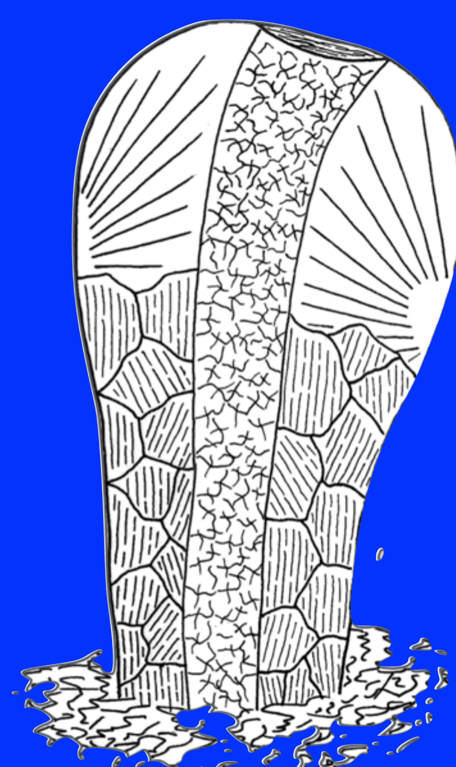
Gheorghe Racoviță Bogdan P. Onac

SCĂRIȘOARA GLACIER CAVE

Monographic study



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Gheorghe RACOVIȚĂ Bogdan P. ONAC

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Foreword

Scărișoara Glacier cave attracted the attention of the great scientist, Emil G. Racovitza, who, in 1927, completed a remarkable monograph concerning the physical speleology of this important natural treasure. Aware of the importance of the research, E. G. Racovitza concluded: *"I think I have shown the great scientific interest presented by the Scărișoara Glacier Cave. Not taking into account the solution of the enigmas presented by the history of the glacier, numerous problems within all the branches of natural history may be thoroughly considered upon this occasion, with the help of periodical or continuous observations and by conceiving experiments*".

Taking this message to heart, the researchers of the Institute of Speleology (M. Șerban, I. Viehmann, Gh. Racoviță), alone or with external collaborators (R. Givulescu, E. Pop, I. Ciobanu, L. Blaga), performed complex studies over several decades on the perennial ice deposit from.

The observations and interpretations made by the speleology researchers from Cluj are a scientific priority, which has to be remarked on this occasion. Today, it is well known that climatic information on the Quaternary period, as well as long-term climatic prognoses, rely on complex research performed by multidisciplinary teams on ice cores extracted from the ice sheet from Greenland and Antarctica. In recognition of the scientific merit of the work of Romanian speleologists, they have been invited to Austria and Norway to study renowned subterranean glaciers.

I am pleased to note that at the first National Symposium on Paleoclimatology (Cluj-Napoca, December 3-4, 1989), organized by the Department of Geology of the University of Cluj, Gh. Racoviță and M. Șerban presented an interesting paper concerning the paleoclimatic fluctuations – in the last 4,000 years – deciphered through the complex study of the perennial ice deposit from the Scărișoara Glacier Cave. The work undertaken by the undersigned to publish the present monograph is in homage to the authors of the work, as well as to their predecessors who toiled for the renown of the Institute of Speleology.

Cluj-Napoca, June 15, 2000

Prof. dr. Iustinian PETRESCU
Department of Geology
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1

Introduction

Among the great diversity of caves, the karstic cavities in the temperate climate and which preserve permanent ice formations represent a very special category. In many cases, they are high altitude shafts (pits/vertical caves), in which ice forms from accumulation of snow on their bottom. Caves containing ice can also be found at average altitudes, but the ice inside them is not due to the external climate conditions, but to a particular ventilation regime that determines a glacial type subterranean topoclimate.

The most remarkable and, at the same time well known of the great European caves that fall under this last category are the famous Eisriesenwelt from the Austrian Alps, its galleries reaching 42 km in length and its ice formations covering a surface of approximately 30,000 m^2, and the Dobšiná from Slovak Republic, in which the total ice volume is estimated at approximately 145,000 m^3.

In Romania, most of the caves hosting underground glaciers are to be found in the Apuseni Mountains. The volume of the ice they shelter is rather small: 30,000 m^3 in the Borțig Glacier Cave, 24,900 m^3 in the Focul Viu Glacier Cave, and only 133 m^3 in the Barsa Glacier Cave (Vălenaș et al., 1977). There is however, an important exception: the Scărișoara Glacier Cave.

The special importance that the Scărișoara Glacier Cave has from a scientific point of view was first outlined by the founder of the Institute of Speleology in Cluj, the renowned biospeleologist Emil Racoviță. In a time when the cave was only partially known, the scientist understood that it offer many various, and very interesting research subjects. He even planned to set up an underground laboratory that would facilitate the development of complex studies.

Emil Racoviță's ideas were the basis for a vast research program completed by the ones who continued his scientific work. Started in 1947 and strongly intensified after 1963, these studies lead to the finding an answer to many of the questions raised by the Scărișoara Glacier Cave. But, as the results obtained in such a great research collective effort are spread in almost 40 scientific papers, a complete presentation of what is essential out of the information accumulated until now is not only justified, but also necessary. This is what the present monograph is trying to accomplish.

2

History

Unlike most caves, Scărișoara Glacier Cave's exact discovery date is unknown. Because of the size of its surface opening, it can be assumed that local inhabitants have known about it for a very long time. Older residents remember that people used to take ice out of the cave in dry summers and melt it for drinking water. It is known that around the middle of the last century it was possible to descend into the Sala Mare of the Glacier on wooden ladders. This is noted in a document with which Empress Maria Theresa authorized the forest administration of the village of Scărișoara to cut down trees in order to repair these ladders.

The first publications referring to the Scărișoara Glacier Cave date from the same period. The oldest ones are tourists' descriptions published by Szirtfi in 1847 and Vass in 1857. Two scientific papers followed which both presented results from an Austrian expedition in the Bihor Mountains financed by Archduke Albrecht. The first paper, published by geologist Karl Peters in 1861, contains a summary description of the cave and its ice stalagmites. Perhaps more importantly, the paper also contains information about the age of the limestone bedrock and their tectonic setting. The second paper, which was printed in 1863, was written by the well-known geographer Adolf Schmidl. This paper contains a more detailed and surprisingly accurate description of the cave, a map, and two schematic profiles. It also mentions the first attempt to explore the deeper reaches of the cave. Shortly after the expedition left the area, Kulmer, the forest warden, climbed down into an abyss which opened from the left side of the gallery next to the entrance. Using wooden ladders tied together, he descended to a depth of 76 m without reaching the bottom.

These early papers are mainly descriptive. Explanation of the processes that make underground ice conservation possible under temperate external climate conditions, and a general response to the many questions raised by the scientific exploration of the Scărișoara Glacier Cave did not start until 60 years later.

The first research of this kind was conducted by the renowned Romanian biologist Emil Racoviță, founder of biospeleology and of the Institute of Speleology in Cluj. During the three years between 1921 and 1923, he visited the cave five times. His findings and the hypothesis he formulated were presented in a monograph published in 1927. It was his only important paper in the field of physical speleology. Emil Racoviță's merits are indisputable. Despite the fact that the cave had not yet been completely explored, he was able to infer that the ice floor reaching beyond the portal was only the visible portion of a deposit that was probably dozens of meters thick. He expressed his opinion that this ice must have been very old; dating from a time when "*ice covered a much greater surface in the area*" (p. 107). He specified that the melting and re-freezing processes created by seasonal variations in air temperature affected only the superficial layer of the deposit. He described in detail the crystalline structure of the ice stalagmites and their cycles during a year. He emphasized the fact that the cave was an accumulator of cold air because "*the winter temperature influences directly and immediately the temperature in the glacier, but this influence stops as soon as the outside temperature exceeds +1°C*" (p. 103). Finally, he pointed out that the Scărișoara Glacier Cave was of special scientific interest that would have justified it as the location of an underground laboratory. Unfortunately, as with many other scientific projects he conceived, this remained an unfulfilled dream. What he did manage to achieve was to place the cave under legal protection. In June 1933 Scărișoara Glacier was the first karst area in Romania to obtain the official status of a natural monument.

A second important event in the research history of the cave was the expedition initiated in 1947 by Maxim Pop, a lawyer and member of the Romanian Touring Club. Rock climbers Gheorghe Bantu and Mircea Gogonea, naturalist Răzvan Givulescu, and speleologists Mihai Șerban and Dan Coman, (who were scientists at the Institute of Speleology), also participated. The results of their expedition were truly spectacular. The descents made on the flanks of the great ice deposit led to the discovery of the two galleries that form the scientific reserves today. The cave's documented length was increased from 160 m to almost 650 m. In addition, the configuration of ice deposits was mapped and the first deductions were made about the paleoclimatic significance of the stratified structure of the ice visible on the sides of the glacier.

The success of the expedition was immediately followed by an another valuable scientific achievement. The pollen analysis that Emil Pop and Ioan Ciobanu performed in 1949, based on vegetable remains extracted from the northern wall of the ice block allowed an estimation of the age of the basal ice layers.

The last and most fruitful stage of the research of Scărișoara Glacier is in the extremely detailed and systematic studies made by the Cluj-Napoca branch of the "Emil Racoviță" Institute of Speleology. This program included observations and monthly measurements on climatology, glaciology, and underground ecology in two stages, each several years long. The first stage, conducted over a five-year period (1963-1968), also included an accurate and detailed topographical survey of the entire cave. The second stage, which lasted ten years (1980-1990), was done with the financial support of the Alba District Council. It intended, among many other objectives, to establish a program for optimum tourist use for the glacier incorporating appropriate modern cave use standards.

These systematic studies are the sources for most of the data in this monograph.

3

Geographic and geologic settings

The Ocoale – Ghețar – Dobrești karst system is part of the Scărișoara karst complex, located in the central area of the Bihor Massif, the core unit of the Apuseni Mountains. The area is a karst plateau bounded on the east and west by Ordâncușa and Gârda Seacă valleys, respectively.

Access to this region is provided by National Road 75 from both Oradea (125 km) and Cluj (146 km), connecting with a county road (18 km) at Gârda de Sus. This latter road is not accessible during winter and early spring time.

The landscape around the Scărișoara Glacier Cave generally consists of rolling summits or isolated massifs, separated one another by several saddles and small karst depressions (dolines, uvalas). These morphological features give the region a chaotic appearance.

Two different hydrographic networks are located within this karst complex. These are the Ocoale Valley – Polița, along which the Ocoale – Ghețar – Dobrești karst system develop, and the Ordâncușa Valley, transformed in its lower third part into an impressive canyon (Fig. 1) (Rusu & Cocean, 1992).

Sinkholes and cave entrances provide moist microclimates for plant species that differ from those found in other parts of this massif.

Most of the terrain is densely wooded, providing a home to a variety of wildlife. Bears, lynxes, wild pigs, and deer's are the most commonly seen mammals.

The traditional architecture and the folklore of the population living on the Ocoale – Ghețar Plateau is worth noting. Wood processing is the primary occupation of the inhabitants of this region.

Ocoale – Scărișoara Karst Depression

With a surface area of 3.6 km^2, the Ocoale Depression is a classical example of the formation and evolution of a closed karst depression created by a subterranean stream piracy through a series of stream sinks and ponors that migrated upstream close to the spring area. It is bordered by Ocoale Hill to the north, Comărnicel and Bocului Hills to the west, Culmea Pârjolii to the south (where Scărișoara Glacier Cave is located), and in the east, a series of limestone hills separate it from the basin of the Ordâncușa Valley.

The heart of the depression shelters the Ocoale Hamlet, is crossed by the Gârda de Sus-Ordâncușa-Ocoale-Ghețar tourist road (18 km) and is situated at 260 m below the highest altitude of the surrounding hills. A permanent stream in the upper (northern) sector and temporarily active streams in the middle sector drain it. The southern partially forested sector is without surface drainage, but has a blind sinkhole valley, along which there are some temporarily active swallets and two permanent springs in the Vuiagă area.

In the southern extremity, the steep side of Culmea Pârjolii Hill (30-45 m in height) borders the Ocoale Depression. Its base is almost horizontal, and is punched by several uvalas, dolines, and a short gorge section between the Ponorul de la Vuiagă and the depression in which the Avenul din Șesuri (Șesuri Pit) opens.

In conclusion, all of the streams in this depression migrate underground, where they form two important subterranean drains. One is temporarily active with a karstic spring in the Polița Izbuc through which the water caught in the southern sector reappears. The other is the permanent and inaccessible karst spring of Izbucul Cotețul Dobreștilor. It drains the surface water from the middle and upper sectors of the depression (Fig. 1).

From a hydrographic point of view, the surface of the karstic complex is furrowed by three important valleys: the Ocoale Valley, from the depression with the same name, the Poliței Valley, which represents the downstream branch of the Ocoale Valley, and the Ghețarului (Glacier) Valley, the right hand tributary of the Ordâncușa Valley. The first contains a stream fed by the spring in the upstream sector of the Ocoale Depression. The second is drained by the temporarily active streams that rise to the surface through the Poliței Izbuc. The third accumulates waters from the Fântâna de la Iapa and the springs in the Ghețarului Valley.

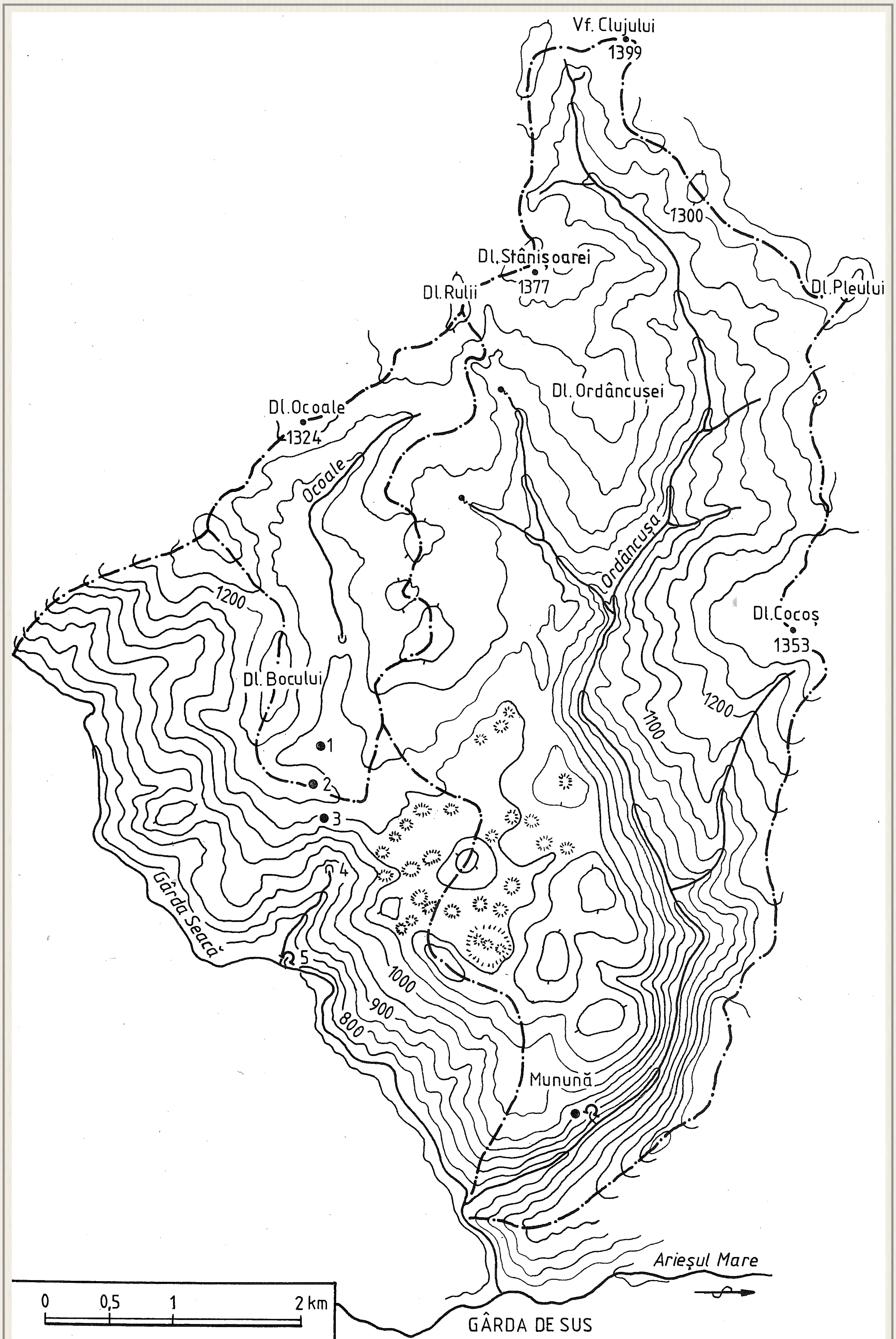

Fig. 1. – Morphohydrographic map of the Scărişoara karst plateau. 1 = Şesuri Shaft; 2 = Scărişoara Glacier Cave; 3 = Pojarul Poliţei Cave; 4 = Poliţei Spring; 5 = Coteţul Dobreştilor Cave.

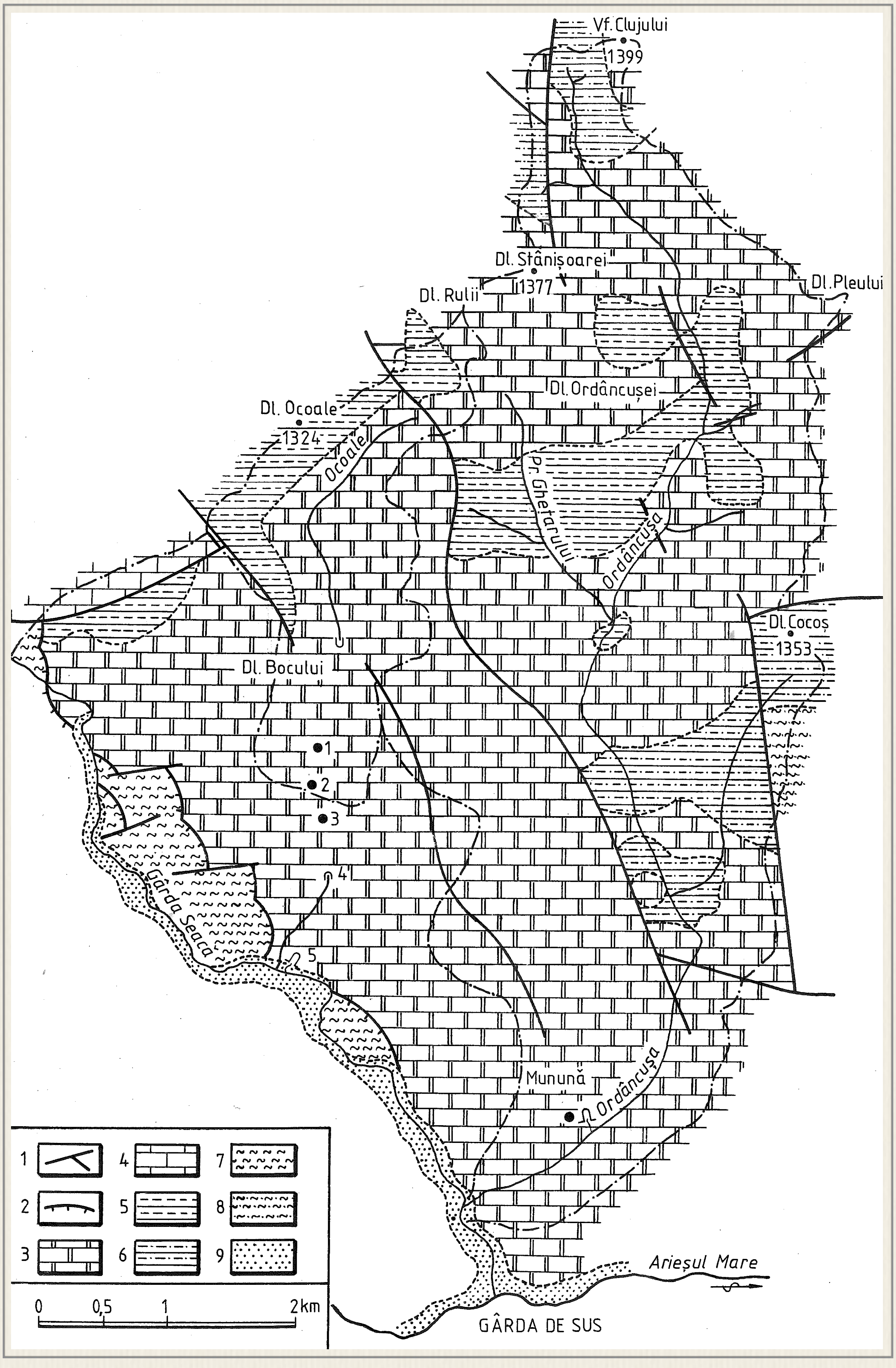

Fig. 2. – Geologic map of the Scărişoara karst plateau.
1 = fault lines; 2 = overthrust lines; 3 = Upper Jurassic limestones; 4 = limestones; 5 = Jurassic quartzites and shales; 6 = Triassic quartzites and shales; 7-8 crystalline basement; 9 = alluvial deposits.

Within the karst complex there are many springs, which provide most of the water for the farms on the karstic plateau. The most important ones are those from Izvoarele de sub Comărnicel, those from the southern slope of the Ocoale Hill, those along the Ocoale Valley, the Vuiagă Spring, the Șes Spring, the Apa din Cale, the Troaca Spring, the Rădăcini Spring, the Fântâna de la Iapa and the Ghețarului Valley Springs. The water discharge of these springs is rather low (0.0-2.0 l/s) and comes from the aquifer located in the impermeable Liasic formations that cover the limestones in some of the hills (Ocoale, Comărnicel and Bocu). It also comes from alluvial deposits that are situated along the Ocoale Valley.

The few water sources with their low and temporarily discharge make the Scărișoara Plateau deficient with respect to water supply. The permanent sources are situated at the edge of the plateau, in the Ordâncușa and Gârda Seacă rivers, at considerable distance (4-8 km) and an altitude difference of about 300 to 450 m. These two major river valleys are very deep and show different morpho-hydrographical features, mainly determined by the geological context. Thus, while the Gârda Seacă River flows in a large valley with relatively symmetrical sides at the contact between the karst and non-karst formations, the lower part of Ordâncușa River Valley traverses a large limestone barrier, is very narrow and deep, having a classical gorge outlook.

Geologic data

The geological setting of the Ocoale – Ghețar Plateau is rather simple. The entire plateau is developed on Mesozoic sedimentary rocks belonging to the Bihor Unit (autochthonous). To the west, the autochthonous is overthrust by the Permian detrital formation developed in a typical Verrucano facies (purplish-red colored quartzite sandstone, conglomerates, and shales). This latter one is part of the Gârda Nappe (Fig. 2) (Balintoni, 1997).

The Scărișoara Glacier Cave was believed to develop in massive reef limestone of Ladinian (Middle Triassic) age (Ianovici et al., 1976). The authors estimated the age of the limestone by using paleontological and structural elements.

