K-és Bgkut Évkönyv

CONTRIBUTION TO THE ORIGIN OF "EXCENTRIC" CONCRETIONS

by
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Helictites, the so-called "*excentric*" concretions, were discovered early in the history of speleological research (1). They were regarded as rather unfrequent phenomena, but recently have been found not to be rare at all. They are present in most of the karst caves.

In Hungary helictites were first found in the *Béke-cave* at Jósvafő (2). Later on, a number of these concretions were encountered in the *Vass Imre-cave* and the *Kossuth-cave* at Jósvafő, and in the *Szabadság-cave* at Égerszög, too.

Discoverers of the *Meteor-cave* at Bódvaszilas and the *Rákóczi-cave* at Bodvarákó found plenty of helictites there. Based on our theory presented in this paper, we could find a lot of helictites in the *Baradla-cave* as well.

We have started a study on the mechanism of formation of these concretions because of their frequent occurrence in the Hungarian caves and of the contradictions in relevant literature references.

On the basis of morphologic and crystallographic investigations, the helictites can be referred to the following types:

Type 1. These formations are needles sticking out of the wall and the ceiling of the cave. They are often zig-zagged (Fig. 1., 2.). Crystallographic investigations have shown their being single calcite crystals or polycrystals grown together. Their end — the peak of the calcite rhombohedron — is pointed. Their cross-section is mostly a triangle or, in the case of thicker formations, a deformed, rounded triangle. They are mostly colourless and transparend and never contain capillaries inside. The axis of the concretions is axis *c* of calcite. Helictites of this type are encountered on the walls of separate caverns with a slow, rising air-current (Fig. 3., 4.).

Type 2. White, frequently opalescent claspers, bent usually upwards (Fig. 5., 6. and 7.).

Their cross-section is often irregular, but sometimes triangular. They always contain capillaries inside. They are calcite crystals and the orientation of axis *c* is always that of the capillary. They occur along cracks (Fig. 8.), stalactites, tubed stalactites, and other concretions in caves (Fig. 16.).

