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THE INTERNAL ORGANIZATION OF SPELEOTHEMS

NOTRANJA ZGRADBA SIGE

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Charles A. Self: The internal organization of speleothems

Speleothems are secondary cave mineral deposits whose internal organization can be studied by mineralogical techniques. The ontogeny of minerals is a technique developed in Russia whereby individual crystals and their aggregates are studied as physical bodies rather than as mineral species. This paper gives a concise guide to the terminology of ontogeny, as applied to cave mineral deposits.

Key words: speleothem, genetic mineralogy, ontogeny of minerals, mineral individual, mineral aggregate, kora, geometric selection.

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Charles A. Self: Notranja zgradba sige

Siga se izloča kot sekudarni jamski mineral, njeno notranjo zgradbo lahko preučujemo z mineraloškimi metodami. Ontogenija mineralov je metoda, razvita v Rusiji, pri kateri so posamezni kristali in njihovi agregati preučevani kot fizična telesa in ne kot mineralna vrsta. Članek podaja kratek vodnik po terminologiji ontogenije s poudarkom na jamskih mineralih.

Ključne besede: siga, genetska mineralogija, ontogenija mineralov, posamezen mineral, mineralni agregat, skorja, geometrični izbor.

SPELEOTHEMS AND SPELEOTHEM TYPES

A *speleothem* is a secondary mineral deposit formed from water in caves (Moore 1952). The phrase “from water” (meaning from aqueous solution) was included in the original definition to distinguish between chemogenic and mechanically accumulated deposits; it has been dropped from many modern definitions (e.g. Hill and Forti 1997) since “secondary mineral deposit” already implies chemogenic deposition. Speleothem has become an internationally popular term, but is often used incorrectly as “a collective term for stalactites, stalagmites etc”. Only such mineral deposits in **caves** are speleothems.

Typical speleothems include stalactites, stalagmites, frostwork, flowstone, gours, helictites and cave pearls. These *speleothem types* can be found in both cave and non-cave settings, since they are defined by their morphology, not by their location. Of importance to mineralogists, a stalactite from a cave is indistinguishable from one growing in a mine, a tunnel or in the cellar of an old house. We therefore have the curious situation whereby speleothem types are routinely named in mineralogy publications, but the term speleothem itself is not used.

In the terminology of different speleothem types, morphology takes precendence over both the origin of a mineral body and its crystallography (Hill and Forti 1997). This has serious limitations, since speleothems can have a broadly similar appearance, but grow by quite different mechanisms. To understand the differences between such speleothems, it is necessary to study their internal organization. A system for such study, complete with its own terminology, has been developed in Russia and is called the *ontogeny of minerals*.

ONTOGENY OF MINERALS

The study of the origin and evolution of mineral bodies is termed *genetic mineralogy*. In the 1950s, Grigor’ev divided genetic mineralogy into two main branches: ontogeny and *phylogeny* (these terms are familiar from biology and are used in a broadly similar sense here). Ontogeny is the study of individual crystals (mineral *individuals*), how these crystals combine as *aggregates*, and their development as physical bodies. Phylogeny is the study of mineral species and their paragenesis and closely corresponds to the Western view of genetic mineralogy.

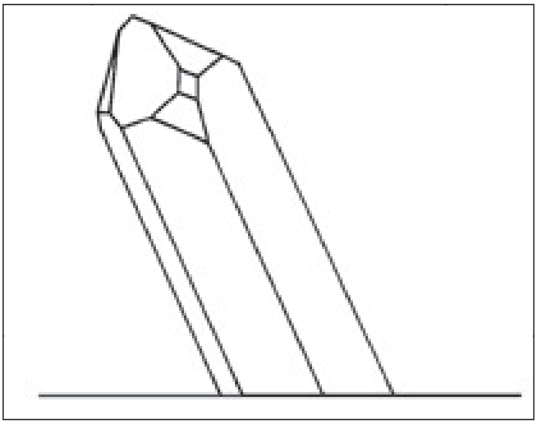

Fig. 1: A first-order individual growing on a substrate.