Bucur & Onac (2000) have recently sampled the limestone in different point of the cave and studied by means of thin section. They found the following algae (*Salpingoporella pygmaea* (GUEMBEL), ?*Salpingoporella annulata*

(CAROZZI), *Linoporella capriotica* (OPENHEIMER), ?*Petrascula* sp., *Nipponophycus ramosus* YABE & TOYAMA, *Solenopora jurassica* NICHOLSON, *Thaumatoporella parvovesiculifera* RAINERI) and foraminifera (*Labyrinthina mirabilis* WEYNSCHENK, *Andersenolina alpina* (LEUPOLD), *Troglotella incrustans* WERNLI & FOOKES.

This association is characteristic for the Upper Jurassic, most probably Lower Tithonic. Therefore the limestones in which the cave is cut are equivalent to the Cornet Limestone in the Pădurea Craiului Mountains.

Hydrogeologic aspects

The existence of the Scărișoara glacier has stimulated many speleological investigations in the area. In particular, the water divide between Gârda Seacă and Ordâncușa valleys, dominated by the Ocoale – Scărișoara close catchment basin, was the object of many groundwater observations. Among these, groundwater flow directions and flow rate values were measured in combination with fluoresceine tracer tests (Orășeanu, 1996).

The Munună – Ghețar Fault is of crucial importance in the hydrogeology of this region as it separates two distinct tectonic blocks. Each block contains is own karst aquifer and resurgent spring. Waters entering the aquifer on the eastern side of the fault (Munună – Hănășești Block) resurge out in Poarta lui Ionele spring (average flow rate 90 l/s). On the western side of the fault (Ocoale Block) waters entering the aquifer are drained by the Cotețul Dobreștilor spring. This latter drainage is the longest (2800 m) and it has the largest relief (390 m) recorded in the Upper Arieșul Mare Basin. It drains the waters of Ocoale rivulet that sink within the Ocoale – Scărișoara close catchment basin (Orășeanu et al., 1991). The average flow rate recorded for the Cotețul Dobreștilor spring over the observation period (October 1984 – September 1985) was 280 l/s. A flow volume of 1.06 m^3/s was the monthly maximum. During periods of prolong draught the spring flow rate declines progressively until complete dry. The outlet is actually an overflow spring of the system. The perennial outlet is Izbucul Morii, located some 100 m downstream from Cotețul Dobreștilor, as well as a number of springs that occur at stream level or below over the same distance. These springs including the Izbucul Morii have occasionally been gauged (during periods when Cotețul Dobreștilor outlet dried up) giving resulting values of approximately 85 l/s (Orășeanu, 2000). Parameters measured from the correlative and spectral analysis of Cotețul Dobreștilor indicates the karst system has relatively important groundwater reserve (Orășeanu, 1996).

Avenul din Șesuri (Șesuri Shaft) – Poliței spring (mean average flow ~ 5 l/s) is another hydrokarstic system. Much of the water is derived from sinking of temporarily surface streams in the southern part of the Ocoale – Scărișoara close catchment basin (Fig. 1).

4

General description of the cave

The Scărișoara Glacier Cave opens with an elliptical, funnel shaped shaft of impressive dimensions: up to 60 m in diameter and 48 m in depth (Figs. 3 and 4). The walls of the upper half of the shaft are partially covered with vegetation. Borza (1918) made the first phanerogram inventory and identified the plants collected by Racoviță during his visits in August, 1921, and June, 1923. Out of 30 identified species, the most interesting one is *Doronicum columnae*. Usually, this plant blooms in the springtime, but in the shaft it blooms several months later, so that in full summer it forms a girdle of yellow flowers clearly marking the outer limit of the cold air. The bottom of the shaft is covered with a thick layer of snow, which does not melt even in the hottest summers.

The cave entrance is located in the western wall of the shaft and has an imposing arch 24 m high and 17 m wide. Beyond is the "Sala Mare's" (Big Room's) ice floor, a 3,000 m^2 perfectly horizontal surface, with just four massive conic ice formations. One is on the left side and the other three are attached to each other near the wall opposite to the cave entrance. Usually, these form large ice columns. During springtime, ice stalactites form on the room's ceiling, but their existence is ephemeral.

To the north, there is a second opening towards the surface, a progressively narrowing chimney linked to the ceiling of Sala Mare by a slanting tunnel approximately 3 m in diameter. Towards the northwest, the horizontal floor ends with a steep slope dipping 8 m that can be descended by steps carved into the ice leading into a second room. Local residents have named this area "Biserica" (The Church). Here, ice speleothems dominate the underground scenery. On sunny days, the tips of the stalagmites shine in the reflected light from the snow accumulated at the bottom of the shaft, creating

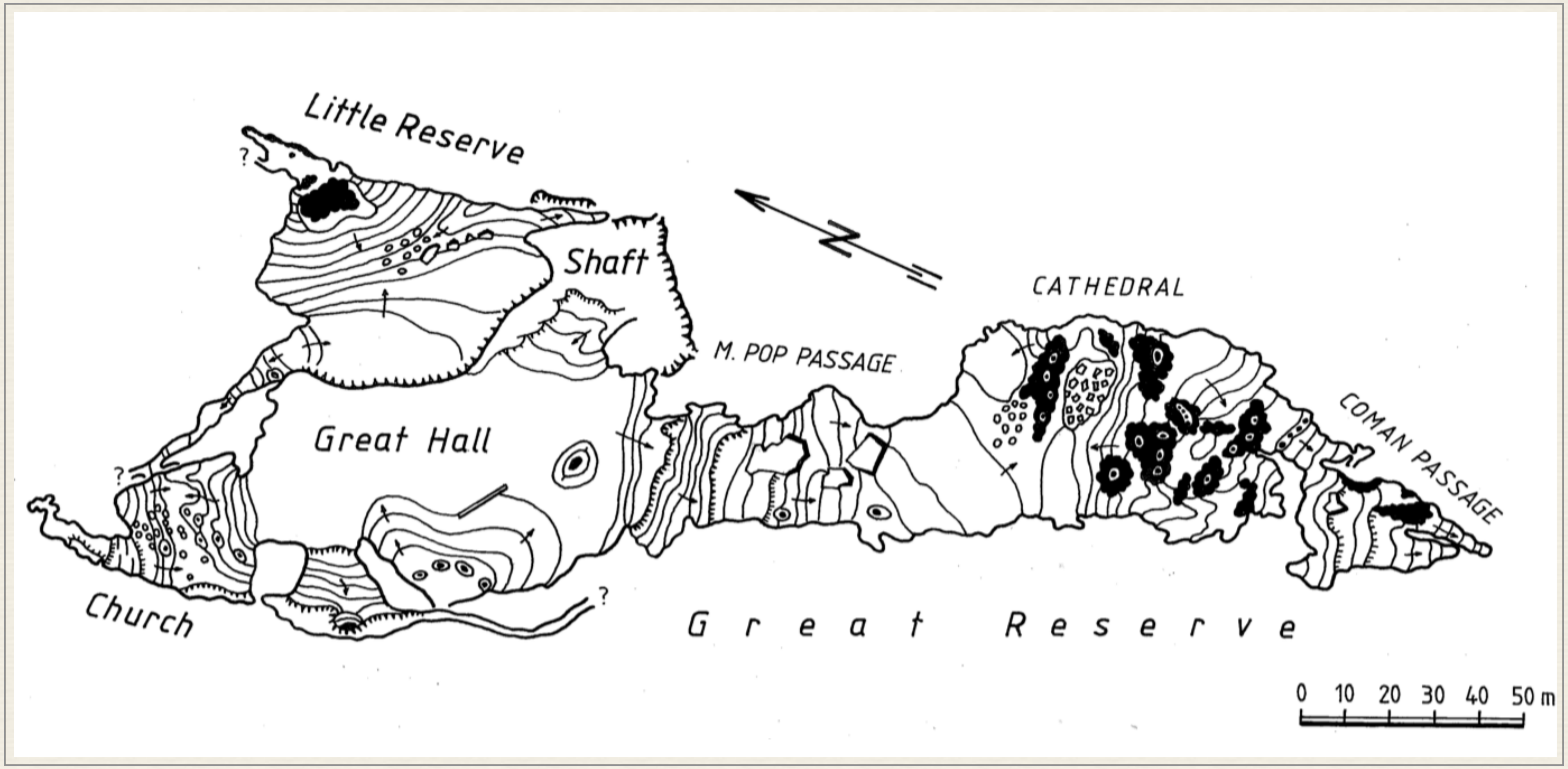

Fig. 3. – Plan of the Scărişoara Glacier Cave (after Rusu et al., 1970,

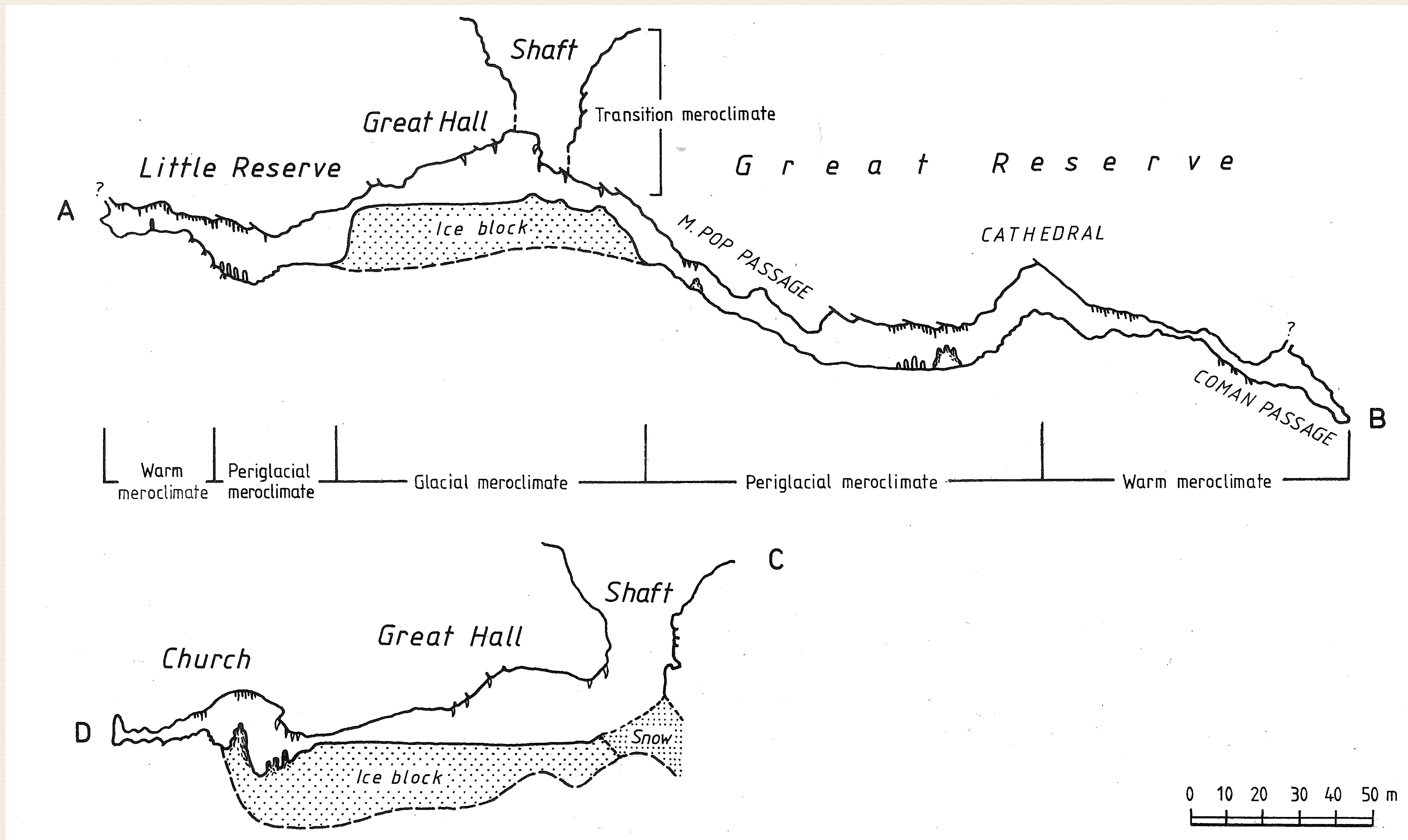

Fig. 4. – Scărişoara Glacier Cave. Longitudinal sections A-B (with meroclimatic zones) and C-D (after Rusu et al.,

the impression of gigantic lighted candles. The “Biserica” continues with a narrow side passage lacking ice formations. At its end is a succession of three small circular-shaped cavities (Fig. 4, profiles C-D) with walls bearing traces of water flow.

Another ice slope can be descended on the left side of the Sala Mare before entering the “Biserica”. At its base, a narrow space between the glacier and the cave’s limestone wall (crevice) formed due to wall’s higher temperature.

The shaft, the Sala Mare, and the “Biserica“ are parts of the tourist section of the cave and are toured without caving gear. On the other two sides of the Sala Mare, the space between the ice and the limestone walls allows access into the deep parts of the cave that have been declared scientific reserves. Visiting these areas requires a minimum of underground climbing experience, as both passages are either vertical or almost vertical cliffs.

The Rezervația Mica (Small Reserve) is on the northern side of the Sala Mare and can be entered by descending a 15 m vertical cliff (Fig. 4, profiles A-B), along which the ice stratification is visible. Two other crevices form at the side edges of the ice cliff near the limestone walls, which both descend steeply and almost reach the base of the ice block. In the central part of the room, not far from the ice block, a field of ice stalagmites forms. They differ from the ice stalagmites found in the “Biserica” in that they do not appear as massifs but as isolated stalagmites. Beyond these, the cave floor is partly covered by a calcite crust and rises abruptly towards a short passage called “Palatul Sânzienelor” (Sânziana’s Palace) in which there are only calcite speleothems. There are still two unexplored chimneys at its end, which could be very important in the depicting the genesis of the Scărișoara Glacier Cave.

The entrance to the Rezervația Mare (Big Reserve) is much larger than the previous one and is located on the southern side of the Sala Mare. Within this part of the cave, the largest rooms are found (20 to 45 m wide and up to 20 m high). Here the ice forms a steep slope to a depth of 90 m below the surface. This passage was named Galeria “Maxim Pop” (the Maxim Pop Passage) in the memory of the man who initiated the 1947 expedition. On the horizontal bedrock floor in the central part of the Rezervația Mare is another field of ice stalagmites similar to the ones in the Rezervația Mică. Beyond this area, the cave floor rises abruptly and is covered by huge collapsed limestone blocks. On top of these, large calcite domes have formed. Thus, this part of the

Rezervația Mare is called “Catedrala” (The Cathedral). At the end of The Cathedral, a narrow passage opens through a grate of stalagmites and gives access to the Galeria Coman (Coman Gallery). Besides being well decorated, this passage reaches the cave's maximum depth of -105 m.

Based on topographic surveys performed on 1965, the total length of the Scărișoara Glacier Cave is 700 m (Fig. 3).

5

Speleogenesis of the Ocoale - Ghețar - Dobrești karst system

The enlargement of fissures in karstic rock after the onset of karstification affects the geometry of the caves that later develops in a multiphase system. The length of flow paths tends to increase from one karstification level to another.

The general evolution of the Ocoale-Ghețar-Dobrești karst system closely follows Davis' model (1930), whereby the deepening of the valley determined the draining of the aquifer and the genesis of the three cave levels, respectively (i.e., not in separate cycles, but as stages in a continuous process) (Fig. 5).

The first level of this karst system originates from a interfluvial aquifer (Culmea Pârjolii, which represents the water divide between Gârda Seacă and the Ocoale Valley) and was formed by the water percolating along the bedding planes. The phenomenon exemplifies the way the water circulates in limestone massifs whose stratification dips steeply towards the resurgence (formulated by Ford (1971) (Fig. 6). The main passages of the Scărișoara Glacier Cave develop along bedding planes (Maxim Pop and Coman galleries), while the pit at the entrance has formed through the coalescence of the doline above the cave and an "upward chimney" generated by ascending waters flowing under pressure (Rusu et al., 1970) (Fig. 7).

Șerban et al. (1957) and Viehmann (1995) believes that the entrance shaft of the Scărișoara Glacier developed as a result of solution of the bedrock by vadose water that descends initially along a joint plane.

The middle level, corresponding to the second karstification stage, has 3,840 m of passages with a relief of about 220 m. These values reflect an increased tectonic role in the cave's morphology. The stair steps morphology in the entrance area of the Avenul din Șesuri was determined by the presence of major joints that were enlarged by dissolution and erosion.

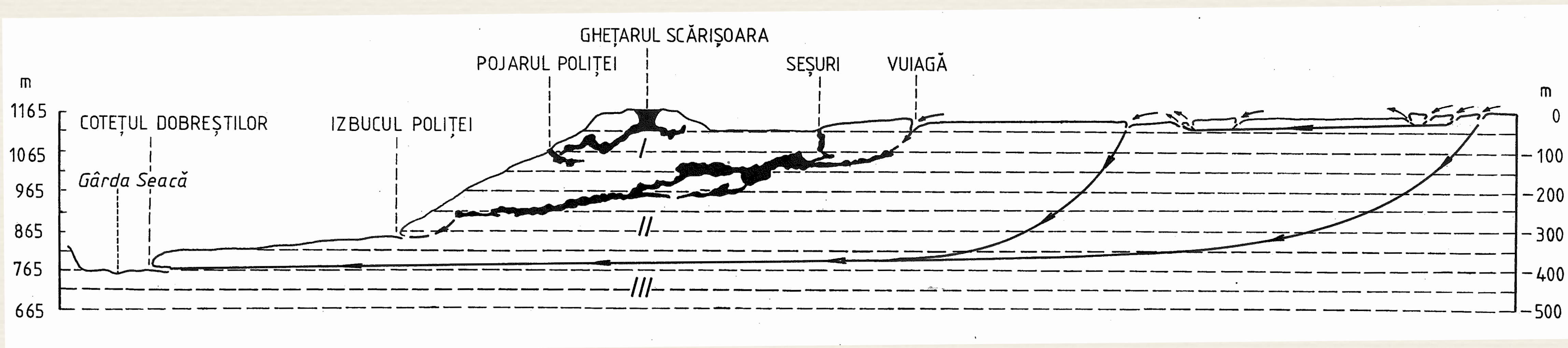

Fig. 5. – Ocoale –Coteţul Dobreştilor karst system. Longitudinal section (after Rusu et al., 1970).

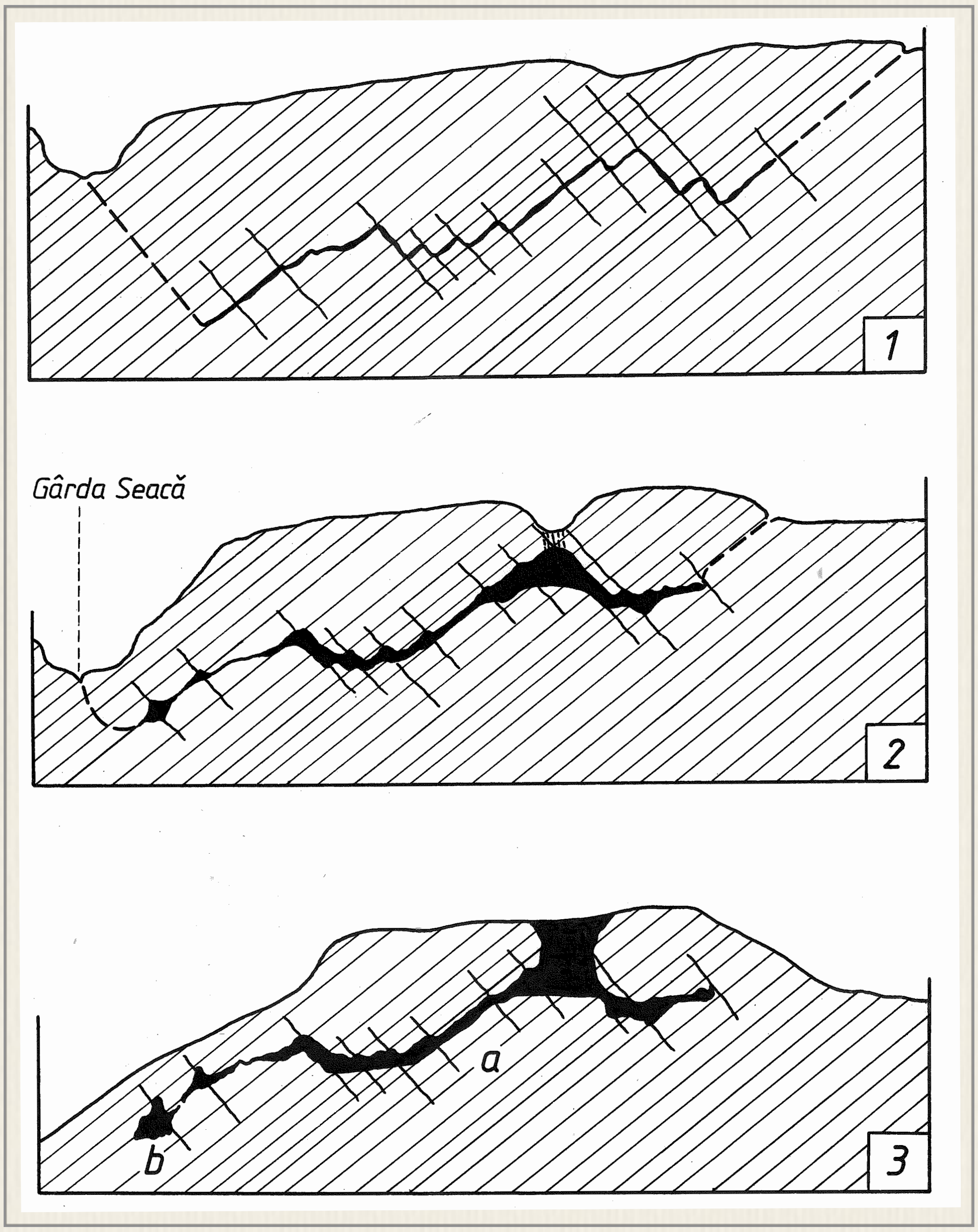

Fig. 6. – The genetic stages of the first karstification level. a = Scărişoara Glacier Cave; b = Pojarul Poliţei Cave (after Rusu et al., 1970).