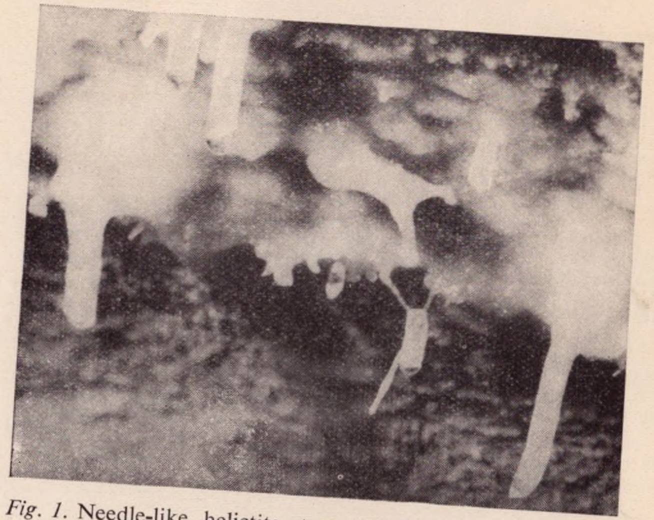

Fig. 1. Needle-like helictite, type 1. Vass Imre-cave, Jósvafő

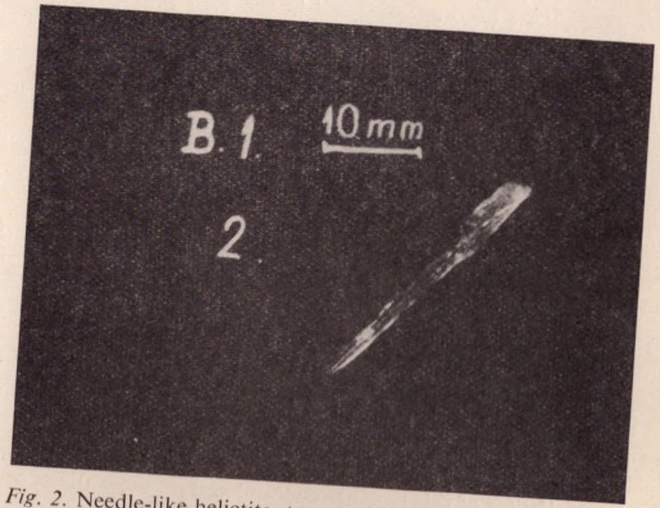

Fig. 2. Needle-like helictite, type 1. Rákóczi-cave, Bódvarákó

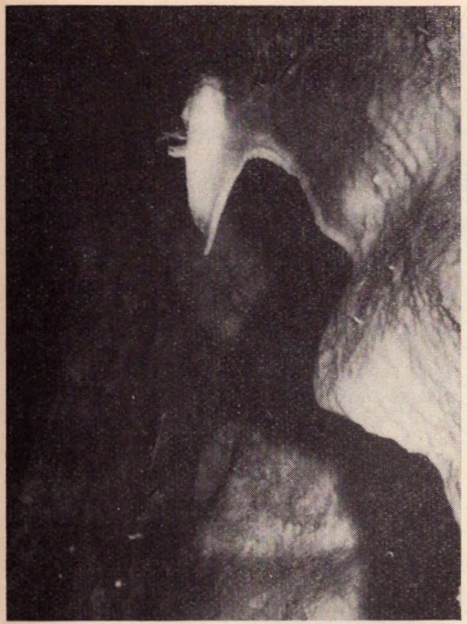

Fig. 3. Settlement of helictites, type 1. Vass Imre-cave, Jósvafő

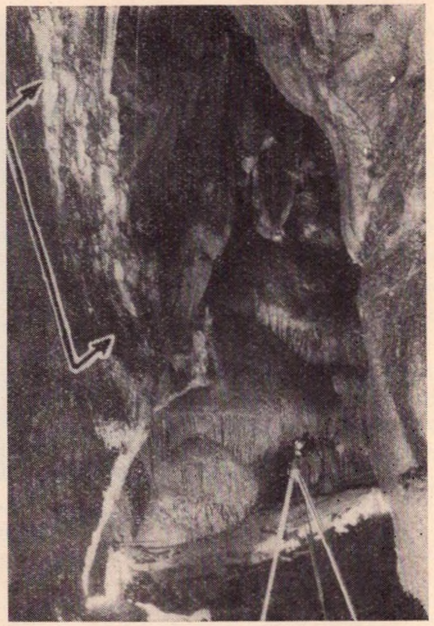

Fig. 4. Settlement of helictites, types 1. and 2. Vass Imre-cave, Jósvafő

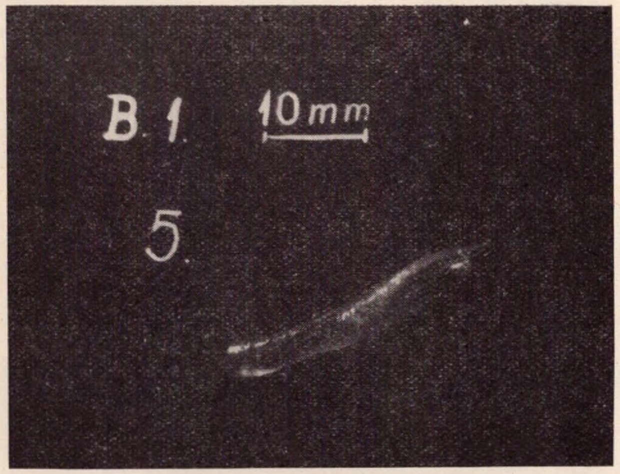

Fig. 5. Capillary containing helictite, type 2. Rákóczi-cave, Bódvarákó

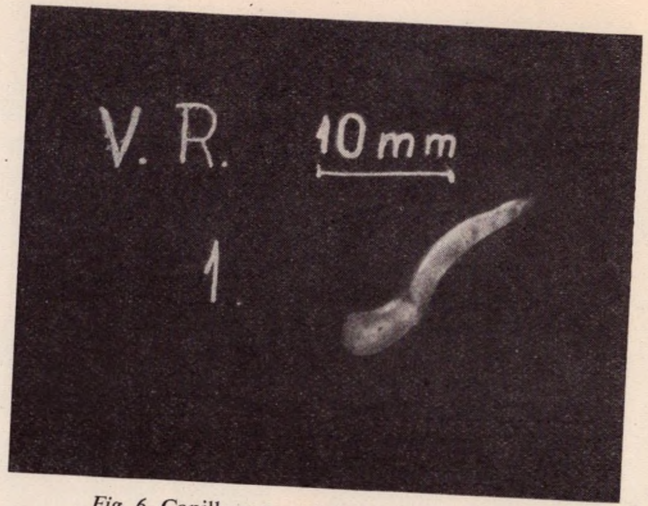

Fig. 6. Capillary containing helictite, type 2.
Vass Imre-cave Jósvafő

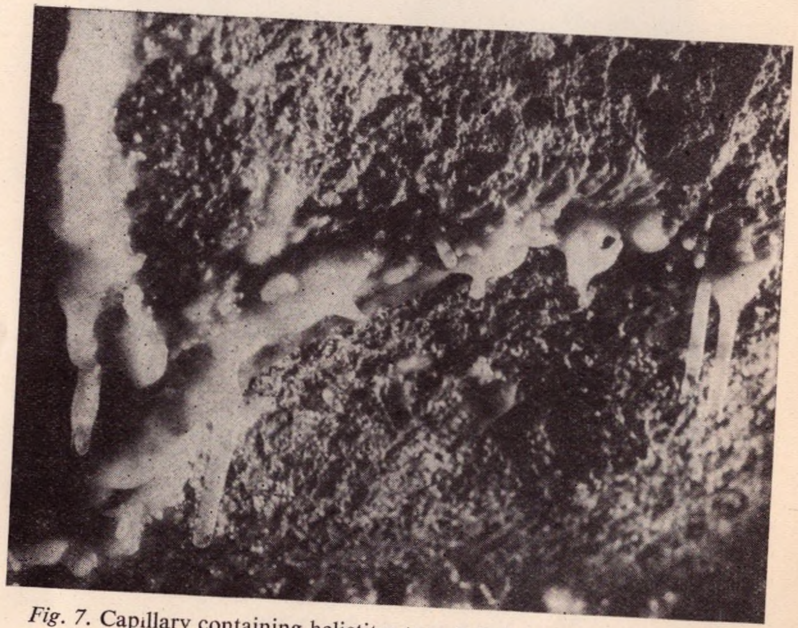

Fig. 7. Capillary containing helictites type 2. Rákóczi-cave, Bódvarákó

Fig. 8. Settlements of helictites, type 2.
Vass Imre-cave, Jósvafő

Type 3. White, transparent stalactites without an inner capillary or tube (Fig. 9., 10.). They are composed of single calcite crystals of circular cross-section. A water drop is hanging on their tip having one or two faces. The crystallographic axis *c* does not always coincide with the direction of growth. Helictites of this type occur on thin bridges, on the lower portion of *baldachins*, mostly in upper corridors, where the air-current is intensive.

Type 4. These formations are complex. The majority of helictites belong to this type. The base of such a helictite is, as a rule, like types 2 or 3, but growth is rather similar to that of type 1 (Fig. 11., 12. and 13.).