Ontogeny of minerals has received little attention outside Russia, despite the publication (and translation into English) of a book by Grigor’ev (1961). Although ontogeny has its origins in ore mineralogy and the mining industry, caves prove to be ideal for ontogeny studies. There are few mineral species (only calcite, aragonite and gypsum are common) yet there is a great variety in the speleothem forms that these minerals can take. This has allowed more complex mineral bodies to be studied in caves compared with mines. This line of research was pioneered by Stepanov (1971, 1997) and further developed by other Russian cave scientists, particularly Maltsev (1996; 1997a,b,c; 1998). The purpose of this present paper is to give a concise outline of the ontogeny of cave minerals, with particular reference to terminology. A large paper giving a more detailed overview of the subject has recently been published (Self and Hill 2003).

MINERAL INDIVIDUALS

The fundamental building block for all mineral bodies is the *mineral individual* (Fig. 1). Individuals are mineral bodies that grow from a single crystal nucleus (termed a crystallite), during one phase of crystallization, and which have a "through" crystallographic structure. *Crystallites* are minute crystal grains that represent the initial stage of crystallization, and which act as seeds for further crystal growth. When crystallites are widely separated from each other, they grow freely into separate mineral individuals. But when they grow close together, there is competition for growth space and a *mineral aggregate* is formed (Fig. 2). It should be emphasized that mineral individuals are not speleothems (except in a few special

Fig. 2: An aggregate of first-order individuals. Photo P. Forti.

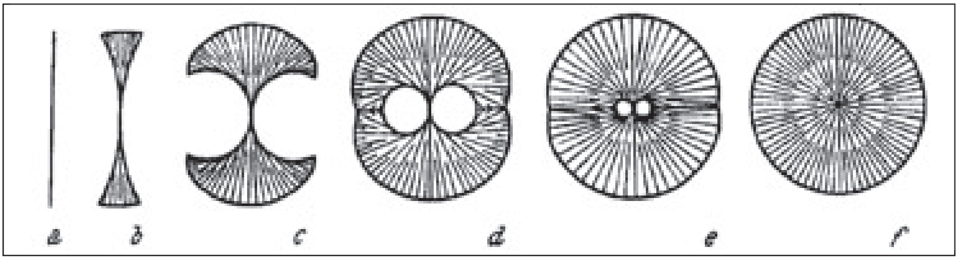

Fig. 3: The splitting of crystals. From Maleev 1972.

cases, e.g. selenite needles): they are the building blocks from which speleothems are made.

First-order individuals are single crystals having no other structure except a standard crystallographic network, which is determined by the mineral species itself (Fig. 1). *Second-order individuals* are single crystals that subdivide or split into a number of *subindividuals*. Examples include skeleton crystals, block crystals, twins and split crystals. Skeleton crystals have their growth inhibited on some crystal faces or edges and so appear "lacy", e.g. a snowflake. Block crystals are formed when a growing crystal incorporates nearby crystallites into its crystal lattice; this is common for hydrothermal minerals. Twin crystals grow as two or more parts, with a crystallographic network reflected across some definite plane called a twin plane. Split crystals (Fig. 3) partially separate during growth into subindividuals as a result of the accumulation of structural defects *(mechanical splitting)*, or when different ions are incorporated as impurities from the parent solution *(chemical splitting)* (Grigor'ev 1961).

The splitting of crystal individuals can continue until a *spherulite* is formed (Maleev 1972). When spherulites grow in free space, they are spherical in form (Fig. 3f); if nucleated on a substrate, they grow as hemispheres. If there is a strongly directional supply scheme, only one sector of the spherulite may develop; beaded helictites and spathites grow this way. *Spheroidalites* are spherulites with curved subindividuals and nonsymmetrical structure; the various coralloid speleothems that grow in the capillary film environment are built from spheroidalites. *Spherocrystals* are formed by splitting at the molecular level, to produce smooth and rounded crystal surfaces (e.g. botryoidal malachite and chalcedony).