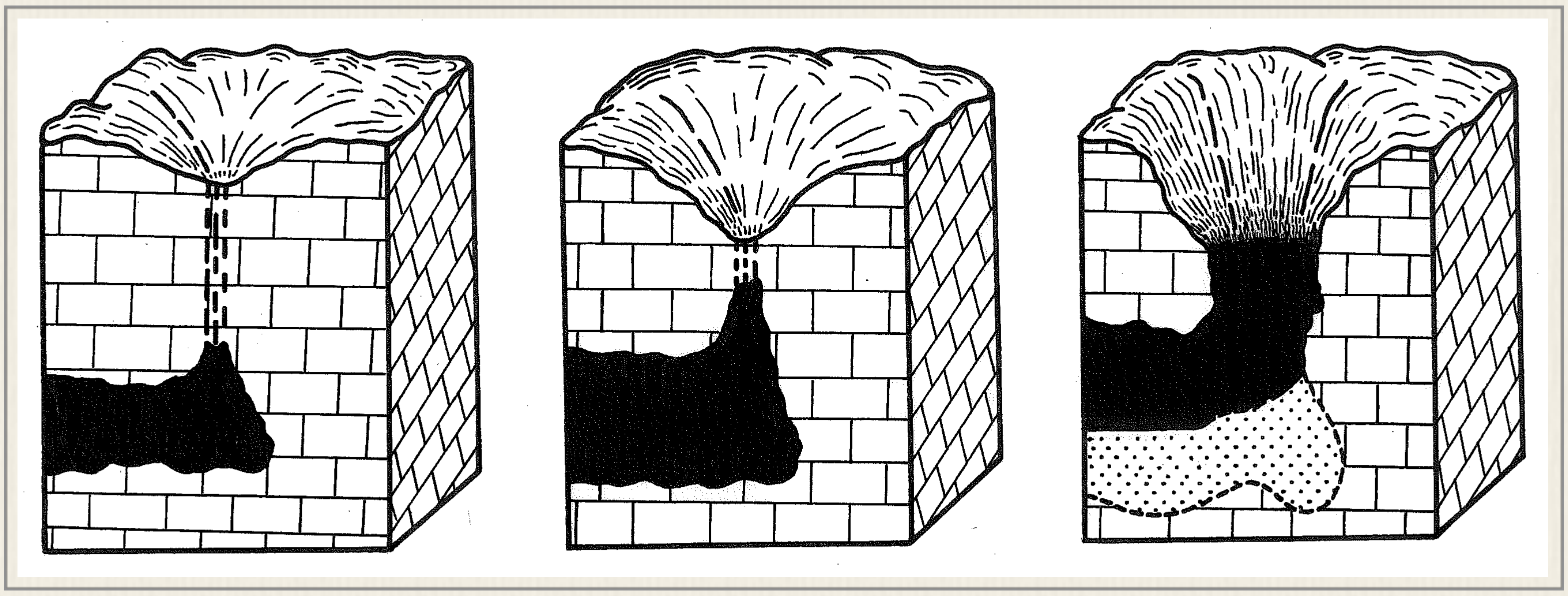

Fig. 7. – The scheme of the shaft formation (after Rusu et al., 1970).

During the third stage of karstification, the underground drainage of the Ocoale stream was very limited because it approached the underlying non-carbonate bedrock. At the same time, the deepening of the Valea Gârda Seacă exposed the lowest part of the aquifer that is drained through the Izbucul Cotețul Dobreștilor and few other karst springs.

The upstream migration of insurgences, continuous lowering of drainages, and the evolution of the whole system as a cave network in almost vertical alignment are all features that strongly differentiate the Ocoale-Ghețar-Dobrești from other karst systems in the Apuseni Mountains and other European karst regions.

Paleokarst in Scărișoara Glacier Cave

Silvestru & Ghergari (1994) examined several paleokarst features in Scărișoara Glacier Cave. The feature that they considered paleokarst is represented by a red clay matrix formation in which irregular limestone cobbles and blocks are chaotically disposed. The authors noticed the first signs of paleokarst features along the Maxim Pop Gallery in the form of ceiling pockets and tubes intensely colored red.

The most striking paleokarst deposits are located in the "Cathedral", around Margaret's Window, and throughout the Coman Gallery. A large section of the Pojarul Poliței Cave (the natural continuation of Scărișoara Glacier Cave) also develops within this paleokarst formation.

The spatial setting of the paleokarst formation is one that resembles an elongated body in which the long axis coincides with the dipping of the limestone strata. Therefore, the authors speculated that this spatial setting provided a weakness in the limestone body that was exploited by speleogenesis and, as a consequence, the lower half of the cave developed along the paleokarst formation.

Limestone cobbles and red clay material was further investigated by means of X-ray diffraction, scanning and transmission electron microscope, and thin sections under a polarizing microscope. Detailed studies of the clay mineral association, using the above techniques, gave the most valuable information. These studies revealed that the alteration processes that affected the paleokarst formation in which the clay minerals were produced could be ascribed to the following two distinct zones:

- the illite-smectite zone suggesting poor drainage and slightly alkaline pH.
- the kaolinite zone superimposed on the previous, characterized by an active drainage and slightly acidic pH (Silvestru & Ghergari, 1994).

The two authors considered the mixture of clay and limestone cobbles an allochtonous infill of an ancient karst void. Several observations were interpreted as transport indicators and used as arguments for allochtonous origin of the infill (e.g., the presence of the sparite exclusively in the red formation, the anhedral crystals of kaolinite and illite, significant amounts of chlorite, etc.).

Silvestru & Ghergari (1994) proposed a Paleogene age for the paleokarst in Scărișoara Cave. They estimated the age of the paleokarst by taking into consideration the paleogeographic reconstruction done by Rusu & Cocean (1992) and the paleoclimatic information reconstructed based on the clay mineral assemblage (arid conditions).

6

The underground topoclimate

The ventilation system

As a whole, the Scărișoara Glacier is a descending cavity that opens to the surface only on its upper side. As a result, it belongs to the category of cavities with seasonal bi-directional ventilation, in which the active phase is limited to the winter season (Racoviță, 1975).

The air movement exchanges between the cave and the surface is mainly achieved through thermocirculation (convection). This phenomenon implies that the force generating the air currents results from the temperature differen-ce, and hence density differences between the external and underground air (Trombe, 1952; Andrieux, 1970a). During winter, the outside air is colder and denser than the air inside the cave, and when it enters the cave, it replaces an equivalent volume of underground air. Therefore, two air currents with opposite directions can be noticed through the same cave opening: a cold one that enters the cave, and a second one, relatively warmer, which leaves the cave. In the summer, the thermal ratio reverses and these exchanges stop because the under-ground air is now colder and cannot rise to the surface. The major effect of this system is that the cave constantly accumulates cold air, supercooling the substrata and finally leading to a glacial-type topoclimate (Șerban et al., 1948).

From both thermo-hygrometric data and direct observations, during winter the cold air flowing into the cave reaches the innermost limit of the ice stalagmite fields in the Biserica and the two reserves. In all these places the air current reverses its direction and the warm air is pushed out, initiating the emergent current of the bi-directional ventilation. Consequently, the deepest sectors are not influenced by the air movement exchanges, and therefore ice speleothems never form. In the Rezervația Mare, however, the situation is somewhat different because an ascending warm air current flows through the whole Coman Gallery. This can only be explained by part of the air, which penetrate from the surface flowing along the "Catedrala's" ceiling and reaching the lower part of this gallery (Fig. 8A). This hypothesis is confirmed by observations made during very cold periods, in conditions of strong convection currents, when a descending air current in this passage next to the ceiling, becomes perceptible. For example, this situation was recorded on February 23, 1965, when the temperature in the Sala Mare dropped to –11.4°C.

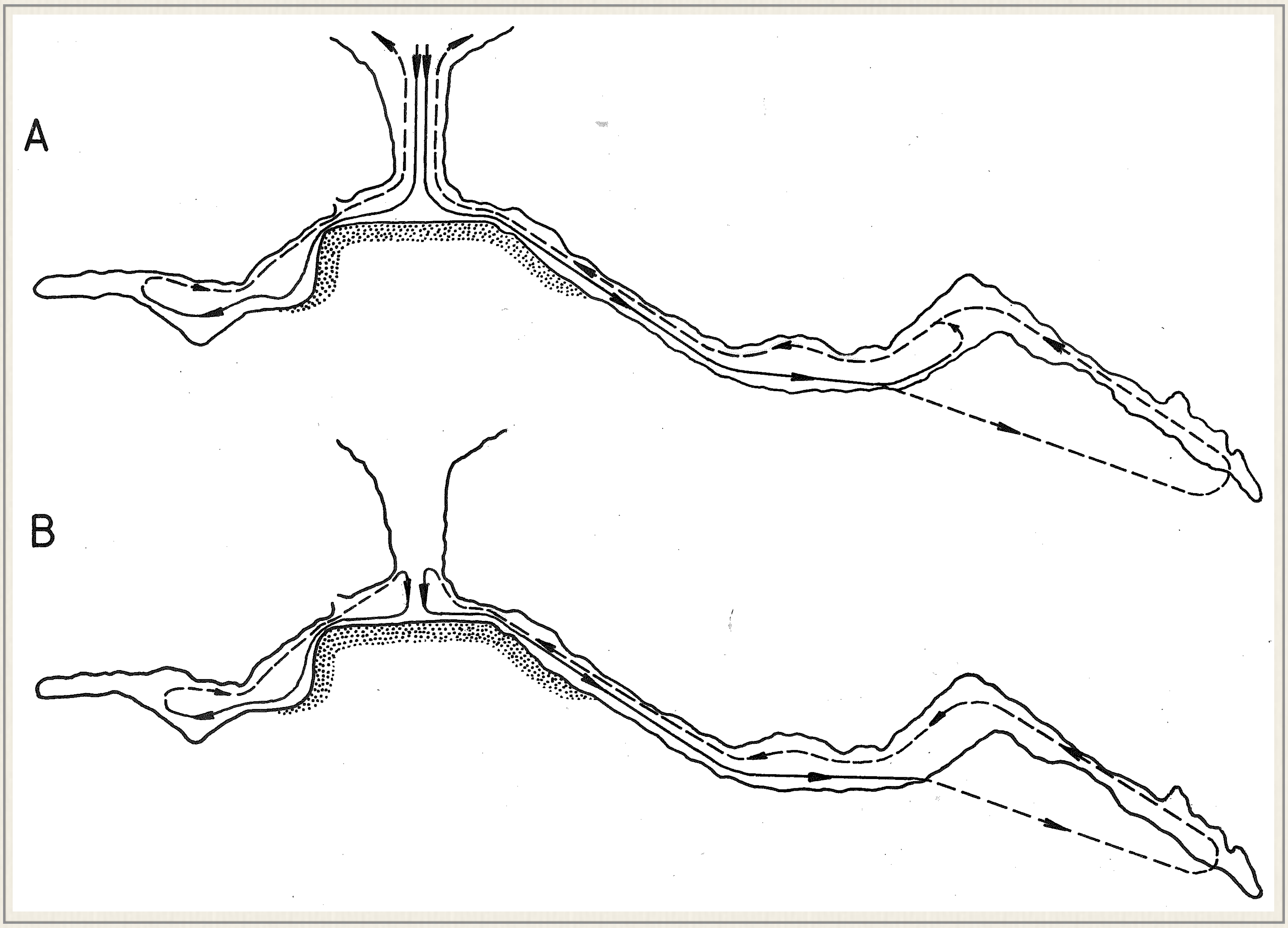

Fig. 8. – The air circulation in Scărişoara Glacier Cave in winter (A) and in summer (B).

The warm air current rises along the western wall of the shaft, causing the vegetation to agitate, while the cold air current can be noticed at the level of the ladders anchored on the opposite wall.

In summertime, the lack of air exchange between the cave and the surface does not stop the underground convective flow. The supercooled state of the limestone walls and the presence of the ice deposit maintain a temperature difference between the Sala Mare and the other areas of the cave. This difference is enough to generate convection cells, and except for the shaft, the air currents follow the same path as in winter but are much lower in intensity. The existence of the same ascending air current during summer in the Coman Gallery is the most conclusive proof of this. Additionally, we can assume that because of the lower convective flow in summer, the convection cell within the Rezervația Mare does not end at the ice formations limit, but at the bottom of the Coman Gallery (Fig. 8B).

The average duration of the two alternating seasonal ventilation phases was mainly established by recording of the temperatures in the cold area of the cave. The winter phase lasts five months (November-March) and the summer phase is six months (May-October). April is a transition period when the external temperature may oscillate above or below the "critical" point.

Air movement

Because of the remarkably large voids that characterize the Scărișoara Glacier Cave, it is very difficult to measure air current speed throughout the year with classical anemometers. However, this method can be used during the coldest periods of winter. The only point in which such measurements could satisfactorily be taken was "Fereastra Margaretei" (Margaret's Window), which is the narrow entrance into the Coman Gallery. The data collected at this point between March 1983 and May 1990, confirm the existence of a permanent warm air current. They also show that the ventilation rate does not have significant seasonal variations, as the measured average values are 34 cm/sec in winter and 30 cm/sec in summer (Racoviță, 1994a). The fact that this parameter does not significantly increase in winter suggests that the pile of breakdown blocks located in the central part of the "Catedrala" act as an airflow regulator. Therefore, the cold outside air current reaching this point will reverse its direction without flowing all the way down the bottom of the cave, regardless the volume of air exchanged.

The meroclimatic structure of the cave

The word meroclimate is derived from the Greek word μεροζ (meros), meaning "part of a whole". The term was introduced to underground climatology to hierarchically order the levels at which the mass and energy exchanges take place. It is defined as "*the entire assembly of physical phenomena that are produced in certain sectors of the cave atmosphere, and which may or may not be separated by topographical elements, but which are always characterized by specific climatic elements*" (Racoviță, 1975). Two distinct meroclimatic zones can usually be defined in a cave. The first corresponds to a perturbation area and is located near the cave entrance where it is directly exposed to external influences. The second zone is represented by a stable area, deep inside the cave. Here the external influences are very much diminished or are sometimes completely missing. The temperature data show that the Scărișoara Glacier Cave has a more complex structure than this general model because one can recognize not two, but four meroclimatic zones (Racoviță, 1984): first, a transition meroclimate located in the shaft; second, a glacial meroclimate in the Sala Mare; third, a periglacial meroclimate specific to all peripheral zones around the ice block; and fourth, a warm meroclimate specific to all cave passages beyond the extent of the ice (Fig. 4).

The air temperature

The monthly measurements taken during two multi-year research periods show that except for the transition and the warm meroclimatic zones, air temperatures are related to the particular ventilation cycle of the Scărișoara Glacier Cave. This close relationship means that within the cold sector of the cave, the are only influenced by the winter oscillations of the external temperature, whereas the summer temperature variations can not be traced (Fig. 9). Consequently, the subterranean temperatures may decrease indefinitely during winter. The lowest ever recorded temperature in the Sala Mare (registered on January 8, 1966, when the temperature at the surface measured –20°C) was –14.5°C. In addition, the daily measurements undertaken between December, 1965 and January 1966 clearly showed that the negative variations of the temperature recorded outside the cave were almost instantaneously transferred into the cave (Racoviță, 1967). This does refute the existence of a hypothetical "delay phenomenon" for the influence of external meteorological factors over the cave topoclimate (Viehmann, 1976).

Yet, during summer, the exchanges of air between the cave and the surface are ceased and the underground temperature never exceeds +0.5°C. Therefore, one can assume that the "critical" value of the external temperature below which these aerodynamic exchanges resume, is generally 0°C.

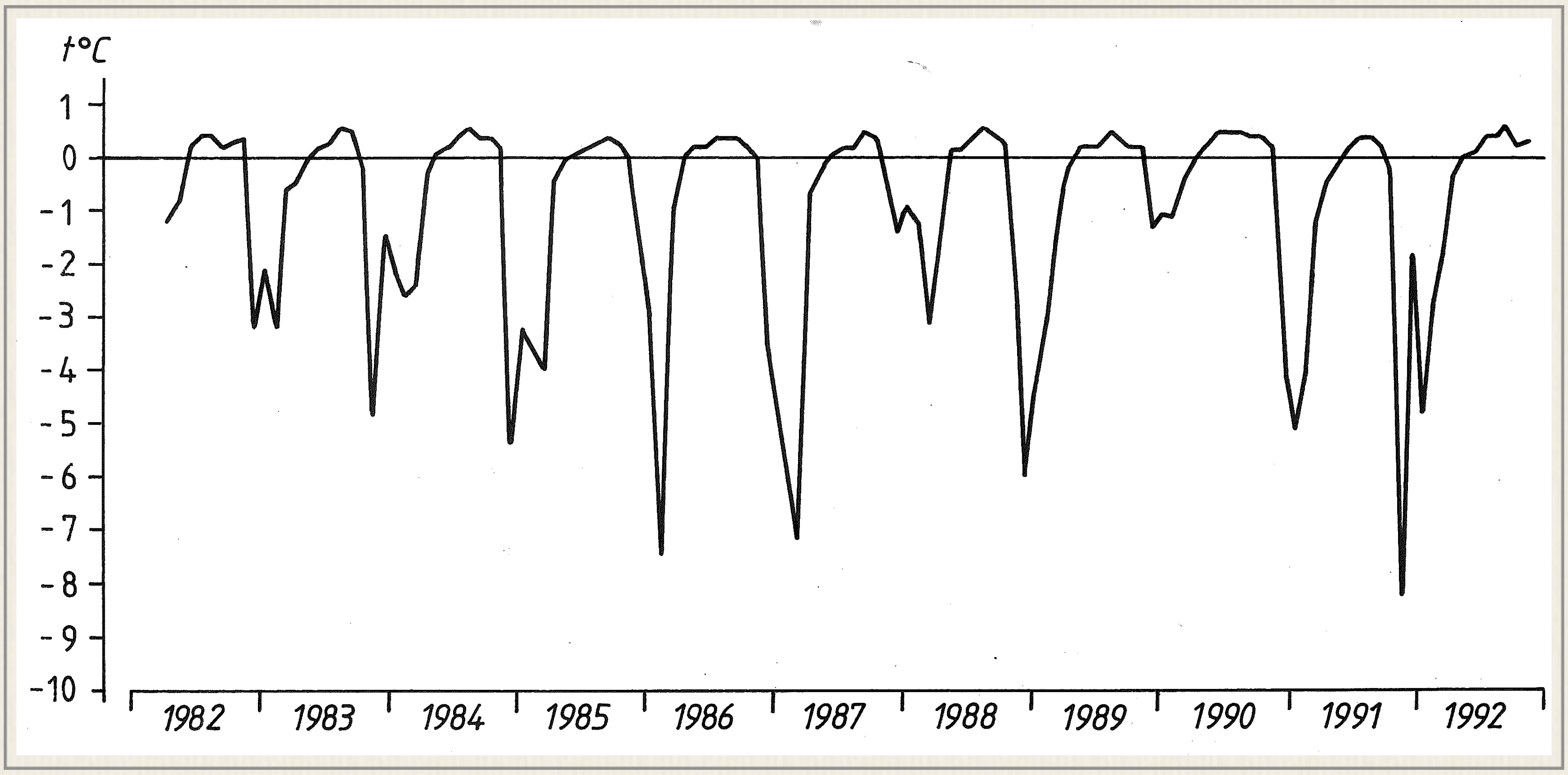

Fig. 9. – Diagram of the temperatures registered in Sala Mare (Station 6) between 1982 and 1992.

The thermal gradients

It is well known in the underground climatology that the tendency of air masses entering the cave is to set a thermal equilibrium with the host rock. As a result, the underground temperature varies with the increase of distance from the cave entrance, so that the existence of longitudinal thermal gradients along the galleries is obvious. In ideal physical conditions, these gradients follow an exponential curve that, depending on the external and cave temperature ratio, will increase in winter and decrease in summer (Andrieux, 1971; Choppy, 1982). However, the real mathematical model will differ from one cave to another. This makes thermal values modeling an extremely useful tool in both building underground climatic surveys and comparing cavities that are topoclimatically different (Racoviță, 1993).

In Scărișoara Glacier, the theoretical model of the annual thermal gradient, based on the data collected at 14 points (between the entrance shaft and the bottom of the Coman Gallery) (Fig. 10) (Table 1) in the interval 1982-1992, forms a second degree parabola with a vertical axis (Fig. 11). It is defined by the equation:

$$t_a = 0.000206 \cdot d^2 - 0.0650 \cdot d + 4.10 \quad (1)$$

This curve perfectly describes the cold air accumulation caused by seasonal thermocirculation, which is the most representative topoclimatic element for this cave.

On the other hand, the same modeling method allows us to define the limits of the meroclimatic zones, because equations significantly closer to the real values can be calculated for each partial curve. In order to adopt these curves, the necessary and sufficient condition to be met is that the nonlinear correlation ratio should be higher to that of the whole parabolic curve (Racoviță, 1984).

Table 1
Annual and seasonal amplitudes of the air temperature between 1982 and 1992.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Distance (m)	0	19	29	37	48	73	103	121	173	200	210	240	272	332
Mean annual	7.1	5.4	1.6	–0.1	–0.8	–0.9	–0.8	–0.7	–0.2	–0.1	0.0	2.1	3.6	4.2
Mean winter	–0.7	–1.5	–2.2	–2.4	–2.7	–2.8	–2.5	–2.2	–1.1	–0.9	–0.7	2.0	3.6	4.3
Mean summer	12.5	10.3	4.4	1.5	0.4	0.3	0.3	0.4	0.4	0.4	0.4	2.3	3.6	4.2
Annual amplit.	23.9	23.0	11.4	7.6	5.8	5.7	5.4	4.6	2.8	2.6	2.3	0.8	0.2	0.5
Winter amplit.	8.6	6.6	5.2	4.7	4.5	4.4	4.3	3.5	2.4	2.0	1.8	0.7	0.1	0.3
Summer amplit.	13.6	13.7	4.3	1.8	0.5	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.3

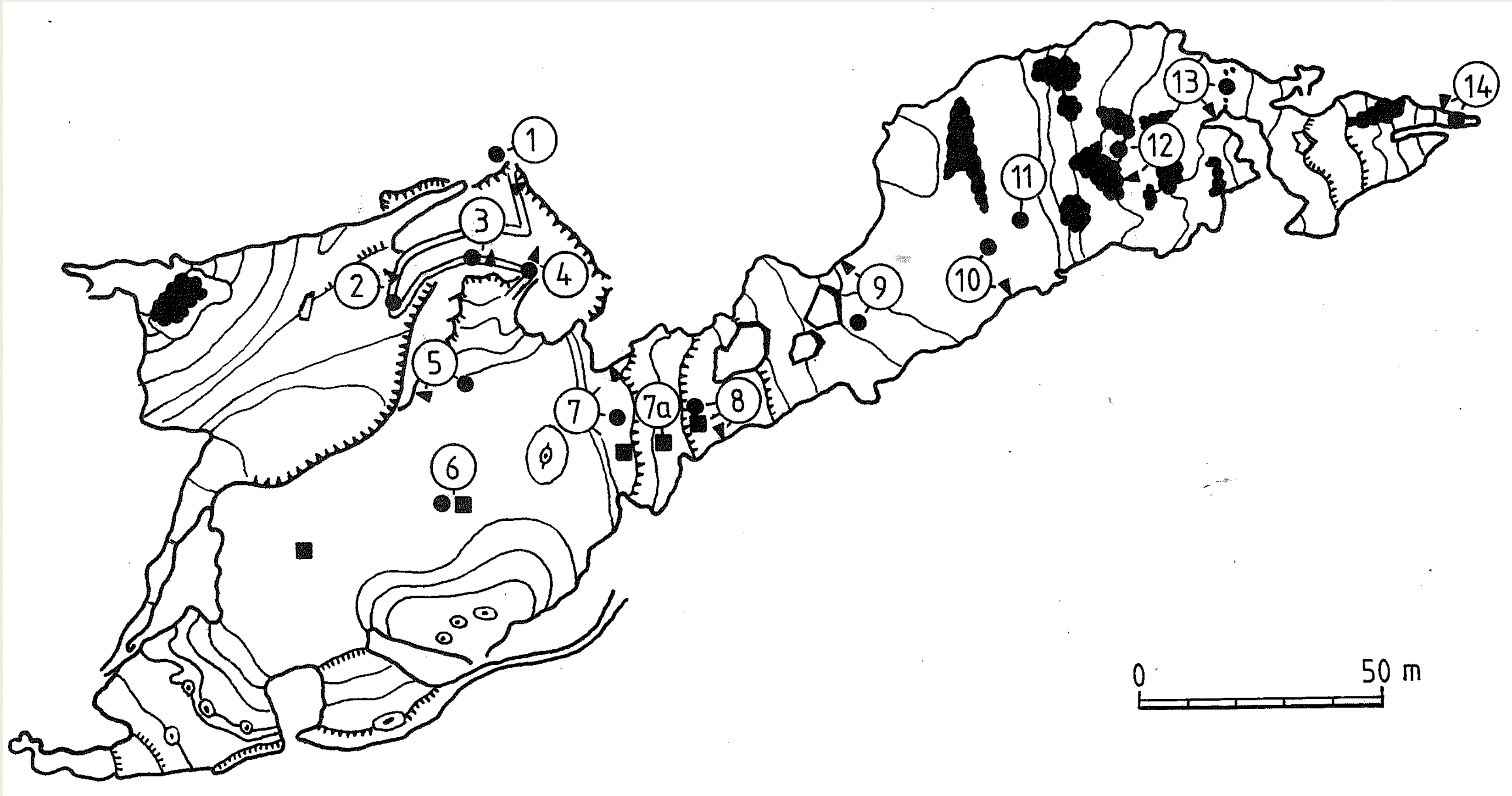

Fig. 10. – Placement of the station points for the atmosphere thermo-hygrometry (circles), rock thermometry (triangles) and ice thermometry (squares).