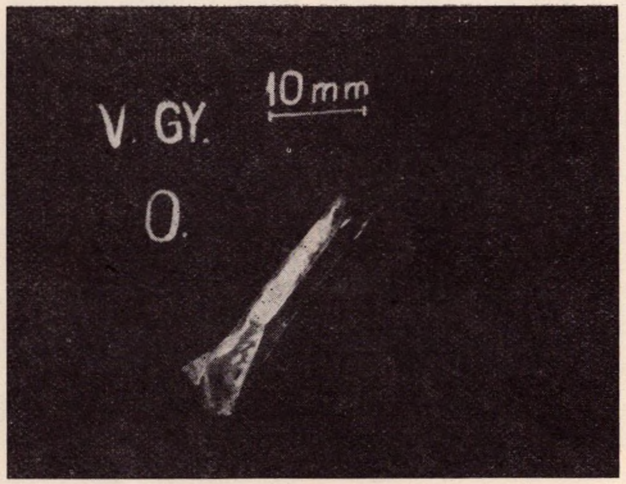

Fig. 9. Helictite, type 3. Vass Imre-cave, Jósvafő

Fig. 10. Settlements of helictites, type 3. Vass Imre-cave, Jósvafő

Fig. 11. Settlement of combined formations.

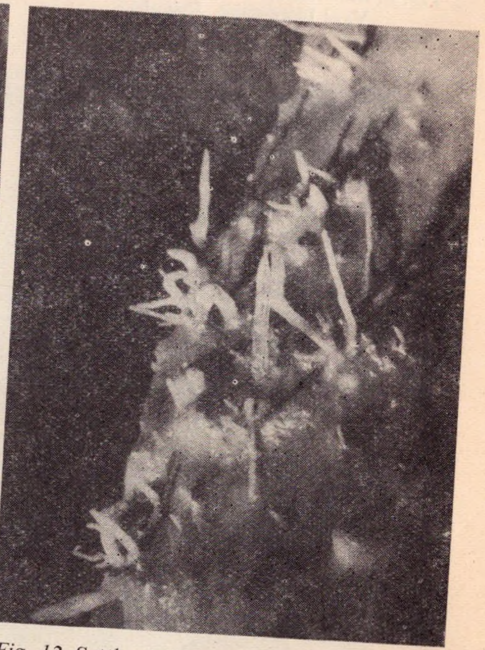

Fig. 12. Settlement of combined formations.

Vass Imre-cave, Jósvafő

Morphology of settling and habit of helictites were studied by photographic methods. Angles of inclination were measured by reflexion goniometer. The etch splits after etching with 10% acetic acid and the split patterns have been studied under polarization microscope with a magnification of 100 x.

The concretions contain Mg (0–2%) and traces of Ba, Sr, Fe, Si and Al, like the water dropping from the stalactites does. This analysis was done by spectroscopic methods (3).

X-ray analyses showed that the examined concretions contained no aragonite.

The results of observations on field and of laboratory experiments have been compared with information from literature references and on these bases an attempt has been made to find the most probable explanation of the phenomenon. A short rewiev of recent literature on helictite formation will be given below.

PRINZ (1) and TROMBE (5) have pointed out that the helictites contain a lot of lattice defects. These have been regarded to initiate irregular growth. VIEHMAN (4) found that the air-current had a marked effect on the formation of bent concretions. JAKUCS (2) tried to explain this phenomenon by the effect of water spirting out of cave wall under high pressure. Others attempted to explain this phenomenon by the effect of bacteria (7). GÈZE (6) and VIEHMAN (4) interpreted the formation of helictites by the capillary effect.

The cave walls cannot be regarded as culture media for organisms, the less so the upper, dry, parts of the walls, where helictites can mostly be found. Thus it is doubtful whether the effect of bacteria is significant.

The role of the air-current cannot be considered a main effect, as the orientation of the needles, etc. is very diverse even within a single settlement (Fig. 13.).

The presence of dislocations is due to growth and cannot be responsible for curvature, as will be shown later in this paper.

Capillary effect has been referred to by various authors as the main agent producing helictites. Relying on the works of GÈZE (6) and VIEHMAN (4), we can summarize two versions of this theory as follows.

According to VIEHMAN, there is a monomolecular film of karst water on the surface of a helictite and it can be removed by capillary action. Since capillary force is much greater than the force of gravity, the film may also move upwards, giving rise to helictites (4).

Fig. 13.
Settlement of combined concretions.
Vass Imre-cave, Jósvafő

GÈZE proposed that the wall of a cave is full of capillary tubes in which there is a very slow water-current. At the tip of such a tube no water-drop can be formed because of the low rate of water movement. Therefore, crystals will grow at the tip of the tube which will grow longer this way (6). The curvature of the concretions is determined by crystal growth.

Let us make some mathematical investigation into these theories. Fig. 14.

Let us assume that a fissure in limestone contains a karst water layer h cm high. This latter is in communication with the cave room through a capillary tube l cm long, having a radius of r cm. Since r is short, it can be written in terms of the Hagen-Poiseuille law:

$$w = \frac{2\,\Delta P}{16\,\eta l}\, r^4 \;[\mathrm{cm}^3\,\mathrm{sec}^{-1}] \tag{1}$$

where w =The outflow velocity of diffusing water $[\mathrm{cm}^3\,\mathrm{sec}^{-1}]$.
ΔP =pressure loss due to friction $[\mathrm{dyn\,cm}^{-2}]$
η =viscosity of water at 11°C=1.4 10^{-2} $[\mathrm{gcm}^{-1}\,\mathrm{sec}^{-1}]$.

Under stationary conditions we can write

$$\Delta P = Ph + Pc,$$

where Ph is hydrostatic pressure,

$$Ph = \varrho g h \;[\mathrm{dyn\,cm}^{-2}]$$

and Pc is the pressure caused by capillary force,

$$Pc = \frac{2\gamma}{r} \;[\mathrm{dyn\,cm}^{-2}].$$

Thus

$$w = \frac{\varrho g h\, r^4 + 2 r^3 \gamma}{8\, l \eta} \;[\mathrm{cm}^3\,\mathrm{sec}^{-1}] \tag{2}$$

where ϱ = density of water=1 $[\mathrm{gcm}^{-3}]$,
g = gravitational acceleration = = 9.81 $[\mathrm{cmsec}^{-2}]$,
γ = surface potential between limestone and water = 74 $[\mathrm{gsec}^{-2}]$.