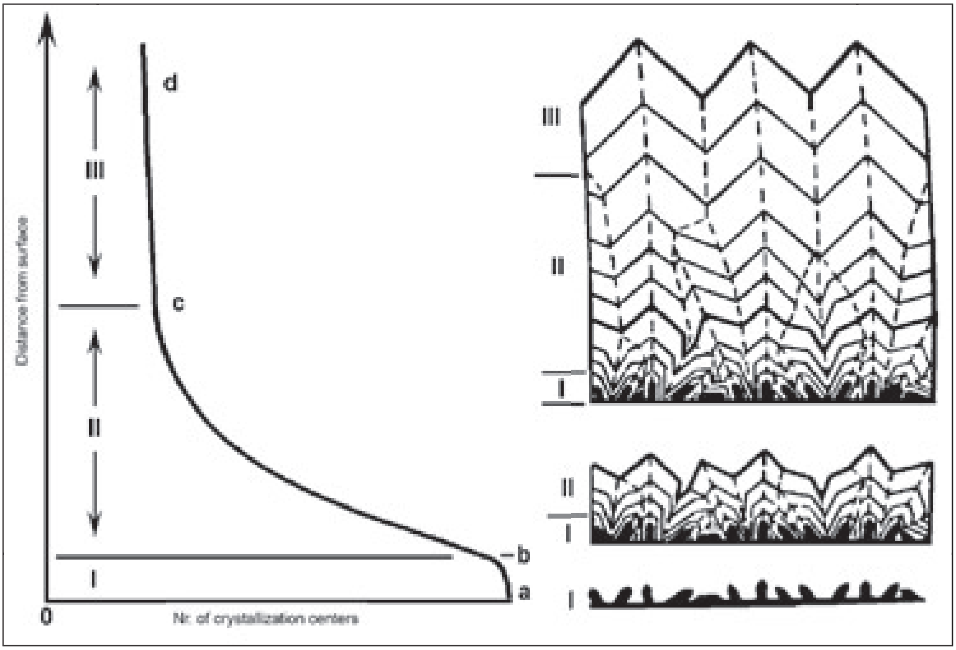

Fig. 4: Geometric selection to produce a parallel-columnar aggregate. From Grigor'ev 1961.

Second-order individuals grow in response to certain environmental conditions, particularly oversaturation – which is a common occurrence in caves because of CO_2 loss and the evaporation of thin aqueous films. The subindividuals of second-order individuals are not completely separate from each other: they grow from the same nucleus and have a joined crystallographic network.

AGGREGATES

Mineral individuals very seldom grow alone; they grow together over a substrate surface as *mineral aggregates*. Aggregates are a co-growth of similar individuals of the same mineral species (Fig. 2), but interaction between individuals directly affects and limits the growth of each crystal. During such "group" growth, there is *competition* between individuals for growth space or for solution supply (and in the capillary film environment, for loss of solvent molecules). Competitive growth on a substrate surface normally leads to a reduction in the number of individuals constituting the aggregate, a situation called *selection*. The most important selection mechanisms are:

(1) *Geometric selection* (Fig. 4): the mineral individual whose greatest growth vector is best aligned for mass-transfer with the environment is the one that will continue its growth at the expense of neighbouring individuals of other orientations. In most cases, this direction is perpendicular to the substrate.

(2) *Substrate selection* (Fig. 5): the mineral individual growing from a convex substrate protrusion will continue its growth at the expense of its neighbours growing from flat or concave surfaces.

The term *structure* describes how mineral individuals are constructed, whether they are simple, split, twinned etc. The term *texture* describes the geometric aspect of construction of aggregates, which results from competition between individuals. Ontogeny can only be applied to mineral bodies which have through regularities of structure and/or texture; these are termed *minor mineral bodies*.

Parallel-columnar texture (Fig. 4) is commonly seen in simple mineral veins and also in some shallow-angled flowstones; it is formed by geometric selection on a flat substrate. *Spherulitic aggregate* texture forms in a similar way on irregular substrates (e.g. most flowstones) or when the substrate is sharply curved, as in the case of a cave pearl.