Such a condition is fulfilled when the alignment formed by the station points is divided into three zones corresponding to the transition, the cold (which gather the glacial and the periglacial sectors), and the warm meroclimates, respectively. In all three cases, the spacial temperature distribution follows an exponential curve (Fig. 11) having the following equations:

$$t_a = -1.35 + 35.743 \cdot e^{-0.0879\,d} \qquad (2)$$

for transitional meroclimate,

$$t_a = -4.70 + 3.299 \cdot e^{0.00169\,d} \qquad (3)$$

for cold meroclimate, and

$$t_a = 4.28 - 11929.8 \cdot e^{-0.0359\,d} \qquad (4)$$

for warm meroclimate.

These curves are representative for the thermometric characteristics of the different zones. They show a rapid value drop in the transitional meroclimate (for which the absolute value of the "a" coefficient in the numeric equation is the greatest), a persistent uniformity throughout the cold meroclimate and a progressive increase of temperatures within the warm merolimate. In latter case, the curve is influenced to a certain degree by the fact that “Fereastra Margaretei” (Station 13) is located on the ascending branch of the thermocirculation, close to the ceiling where the values measured are implicitly higher.

We can therefore conclude that within the meroclimatic zones, the thermal gradients are in good agreement with the physical model. This means that the statistical modeling of the thermal values is much more related to the thermocirculation energetic transfers than those recorded at the topoclimatic level.

This difference may be explained if one considers that the mean annual temperature was obtained from measurements taken in totally different conditions that characterized the two seasons. Because of this, the significance of the thermal gradient at topoclimatic scale should always be estimated using seasonal rather than annual values (Racoviță, 1993).

Following this judgement, from a qualitative point of view, the theoretical models are the same. In both seasons they are all represented by parabolic curves, of which outlook is essentially different (Figs. 12 and 13). This fact also results from the numerical expressions of the following functions:

$$t_a = 0.000112 \cdot d^2 - 0.0166 \cdot d - 1.70 \qquad (5)$$

for the winter gradient and

$$t_a = 0.000276 \cdot d^2 - 0.1001 \cdot d + 8.23 \qquad (6)$$

for the summer gradient.

Comparing the coefficients in equation (1), (5), and (6), one can notice that there is a major similarity between the annual and the summer gradients, whereas the winter gradient is very different. Coefficients “a” and “b” have the smallest values in the relationship that defines the winter gradient (0.000112 and 0.0166, respectively) and coefficient “c” is negative (–1.70).

The parabola that models the winter gradient is much broader (the slope of its curves is reduced), its vertex is closer to the origin of the coordinate system, and the entire curve is lower with respect to the ordinate.

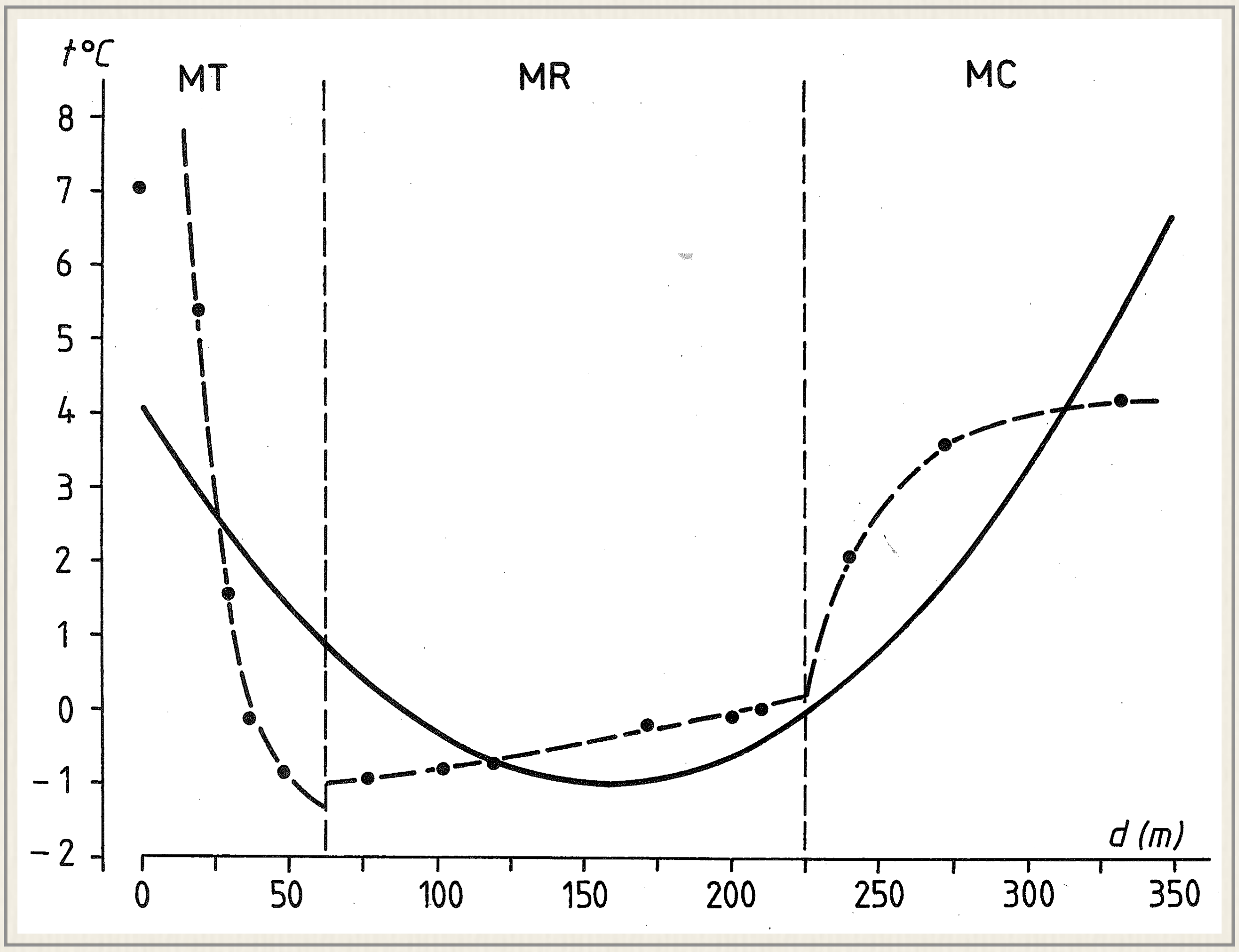

Fig. 11. – The annual thermal gradient in the cave atmosphere. Solid circles=real values; continuous thick line=theoretical curve at topoclimatic level; thin dotted lines=theoretical curves at meroclimatic level; TM=transition meroclimate; CM=cold meroclimate; WM=warm meroclimate.

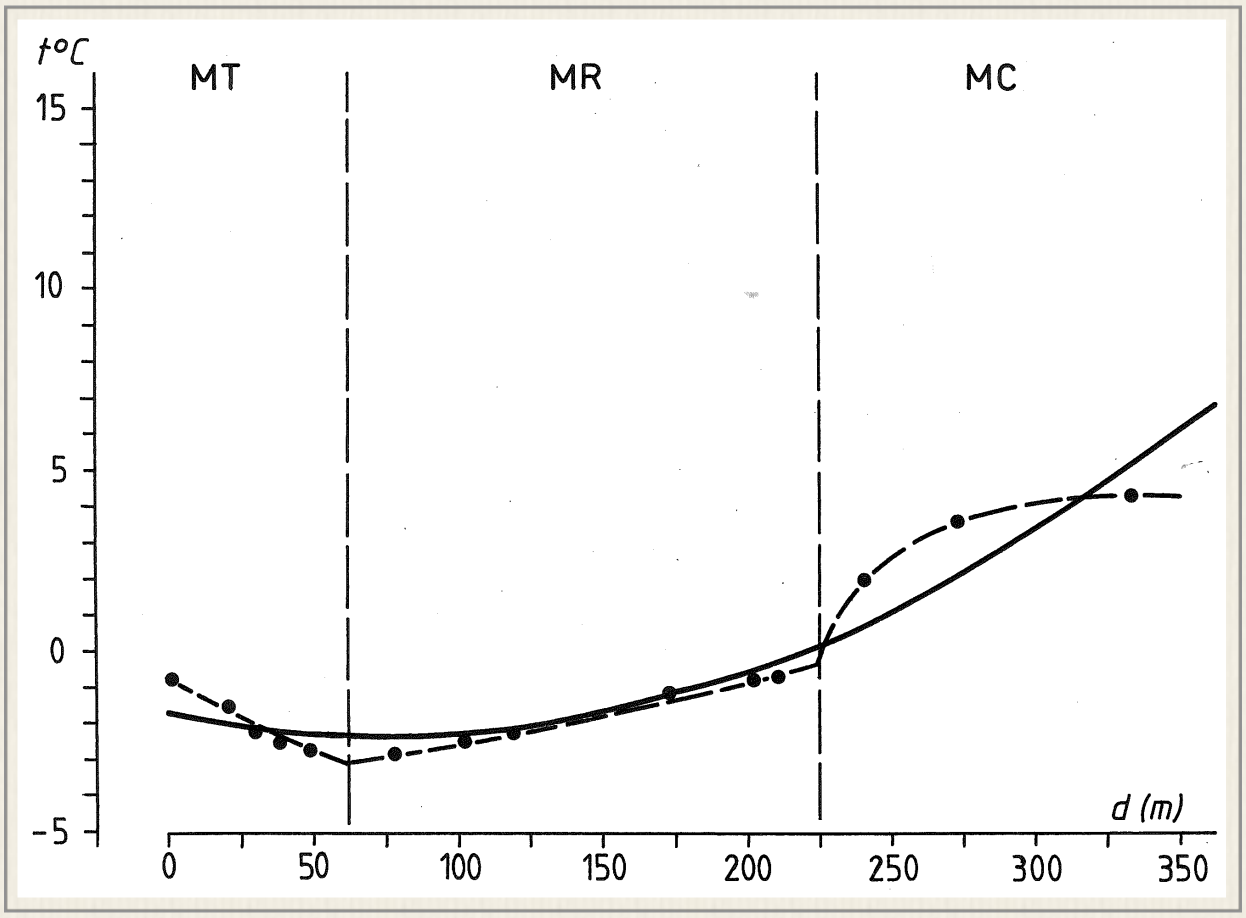

Fig. 12. – Winter thermal gradient.

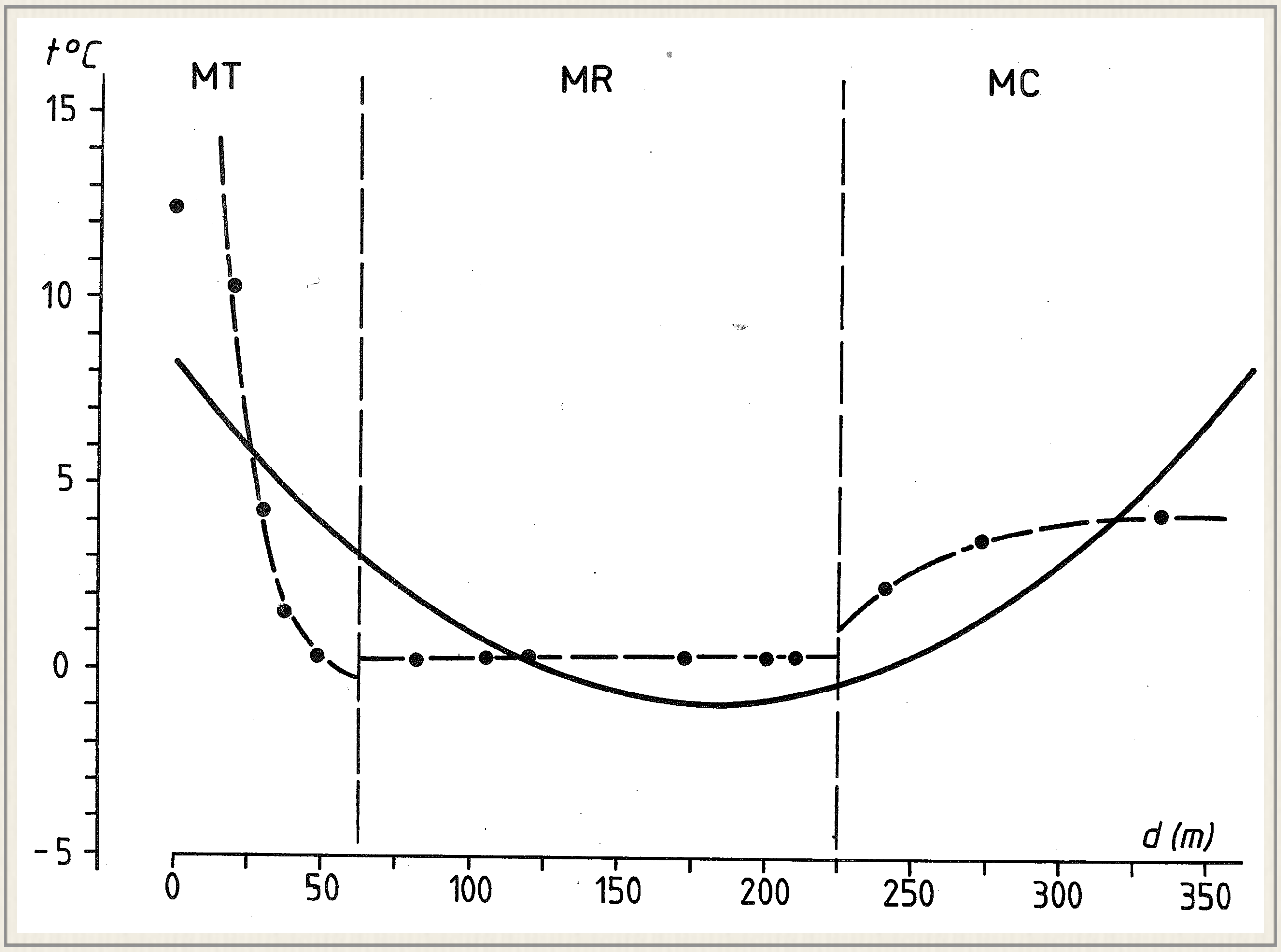

Fig. 13. – Summer thermal gradient.

These differences are not enough for the theoretical model of the winter gradient to properly illustrate the physical reality in the cave, because the underground temperatures during the active phase of the seasonal bi-directional ventilation should have an exponential distribution. To statistically apply such a model to real temperatures, one should consider using the values determined at certain moments in time, and not the mean seasonal values. The latter may include thermal variations in which surface temperatures exceed the "critical" level at which more or less frequent breaks in thermo-circulation may occur and thus the influence of the external conditions can temporarily cease. On December 9th, 1988 when the surface temperature was –7.6°C, we tested this alternative based on series of measurements within the cave. The result is not entirely satisfactory, because the model using real values with the highest level of statistical meaning, is a branch of a parabolic curve (Fig. 14) from which is missing the inflection associated with the cold air accumulation. Its equation is:

$$t_a = 3.74 \cdot 10^{-5}\, d^2 + 0.0266\, d - 7.80 \qquad (7)$$

The preceding data show that in the study of the cave climate, the most important statistical meaning is found in the spacial distribution of mean annual temperatures. As this distribution corresponds more closely to the configuration of the summer gradient rather than the winter gradient, the fact is proven that the topoclimate of Scărișoara Glacier Cave's is dominated by the cold air accumulated in the glacial sector as a consequence of a particular ventilation regime.

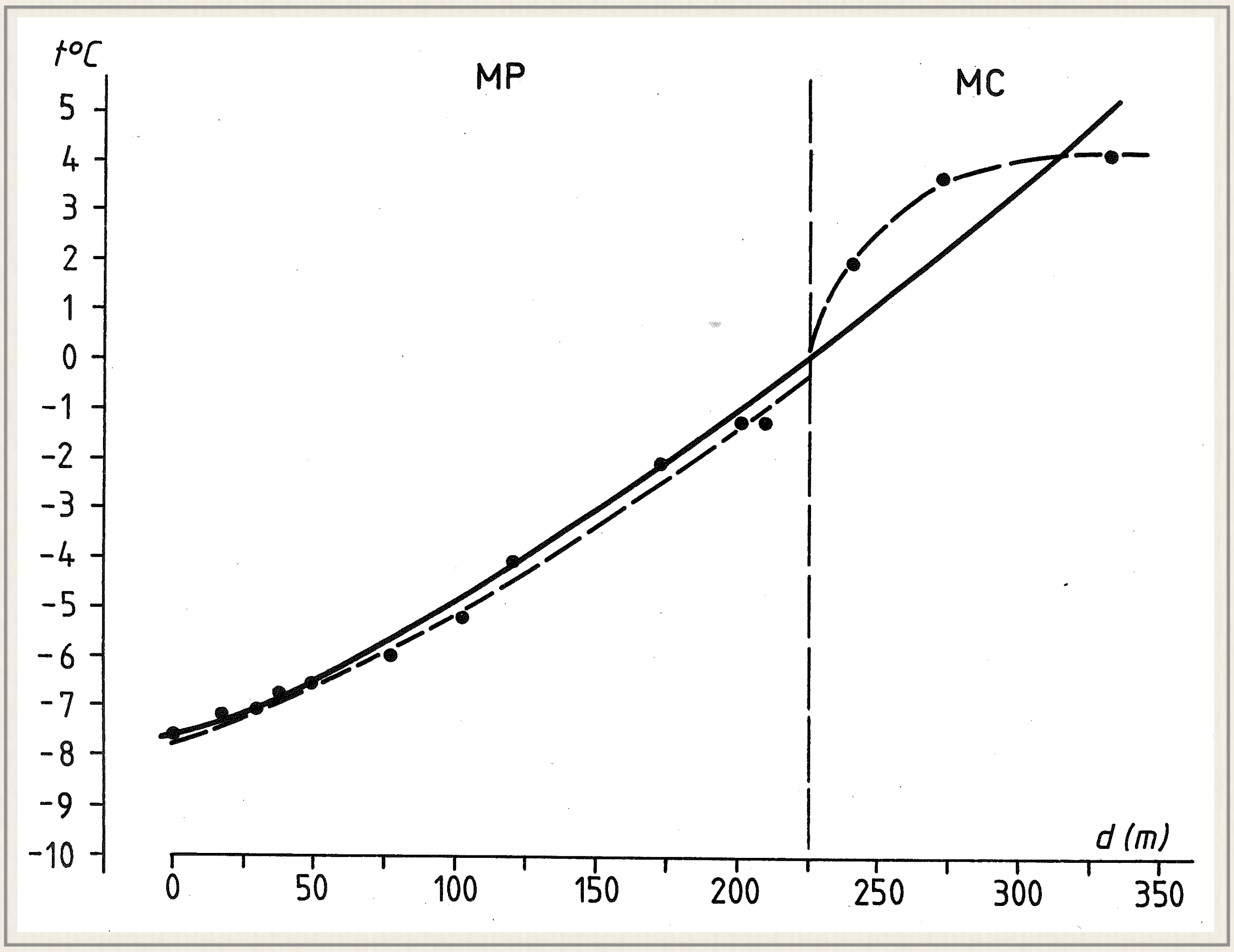

Fig. 14. – Thermal gradient on December 9, 1988.
PM = perturbation meroclimate; WM = warm meroclimate.

The mathematical modeling of the thermal gradients also gives useful information about how much the meteorological differences of a succession of annual cycles at the surface influence the underground topoclimate. As previously stated, the cave is directly exposed to external influences only during winter, so performing such analysis using the distribution of mean winter air temperature appear logical. The elements that distinguish the winter from the summer gradients suggest that, in a very cold winter, at the topoclimatic level, the global parabolic curve will be more open, positioned lower on the coordinates with the inflection point closer to the axis. In the thermal data obtained between 1982 and 1992, the coldest winters were those of 1984-85, 1986-87, 1988-89, and 1990-91, whereas the winters of 1987-88 and especially 1989-90 were milder.

In order to correlate these results with external, typical winter data, the thermometric values recorded at the Baișoara meteorological station were used. This station is located at an altitude of 1,348 m asl and lies approximately 45 km (in straight line) from the Scărișoara Glacier Cave. Using these values, the external average temperature for the November-March period was calculated. This span of time corresponds to the period in the annual cycle when the aerodynamic exchanges between surface and cave take place. The lowest temperatures were measured during 1984-85 and 1986-87 winters (–3.6°C and –3.4°C, respectively), whereas the highest was recorded in the winter of 1989-90 (–0.3°C). These data show that the meroclimate tempe-rature is strictly dependent on the external temperature.

Thermal amplitudes

The consequence of energy transfer associated with air movement in caves not only lead to the formation of a longitudinal thermal gradient, but also cause a progressive decrease of the amplitude variations in the underground atmosphere temperature during an annual cycle. This phenomenon is linked to the same tendency towards achieving the thermal equilibrium between the external and the cave air. This can easily be modeled using a decreasing exponential curve that can be adapted, for real values, to almost all situations (Racoviță, 1993).

The spacial distribution of the annual thermal amplitudes in Scărișoara Glacier Cave corresponds to this general rule (Fig. 15), and its exponential model is given by the following equation:

$$\Delta t_a = 0.197 + 19.874\, e^{-0.0142\, d} \qquad (8)$$

As is the case for the thermal gradients, the deviation of the real values from the theoretical curve allows us to distinguish the same three distinct meroclimatic zones (Fig. 14). If very fast thermal amplitudes decrease is recorded in the transition meroclimate, it will proceed much slower within the cold meroclimate. This can be seen when comparing the numerical coefficients in the following formulae:

$$\Delta t_a = 4.90 + 130.236\, e^{-0.1039\, d} \qquad (9)$$

in the transition meroclimate, and

$$\Delta t_a = 10.691\, e^{-0.00728\, d} \qquad (10)$$

in the cold meroclimate.