Using these numerical values, we obtain:

$$w = \frac{87.6\, r^4 h + 132\, r^3}{l} \;[\mathrm{cm}^3\mathrm{sec}^{-1}]. \tag{3}$$

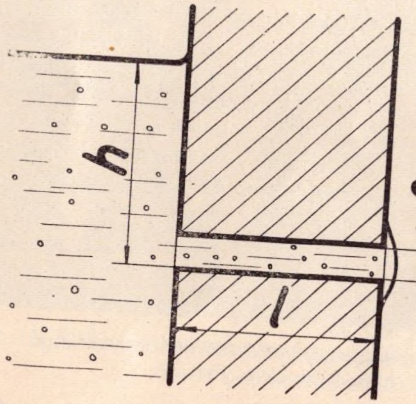

Fig. 14.
The modell of capillary and its measures

In the case of $r=10^{-2}$ the hydrostatic pressure does not dominate up to $h=10^3$ cm (10 m). In our caves no coherent water body higher than 10 m can be supposed to exist. Equation (2) is valid only for laminar flow which, however, is the most probable case.

Since the observed diameters of capillaries were much less than 0.1 mm (10^{-2} cm), the hydrostatic pressure cannot be responsible for the rate of yield at the tip of the capillary. So the effect suggested by JAKUCS cannot play any important role in the formation of helictites.

The water having been oozed through the capillary runs in all directions on the surface around the tip of the capillary. This spread must be asymmetrical, because the force causing the spread of water is the vectorial sum of the capillary force and the force of gravity. So the upper part of the surface will not be wetted as much as the lower. The rate of deposition of $CaCO_3$ is controlled by the rate of diffusion of CO_2 from the solution.

According to the law of diffusion,

$$\frac{dn}{d\tau} = Df\,\frac{\Delta c}{d} \tag{4}$$

where $\frac{dn}{d\tau}$ = number of moles of CO_2 leaving the layer in unit time in $[\mathrm{molesec}^{-1}]$,
D = overall diffusion constant of CO_2 in water and air in $[\mathrm{cm}^2\mathrm{sec}^{-1}]$,
Δc = difference in concentration of CO_2 between the solution and the air surrounding it, $[\mathrm{molecm}^{-3}]$,
d = thickness of the layer in [cm].
f = surface of the layer in $[\mathrm{cm}^2]$.

The diffusion constant in the gas phase is comparatively high with respect to solution, so that calculation may be restricted to the aqueous phase.

After integrating:

$$1n\left(\frac{n_0}{n}\right) = D_1\,\frac{f\tau}{dv} \quad \text{since } c = \frac{n,}{v} \tag{5}$$

where n_0 = number of CO_2 moles in the solution at 0 time in [moles],
n = number of CO_2 moles in the solution at τ time in [moles],
d = thickness of the layer in [cm],
v = volume of the layer in $[\mathrm{cm}^3]$,
D_1 = diffusion constant of CO_2 in water in $[\mathrm{cm}^2\mathrm{sec}^{-1}]$.

If $\tau_{1/2}$ be the time needed to decrease the concentration of CO_2 in the solution to its half and if $D_1=1.16\;10^{-6}$ (8), the following result will be obtained:

$$\tau_{1/2} = 5.9\;10^5\, d^2 \;[\mathrm{sec}]. \tag{6}$$

It is obvious that for a layer less than 10^{-2} cm thick, the rate of deposition is very high. It is very difficult to imagine that a monomolecular layer of solution could transport any large amount of $CaCO_3$ to the top of a helictite.

The distribution of the probability of deposition, represented by the amount of $CaCO_3$ around the tip of a capillary, is shown in Fig. 15. The rate of deposition is higher on the lover side than it is on the upper side, so that the helictite tends to bend progressively upwards (Fig. 16., 17.). By analogy, this effect has been termed "*volcano effect*". Helictites of this kind belong to type 2.

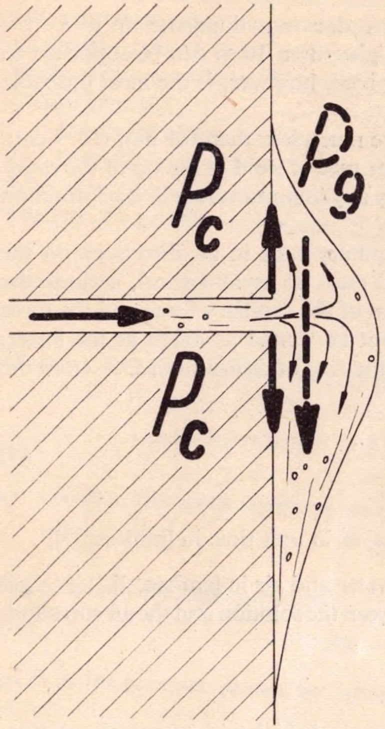

Fig. 15. The distribution of deposition probabilities around the capillary

Nevertheless, surface capillarity may produce depositions of $CaCO_3$. These belong to type 3.

The water oozing down the *baldachins* form drops. This water may not be supersaturated, since it contains only a small amount of $Ca(HCO_3)_2$. It may evaporate into the air-current, and $CaCO_3$ will deposit on the ceiling. This water migrates through capillary action on the surface of a helictite and accumulates at its tip (Fig. 18.).

The formation of helictites of type 1 cannot be explained by the above mechanism.

