SPELEOTHEMS OF AEROSOL ORIGIN: DISCUSSION

VLADIMIR A. MALTSEV
VNIIGEOSYSTEM Institute, Varshavskoye shosse 8, Moscow 113105, RUSSIA

The aerosol model of speleothem origin suggested by Klimchouk and others (1995) contradicts physical principles, because aerosol generation driven by radiation from the decay of radon gas required for this model would accumulate lead and other heavy metals in unrealistic and never-observed quantities. The aerosol hypothesis was offered as an alternate to mechanisms based on vapor condensation and thin-film evaporation. The reasons were intuitive-if something looks like hoarfrost, it must have a similar origin. But the condensation, thin-film, and aerosol environments have very different properties. In the cases of condensation and thin-film evaporation, the curvature of the depositional surface controls the process (Jabin, 1979; Stepanov, 1971). Following the Curie principle, this results in an inverse-conical symmetry for the mineral deposit in the case of condensation, and a conical symmetry in the case of evaporation. The Curie principle says that as long as a mineral aggregate is considered a product of some crystallization environment, then its depositional symmetry is a reflection of the environment's mass-transport symmetry (Stepanov, 1971).

In the aerosol-precipitation case, the surface geometry doesn't affect the process, only its orientation relative to the vertical or to the wind direction. This results in cylindrical symmetry for the deposit. Figure 1 shows vector diagrams of speleothem growth for these cases. In these diagrams, we can note an interesting feature. In analogy with the ice case of condensation-crystallization, real ice hoarfrost shows symmetry and growth speeds corresponding not with the condensation-controlled environment, but with an evaporation-controlled environment. The supply is condensation controlled, but the crystallization is really evaporation controlled. Both condensation and crystallization of water release much heat, and when the growth is fast, the thermal conductivity of both the ice and the surrounding air is insufficient to remove this heat. On the other hand, evaporation can remove a significant part of the heat. So, if the humidity allows condensation on depositional surfaces with a low relief, and at the same time allows evaporation from surfaces with a high relief, we receive the pattern seen in the figure. The mass transport from condensation areas to evaporation areas goes through a "quasi-liquid" phase on the ice surface (Parungo, 1983). This example clearly shows the difference between the supply mechanism and the crystallization mechanism that is even more significant for the aerosol case.

Several mechanisms are known to generate aerosols in caves. The most common mechanisms involve splashing from water drops and streams (Mavludov & Morozov, 1984; Gadoros & Cser, 1986), vapor condensation (Zamorsky, 1955), and the falling of small particles from the ceiling (Pashchenko & Sabelfeld, 1992).

Klimchouk and others (1994, 1995) suggested a new mechanism for aerosol generation in caves. This mechanism involves ions and particles knocked out from the gypsum rock by alpha particles and reactive atoms, produced by the fission of radon atoms. They consider that this aerosol generates gypsum crystalline crusts, hoarfrost, "snow," rims, and hollow stalagmites.

Indeed, some alpha particles coming from radon gas have enough energy (up to 7 Mev) to knock out ions and gypsum molecules. This cannot be said about "reactive atoms", however. Simple consideration of Newtonian mechanics shows that a "reactive atom" has kinetic energy about 2500 times lesss than that of the alpha particle. So, we will consider herein only the possible effects of alpha particles. The probability of the alpha particle knocking something out is very low, but we'll ignore this and let the probability equal 1. We will, however, use the geometric considerations that only about 1/3 of the particles move in a proper direction to hit the walls, and only those originating 1 to 3 cm from the walls (the effective distance of alpha particles in air) can reach them. For the gypsum caves at Podolia, that is about 5% of their volume, so only about 1 particle in 60 has a chance to knock something from a wall. In the best case, one Ca2+ ion, taken into the aerosol, balances with 60 ions of lead and other heavy metals, formed originally in aerosol from the Rn decay. For the weight of gypsum crystals in Optimisticheskaya Cave considered to have an aerosol origin, we calculate 12,000 to 35,000 tons of lead. But, of course, no such quantities of lead are known for the Ukrainian caves.

Any lead produced must be precipitated at the points of aerosol precipitation, at just the places where Klimchouk and colleagues search for the aerosol-crystallized gypsum. In those places, much more Pb than Ca must appear, so much more that it would be seen without special study. The Pb/Ca ratio in the places of aerosol precipitation would remain constant at about 60 to 1 for the Ukranian caves with narrow passages, and much greater for others.

Klimchouk and Nasedkin (1994) note that some cave silt and clay contains Pb levels up to 6 times that of the average for the Earth's crust (Gorbunova & Kropachev, 1970). But these are reasonable values, corresponding to the fact that in karst areas most of the short-lived radon gas decays in the caves. But the values are several orders of magnitude less than those that must appear as a result of the aerosol model.