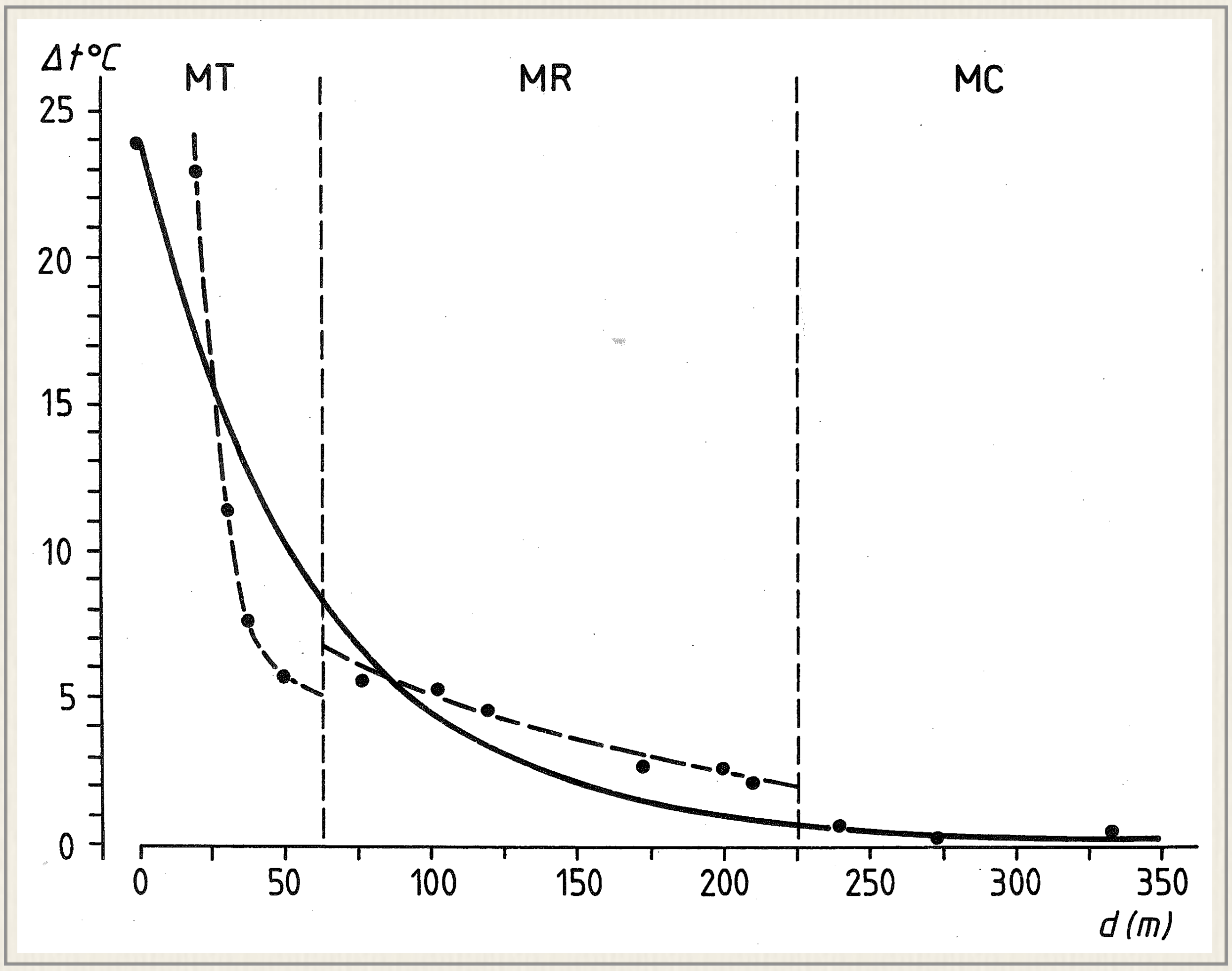

Fig. 15. – Damping of the annual thermal variations in the subterranean atmosphere.

The absence of any external influences in the warm meroclimate make the thermometric variations so small (tenths of a degree) that mathematical modeling has no further use. Damping of air temperature fluctuations shows large differences when seasonal amplitudes are considered. In the winter cycle the phenomenon continues to replicate the model (Fig. 16), but the calculated curve at topoclimatic level is less steep than the one based on annual amplitudes, because the initial values are smaller. The exponential function is:

$$\Delta t_a = 9.385\, e^{-0.0108\, d} \qquad (11)$$

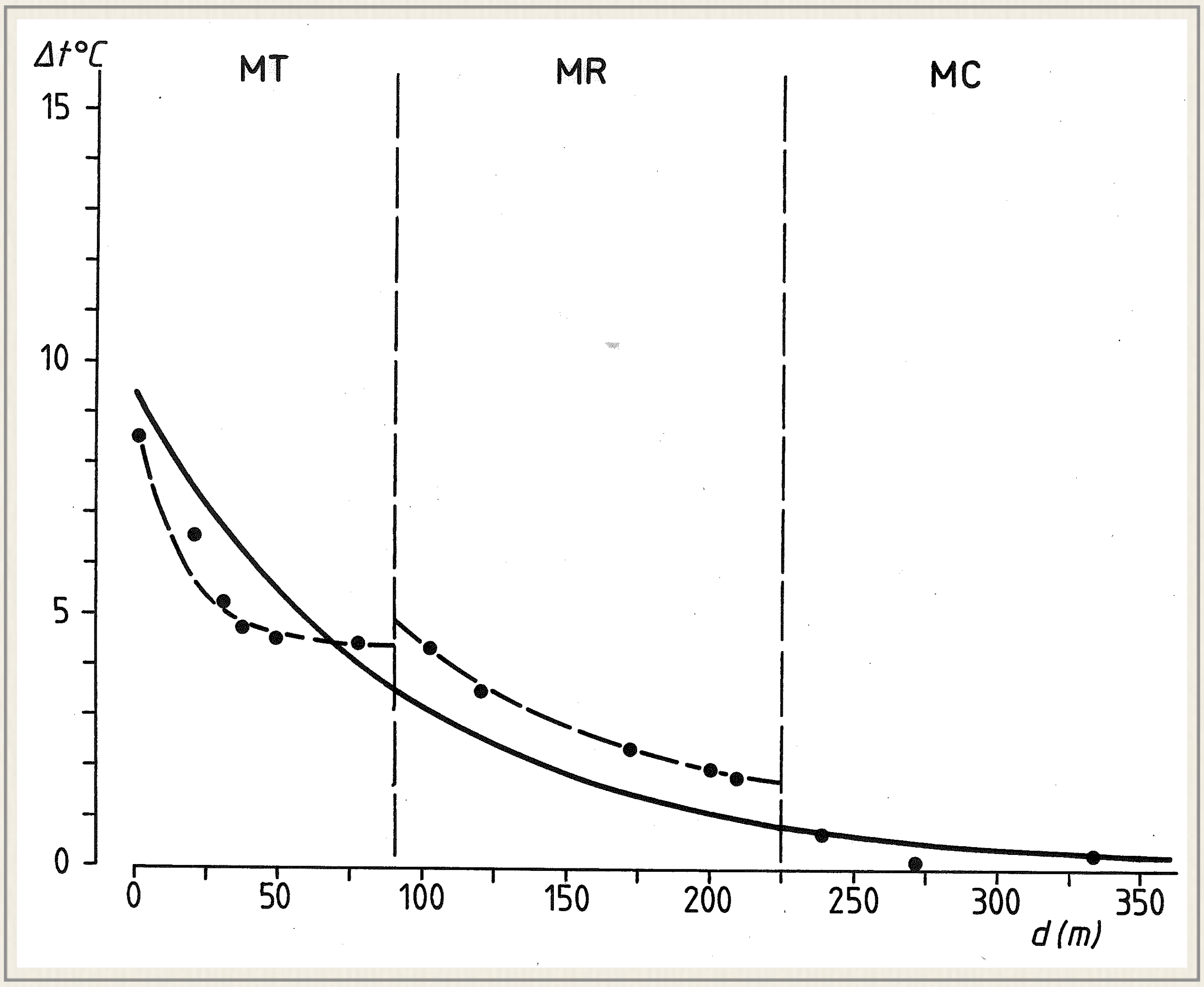

Fig. 16. – Damping of the winter thermal variations.

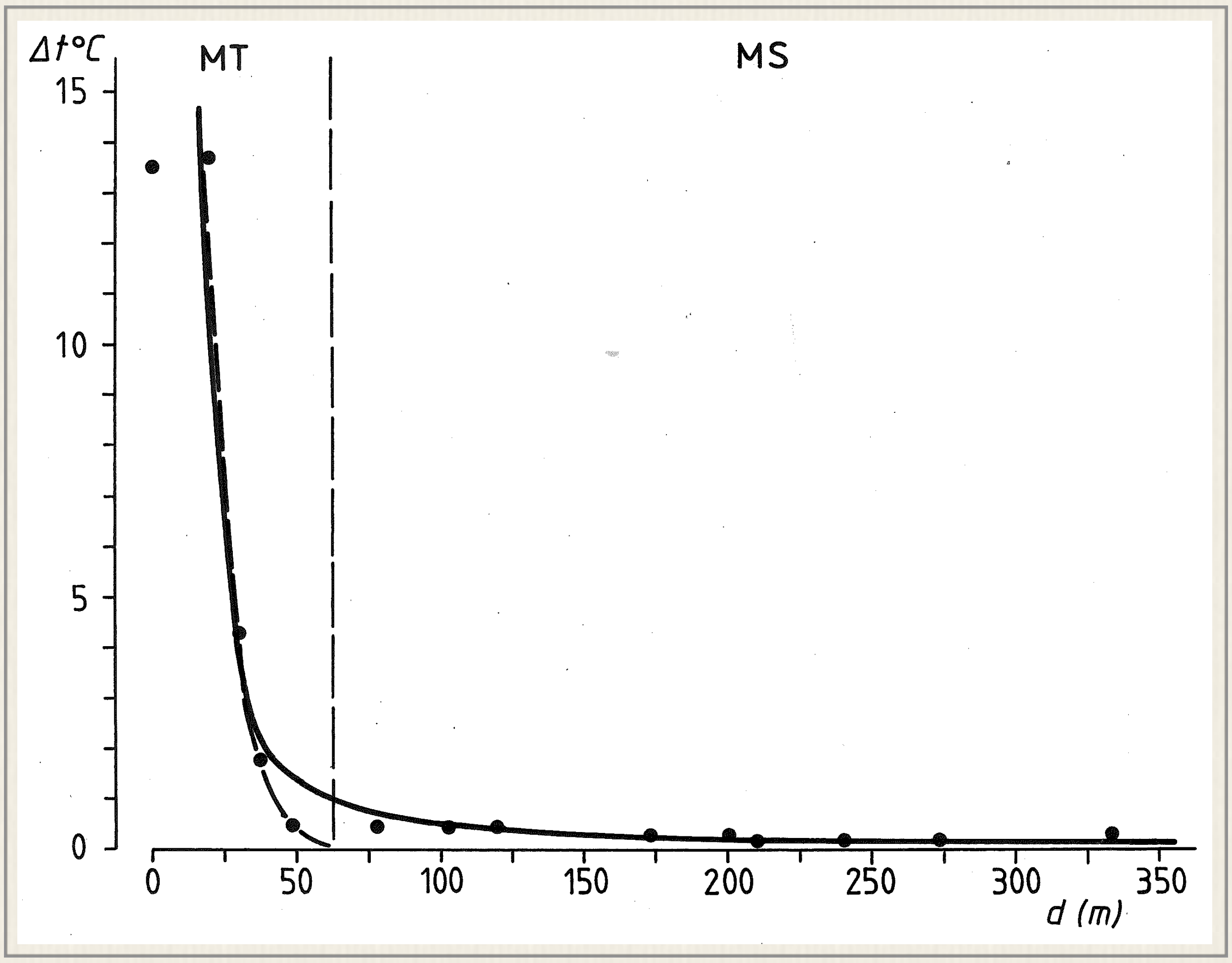

Fig. 17. – Damping of the summer thermal variations.
MT=transition (perturbation) meroclimate; MS=stability (warm) meroclimate.

Especially remarkable, at meroclimatic scale, is that because of the presence of the down flow air current, the decreasing tendency of the thermal amplitudes is much more attenuated in the shaft, and therefore their distribution in the transition meroclimate is more similar to the one in the cold meroclimate. The numerical equations that define the exponential curves in the two zones are:

$$\Delta t_a = 4.33 + 4.296\, e^{-0.0571\, d} \qquad (12)$$

and

$$\Delta t_a = 1.10 + 12.710\, e^{-0.0135\, d} \qquad (13)$$

The cease of the aerodynamic exchanges with the surface during summer has such important repercussions to the underground temperature variations, that it significantly changes the distribution of amplitudes. At topoclimatic level, the most appropriate damping model for the thermal variations is not the exponential, but hyperbolic (Fig. 17). Its equation is:

$$(\Delta t_a - 0.05)\ (d - 15) = 52.7839 \qquad (14)$$

At the same time, the meroclimatic structure of the cave appears to be much simpler, containing only two zones. The first one is the transitional area that is maintained because the upper part of the shaft is under the influence of solar radiation year round. However, the thermal variations damping is still exponential, even though it is much faster than in the winter season. The theoretical model is given by the following equation:

$$\Delta t_a = 118.635\, e^{-0.114\, d} \qquad (15)$$

The second area is a vast stabile one that occupies the rest of the cave. Within this zone the thermal amplitudes never exceed 0.4°C (Table 1).

Comparing the results obtained from mathematical modeling of the thermal amplitude variations one can observe that, at topoclimatic level, the curve representing the annual values (Fig. 15) is similar to the one calculated from the winter values (Fig. 16). This shows once again the important role that thermocirculation plays in determining the climatic features of the Scărișoara Glacier Cave.

The substrata temperature

The bedrock temperature

Long term climatological studies using high tech equipment show that in some caves, the underground atmospheric temperature is influenced by the temperature of the limestone walls, which in turn depend on the caloric flux generated by the solar radiation collected through the bedrock at the surface of the karstic massif. Likewise, the temperature of the percolating water, sometimes acts as a significant thermal vector (Andrieux, 1973, 1974; Delay, 1978). This influence may only be noticed at microclimatic level because it is limited to a few centimeters thick air layer next to the walls (Andrieux, 1971; Racoviță, 1975).

The importance of the bedrock thermometry studies in Scărișoara Glacier Cave was tremendous because the phenomenon of bedrock overcooling had already been hypothesized by Șerban et al. (1967), but never proved through adequate measurements. To fill this gap these types of measurements were undertaken between 1982 and 1992. Initially taken only at a depth of 5 cm in the bedrock, the measurements were extended upon in 1988-89, when they were also taken at the contact layer and at -20 cm from the surface of the walls.

Thermal variations in the depth of the bedrock

The preliminary analysis of the data shows that the amplitude of the thermometric variations recorded at a depth of only 20 cm was too small (under 1°C) to have significant statistical results. For more accurate sampling, the value sets that were most representative for both phases of thermocirculation (December for the winter period, and August for the summer period) were used instead of mean seasonal values (Racoviță et al., 1991).

The results obtained demonstrate two major findings. The first is that the theoretical models correlate to the real values much more closely when the calculations refer strictly to the temperature measured inside the bedrock rather than those obtained from the contact layer. This means that thermal flux conduction is highly disrupted by the air-rock interface, but this influence is minimized as the distance from the cave entrance increases. In the stable meroclimate, the average air temperature in the contact layer can be just 0.08°C higher than the temperature at the bedrock surface.

The second finding concerns the type of curves that model the thermal gradients deep in the bedrock. In the close vicinity of the shaft, the curves are defined in both seasons by exponential functions, but in the glacial sector of the cave the spacial variation of the temperature becomes linear. Such a transformation of the gradient configuration represents a perfect indicator of the multiple effects determined by the cold air accumulation in the Scărișoara Glacier Cave. The linear distribution shows on one hand that the seasonal inversion of the direction in which the reciprocal influence between air and rock is exerted has a more important role inside the cave than outside, because during summer the overcooled walls solely determine the under-ground atmosphere temperature. The most relevant expression of this determinism is the +0.5°C level, that limits the summer temperature increases. On the other hand, the same distribution shows a pronounced thermal homogeneity in the depth of the bedrock, which means that the overcooling process affects the thermal state of the walls at least to a depth of 20 cm.

Longitudinal thermal gradients

The monthly data registered in points close to stations in which the air temperature was measured (Table 2) show that the seasonal bedrock temperature fluctuations are completely analogous to the ones in the cave atmosphere. These fluctuations are characteristic for the glacial sector of the cave, having the same indefinite decreases during winter and the same increase limit during summer. Consequently, it is assumed that the spacial distribution of the bedrock temperature follows the same statistical laws, and the mathematical modeling offers the best confirmation for such a concordance.

Except for small differences in the curves that model (in winter) the thermal gradients at meroclimatic level (Racoviță, 1994), the model that adapts with the highest degree of statistical accuracy to the spacial variation of the annual averages of the bedrock temperatures at a topoclimatic level is also a second degree parabola with vertical axis (Fig. 18). This is shown by the equation (16), where t_r represents the bedrock temperature:

$$t_r = 0.000203\, d^2 - 0.0653\, d + 4.49 \qquad (16)$$

The numerical coefficients are practically the same to those in equation (1), which defines the air temperature's annual gradient. Even if less obvious, this similarity can also be found at the meroclimatic level, where the annual gradients are also modeled by exponential curves, decreasing in the transition meroclimate and increasing in the other two zones. The functions that define them are expressed by:

Table 2

Annual and seasonal amplitudes of the rock temperature between 1982 and 1992.

Station	1	2	3	4	5	7	8	9	10	12	13	14
Mean annual	6.0	5.6	2.1	0.5	–0.9	–0.7	–0.7	0.1	0.4	2.3	2.7	4.5
Mean winter	–0.9	–0.8	–2.1	–2.0	–2.9	–2.1	–2.3	–0.6	–0.1	2.2	2.6	4.5
Mean summer	10.6	9.9	5.0	2.2	0.5	0.3	0.3	0.5	0.8	2.4	2.8	4.5
Annual amplit.	19.3	17.1	10.3	6.3	5.3	3.6	4.0	1.7	1.4	0.4	0.4	0.3
Winter amplit.	5.5	4.6	4.2	3.3	3.7	2.2	2.6	1.1	0.9	0.2	0.3	0.2
Summer amplit.	12.2	9.7	4.2	1.7	0.6	0.6	0.5	0.3	0.3	0.3	0.3	0.3

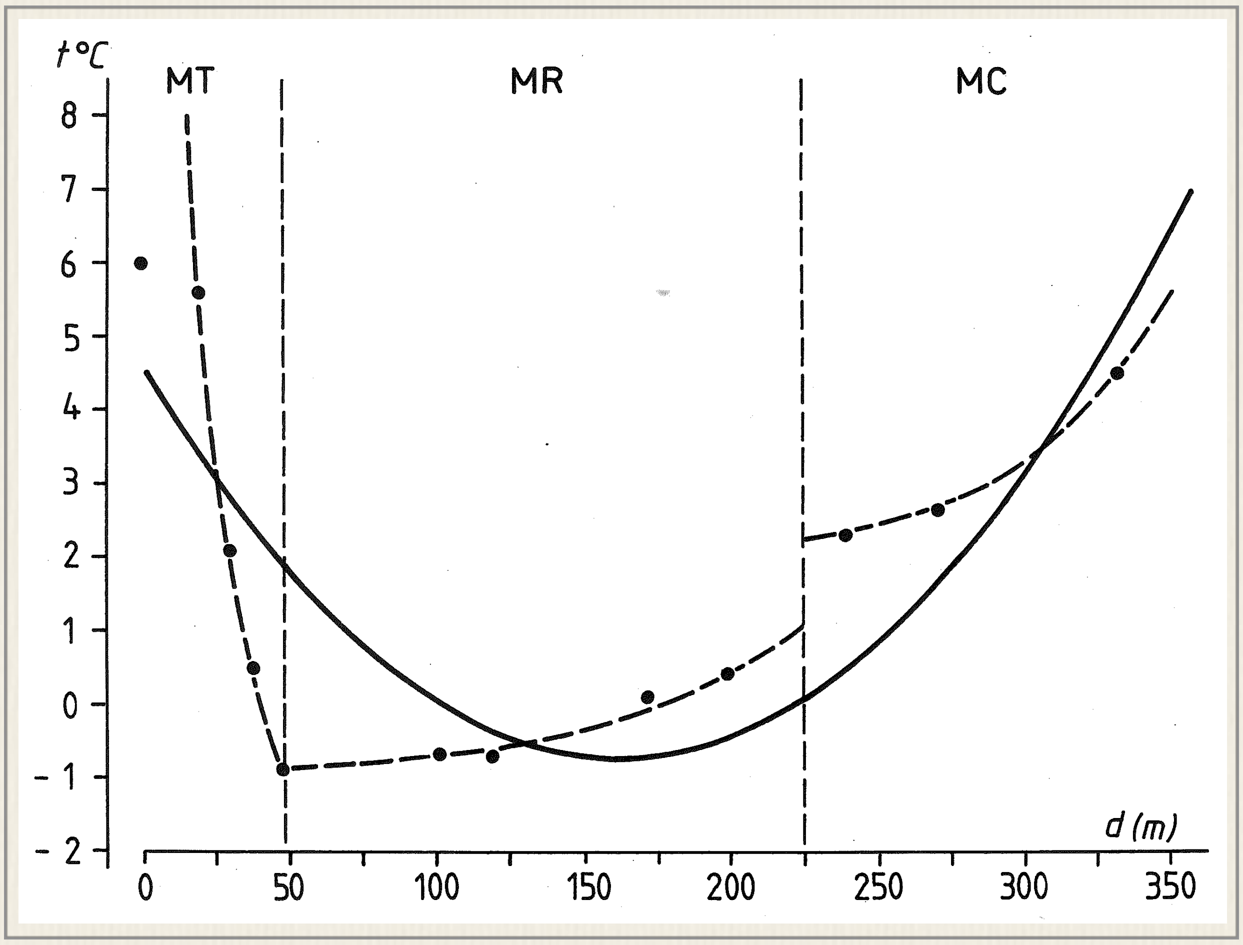

Fig. 18. – Annual thermal gradient in the bedrock.

$$t_r = -2.49 + 23.404\, e^{-0.559\, d} \qquad (17)$$

for the transition meroclimate,

$$t_r = -1.09 + 0.0897\, e^{0.0141\, d} \qquad (18)$$

for the cold meroclimate, and

$$t_r = 1.80 + 0.00615\, e^{0.0183\, d} \qquad (19)$$

for the warm meroclimate.

The only element that differentiates these models from those calculated for air temperature is the configuration of the curves corresponding to the warm meroclimate. As results from equation (4) and (19) - the asymptote of the air temperature lie above the curve (Fig. 11) but below the curve in the case of bedrock temperature (Fig. 18). This is because at "Fereastra Margaretei" (Station 13), the bedrock temperature was measured in the close vicinity of the narrow window, so that the recorded values were not influenced by the ascending warm air current.