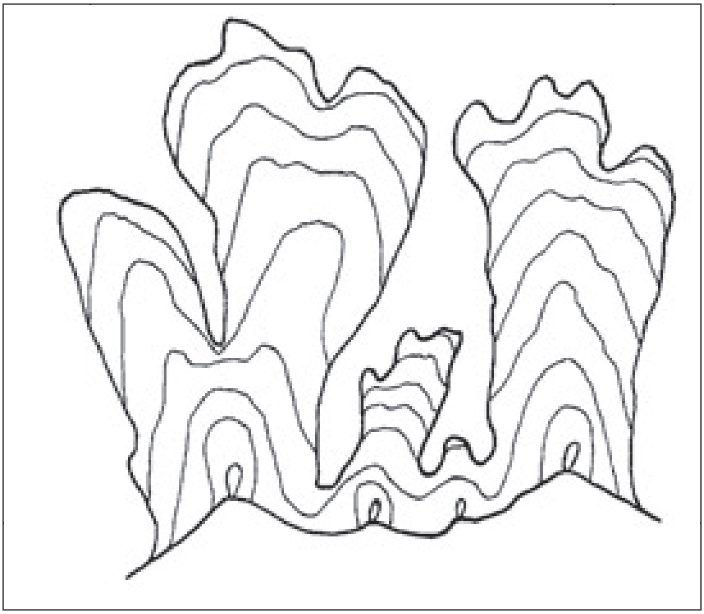

Fig. 5: Substrate selection between competing corallites.

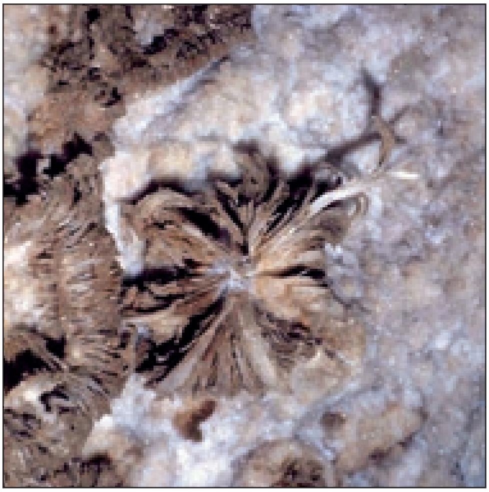

Fig. 6: Different solution supply rates between pores cause gypsum "flowers" to divide into separate "petals".

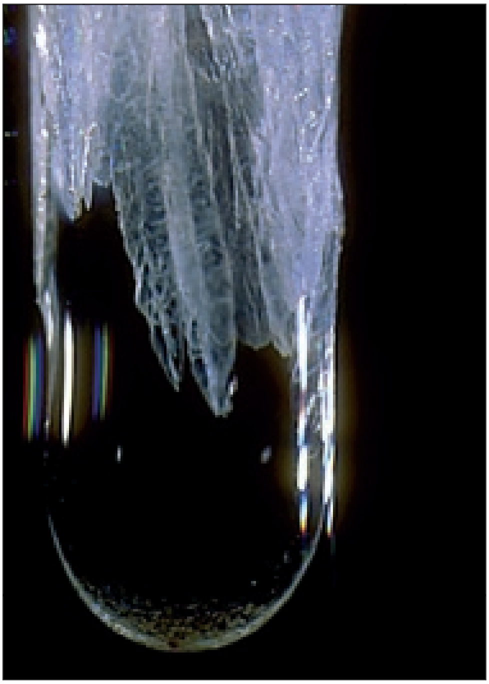

Fig. 7: A "crown" of skeleton crystals at the tip of a straw stalactite. Photo by V. Maltsev, courtesy of the University of Bristol Spelaeological Society.

Radial-fibrous texture is a variation on parallel-columnar and spherulitic aggregate texture where some individuals have begun to split.

Branching aggregates grow by evaporation in a capillary film environment. They include corallites which are formed of split crystals (spheroidalites), and crystallictites which are formed of faced crystals. The speleothems included in this category are thin film generated varieties of coralloids and frostwork (Figs. 5 and 10). In this environment, there is competition within each aggregate for the loss of solvent molecules, but not selection. This is why competing branches never touch each other. However, when these aggregates grow together in close proximity, substrate selection very strongly favours growth from protrusions and less favourably situated aggregates have their growth suppressed or distorted away from nearby large bushes (Slyotov 1985).