The question can be answered on the ground of analogy. Icicles and stalactites are so much the same. Helictite needles resemble hoarfrost. The authors have attempted to demonstrate that possible subaerial deposition may result in the production of helictites.

The *Tyndall* phenomenon in the caves is well known. If we use a well-focussed lamp. we can see a lot of lighting points in the light-beam. These are minute drops of karst water. These drops are very great in number, as shown by measurements of Ca^{2+} and Mg^{2+} contents in the air of the *Béke-cave* at Jósvafő. Air is like an aerosol.

Water does evaporate in the caves despite the presence of water-drops in the air. We observed that on the glass surface of our instruments held for some time in the caves, water drops were precipitated, and evaporated then in a few minutes. This points to the seemingly antagonistic fact that the air is not completely saturated with water vapour in spite of containing plenty of droplets.

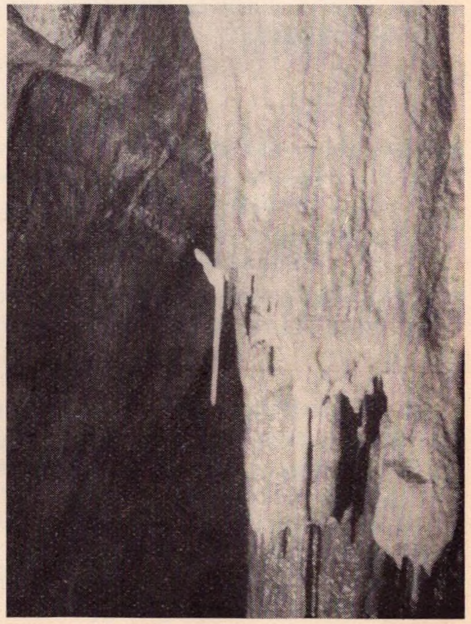

Fig. 16. Deposition due to *volcanic* effect. Vass Imre-cave, Jósvafő

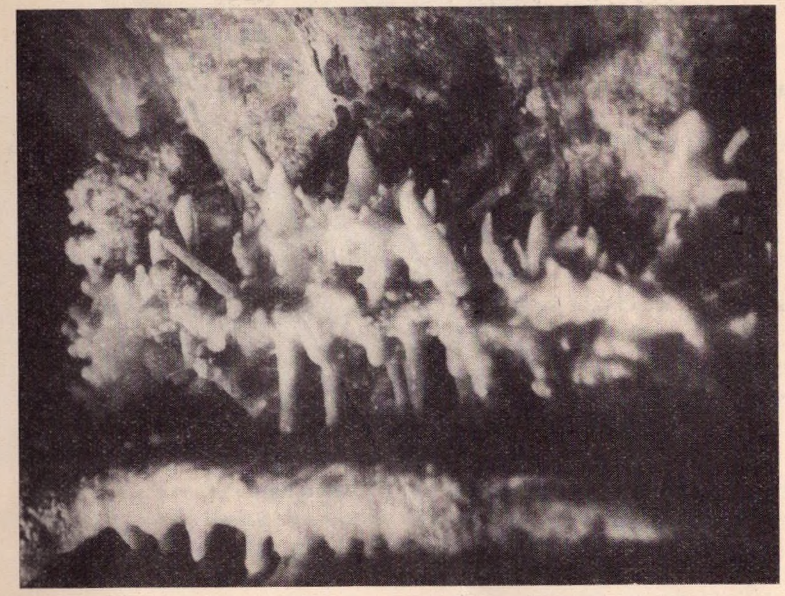

Fig. 17. Deposition due to *volcahic* effect. Vass Imre-cave, Jósvafő

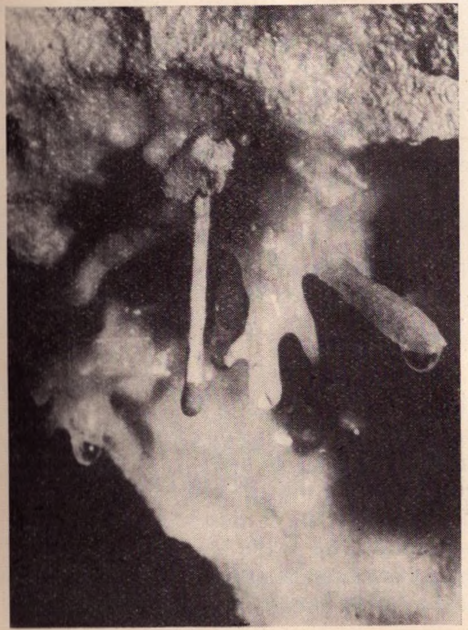

Fig. 18. Deposition due to outer capillarity. Vass Imre-cave, Jósvafő

To account for this observation, we have calculated the time necessary for the complete evaporation of a water-drop having a radius of r_0 cm. Water concentration in the air is C_0 at large and C_s close to the drop — temperature — controlled saturation concentration. The concentration gradient responsible for diffusion is ΔC. Eq. (7) is used for calculation.

$$\frac{dn}{d\tau} = -Df\frac{dc}{dx} \qquad (7)$$

The number of water moles evaporated is

$$n_l = \frac{4(r_o-r)^3}{3}\pi\frac{\varrho}{M}\,[\text{moles}], \qquad (7a)$$

where r_0 = original radius of water drop, in [cm],
r = eventual radius of water drop at τ time, in [cm],
ϱ = density of water, in [gcm^{-3}],
M = molecular weight of water, in [$gmoles^{-1}$].

The number of water moles diffusing through the gas phase is

$$n_g = \frac{4\,(x-r)^3\pi}{3{,}2}(C_s-C_0) = \frac{4\,(x-r)^3\pi}{6}\,\Delta C \text{ moles} \tag{8}$$

where x = radius of a sphere, where concentration in the air is C_0, in [cm].