The thermal amplitudes

The analogy of both underground atmosphere and superficial layer of the walls, shown by the thermal gradients, is also demonstrated by comparative analysis of the thermal amplitudes. This is because the same type of functional curves in both physical environments also reproduces damping of the variations. The qualitative similarity is absolutely general and covers on one hand all the climatic levels, and on the other hand, both seasonal and annual values (Racoviță, 1994). There is however an important difference but at quantitative level. It is the fact that, although obvious at physical scale, the temperature of the limestone bedrock, which has a higher calorific capacity than the air, varies within limited intervals (Table 2).

The exponential distributions of annual thermal amplitudes recorded in the bedrock have the following numerical expressions:

$$\Delta t_r = 0.26 + 18.872\, e^{-0.0177\, d} \qquad (20)$$

at the topoclimatic level,

$$\Delta t_r = 3.58 + 63.041\, e^{-0.0794\, d} \qquad (21)$$

in the transition meroclimate, and

$$\Delta t_r = 1.19 + 149.298\, e^{-0.0328\, d} \qquad (22)$$

in the cold meroclimate, respectively.

In agreement with the statistical significance, the theoretical models of these distributions have as particular characteristic a greater extension of the transition meroclimate than usual (Fig. 19). Its limit is placed not at the entrance in the "Sala Mare" but at the upper extremity of the Maxim Pop Gallery (Station 7).

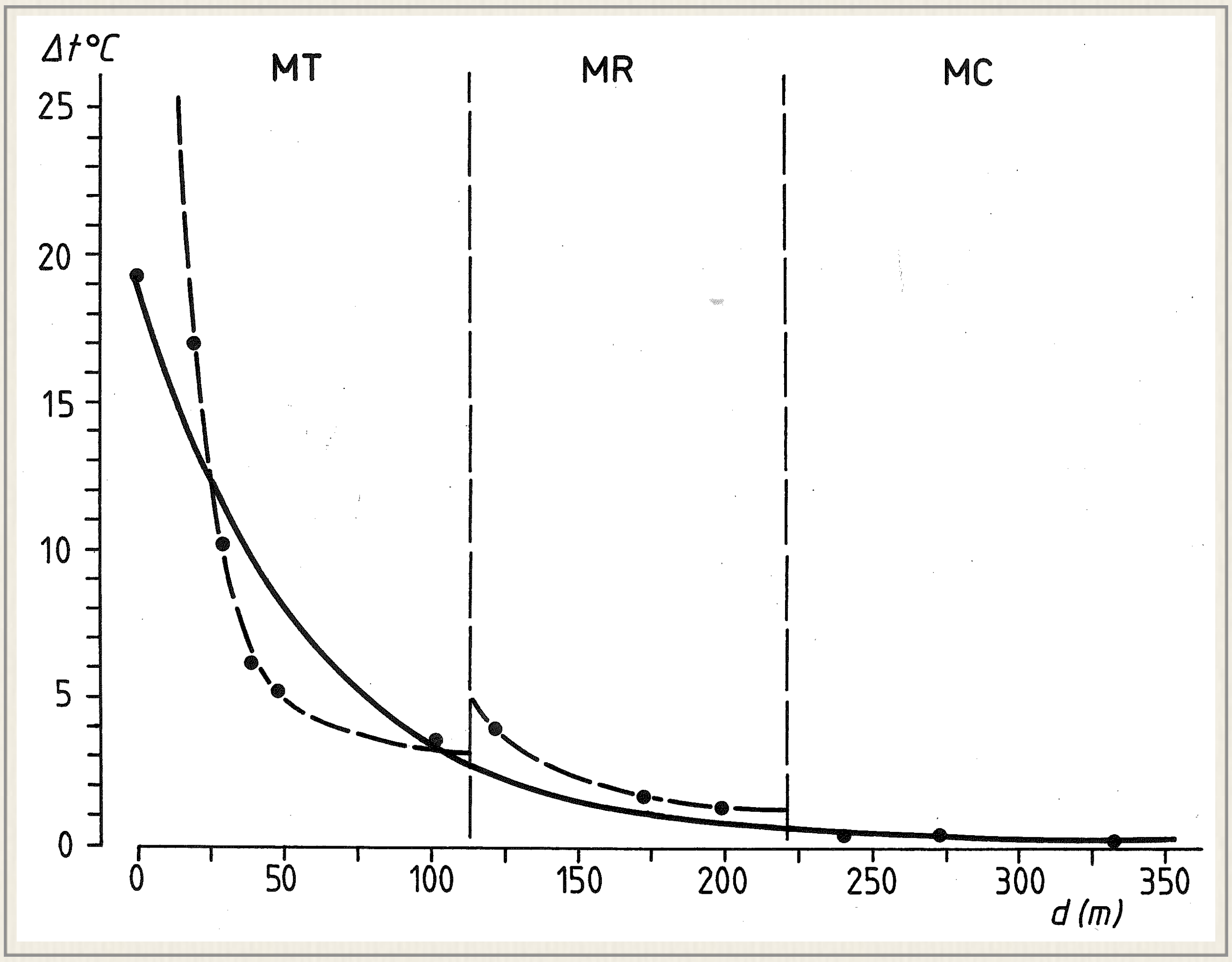

Fig. 19. – Damping of the annual thermal thermal variations in the bedrock.

The ice temperature

Because the ice has different thermal properties when compared with limestone, it can be assumed that the temperature variations produced within the glacier show some particularities. These can be best detected if the variations are examined under the same conditions followed when bedrock thermometry was analyzed.

The ice temperature was determined during one annual cycle (November 1988 - October 1989). The sensors of the electronic thermometers were inserted to depths of 10, 40, 70, and 100 cm. The measurements were taken both on the upper face of the ice block (the floor of the Sala Mare), and on its southern flank, in five stations (Fig. 10). We will refer however, only to four of these, the fifth one being located in front of the entrance in the "Biserica", an uncharacteristic position if compared to the alignment chosen for the previous mathematical modeling.

The thermal variations within the ice block

The results obtained using the temperature gradients within the ice block led to more significant results because the depth to which the temperatures were measured was greater than in the bedrock.

The recorded data show that the ice temperature varies in close correlation with the underground atmospheric temperature. During winter, the cold air entering the cave causes a rapid decrease of the ice temperature. The minimum value measured at a depth of 100 cm in the central part of the "Sala Mare" (January 1989) was –3.1°C (Racoviță et al., 1991). The first important finding is that the overcooling phenomenon is not restricted to the superficial layer, but also acts in the depth of the glacier, thus affecting a considerable volume of ice. Once the air exchanges with the surface ceases during summer, the ice temperature increases to a few tenths over 0°C (but never exceeds 0.1°C at –100 cm). This temperature remains much more constant compared to that of the bedrock because the absorbed caloric energy causes the melting of the superficial ice layer and not the warming within the glacier.

Changes of the ice temperature create positive and negative gradients in winter and summer, respectively. Depending on the position, these gradients show important differences. They may be best evidenced if the seasonal averages are calculated for the extreme topographic points, represented by the surface of the glacier (Station 6) and the base of its southern flank (Station 8) (Table 3). The mathematical modeling of these values shows that, in all cases, the temperature varies as a function of depth following a linear function (Fig. 20).

The equations that define the lines expressing the winter gradients are:

$$t_g = 0.00953\ a - 3.23 \qquad (23)$$

for station 6 and,

$$t_g = 0.00553\ a - 2.59 \qquad (24)$$

for station 8 (t_g represents the ice temperature, whereas a is the depth of the measurement).

Comparing, the two equations, one can conclude that the temperature gradient is higher and implies lower absolute values on the surface of the glacier, this one being more exposed to direct influences of the external cold air. We must note, however, that the temperature cannot vary linearly except in an ice layer of limited thickness. The extrapolation of the two equations leads to positive theoretical values for a depth greater than 3-4 m, result that is incompatible with the physical reality within the cave.

In the summer regime, the two linear models are given by the equations listed below:

$$t_g = -0.00327\ a - 0.23 \qquad (25)$$

and

$$t_g = -0.00147\ a + 0.06 \qquad (26)$$

They indicate on one hand, a general tendency to equalize the temperatures, and on the other hand, the fact that the superficial ice layers warming during summer is slightly more evident on the surface of the glacier, which at this time receives more caloric radiations (Fig. 21).

Similar differences appear in the case of seasonal thermal amplitudes (Table 3). In the winter period, damping of the thermometric variations as a function of depth corresponds in both station points to decreasing asymptotic exponential curves (Fig. 22). There equations are:

$$\Delta t_g = 1.69 + 1.260\ e^{-0.0273\ a} \qquad (27)$$

for the surface of the ice block, and

$$\Delta t_g = 0.77 + 1.438\, e^{-0.00703\, a} \qquad (28)$$

for the base of its southern flank.

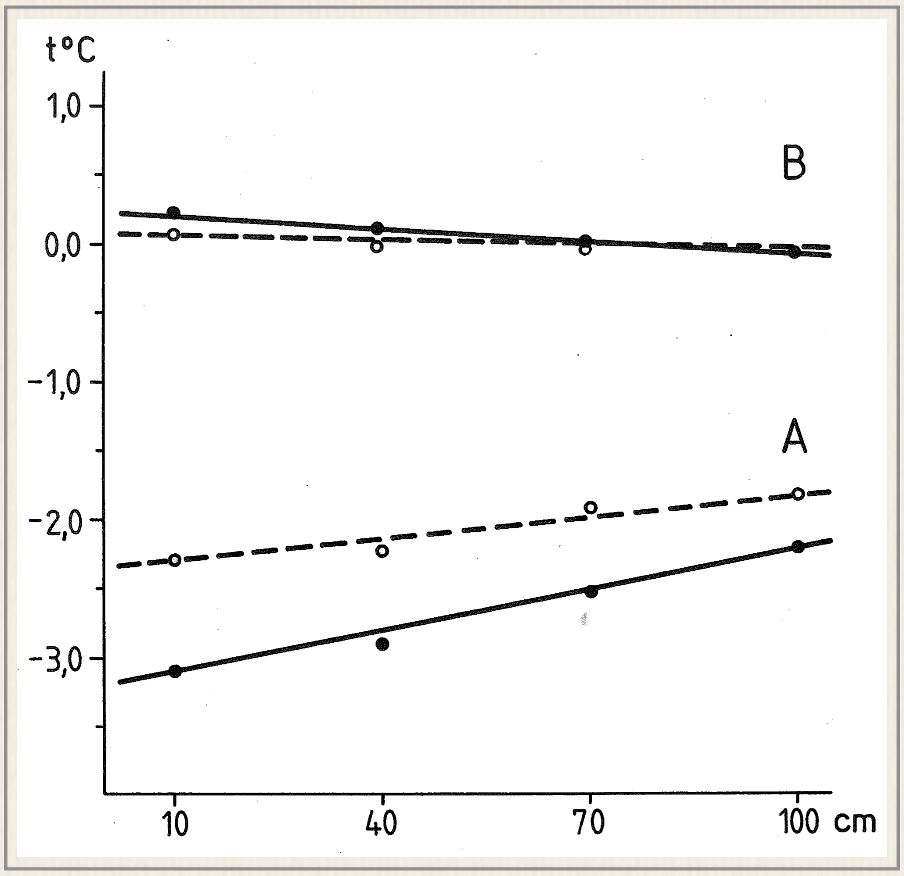

Fig. 20. – Thermal gradients within the glacier in station 6 (solid circles and line) and in station 8 (open circles and dashed line, during winter (A) and during summer (B).

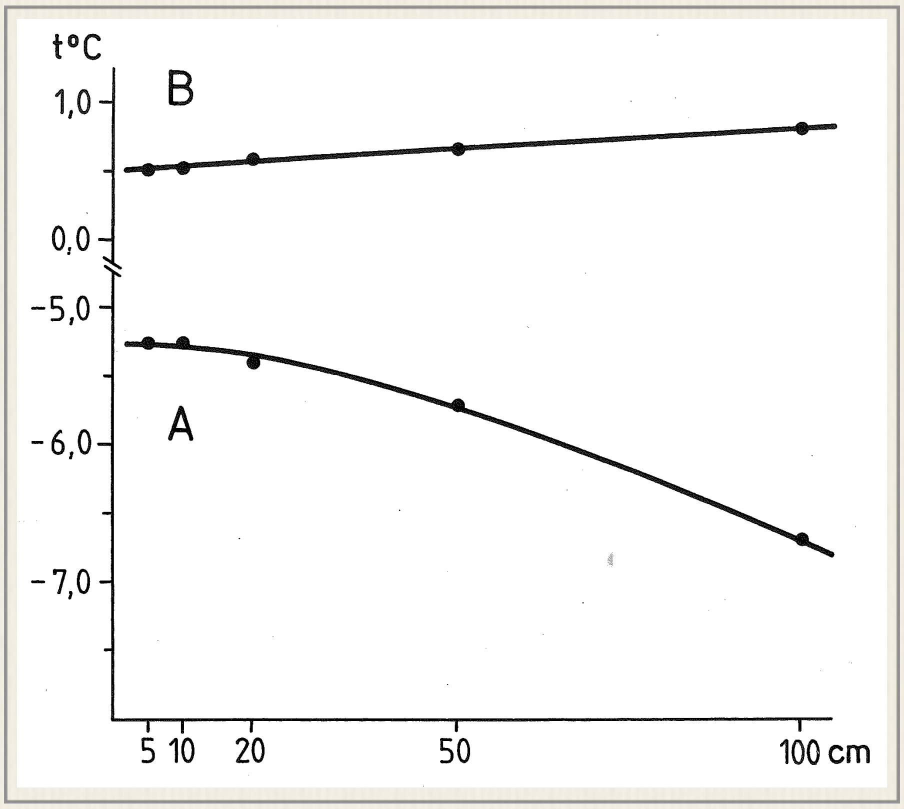

Fig. 21. – Air thermal gradients up to 100 cm from the limestone wall. A = values registered in December 1988; B = summer mean values.

These equations reveal that in agreement with the results obtained in the analysis of the thermal gradients, the temperature is more variable in the superficial layers of the ice block, but tends to stabilize at depth. The extrapolation of the theoretical values in this case leads to acceptable results, because the depth at which temperature of the ice becomes stable (and where the amplitude is just few hundredths of a degree) is 12-13 m, that is approximately half the total depth of the block.

Table 3
Seasonal means and amplitudes of ice temperatures between November 1988 – October 1989.

Station	Center of Sala Mare (Station 6)				Southern limit of Sala Mare (Station 7)			
Depth (cm)	–10	–40	–70	–100	–10	–40	–70	–100
Mean winter	–3.10	–2.90	–2.56	–2.26	–2.66	–2.56	–2.38	–2.14
Mean summer	0.20	0.11	0.00	–0.09	0.09	0.00	–0.14	–0.20
Winter amplit.	2.7	2.2	1.8	1.8	2.4	1.8	1.8	1.7
Summer amplit.	0.2	0.3	0.7	0.8	0.6	0.7	0.7	0.8
Station	Middle zone of the ice wall (Station 7a)				Base of the ice wall (Station 8)			
Depth (cm)	–10	–40	–70	–100	–10	–40	–70	–100
Mean winter	–2.04	–1.72	–1.60	–1.44	–2.30	–2.24	–1.96	–1.84
Mean summer	0.04	–0.04	–0.13	–0.19	0.06	–0.01	–0.06	–0.07
Winter amplit.	1.5	1.3	1.1	1.0	2.1	1.9	1.6	1.5
Summer amplit.	1.0	1.1	1.1	1.1	0.6	0.7	0.8	0.7

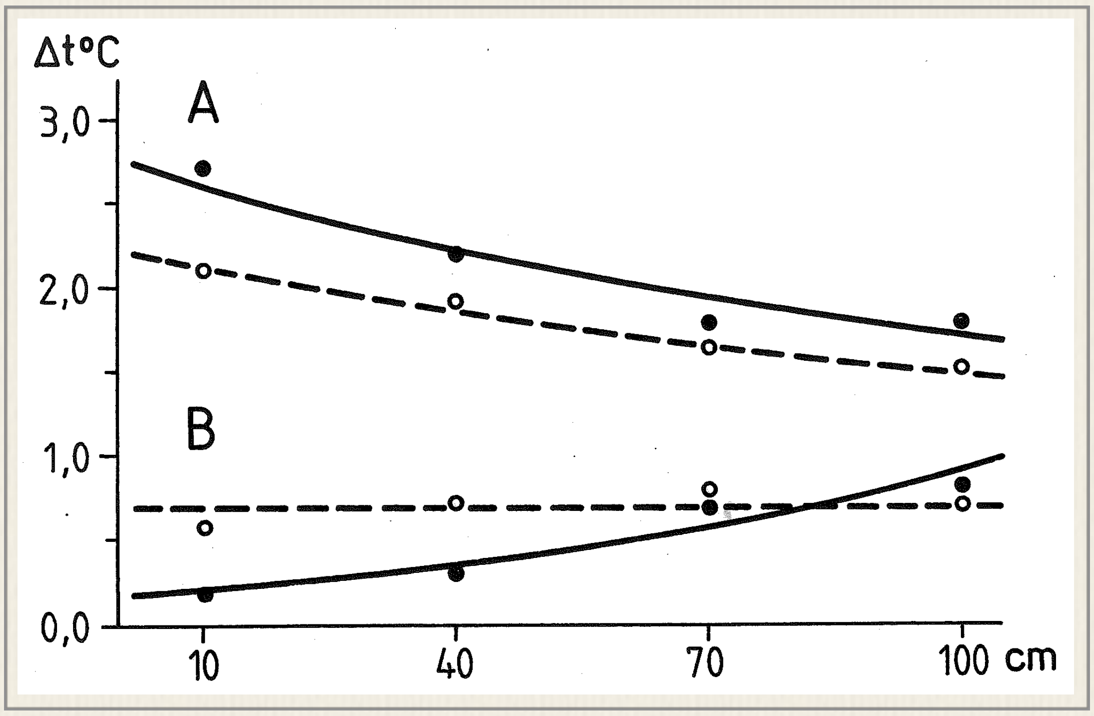

Fig. 22. – Damping of the thermal variations within the glacier in station 6 (solid circles and lines) and in station 8 (open circles and dashed lines). A = winter regime; B = summer regime.

During summer the situation is completely different. The solar radiation received by the floor of "Sala Mare" causes a rapid temperature increase of the upper ice layers, where a state of equilibrium is quickly established. This effect is missing at greater depths so a relatively low temperature is maintained in the upper part of the block at the beginning of the season. These temperatures are interpreted as being a "residual" effect of the winter influences. The relationship between the depth and the thermal amplitude can now be expressed by an ascending exponential curve and the equation is:

$$\Delta t_g = 0.171\, e^{0.0167\, a} \qquad (29)$$

At the base of the southern flank that is unaffected by direct caloric radiation, this phenomenon attenuates in such a degree that the thermal amplitudes become almost equal and the exponential curve is replaced by a line parallel to the abscissa axis.

The thermal gradients near the substrata

For a more accurate image of the thermal relationships between the cave atmosphere and the two types of substrata, climatological studies for an annual cycle (November 1988 - October 1989) were completed with monthly atmospheric measurements. These were taken successively at distances of 5, 10, 20, 50, and 100 cm from the surface of the limestone walls and ice block. An electronic thermometer (DTL – 70) having its sensor on a support that could be moved along a fixed rod was used for this purpose. The measurements near the wall were taken in station 5 with the rod set in horizontal position, and for the ice block in station 6, with the rod in vertical position. The values recorded in the latter station were visibly influenced by the thermal gradient (also vertical and normally appearing in the cave atmosphere), which substantially altered the thermal interference between the air and the ice (Racoviță et al., 1991). For this reason, we will further consider only the data referring to the phenomena occurring near the limestone walls.

The analysis of these data confirms the existence of significant seasonal differences. As expected, during winter the cave and the external temperatures vary in close correlation. It is therefore more useful to describe the features of the caloric transfer using the set of values recorded in the most characteristic moment of the season and not the mean seasonal values calculated for each of the five measurement points. This moment appears when the thermocirculation is the most intense (i.e., when the external temperature is the lowest). In the annual cycle considered here, such a moment was recorded in December 1988, when the surface temperature was –7.6°C.

Mathematical modeling shows that under such conditions the air temperature increases as the distance to the wall decreases; the difference between the values measured at 100 cm and 5 cm being 1.4°C. This increase generally follows a parabolic curve (Fig. 21), whose numerical equation is:

$$t_a = -0.000116\, d^2 - 0.00261\, d - 5.28 \qquad (30)$$

This clearly shows that during winter, the most important element driving the caloric exchanges between different underground physical environments is the external cold air flowing into the cave.

In the summer regime, seasonal averages can be used for mathematical modeling because temperatures tend to be equal. The direction of the gradient reverses in this period and the difference between the extreme values reduces at 0.26°C, so that the theoretical model corresponds to a slightly inclined line, defined by the formula:

$$t_a = 0.00260\, d + 0.51 \qquad (31)$$

These results confirm that in winter period the underground atmosphere temperature is the one that determines the thermal state of the substrata. In turn, during summer the substrata are the ones that influence the air temperature due to their overcooling during winter.

Relative humidity

Unlike temperature, the external relative humidity variations do not have any seasonal periodicity. This parameter has less importance in determining the air density that is driving the thermocirculation. These common facts for both meteorology and physics apply to cave climatology and have two important consequences. First, there is no evident relationship between external fluctuations and those recorded within the caves, and second, the hygrometric parameter of the cave atmosphere rarely suites to a mathematical modeling.

With respect to the latter point of view, the Scărișoara Glacier Cave represents an exception, because all the results of statistical tests were positive. Furthermore, the data modeling pointed out the same meroclimatic zones already revealed by the thermometric values. This shows once again the importance the functional curves have in cave topoclimatic description.

Hygrometric gradients

On a topoclimatic scale, the relative humidity mean annual values are modeled by an equilateral asymptotic hyperbola (Fig. 23), defined by the following formula:

$$(98.3 - RH)\, d = 205.888 \qquad (32)$$

that perfectly illustrates their rapid increase and also the fact that, starting from Sala Mare (Station 6) and all the way to the lowermost part of the Coman Gallery (Station 14), these values remain very high (between 94.8 and 98%; see Table 4).

In the first two meroclimatic zones, the distribution of these mean annual values becomes exponential, being somehow similar to those describing the thermal values, but of course, it is oriented in opposite direction. The curves that model it are given by the following equations:

$$RH = 100 - 24.287\, e^{-0.0381\, d} \qquad (33)$$

in the transition zone, and

$$RH = 93.379\, e^{0.000149\, d} \qquad (34)$$

in the cold zone.

The most accurate model that applies for the warm meroclimate zone is a second degree reversed parabola, with the numerical expression:

$$RH = -0.000460\, d^2 + 0.251\, d + 63.7 \qquad (35)$$

The air flowing down the bottom of Coman Gallery year round causes a slight decrease of the relative humidity, fact reflected by the above formula.

