of the first shaft is analogous, with a few differences, to the mineralization of Ouzundja Cave. Black stalactites of generation 1 are here less common. Corallites of generation 2 are abundant in niches in every passage. Corallites here, in contrast to the ones in Ouzundja Cave, do not have a fungoidal shape, but are coral-like and branching and often grow on the debris of fallen stalactites.

On corallites of generation 2 are observed small conical stalactites of generation 3. Stalactites of generation 2 quite often produce a gradual transition to corallite stalactites of snow-white color (Figure 1). A distinctive feature of Uralskaya Shaft is the negligible amount of tufa stalactites and tufa stalactite kora - apparently of the current cycle of crystallization. The most significant of the studied facts for Kristalnaya Shaft is the determination of the correlations between stalagmites of different generations and periods of breakdown. The greatest breakdowns preceded the formation of the tufa stalactite-stalagmite kora of generation 1. Heaps of the old collapse are covered by a uniform tufa stalagmite kora with tufa "pagoda" stalagmites of generation 1. Stalagmites of generation 2 of "fried eggs" type (Folsom, 1956) grow on a young collapse of small blocks.

Anakopiiskaya Cave is situated not far from Novi Afon in Abkhasia. It comprizes a vertical shaft passing into a horizontal cave with very extensive passages. Studies made there by the author in the winter of 1965 revealed a clearly expressed periodicity of the processes of crystallization.



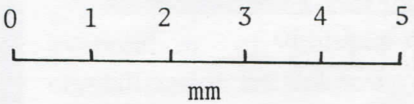


Figure 5. Fungoidal corallites of generation 1 on an eccentric stalactite of generation 1, Ouzundja Cave.

The most vigorous growth was generated in the tufaceous stalagmite kora of the first cycle of crystallization, which covers some thousands of square metres of blocky collapse, and the surface of both grottos and galleries. On the steep gradient parts of blocky collapses, huge tufa cascades are seen with tufa draperies up to 15 metres in height. On gentle slopes are seen cascades of tufa dams (gours). On the tufa cascades are observed huge tufa stalagmites with a flat surface. On the tufa kora of generation 1 and on the gours grow tufa-calcite stalagmites of "pagoda" type up to 3 metres in height. More often, on the tufa kora are observed obelisk-like stalagmites and a uniform covering of hard calcite stalagmite kora. Under overhangs of the blocky collapse, the stalagmite kora is often edged with a screen of stalactites and curtains.

In the narrow parts of galleries, in niches of the blocky collapse and earlier crystallization products (tufa and stalactite-stalagmite kora) there are often observed corallites of various shapes. In many places it can be seen how corallites are being overgrown by a thin stalagmite kora of generation 2. Particularly spectacular are stalagmites of generation 2, growing on stalagmites of generation 1 overgrown by corallites (Figure 6). Less commonly observed are regenerated stalactites on aggregates of corallites.[18]

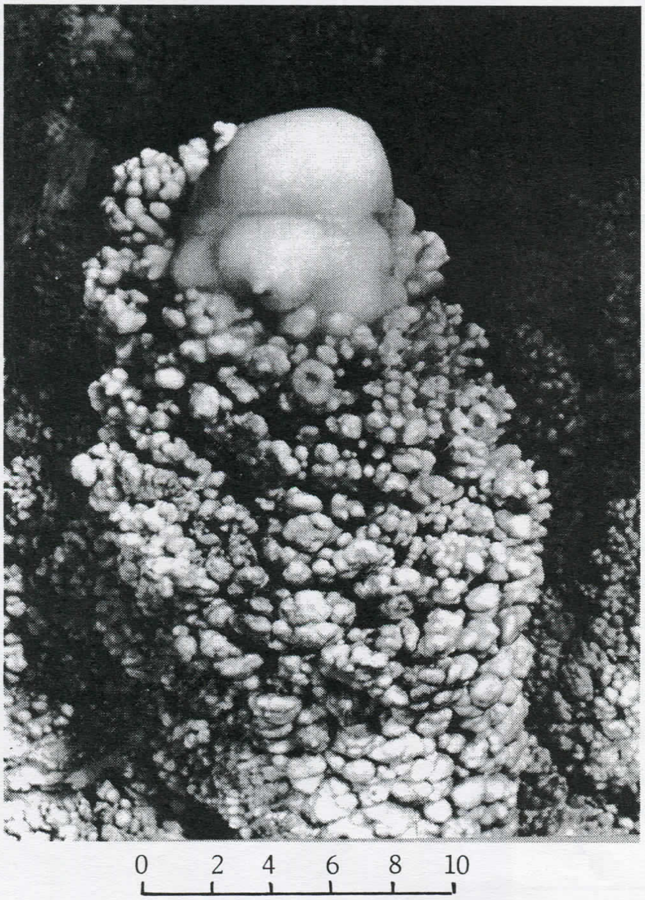


Figure 6. Stalagmite of generation 2, growing on an aggregate of corrallites covering an earlier stalagmite of generation 1, Anakopiskaya Cave. Photograph by V. Nejhuri.