Since $n_l=n_g$, we obtain for r the following results:

$$r = \frac{Kx-r_0}{K-1}\ \text{[cm]},$$

where $K = \sqrt[3]{\dfrac{\Delta CM.}{\varrho}}$

Since $f=4\,r^2\pi$, after substituting in Eq. (7), we obtain

$$\frac{(r_0-x)^3}{(Kx-r_0)^2}\,dx = -Dd\tau \tag{9}$$

The Eq. 9 can be solved by step-by-step integration.
This will yield the following result:

$$\tau = \frac{r^2{}_0}{D}\,Q,$$

where Q contains ΔC in the form of

$$Q = \frac{1}{k(K-1)} - \frac{3}{2K^2} + \frac{3(K-1)}{K^2} + \frac{3(K-1)^2}{K^3}\log\frac{1}{K-1}$$

D = diffusion constant of water in the air (0.102 $cm^2\,sec^{-1}$ according to (8).

(The decrease of water-vapour pressure due to the increase of concentration has not been taken into consideration.)

Using this correlation, we obtain the following result

$$\tau=1.67\ 10^6\ r^2 \text{ sec at } 90\% \text{ rel. hum.} \tag{10}$$

All these calculations are valid for 10°C.

Since the rate of sedimentation of drops *(Stokes law)* is

$$Vr=1.22\ 10^4\ r^2 \text{ cm sec}^{-1},$$

a water drop having a radius of 10^{-2} cm remains in state of floating in the air for an hour, and its rate of settling is as low as 1 [$cmsec^{-1}$] (at 95% rel. hum.).

The karst water contains some 400 mg of $CaCO_3/1$, thus a drop having a radius of about 10^{-2} cm contains about 10^{13} molecules of $CaCO_3$. If this is completely precipitated, a crystal of about 10-μ size will be formed. This is the lowest crysta l size of a substance as soluble as $CaCO_3$ that will precipitate from a drop of less than 10^{-2} radius, so that the drop remains a supersaturated solution. Should the value of r diminish

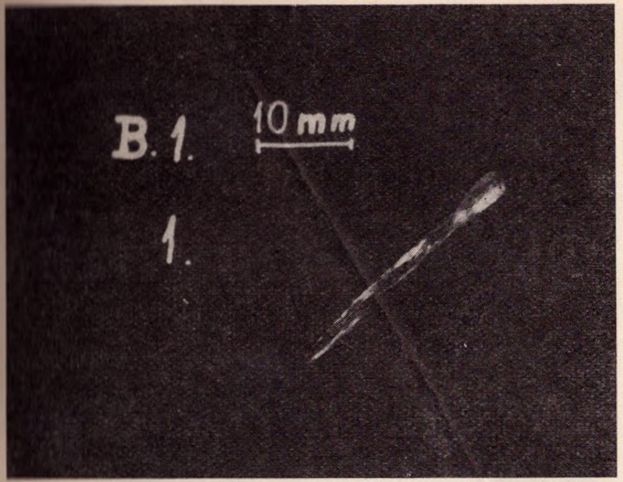

Fig. 19. Helictite deposited by aerosol effect, Rákóczi-cave, Bódvarákó

to one tenth of the initial figure, so during evaporation the vapour tension of the solution will decrease by 10% and evaporation will no longer continue even at a relative humidity of 90%! These water drops will go on floating in the air. The *Tyndall* phenomenon permits to recognize drops having radii of about 10^{-3} to 10^{-5}cm.

When a drop touches the wall, $CaCO_3$ will immediately precipitate. Since the rate of growth of a calcite crystal is greatest along axis c, oriented needles will grow on the wall (Fig. 19., 20. and 21.).

Drops dispersed in the air are mostly electrically charged. The cave is an electric conductor, so that the interior of the cave is a field free from potential. The electrically charged particles moving in this field can precipitate on the surface of all salients issuing drops into the field. This effect may play an important part in the deposition of drops on the tips of helictites. The formation of helictites belonging to type I can be accounted for by this phenomenon.

We have attempted at making helictites grow by this mechanism. Conductor needles have been built on the wall of the cave, and the increase of weight of the helictites has been measur-