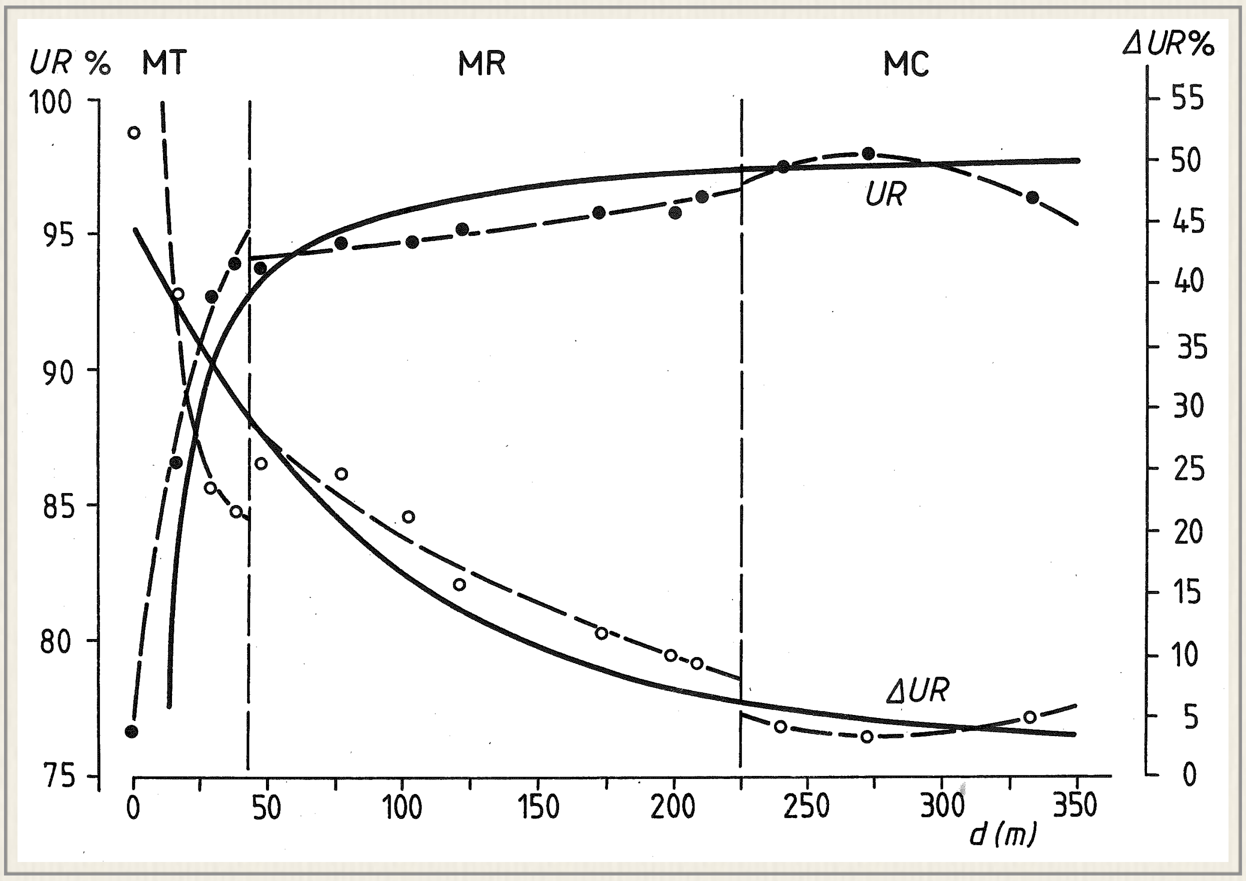

Fig. 23. – Hygric gradients and their annual variations damping.

The hygrometric seasonal gradients established for the topoclimatic level are completely different when compared with those obtained from mathematical modeling of temperatures. During winter, the increase of the relative humidity follows an exponential curve, according to the equation below:

$$RH = 98 - 15.3889\, e^{-0.00963\, d} \qquad (36)$$

Table 4

Annual and seasonal means and amplitudes of the relative humidity between 1982 and 1992.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mean annual	76.7	86.6	92.7	94.0	93.8	94.8	94.7	95.2	95.9	95.9	96.5	97.5	98.0	96.4
Mean winter	78.9	84.9	88.5	89.8	89.5	89.8	91.2	93.0	93.3	94.6	94.5	97.3	97.8	96.1
Mean summer	77.2	89.2	93.9	96.4	97.6	97.8	98.1	97.8	97.5	96.6	97.8	97.8	98.1	96.7
Annual amplit.	52.2	39.2	23.3	21.5	25.5	24.9	21.3	15.3	11.6	10.0	9.5	4.2	3.4	5.0
Winter amplit.	29.5	23.0	19.5	18.5	17.7	23.2	18.6	13.0	8.7	8.2	7.0	3.4	2.7	3.8
Summer amplit.	35.6	22.6	9.7	7.6	4.3	3.3	2.9	3.4	3.5	2.9	3.4	2.3	2.7	3.6

while during summer, the same phenomenon can be expressed by a hyperbolic function:

$$(98.16 - RH)\ (d - 10) = 77.0615 \qquad (37)$$

At meroclimatic level however, the configuration of the seasonal gradients remains unchanged. This configuration is illustrated in both periods by increasing exponential curves closely related to the annual gradient model. It must be mentioned that during summer, the deviation of the real values from the theoretical curve allows only two zones to be defined. This is because in the rest of the cave, except for the shaft, the hygrometric values are too constant to be modeled (Table 4).

Statistical processing of data emphasizes a new and extremely important element. This is the finding that the annual hygrometric gradient is qualitatively similar to the summer one, but different from the winter one. Thus, it can be stated that the hygrometric survey specific to the Scărișoara Glacier Cave is dominated by the perturbations caused by winter thermocirculation. These perturbations have completely different effects than those related to temperature, because the "accumulation" phenomenon is impossible to imagine in this case.

Hygrometric amplitudes

If any analogy between the spacial variations of temperature and of relative humidity in the cave atmosphere is excluded, the situation is completely different when taking into account the amplitude of these variations. That is so because both climatic factors tend to stabilize in the profound zones of the cave. Indeed, the mathematical modeling demonstrates that, due to the great similarity of oscillations tendency to attenuate, there is no qualitative element that would allow distinguishing the two parameters. Regardless of the climatic level or whether annual or seasonal values are used, the curves that best adapt to the real values (i.e., those being statistically significant) are all of exponential type (Racoviță, 1994).

The decrease of annual hygrometric amplitudes at the same time with increase of distance from the cave entrance is modeled by the following numerical equations:

$$\Delta RH = 2.79 + 41.776\, e^{-0.0110\, d} \tag{38}$$

at the topoclimatic level,

$$\Delta RH = 21.1 + 1014.52\, e^{-0.2117\, d} \tag{39}$$

in the transition meroclimate,

$$\Delta RH = 38.234\, e^{-0.00071\, d} \tag{40}$$

in the cold meroclimate, and

$$\Delta RH = 0.000562\, d^2 - 0.313\, d + 46.9 \tag{41}$$

in the warm meroclimate, respectively.

Compared to formulas (8), (9), and (10) established for air temperatures, these equations show only one characteristic element, that is, the hygrometric amplitudes modeling becomes possible in the warm meroclimate as well. As for the hygric gradients, the result will be a parabolic curve (Fig. 23) due to relatively large variations registered at station 14 (Table 4). These variations are induced by the perturbations produces by the air flow in the bottom of the cave.

Evapocondensation

Determining the evaporation and condensation processes that take place in the underground atmosphere or at the level of different layers by direct measurements is extremely difficult, because these processes are caused by complex interactions of many climatic factors and their intensity is often low (Andrieux, 1970b). As Decu et al. (1982) pointed out, it is practically impossible to measure the natural condensation, because any device used for this purpose induces condensation to take place on an artificial surface.

In spite of the inherent difficulties, the topoclimatic studies program in the Scărișoara Glacier Cave also included evapocondensation, and the measurements supplied significant results in both research periods (1963-1968 and 1982-1992).

Condensation

In order to determine the quantity of condensed water, a genuine device was used. It consisted of a metallic cone having a surface of 2,500 cm^2 and a collecting graduated vessel below it (Viehmann, 1969). Using this device, two sets of data were collected. The first one contains values that were recorded monthly between April 1965 and January 1967, when the device was set 9 m above the floor at the limit of the glacial zone in the Rezervația Mare (Station 1). The readings were made 48 hours after the device was set in its station. The second one also includes monthly measurements, taken during only one annual cycle (February 1983 to March 1984) with the device placed on top of the collapse blocks in "Catedrala", at a height of 1.5 m above the floor (Station 2). In this instance it functioned continuously, and the collected water volumes correspond to a 30-day average period. Both stations were in the warm ascending branch of the bi-directional ventilation area.

The theoretical values of the condensation intensity, inferred from the absolute humidity calculation, were use in order to establish a reference point that allows to evaluated the degree in which the measurements reproduce the natural phenomenon. The relationship that expresses this parameter as a function of temperature and relative humidity is:

$$f = e \cdot \frac{289.38}{273+t} \qquad (42)$$

where: f = the absolute humidity (g/m^3), e = the water vapor pressure for the given relative humidity and temperature (mm Hg), and t - the air temperature (°C) (Racoviță, 1975).

The maximum quantity of water that can form by condensation results from the difference between the absolute humidity monthly calculated for the two extreme points of the convection cell: the bottom of the Coman Gallery and the Sala Mare.

The results show that there is a good agreement between the measured and the calculated condensation (Table 5 and Fig. 24). Therefore data can be considered representative at least on a relative value scale, namely the variations in space and time of this phenomenon.

Secondly, the two series of data show that the intensity of the condensation significantly increases during winter, when the quantity of water condensing per surface unit is two times greater than the one formed during summer. This supposition is obvious because it corresponds to the seasonal variations that affect the physical state of the cave atmosphere. These variations originate in the increased flow rate, and from the accentuated cooling of the air transported by the ascending branch of thermocirculation during winter.

The third important assumption is that, comparing the volumes collected in the same period of time, the intensity of the condensation proves to be about 6.5 times greater in station 1 than in station 2. A water-collecting device was placed at the bottom of Coman Gallery in November 1983. It remained dry throughout the winter period. Considering the topographic position of the three points (station 1, 2, and the bottom of the Coman Gallery), one can define two gradients for the condensation intensity in Rezervația Mare and by analogy in Rezervația Mică as well. One gradient is horizontal, from the deeper parts towards Sala

Table 5

Intensity of evapocondensation.

Station I			Station II				
Date	Condensation		Date	Condensation		Evaporation	
	measured (cm³/m²/48 h)	calculated (g/m³)		measured (cm³/m²/30 z.)	calculated (g/m³)	measured (mm/30 zile)	calculated (mm/30 zile)
IV 1965	68.0	1.59	II 1983	134	2.51	–	–
V	60.8	1.58	III	120	1.70	0.63	3.04
VI	62.0	1.38	IV	105	1.59	1.06	2.21
VII	53.2	1.28	V	97	1.40	0.62	2.35
IX	60.0	1.38	VI	103	1.49	0.61	2.35
X	61.2	1.38	VI	103	1.51	0.61	2.35
XI	88.0	2.72	VIII	203	1.40	0.59	2.35
I 1966	100.0	2.92	IX	227	1.50	0.63	2.35
II	77.2	2.50	X	218	1.91	0.91	3.05
III	84.0	3.14	XI	201	4.31	1.06	3.87
IV	76.0	1.80	XII	489	2.30	1.10	5.25
V	76.0	1.69	I 1984	104	2.20	1.73	5.25
VI	60.0	1.49	II	136	2.20	1.29	2.21
VII	64.0	1.60	III	122	2.10	1.31	2.21
IX	66.0	1.29					
XI	88.0	2.40					
I 1967	156.0	3.65					

Mare, and the other is vertical, from the floor level to the ceiling (Racoviță and Viehmann, 1985). A spacial variation having the same feature was also found in the Cloșani Cave (Decu et al., 1982).

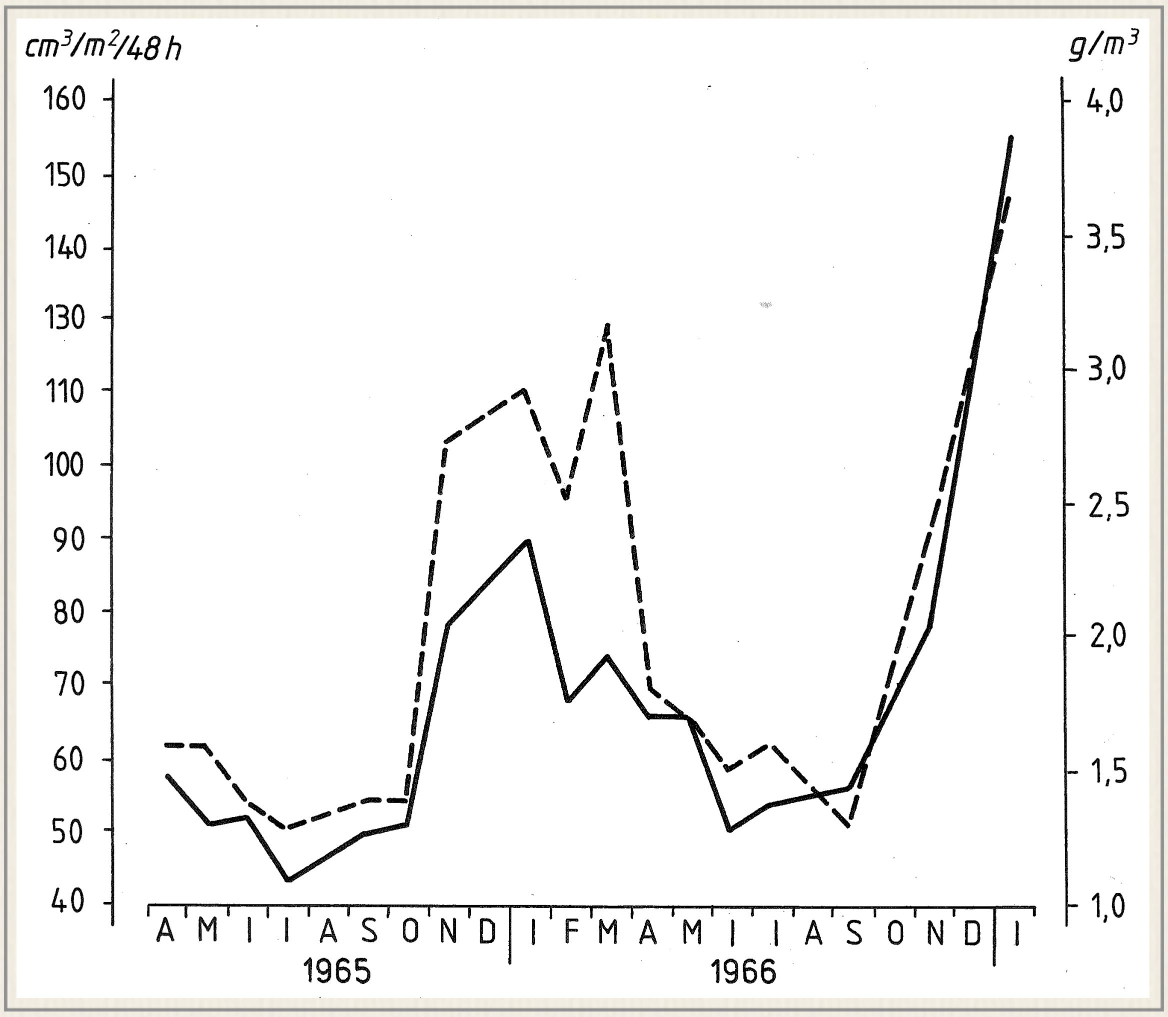

Fig. 24. – Intensity of condensation in Rezervația Mare (station 1), between April 1965 and January 1967. Solid line = measured values (cm³/m²/48 h); dashed line = calculated values (g/m³).

In the Scărișoara Glacier Cave the condensation role is great as it generates frost that deposit on the walls of Sala Mare during winter, and also supply some feeding water for the ice stalagmites. We will further discuss these aspects in the following chapters.

Evaporation

Monthly measurements of evaporation intensity were continuously undertaken between March 1983 and August 1992. These observations were restricted to station 2 in Rezervația Mare where a Piche evaporimeter was installed next to the condensometer. As in the case of condensation, the data offered by this device in the first annual cycle were correlated with the theoretical evaporation values, calculated by means of Lugeon formula (Castany, 1967). Adapted to the underground conditions, this formula is:

$$E = 0.398 \cdot n \cdot (e' - e)\frac{273 + t}{273} \cdot \frac{760}{P - e'} \quad (43)$$

where *E* represents the quantity of evaporated water (mm), *n* - the number of days, *e'* - the pressure of the saturated vapors at temperature *t* (mm Hg), *e* - the real pressure of the water vapor at the same temperature and at the measured relative humidity (mm Hg), *P* - the atmospheric pressure (mm Hg), and *t* - the air temperature (°C).

The obtained data show that in the central part of the "Catedrala" the condensation and the evaporation are simultaneous (Table 5). This phenomenon was also reported from other Romanian caves (Racoviță & Crăciun, 1981; Racoviță et al., 1983). It was explained as follows: either the relative humidity never reaches the saturation point, which is the necessary and sufficient condition for the evaporation to take place, or the bedrock temperature is lower than the air temperature, and the condensation process take place over all substrata as well. Thus, when relative humidity values are close to the saturation point, it is possible to have simultaneously evaporation [if the vapor pressure corresponding to the air temperature and relative humidity (e_a) is smaller than the saturated vapor pressure at the same temperature (e')], and condensation on the substrata [if e_a is greater than the saturated vapor pressure corresponding to the bedrock temperature (e'_r)]. For the central part of the "Cathedral" the measurements taken at station 2 show average values of 2.5° C for the air temperature, 97% for the relative humidity, and 1.8° C for the bedrock temperature. Completing the calculations, the values obtained are e_a = 5.32; e' = 5.48; e'_r = 5.22 mm. Because $e_a < e'$, evaporation will take place into the cave atmosphere, but at the same time given the fact $e_a > e'_r$, condensation will take place on the substrata.

Intensity of evaporation varies in time, showing the same seasonal pattern as the condensation. Both measured and calculated values increase significantly in the winter months (Table 5). Based on the data collected throughout 9 years of measurements, the calculated mean intensity was 0.70 mm/30 days in summer, and 0.92 mm/30 days in winter (Racoviță, 1994). Such an increase recorded over the winter period could have only been caused by the relative humidity decrease, because the ventilation regime definitely excludes the second theoretically possible case, which would be air warming within the cave during winter.

Sparsely measurements taken in the lowermost part of the Coman Gallery indicate almost four times more intense evaporation in this point than in the central part of the “Cathedral” (Racoviță and Viehmann, 1985). As expected, one may conclude that there is an evaporation gradient within the cave that has an opposite direction to the condensation gradient. It is certain that this spacial variation, oriented in opposite directions, simultaneously favors either evaporation or condensation in different parts of the cave.

The cooling effect

The visible differences between the curves that model the thermal and hygric gradients suggest that, at least in some parts of the cave, the increase of the relative humidity is not only caused by a decrease in temperature, but also by water vapor enrichment of the subterranean atmosphere. This phenomenon can only be the result of a more or less intense internal evaporation, which is an endothermic process that will cause the cooling effect. It is especially characteristic to the winter period, when masses of cold and dry surface air enter the cave.

In order to estimate quantitatively the cooling effect, the formula established by Trombe (1952) can be applied:

$$F = C_v / C_s \cdot \Delta f \,, \qquad (44)$$

where F represents the cooling effect (°C), C_V, the vaporization heat of water (in average, 596 cal/g), C_S, the specific heat of air (in average 260 cal/m^3), and Δf, the difference between the absolute humidity of the external and the cave air, determined by the relationship (42).

Relative humidity and winter temperature mean values obtained from the measurements taken between 1982 and 1992 were used for the calculation. For more accurate results, the term Δf was obtained from the difference between successive values of this parameter in each station point, beginning with the surface and extending to the limit of the warm meroclimate. As the calculation algorithm does not assume direct contact between the external atmosphere and the cave air, changes of the absolute humidity are better highlighted (Racoviță, 1994a).

The results (Table 6) show that in the shaft and Sala Mare, the increase of relative humidity is not related to an equivalent increase of absolute humidity, but is due to temperature decrease. Beyond the ice block limit (Station 10), an enrichment of the cave atmosphere in water vapor is pointed out by the absolute humidity values. This implies that favorable conditions are met for the cooling effect to take place (Fig. 25). Normally, this effect appears around 0.5°C (for average values), but sometimes, it can surpass 2°C depending on the intensity of the thermocirculation and on the hygrometric state of the external atmosphere (Racoviță, 1967).

Table 6
Cooling effect.

Station	t°C	UR%	e (mm)	f (g/m³)	Δf	F°C	t'°C
1	–0.7	79	3.4	3.61	–	–	–0.70
2	–1.5	85	3.5	3.73	–0.12	–0.28	–1.22
3	–2.2	89	3.4	3.63	+0.12	+0.23	–2.43
4	–2.4	90	3.4	3.64	–0.01	–0.02	–2.38
5	–2.7	90	3.4	3.64	0.00	0.00	2.70
6	–2.8	90	3.4	3.64	0.00	0.00	–2.80
7	–2.5	91	3.4	3.64	0.00	0.00	–2.50
8	–2.2	93	3.6	3.85	–0.21	–0.48	–1.72
9	–1.1	93	3.9	4.15	–0.30	–0.69	–0.41
10	–0.9	95	4.1	4.36	–0.31	–0.48	–0.42
11	–0.7	95	4.2	4.46	–0.10	–0.23	–0.47

The last aspect to be mentioned is the degree in which the cooling effect adds to the thermal variations determined by various caloric transfer mechanisms that take place within the cave. This can simply be established by subtracting the corresponding value of the cooling effect from each winter mean temperature (Table 6, t'). The new series of values recorded between stations 8 and 11 (periglacial meroclimate) have as theoretical model an asymptotic exponential curve, defined by the equation below:

$$t' = -0.16 - 18.561\, e^{-0.0213\, d} \qquad (45)$$

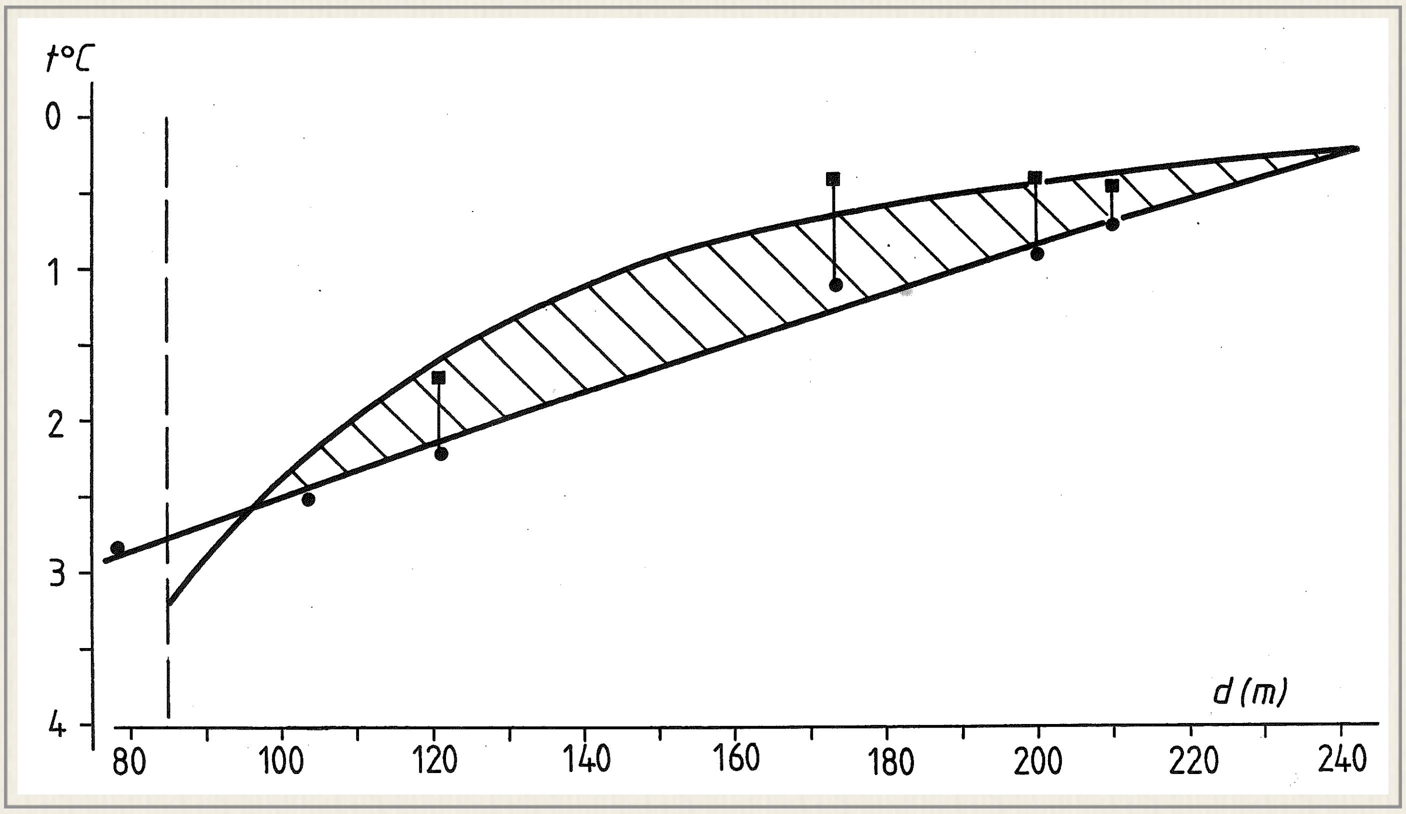

Fig. 25. – The cooling effect in the periglacial meroclimate. Theoretical curves corresponding to the distribution of the winter mean temperatures (solid circles) and of the same values after eliminating the cooling effect (solid squares).