Fibrous aggregates are built from filamentary individuals of evaporite minerals. They grow from a porous substrate that may be solid such as the cave walls (e.g. hair, beards, flowers) or plastic such as clay sediments (e.g. selenite needles). The collective name for such aggregates is antholites (Stepanov 1971). Fibrous aggregates grow from the base, which means that selection between individuals is impossible and there is only competition between pores. This leads to different growth rates, usually with the fastest growth in the centre of the aggregate. This causes gypsum "flowers" to burst into separate curving "petals" (Fig. 6).

Interactive aggregates create their own environmental conditions at the crystal growth tips, so are independent of the environmental controls of the crystallization space as a whole. Examples include crystalline shields and some common types of helictite, where solute deposition is caused by a sudden drop in pressure when the feeding solution leaves their central capillary channels.

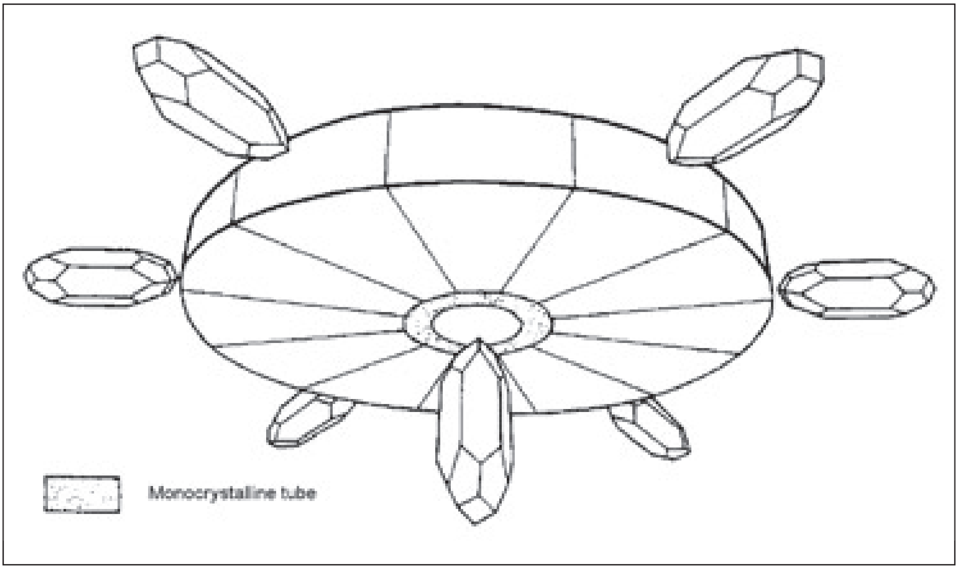

Fig. 8: Schematic cross-section through a conical stalactite, showing a spherulitic aggregate surrounding a monocrystalline tube. From Moore 1962.