In the areas of propagation of recent blocky collapses and in particular on sandy-clayey deposits there is often observed a tufa kora of generation 2.

By appearance, thickness of deposition and abundant gours of small size, this tufa kora differs strongly from that of the first crystallization cycle In the shallow gour trays are observed thousands of tufa pisolites. Tufa stalagmites of generation 2 are much smaller than the tufa stalagmites of the first crystallization cycle and are noticeably different in shape On aggregates of the tufa kora of generation 2 and on "pagoda" stalagmites, abundant spiral and short-columnar cylindrical stalagmites are seen, often of the characteristic "fried eggs" type (Figure 7). Corallites of generation 2 were not found in the cave.

Similar relationships have been observed between stalactites of different relative age. However the stalactite kora in Anakopiiskaya Cave has an incomparably smaller degree of development than the stalagmite koras. Simultaneous with the deposition of tufa kora 1 appear massive tufa curtains (Tbilisi Hall) Upon tufa stalagmites of generation 1 were observed fancifully curved tufa stalactites – anemolites. "Pagoda" and obelisk-like stalagmites correspond to the massive stalactites of the first crystallization cycle. On stalactites of generation 1, often having a dull corroded surface, often grow lustrous stalactites 1, usually distinguished by color.

In some parts of the cave (Helictites Hall), various *helictites* (fancifully curving cylindrical twigs with the finest capillary channels inside) grow in great amounts on stalactites 1. Through those capillaries, feeding of the helictite proceeds during growth (Prinz, 1908). The direction of growth of helictites is not affected by gravitation, which confirms the evidence about their growth from capillary solutions. On the helictites sometimes grow stalactites 2 (Figure 8).

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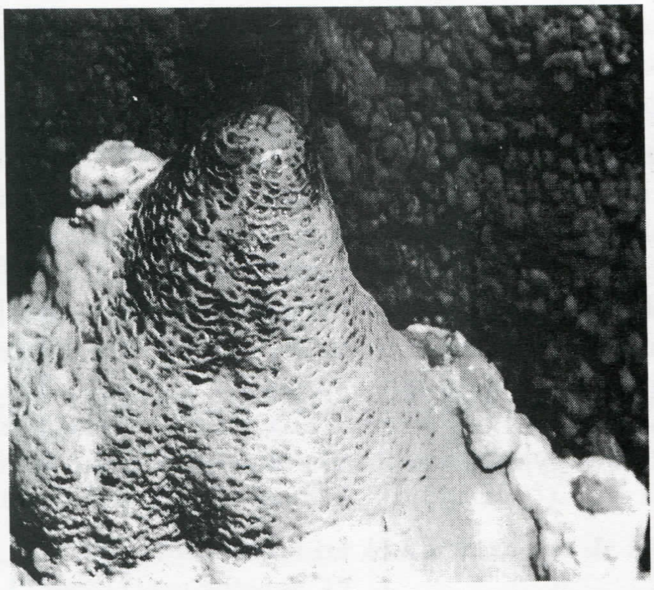
18 Stepanov is using the term "aggregate" rather loosely here (since a single corallite is itself an aggregate in the true sense of the term). The stalactite equivalent of Figure 6 is of course more rarely seen, because the capillary film which creates the drip imperceptibly buries the corallites from their base up. On a stalagmite, the drip is concentrated in one place so some corallites are completely overgrown while others remain unaffected.



A characteristic feature of Anakopiiskaya Cave is the exceptional abundance among the crystallization products of different aggregates of gypsum - gypsum kora, antholites, stalactites, and stalagmites. Age relationships between aggregates of gypsum and calcite formations are much less precisely determined. This may be explained because gypsum is very easily dissolved under the drips or in the water streams where calcite or tufa aggregates originate. However this fact helps to find the conditions in which crystallization of gypsum is possible. Obviously gypsum grows due to evaporation of solvent (other mechanisms of crystallization are unknown), which is only possible in a dry period of the life of a cave. This period is established after an abrupt decrease of water coming into the cave, from the stage of growth of corallites to the stage of limestone dissolution and the shaping of the cave cavity in the second cycle of the life of the cave. A supplementary fact to justify this conclusion is the considerable corrosion of stalactites 1 and stalagmites 1 in the regions enriched in gypsum. It is most likely that crystallization of gypsum was at the end of the first cycle.