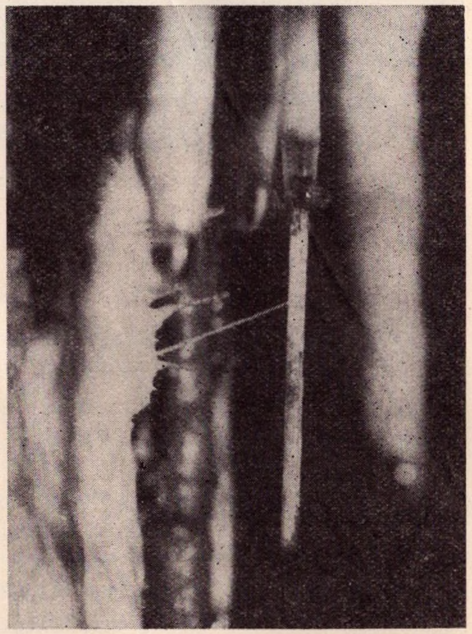

Fig. 20. Deposition due to *aerosol* effect, Vass Imre-cave, Jósvafő

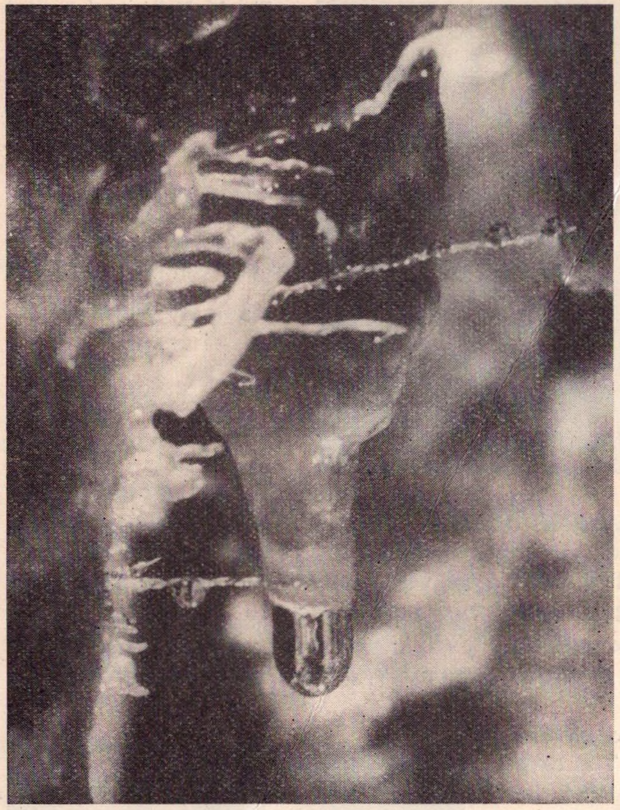

Fig. 21. Deposition due to *aerosol* effect, Rákóczi-cave, Bódvarákó

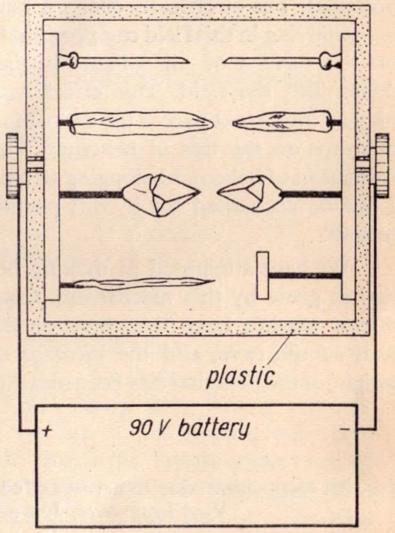

Fig. 22. Frame for the experimental study of growth helictite

ed (Fig. 22., 23.). The measurements are being carried on. Observations concerning the growth of natural helictites have also been continued.

In Fig. 24. and 25. it can be readily seen that the needles grow very quickly. Fig. 24. was photographed in November 1964, Fig. 25. in April 1965. The difference between the two figures is considerable, though they cannot be held for sound evidence to warrant the above theory.

The effect being considered has been termed "*aerosol effect*", the resulting helictites – "*cave hoar*".

The above theory is not inconsistent with any natural law. It is very plausible but requires to study the magnitude of the effects involved.

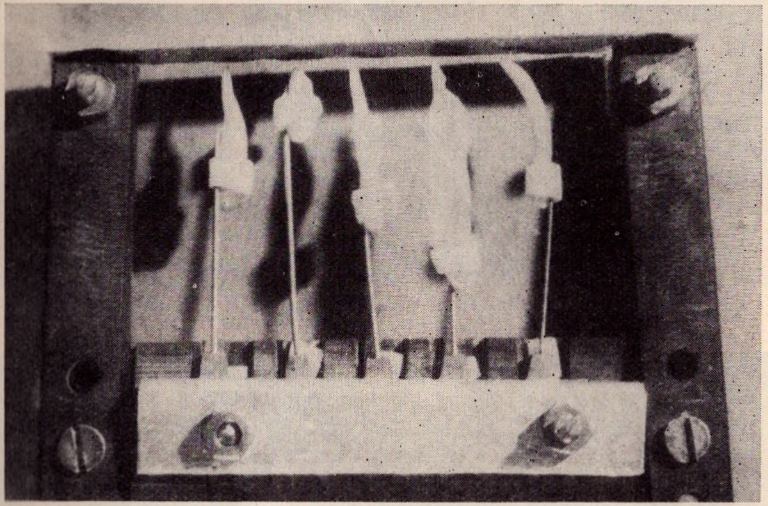

Fig. 23. Instrument for studying the growth of type 1. Helictites in the cave

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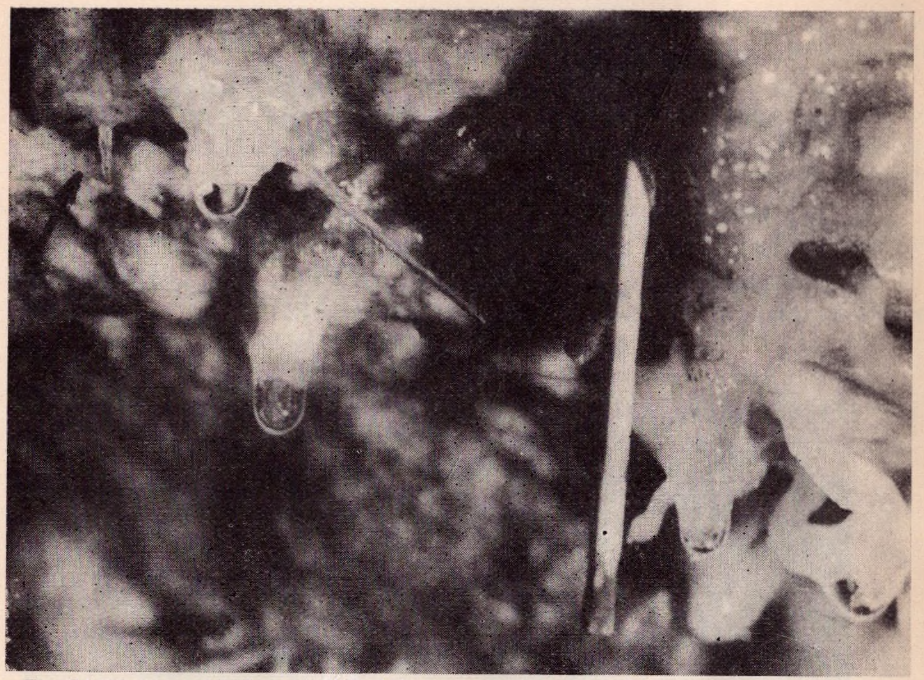

Fig. 24. The growth of needles like helictites. Shot was made on November 12. 1964. Vass Imre-cave, Jósvafő.