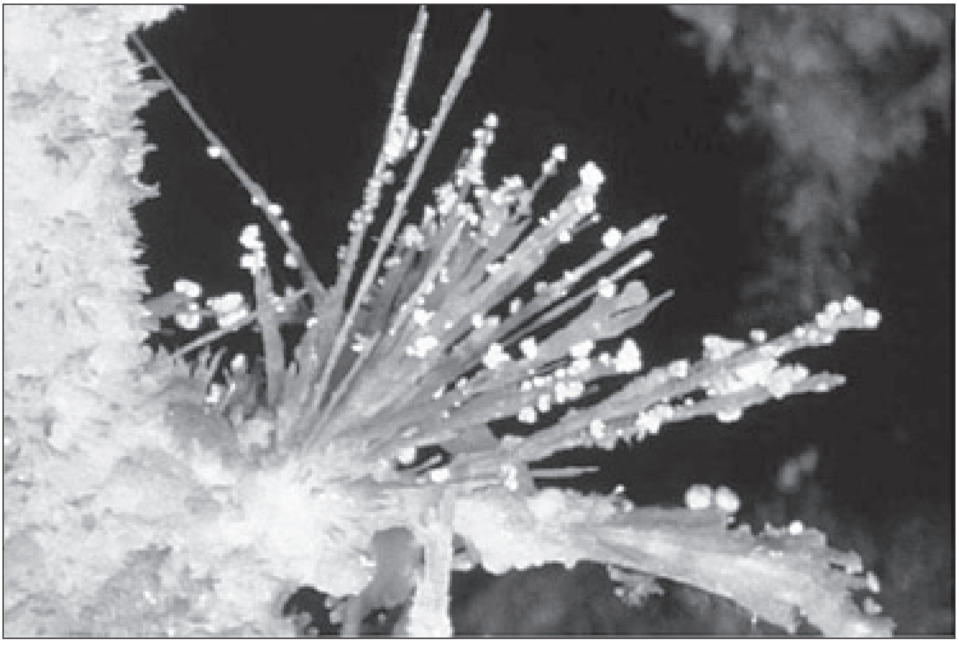

Fig. 9: A multicorallite formed of calcite popcorn, from which grows aragonite frostwork tipped with hydromagnesite.

MULTIAGGREGATES, KORAS AND ENSEMBLES

Multiaggregates are second-order aggregates, i.e. they are built from either first- or second-order individuals, but in a more complicated manner than for ordinary aggregates.

Multiaggregates are a co-growth of different types of aggregates that form simultaneously and syngenetically in the same crystallization environment. They are either polymineral or polytextural.

The best known polytextural multiaggregates are stalactites and straw stalactites. Straw stalactites have a monocrystalline tube with a "crown" of skeleton crystals at the tip (Fig. 7). These skeleton crystals cannot simply grow together to form the tube because they have too much energy tied up in their structure; they must recrystallize. The common conical stalactite grows in a similar way, but with a spherulitic aggregate outer layer (Fig. 8). Conical stalactites are not straw stalactites overgrown by a later surface crust – the three textures are formed simultaneously (Maltsev 1998).

Fig. 10: A corallite/ crystallictite kora (mostly aragonite frost-work) has overgrown a stalactite/stalagmite kora (a conical stalactite) to form an ensemble.

An example of a polymineral multiaggregate is a multicorallite (Maltsev 1997b), which is a branching mineral body formed of calcite popcorn from which grows aragonite frostwork that is often tipped with a soluble mineral such as hydromagnesite (Fig. 9). The magnesium content of the feeding solution becomes more concentrated because of evaporation and mineral deposition, but there is also constant dissolution/ recrystallization taking place (otherwise, the hydromagnesite would coat the entire surface of the aragonite needle).

Pseudoaggregates are disordered and lack "through" structure, but they do have textural regularities and so behave as if they were some form of aggregate. Tufaceous speleothems and chemogenic moonmilk are examples.

In speleothems, it is possible to see higher levels of organization of mineral bodies than is possible in most other geological settings. A *kora* is an assemblage of texturally similar aggregates, growing together at the same time and in the same crystallization space, and forming from the same environmental conditions. One such assemblage is of stalactites, stalagmites, draperies and flowstones; they have a spherulitic aggregate texture and grow together in a gravitational water environment.

Crystallization environments evolve over long periods of time, becoming successively drier until a new wet phase marks the start of the next crystallization cycle. These cycles are not always complete, but the sequence remains the same. An *ensemble* is a sequence of textures that replace each other within a single crystallization cycle (Fig. 10). A typical sequence for limestone caves fed by meteoric water is tufaceous stalactite-stalagmite kora, crystalline calcite stalactite-stalagmite kora, corallite kora, antholite (fibrous aggregates) kora (Stepanov 1971). More complex speleothems, the product of more than one crystallization cycle, lack through regularities and must be studied using petrographic techniques. In ontogeny terminology, they are classed as rocks.

THE TERMINOLOGY OF ONTOGENY

Ontogeny is a relatively young scientific discipline whose terminology is constantly being revised. For non-Russians, the main reference source remains the 1965 English translation of *Ontogeny of Minerals* (Grigor'ev 1961). This book divides the mineral world into individuals and aggregates, but the term aggregate is used very loosely (e.g. a split crystal is described as an aggregate of subindividuals). The modern formulation of aggregate, based on textural regularities, was devised by Stepanov (1970, 1997). Grigor'ev always describes selection between individuals as *geometric selection*, including what we now recognise as *substrate selection*. New definitions separating these selection mechanisms were offered by Self and Maltsev (1999).