The radiation levels, reported by Klimchouk and Nasedkin (1992), as a basis for this theory, are themselves questionable. Maltsev, et al. (1995) compare such data for the Kugitangtou caves, with data from other sources, and from their own measurements. These data, well correlated between the sources, are 3 to 8 times lower, and show nothing unusual. Values ranged from 5-8 mkr/h in deep areas to 20-70 mkr/h in main galleries, where the radioactivity comes from clay, brought from the surface. The only possible reason for this, other than possible methodological error, is that there was a short radon gas concentration increase before the earthquake that happened in 1990 on the fault, intersected by caves.

Klimchouck and others (1995) printed a compilation of the aerosol quantity in caves. But cave air is an unstable system. Any external heat creates a zone of condensation around it. An explorer generates lots of aerosols. All cavers can see fog around themselves. A proper aerosol-measuring instrument must be isolated and must be equalized to the cave temperature for at least several hours-in other cases the aerosol measured will be mostly artificial. The only data on aerosol quantity that can be accepted are the data with a proved absence of artificial effects. Photographs of laser-light beams (Klimchouck et al., 1995) show nothing except fog generated by cavers.

Anthropogenic dust pollution is common in caves. Bartenev and Veselova (1987) carried out measurements of dust sedimentation from aerosols in the Cupp-Coutunn Cave System. They proved that the sedimentation speed rises more than 10 times within 20 meters around the main tourist passages, reaching 0.2 mm/year (Oleg Bartenev, pers. comm.).

Klimchouk and others (1995) state that gypsum hoarfrost (attached crystals) from Ukrainian caves were initially believed to be subaquatic, then were considered as thin-film generated, now as aerosol generated. In reality, Moroshkin (1979) proved their thin-film genesis, described all their symmetry features, all the mass-transport physics, and grew such formations in laboratory experiments. His model is in full accord with physics. All the features that Klimchouk and others (1995) outline as evidence of an aerosol origin (location at passage intersections and so forth) show nothing but enforced evaporation at these localities.

Klimchouk and others (1995) postulate that gypsum “snow” or “frost” (loose crystals) from Ukrainian caves precipitate in aerosol droplets. The alternate model is well known (Maltsev, 1990). This “snow” consists of relicts of gypsum frostwork growing on the ceiling from thin films during dry seasons, and falling down during wet seasons (controlled by cave-wind inversion). Epsomite varieties of the same “snow” were known and described long ago, with the same genetic model (Locke, 1842; Hill & Forti, 1986). All the phases of this frostwork generation, dissolution, falling, and subsequent snow dissolution and recrystallization are easily seen, if observed during the course of a year.

With gypsum rims, the situation is slightly more complicated. The alternate model (Hill, 1987) supposes a thin film of the solution moves by the wind at holes in gypsum blocks. Klimchouk and others (1995) wonder how the wind can lift the film several meters upward. In reality, no aerosols are needed, and no wind is needed. The surface tension of water to air is about 73 erg/m2, and the wetting angle of limestone is 5-10 degrees. From this, the capillary pressure in a 0.01-0.1 mm water film is more than 10 atmospheres, thus providing almost unlimited elevation of such a film toward the evaporation area without any external force. A good example may be found in any desert-the salt rises to the surface through the pores (the same capillary forces, but demonstrably without wind or aerosol) from the water table dozens of meters below the surface, and crystallizes on the surface. If a seasonal humidity cycle provides the water supply, rims appear around any niche (condensation is most likely inside and evaporation outside), and the niche itself grows due to dissolution inside. In the Kugitangtou Caves (Cupp-Coutunn, Geophyicheskaya) the rims grow on highly porous massifs of fallen gypsum crusts, and around niches in limestone where redox processes generate gypsum from the limestone (Korshunov et al., 1994).

Hollow gypsum stalagmites are mostly described from the Cupp-Coutunn Cave System, and their genesis is also known and described (Maltsev, 1990, 1993). They grow only where the cave is near a canyon, and a seasonal humidity cycle exists. Gypsum is a very soluble mineral, and a dripping solution cannot stay continuously saturated. During the periods of undersaturation, a drill hole appears, and then condensation inside together with evaporation outside increases the hole size, recrystallizing the stalagmite walls into crystallictites. This process can be seen clearly from corroded inner surfaces, recrystallized wall structure (bushes with conical symmetry), and rims around accidental holes in the walls. Klimchouk and others (1993) consider the Tres Amigos group from Lechuguilla Cave, New Mexico, as the same type of hollow gypsum stalagmites, but they aren’t speleothems at all-they are dissolution remnants (Hill, 1987).

One can now see that all the speleothems referred to by Klimchouk and others (1995) have their explanations in “usual” mechanisms. According to Occam’s razor, a very strong reason is needed for suggesting some new model against proved and workable ones, and the physics of such a new model must be proved.

Some aerosol effects really do exist. They certainly may form cave sediments and may effect the shape of speleothems generated by other mechanisms (like the aragonite trees at Snesznaya Cave). Their study is needed-but genuine studies, not attempts at new speculative explanations for the most beautiful and best studied speleothems.