Figure 7. Stalagmite of generation 2 of "fried eggs" type on a tufaceous stalagmeit of generation 2. Anakopskaya Cave. Photograph by V. Nejhuri.

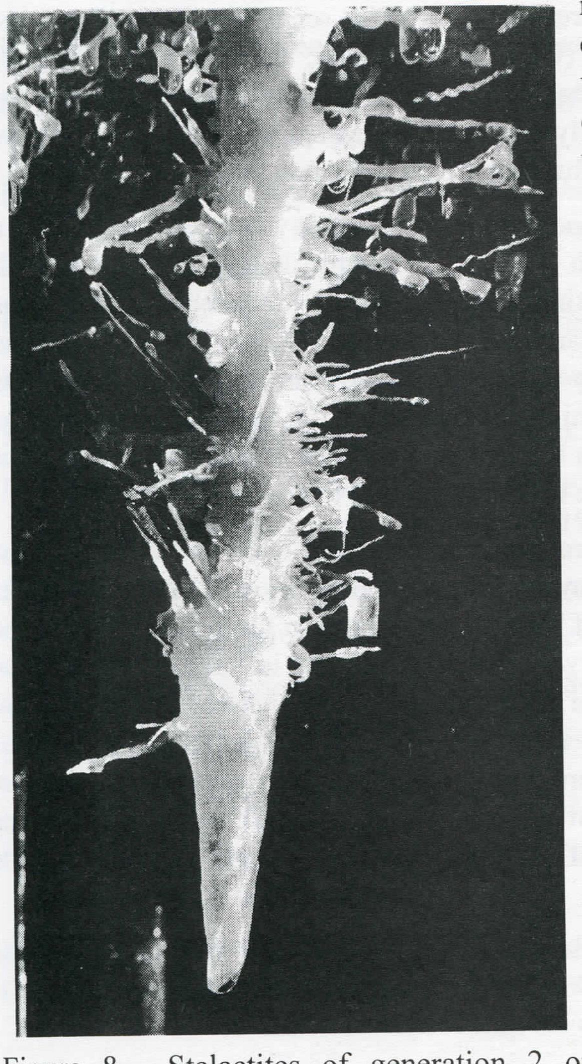


Figure 8. Stalactites of generation 2 on helictites, covering a stalactite of generation 1. Anakopiiskaya Cave. Photograph by V. Nejhuri. Reduced in size.

Thus, the general periodicity of development in Anakopiiskaya Cave results in the following scheme: dissolution of limestone (formation of the cavity) > blocky collapses 1 > accumulation of detrital deposits (gravel, sand, clay) 1 > crystallization accumulation 1 > drying out of the cave > minor collapses of the 2nd cycle > detrital accumulation 2 > crystallization accumulation 2. Clearly traced are two maxima of collapse phenomena and stages of water encroachment in the cave, as well as a sharp minimum of accumulation phenomena and inflow of water between cycles 1 and 2. Crystallization accumulation of cycles 1 and 2 has a similar character, with only the difference that cycle 2 is not yet finished (crystallization of corallites and gypsum are lacking). The general crystallization trend in each particular site follows the scheme: tufa stalactite-stalagmite kora > calcite stalactite-stalagmite kora > corallites > gypsum. A feature of cycle 2 is the formation of helictites and pisolites.

The main research results.

The evidence given in the present work shows that the new method for the study of the general history of development of cave stalactites, proposed earlier by Stepanov (1966), is valid and can produce valuable results. Particularly interesting proved to be the data about a strict periodicity of the phenomena of limestone dissolution, vault failure and the deposition of detrital products, separated by considerable periods of quiescence, moreover in strongly seismic regions (Caucasus, Crimea). Archaeological and geomorphological data (Gvozdetsky, 1954), showing that the age of the caves is to be estimated in many thousands and tens of thousands of years, help to estimate the duration of the quiescent period. The presence of only two or three cycles of accumulation shows that each period in the life of a cave is comparable in duration to the indicated values.[19]

Another important conclusion refers to a periodicity in the amount of water feeding into a cave. The maximum of water supply coincides with periods of collapse before the start of each cycle, which is clearly seen from the degree of sorting and the size of the pebbles and detritus conveyed into the cave. Subsequently (which is clearly traced over the change of crystallization products) the magnitude of the water supply gradually reduces from streams of gravitational waters (stalactite-stalagmite kora, crystallization in pools) at high cave air humidity, to capillary water films (corallites) also at high cave atmosphere humidity, to the dry period when it becomes possible for crystallization of even the slightly soluble gypsum due to evaporation at low cave air humidity.