The terms *corallite* and *crystallictite* were first used (Serban et al. 1961) to describe certain speleothem types in Romanian caves, but these terms only gained international recognition after Stepanov (1971) adapted them for ontogeny. Students of ontogeny should therefore be aware of the origin and publication date of any piece of writing, as the terminology will reflect this. The most complete guide to the terminology in current use is Self and Hill (2003).

REFERENCES

Grigor'ev, D. P., 1961, Ontogeny of minerals: Lvov, Izdatel'stvo L'vovskogo Univ. In Russian. English translation 1965, Israel Program for Scientific Translations, 250 p.

Hill, C. A., & Forti, P., 1997, Cave minerals of the world (2nd ed.): National Speleological Society, Huntsville, Alabama, 463 p.

Maleev, M. N., 1972, Diagnostic features of spherulites formed by splitting of a single-crystal nucleus. Growth mechanism of chalcedony: Tschermaks Mineralogische und Petrographische Mitteilungen, v. 18, p. 1-16.

Maltsev, V. A., 1996, Sulphate filamentary crystals and their aggregates in caves: Proceedings of the University of Bristol Spelaeological Society, v. 20, n. 3, p. 171-186.

Maltsev, V. A., 1997a, A model of structure and genesis for the gypsum "nest" found in the Geophysicheskaya Cave (Kugitangtou Mountains, Turkmenistan): Journal of Cave and Karst Studies, v. 59, n. 2, p. 87-90.

Maltsev, V. A., 1997b, Overview of cave minerals onthogeny: Proceedings of the 12th International Congress of Speleology, La Chaux-de-Fonds, Switzerland, v. 1, p. 219-222.

Maltsev, V. A., 1997c, Stalactites, crystlactites, corlactites, tuflactites – 4 types of "stalactite-like" formations, generated from crystallization environments with different physical properties: Proceedings of the 12th International Congress of Speleology, La Chaux-de-Fonds, Switzerland, v. 1, p. 267-270.

Maltsev, V. A., 1998, Stalactites with "internal" and "external" feeding: Proceedings of the University of Bristol Spelaeological Society, v. 21, n. 2, p.149-158.

Moore, G. W., 1952, Speleothem – a new cave term: National Speleological Society News, v. 10, n. 6, p. 2.

Moore, G. W., 1962, The growth of stalactites: National Speleological Society Bulletin, v. 24, n. 2, p. 95-106.

Self, C.A., & Hill, C.A., 2003, How speleothems grow: An introduction to the ontogeny of cave minerals: Journal of Cave and Karst Studies, v. 65, n. 2, p. 130-151.

Self, C. A., & Maltsev, V. A., 1999, Translators' note: Cave Geology, v. 2, n. 4, p. 193-195.

Serban, M., Viehmann, I., & Coman, D., 1961, Caves of Romania. Meridiane, Bucharest. In Romanian, Russian, French, and German editions.

Slyotov (Sletov), V. A., 1985, Concerning the ontogeny of crystallictite and helictite aggregates of calcite and aragonite from the karst caves of southern Fergana: Novye Dannye o Mineralakh CCCP (New Data on Minerals), "Nauka", Moscow, , v. 32, p. 119-127. In Russian. English translation 1999, Cave Geology, v. 2, no. 4, p. 196-208.

Stepanov, V. I., 1970, On the genesis of so-named "collomorphic" mineral aggregates, in Ontogenetic methods of studying minerals: "Nauka", Moscow, p. 198-206. In Russian.

Stepanov, V. I., 1971, Crystallization processes periodicity in karst caves: Trudy Mineralogicheskogo Muzeya imini A.E. Fersmana, Moscow, n. 20, p. 198-206. In Russian. English translation, 1999, Cave Geology, v. 2, no. 4, p. 209-220.

Stepanov, V. I., 1997, Notes on mineral growth from the archive of V. I. Stepanov (1924-1988): Proceedings of the University of Bristol Spelaeological Society, v. 21, n. 1, p. 25-42.