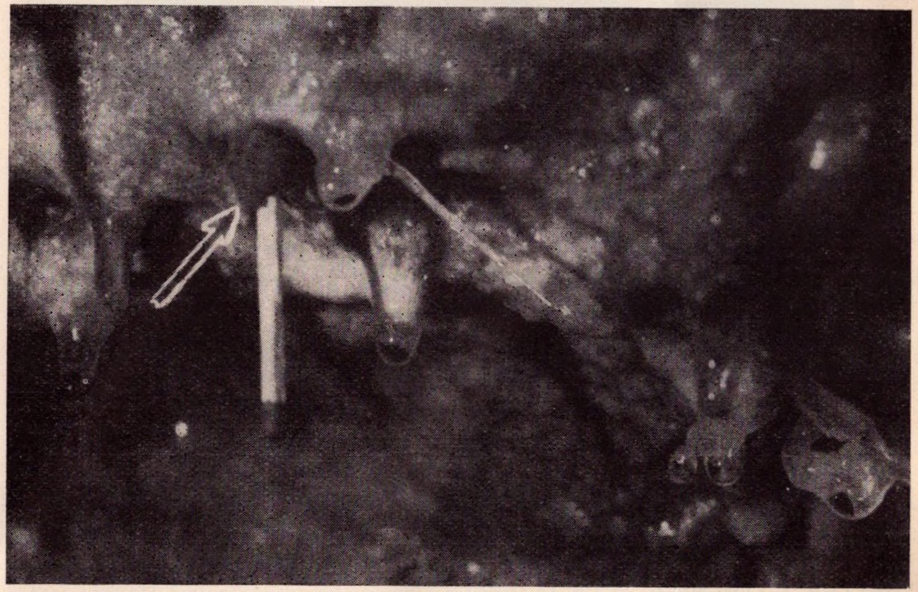

Fig. 25. The growth of needles like helictites. Shot was made on April 4. 1965. Vass Imre-cave Jósvafő

BEITRAG ZUR GENESE VON EXZENTRISCHEN KONKRETIONEN

von

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Zusammenfassung

Die exzentrischen Bildungen (Heliktite) können — auf Grund ihre morphologischen und kristallographischen Eigenschaften — in drei Hauptgruppen geteilt werden. Wir haben festgestellt, dass die in der Literatur, bezüglich des Wachstumsmechanismus der Heliktite veröffentlichten Theorien die Entstehung der Heliktite nicht genügend erklären können. Die Kappilar-Theorie wurde einer mathematischen Prüfung unterworfen und es ist nachgewiesen, dass die Entstehung der eine innere Kapillare enthaltenden Bildungen auf Grund dieser Theorie begründet werden kann. Das oberflächliche Sickerwasser bringt — durch eine langsame Verdampfung — die keine Kapillare enthaltenden Heliktite in Form von massiven Stalaktiten mit Kreisquerschnitt zustande. Wir konnten die Bildung der keine innere Kapillare enthaltenden, nadelförmigen Formationen auf Grund von Analogien erklaren. Es wurde mit der Hilfe einer mathematischen Analyse nachgewiesen, dass in der Luft der Höhlen das Vorhandensein eines stabilen Aerosols möglich ist, und diese Heliktite aus dem im Aerosol gelösten Kalziumhydrokarbonat ausscheiden.

К ВОПРОСУ ФОРМИРОВАНИЯ ЭКСЦЕНТРИЧЕСКИХ СТЯЖЕНИЙ

Ф. ЧЕР — Л. МАУХА

Резюме

Эксцентричные образования (геликтиты) подразделяются на основании своих морфологических и кристаллографических особенностей на три основные группы. Авторы установили, что опубликованные в литературе теории относительно механизма роста геликтитов не могут удовлетворительно объяснить формирование последних. Авторы подвергли математическому исследованию теорию капиллярности и показали, что образование имеющих внутреннюю капиллярность образований может обосновываться этой теорией. Просачивающиеся воды с поверхности медленным испарением создают плотные сталактитообразные геликтиты, без капиллярной структуры и с круглым сечением. Оформление игловидных, не содержащих внутренней капиллярной структуры образований может объясняться на основе аналогии. По результатам математического анализа авторы показали, что возможно присутствие в воздухе пещер стабильного аэрозоля и эти геликтиты осаждаются из растворенного в аэрозоле бикарбоната кальция.

PRI LA ORIGINO DE EXCENTRAJ STALAKTITOJ

F. CSER – L. MAUCHA

Resumo

La ekscentraj stalaktitoj (heliktitoj) estas divideblaj en 3 ĉefajn grupojn, laŭ iliaj morfologiaj kaj kristalografiaj proprecoj. Ni konstatis, ke la teorioj pri la meĥanismo de kreskado de la heliktitoj publikigitaj en la literaturo priskribas nekontentige la estiĝon de la heliktitoj. Matematike ni ekzamenis la kapilaran teorion de la kreskado kaj demonstris, ke la estigo de la formaĵoj havantaj kapilaron estas motivebla laŭ ĉi tiu teorio. La senkapilarajn stalaktitformajn heliktitojn havantajn dikan rondan transversan sekcaĵon estigas la surfaca tralikiĝinta akvo per malrapida vaporigo. La estiĝon de la nadlosimilaj senkapilaraj formaĵoj ni klarigas surbaze de analogeco. Per matematika analizo ni demonstris, ke en la grota aero povas troviĝi stabila aerosolo, kaj ĉi tiuj nadloformaj heliktitoj solidiĝas el kalciohidrokarbonato solvita an aerosolo.