By this way, in the single chain of causal relationships appears such different (on first glance) phenomena as the processes of accumulation by breakdown and by crystallization, processes of formation of cavities in caves, changes of texture of "sinter" aggregates in time, periodicity in the amount of water in caves and, apparently, even the level of seismic activity in large regions. What phenomena of a more vast scale and what causes can produce a close link between such different processes? A partial answer to these questions is given in the book of B.L. Litchkov (1960), "The natural waters of the Earth and the lithosphere". There it is shown, after data of a planetary scale, that there exists a close link between the periodicity of different levels of significant changes of the physico-geographical medium of large regions and of the planet as a whole and regional tectonic processes.

By the investigation, at first glance of specific phenomena, we somehow forget the close causal relationship of absolutely all phenomena of nature. Because of this relationship, it is

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19 More modern dating methods, particularly the U/Th radiometric dating of calcite, suggests that these periods in the life of a cave are to be measured in tens of thousands / hundreds of thousands of years.

particularly important to take a look from the view of periodicity of crystallization phenomena in surface, as well as in sub-surface processes. For all the limitedness of specific material in this article, it is certain that the cause of any periodic processes of crystallization, including the formation of ore deposits, is the periodicity of larger scale phenomena of the life of our planet.

References

Allison, V.C. 1923. *The growth of stalagmites and stalactites.* Journal of Geology, **31** (2), pp 106-125.

Balch, H.E. 1948. *Mendip – its swallet caves and rock shelters.* Clare, Son and Co Ltd., Wells.

Chourakov, A.N. 1911. *On the structure and growth of tubular stalactites.* (in Russian) Works of the St-Petersburg Naturalist Society, **35** (5).

Corbell, J. 1947. *Observation sur la Karst couvert de Belgique.* (in French) Bulletin Society Belge d'Etudes Geographique, **17**.

Dawkins, W.B. 1847. *Cave Hunting.* London, Macmillan.

Fersman, A.E. and Shcherbakov, D.I. 1925. *The Tyuya-Muyun deposit of radium ore in Fergana.* (in Russian) Moscow.

Folsom, F. 1956. *Exploring American Caves.* New York, Crown Publishers.

Gvozdetsky, N.A. 1954. *Karst. Problems of general and regional karst science.* (in Russian) 2nd edition, Moscow, Geographghiz.

Ivanov, B.N. 1963. *Karst phenomena in the Crimea mountains and the basic problems of their investigation.* (in Russian) Works of the complex karst expedition of the Academy of Sciences of the USSR, **1**.

Kriger, N.I. 1955. *Cave dripstones.* (in Russian) Priroda (Nature), **3**.

Kruber, A.A. 1915. *Karst of the Crimea mountains.* (in Russian) Moscow.

Kunsky, J. 1950. *Kras a jaskyne.* (in Czech). Praha.

Litchkov, B.L. 1960. *Natural waters of the Earth and the lithosphere.* (in Russian) Notes of the Geographical Society of the USSR, **19**.

Prinz, W. 1908. *Les cristallisation des grottes de Belgique.* (in French) Nouveaux memoires de la Societe Belge de geologie, de paleontologie et d'hydrologie, **4 (2)**. Royal Academy of Belgium. Republished in English 1980, Cave Geology **1 (7)**, pp 191-258.

Serban, M., Viehmann, I. and Coman, D. 1961. *Caves of Romania.* (published in Romanian, Russian, French and German editions) Bucharest, Meridiane.

Snyder, F.G. 1951. *An unusual stalactite from Saltville, Virginia.* Journal of Sedimentary Petrology, **21 (1)**, pp 26-27.

Stepanov, V.I. 1965. *Exploration de la succession de cristallisation des agregats mineraux comme l'une des facon d'etude de l'histoire de la formation de grottes a concretions calcaires.* (in French) 4th International Congress of Speleology in Yugoslavia. Ljubljana. Summaries of Lectures, pp 54-55.

Trombe, F. 1943. *Gouffres et cavernes du Haut Commines.* (in French) Trav. Scient., **2**, pp 1-80. Club Alpine Francais.

Vitachek, F. 1951. *About the structure, rhythmic growth and the age of stalagmites from the Demenovsky Caves of Slovakia.* (in Russian) News of the Academy of Sciences of the USSR, Geology series, **1**.

Warwick, G.T. 1953. *Cave formations and deposits.* In Cullingford, C.H.D. (ed.) *British Caving*, pp 62-81. Routledge and Kegan Paul Ltd., London.

Additional Reference

Hill, C. and Forti, P. 1997. *Cave Minerals of the World (2nd edition).* National Speleological Society, Huntsville, Alabama.