The curve drawn based on this equation is much closer to the form these mechanisms impose than the nearly linear distribution of measured values (Fig. 25). This correction of the thermal gradient configuration, which appears after cooling effect was eliminated, clearly illustrates the complexity of the factors that influence the temperature measured in a cave in a certain point and at a certain moment of the year.

7

Ice speleothems

Morphology and structure of ice speleothems

One of the most remarkable characteristics that makes the Scărișoara Glacier Cave different from all other glacier cavities in the temperate areas is the fact that the two major morphological types of ice speleothems (the ice block and the stalagmitic massifs, and isolated ice stalagmites) occupy clearly defined sectors. The ice block can be considered a typical glacial formation, while the ice stalagmites are periglacial related speleothems, a particular feature of the cavern glaciation (Șerban et al., 1967).

Three morphological types of ice speleothems will be discussed in this section. These types include ice blocks, ice stalagmites and stalactites, and frost. Of these three types, the massive ice block formed in the glacial mero-climate of the cave is of particular scientific value. Aesthetically not as spectacular as the ice stalagmites, the ice block through its structure, is considered a palaeoclimate archive for the Late Holocene period.

The ice block

The ice block in Scărișoara Glacier Cave is located in the central part close to the entrance shaft (Fig. 4), covering a planar surface area of about 3,000 m^2. The average thickness of the ice is 20 m. Percolation water and melting of snow and ice at the bottom of the entrance shaft are the sources of water that subsequently accumulated in the form of ice in the Scărișoara Cave. The most active percolating zones are located below the chimney, near the Eskimos ice formation, and close to the entrance (Fig. 3).

During the first part of the summer small lakes whose waters are derived from the percolated water and/or melt water, mentioned above, cover season the surface of the ice block. Eventually these small lakes converge to form a larger lake that extends over the entire ice block. These conditions were recorded in April 1964, June 1965, and May-June 1998.

By the end of the summer months, small channels form on the ice block surface. In turn, these channels drain the water from the Sala Mare into the Rezervația Mică. Upon reaching the ice block edge, the waters continued to flow as films up to 2 m in wide. Consequently, the ice block is covered in a few sectors by new ice (the image is that of a flat ice waterfall) that hide the original horizontal structure of the ice block. During the summer period, several such drainage channels are to be found in the northern part of the Sala Mare.

The surface of the ice block in the Sala Mare is mostly flat, with two distinct features worthy of note. The first of these features are hundreds of small, broad knobs of ice that rise from the surface. These are the result of high concentrations of dripping points occurring during the months of June and July in the Sala Mare. These ice knobs will never grow tall enough to be considered real ice stalagmites.

The other feature is an ice wall about 1 m in height along the southern part of the Sala Mare, a few meters before descending into the Rezervația Mare. Above this ice step, the limestone beds forming the ceiling dip at a 45° angle. This inclination produces a mirror effect, which reflects both the light and the air currents. It has been speculated that the position of the ceiling is responsible for the particular morphology in the southern part of the Sala Mare that cannot be found in the northern part.

In the northern sector of the Sala Mare, in the vicinity to the entrance in the "Biserica" many joints are visible in the upper most part of the ice block. These joints form a dense and complicated network, with no displacement of the ice on either side. They range in size up to several meters in length and up to 1 cm in width. Most of the joints are vertical, and are rarely oblique. Since ice is a plastic rock, it will deform rather than fracture. Consequently, folding of ice towards the "Biserica" (Silvestru, 1989) produces both types of joints. Over a period of two to three months, one can observe how the newly formed ice fills these joints. Over time the joints may re-open or a new generation of joints form as the ice layers are folded or tilted.

Recently, ultrasonic investigations undertaken along two alignments in the Sala Mare suggest (at least to a depth of 5 m) that the extension and the thickness of the main impurity layer present significant variations from one point to another (Silvestru & Boghean, 1992). Hence, these variations could not have been traced in the natural section of the ice block in the Rezervația Mică.

Examination of the ice block reveals a horizontal stratified structure consisting of alternating layers of ice (0.5 to 15 cm) formed during the winter with layers containing impurities (2 to 7 mm) deposited during the summer. According to Racoviță and Șerban (1990), this structure is dependent on seasonal variations in the underground temperature, which are in turn determined by the exterior climate.

The ice layers are horizontal and sub-horizontal except for the northwestern portion of the block. In this portion, folding of the ice layers has produced a distinct structure. The best place to observe how ice layers were tilted is the Rezervația Mică. Here, due to lateral flow of ice against the wall, the layers were tilted up almost 180°. A possible explanation for the driving force behind the flow of the ice is that below the ice block the floor may have a pronounced positive relief. The bending of the limits of the ice block in all directions confirms the supposition that it rests on top of a large breakdown pile whose convexity matches the ceiling concavity.

Șerban et al. (1948) suggested that the geothermal gradient (the increase of temperature with depth) might be responsible for partial and uneven melting of the lower part of the ice block. This process would cause asymmetrical tilting and folding of the ice layers. In addition, after the folding, fissures may also form.

The formation of the 16-m height ice wall of the Rezervația Mică was interpreted as follow by Șerban et al. (1948). In the first stage the ice layers accumulate horizontally building up the base of the forthcoming ice block (Fig. 26A). Simultaneously with the ice accumulation, in the lower parts, at the ice/rock contact, the geothermic flux causes gradually ice melt (Fig. 26B, C). As this process goes on, the ice layers extremities are continuously removed, creating a large void between the cave wall and the ice block. When the void open to the surface of the ice block, the air currents will further shape the vertical ice wall. Furthermore, the melted water from the top of the ice block will be drained towards the Rezervația along some channels Mică forming thin vertical ice layers that cover the extremity of the old ice layers (Fig. 26D).

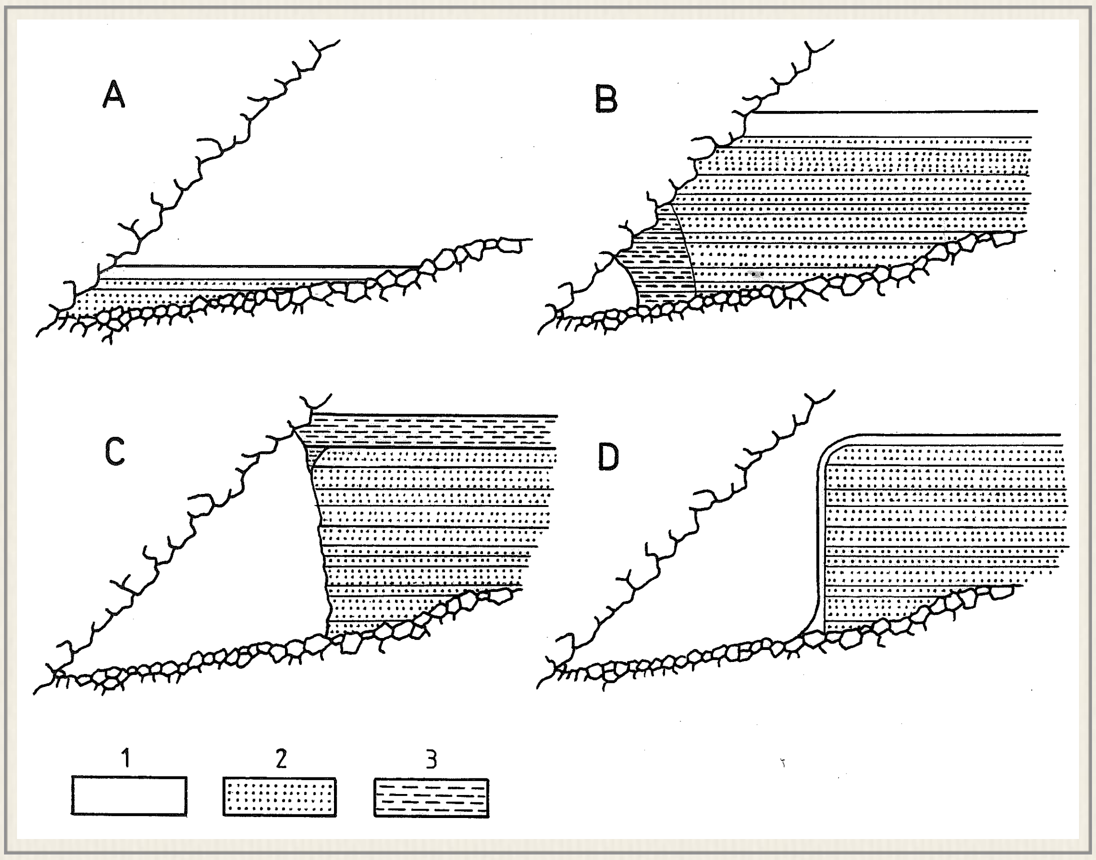

Fig. 26. – Successive phases in the evolution of Rezervația Mică wall.
1 = new ice; 2 = old ice; 3 = ice lost through melting (after Şerban et al., 1948).

During the summer time the surface of the ice block in the Sala Mare is covered with a film of water a few centimeters thick. Percolation and partial thawing of the ice and snow from the bottom of the entrance shaft supply this water. In this film, limestone dust from the weathering (gelifraction) of the carbonate rock accumulates together with other materials (soil particles and vegetal remains, including allochthonous pollen grains). In the winter this superficial water film freezes, forming a new layer of ice that covers the layer on which impurities accumulated. Consequently, the whole block is made up of alternating pairs of clear ice and impurity layers (Racoviță, 1927). Each pair represents an elementary stratigraphic unit, corresponding to one year (Șerban et al., 1967), being somewhat similar to varved sediments.

Observations made since 1947, on the level of the Sala Mare floor have shown that the elementary stratigraphic units that form the primary structure of the ice block are only partially preserved. Between 1947 and 1980, the ice level decreased continuously. During this time period some 1.5 m of ice have been lost from the stratigraphic profile. As a consequence, all the impurity layers included in this melted sequence are now concentrated in a layer considerably thicker than usual, termed *main layer* (Șerban et al., 1967). Such layers are to be found at numerous other levels in the stratigraphic series, and mark a relatively warmer period of time, giving a discontinuity in the primary structure of the ice block.

An estimated age of the ice can be obtained once a record of incremental layers has been established. Each layer of ice can be assigned an age in ice-accumulation years (number of annual layers below the present surface) (Lowe & Walker, 1997). By counting the layers, an approximate age of the ice block can be determined. However, caution should be taken when counting the ice layers and the results must always be correlated with other well-dated proxies (bones, pollen, etc.).

The ice block consists of ice crystals, gaseous and/or liquid inclusions, and rock and/or organic debris. Of these, the ice crystals are the fundamental component. One characteristic feature of the ice crystals is that they are weak and can easily be made to slip on planes parallel to the basal plane. Although other processes are involved, it is the characteristic weakness in the ice crystals, which allows ice accumulations to deform readily under their own weight and to flow.

In some of the newly formed ice layers, one can depict ice crystals (mostly hexagonal prisms) arranged in a definite manner (i.e., having their "*c*" axes perpendicular to the plane of the ice layer) (Racoviță, 1927) (Fig. 27). In the deeper portions of the block, the ice crystals do not possess a definite orientation. This lack of orientation is mainly due to recrystallization driven by pressure increases from the accumulating overburden.

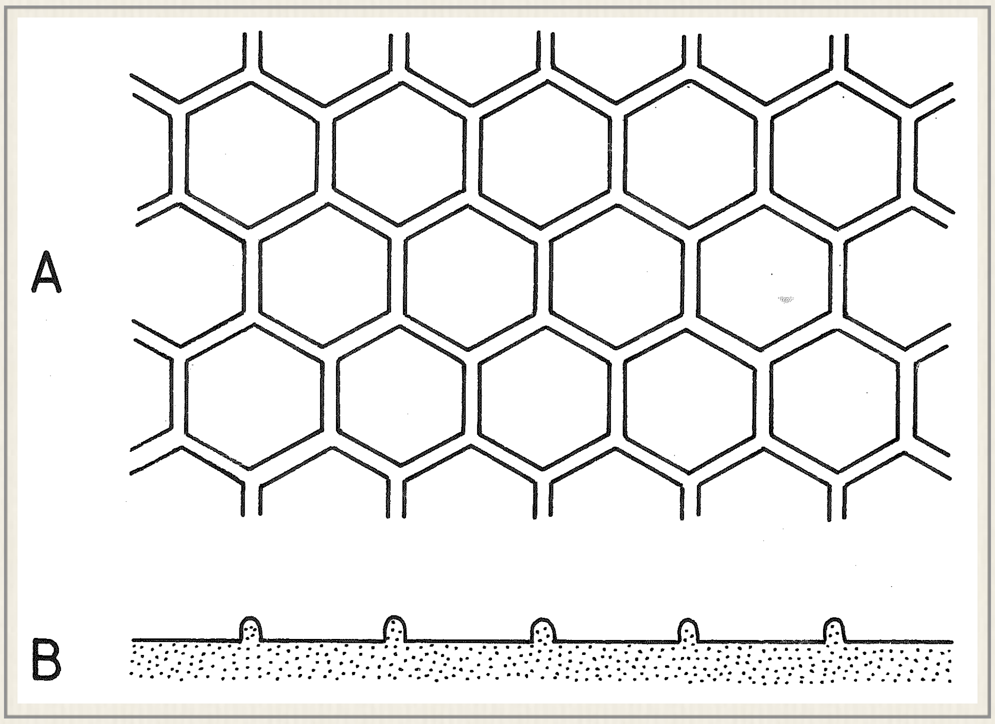

Fig. 27. – Hexagonal structure of the newly formed ice on the floor of Sala Mare in March 1965. A = plane; B = profile.

A visual examination of the superficial layer of ice or over the vertical profile when descending in the Rezervația Mică reveals one common micro-feature of the ice block, the presence of air bubbles. Most of these gaseous inclusions were observed in those parts of the Sala Mare where in the summer the ice block is temporarily covered by small lakes. Viehmann (pers. comm.) speculated that some of the air bubbles within the ice layers might have originated by decomposition of organic matter that takes place during the warmer seasons.

As Șchoumsky (1955) and French (1976) has illustrated, fine particles migrate in front of the freezing plane and air bubbles are formed as the dissolved air in the water is expelled during the freezing process. Since these air bubbles are oriented normal to the freezing plane, their presence in the ice block is a good indication of the direction of movement of the freezing plane. The air bubbles observed in the ice in several locations within Scărișoara Cave are disposed either as stripes or nets, circles, and polygons. Such observations are extremely valuable when interpreting the microclimate and air currents circulation within limited areas in the Sala Mare.

Silvestru (1989) observed one significant modification of air-bubbles in the 16-m ice wall of Rezervația Mică. Here, within the lower 10 layers of ice, there is a transition (downwards) from relatively uniformly distributed spherical bubbles averaging 1.5 mm in diameter, to 0.2-0.3 mm still spherical ones, aligned in distinct levels. Eleven such levels were counted in the lowest 60-mm thick layer. Such a pattern advocates for vertical lithostatic pressure, without tangential vectors suggesting that the ice block is in equilibrium with the available karstic void.

Once compressed into bubbles the air remains under pressure and isolated from the atmosphere. Trace gases (e.g., carbon dioxide, methane) are usually trapped in these minute air bubbles. Analysis of these air bubbles provides evidence for short and long-term changes in both atmospheric gas and stable isotope composition (particularly isotopes of oxygen). Variations in these compositions act as a proxy record for climate change (Șerban et al., 1961) (see discussion in the palaeoclimate chapter).

The pressure within the air bubbles is evident when a piece of ice is melted, and a minor explosion results. The snapping, crackling, and popping may be heard when walking through the Sala Mare or around it.

Ice segregation processes are responsible for the accumulation of fine limestone dust that forms various patterns on the surface of the ice speleothems (either massive ice or stalagmites). The movement of these fine particles, from the inner part of the ice towards the outer surface, depends on the rate of freezing, the size of the particles, the amount of moisture, and orientation of the freeze-thaw plane.

The ice stalagmites

Genesis

The formation of all types of ice stalagmites is essentially similar to the formation of calcite stalagmites (Racoviță, 1927). The same percolation water creates them, so that the necessary and sufficient condition for the development of a seasonal ice formation is the stability in time of the point in which the drops leave from the cave ceiling. As a consequence, the present distribution of the ice massifs and columns in the "Biserica" is completely alike the one described by Schmidl (1863), a century and a half ago.

The growth of a stalagmite usually begins with the deposition of a more or less circular ice plate on the cave's floor. Flat at the beginning, it soon build up its central part, changing into a cone with a rounded tip and then into a short cylinder. Once this first phase is surpassed, the evolution of stalagmites can follow different paths, as a function of the conditions in which each one develops separately.

Air temperature, dripping rate, and percolation water's temperature are the three physical factors that control the development of ice stalagmites. The first two are the ones responsible for both the growth and the development of the speleothems' morphology. In the progress of these two processes, the essential element, which depends on the freezing rate, is the quantity of ice that deposits on the stalagmite top. When this rate is high, the water drops freeze close to their falling point, and the new formed ice mainly determines the stalagmites to grow in height. When the rate is low, the drops have enough time to flow on the sides of the speleothems, and hence they will mainly grow in diameter. As the freezing rate depends on both air temperature and dripping rate, the growth in height is maximum when, for a given temperature, the dripping rate provides the greatest volume of water that can freeze on the stalagmites' top (Racoviță & Viehmann, 1966). Consequently, it can be admitted as a general rule that – between certain limits – the growth in height is conversely related to the temperature for a constant drip rate and directly related to it when temperature is constant.

The observed growth mechanism for the ice stalagmites in Scărișoara Glacier is completely analogous to the one reported by Kyrle (1929) from Lur Cave (Lurhöhle, Austria).

Structure

The internal structure of ice stalagmites and stalactites is very similar to that of carbonate speleothems. The growth of large ice monocrystals is governed by the law of geometric selection (i.e., only those hexagonal prisms will successfully develop in which the "*c*" axis is perpendicular to the growing surface) (Racoviță, 1927).

Ice stalagmites begin to melt when the temperature rises over 0°C in the cave. In the first stages of melting, a hexagonal network can be observed at the surface of the speleothem; i.e., the melting process primarily affects the edges of all hexagonal prisms. Therefore, a thin water film will delimit the ice monocrystals from one another, giving the stalagmites a honeycomb like structure.

Localization

Spatial distribution of speleothems is dependent on meroclimatic conditions especially when this phenomenon is analyzed exclusively in comparison with the ice stalagmites.

In the "Biserica", where the stalagmites develop at the lowest temperatures, the predominant form is that of stalagmitic massifs. Isolate columns are very few and noticeably thicker than the ones in the other sectors of the cave. In the two Reservations, where the negative oscillations of air temperature are less accentuated, most ice speleothems are isolated stalagmites, grouped in fields placed far from the ice block as the room's dimensions are themselves greater. In addition, in the distal area of these fields, the stalagmites melt entirely during summer, so they become seasonal. Finally, at the edge of the glacial sector of the cave, where ice forms at the highest temperatures, it appears under the form of a crust developed on the floor. Therefore, one may conclude that the spatial distribution of the ice formations is associated with a “morphological gradient” in obvious correlation with the thermal gradient existing in the underground atmosphere.

The fact that the ice stalagmites are so obviously positioned only on certain areas of the cave could be determined by three hypothetical causes.

The first one derives from the thermal condition of the cavern ice genesis. As it is well known (Schoumski, 1955), there is an inversely proportional dependency between the ice monocrystals dimension and the temperature at which they form. Therefore, the ice cannot be deposited as stalagmites but in a certain temperature range. In the Scărișoara Glacier Cave, this interval is between –1°C and –5°C (Racoviță & Crăciun, 1970).

The second cause results from the differences that appear in the position that these formations have in “Biserica”, where they grow in the close vicinity of the ice block, and in the two Reservations, where the stalagmite fields are separated from the ice block by sectors of gallery where ice shows only as crusts on the floor and rare stalagmitic massifs. The explanation could be the ceiling form, the “Biserica” being the only place in the cave where the ceiling is shaped as a cupola (Fig. 4), a space in which the warm air accumulation permanently maintains a positive temperature. Therefore, where the ceiling is flat, especially in the Maxim Pop Gallery, the absence of the ice stalagmites is caused by the negative values that the air temperature reaches during winter, and which produces the freezing of the percolation water (Șerban, 1970) that would feed the stalagmites. The growth of large ice stalactites, on the ceiling of Sala Mare and sometimes along the Maxim Pop Gallery, constitutes the physical proof of such a phenomenon.

Finally, the third possible cause is the participation of the condensation water to the genesis of the ice stalagmites. Initially formulated by Șerban et al. (1967), the hypothesis is much more plausible as it was observed that the feeding water dripping frequency of the stalagmites is proportional with each of the three rooms’ dimensions (minimum in the “Biserica” and maximum in “Rezervația Mare”). Still, for such a supposition to be confirmed, it is necessary to demonstrate that between the intensity of the condensation process and the feeding water dripping rhythm there is a significant correlation. The attempts made towards this goal, on the basis of daily measurements of the two parameters in February 1965, have lead to the conclusion that the water coming from the condensation process does participate in the stalagmites genesis, but its weight is too small to be considered as a determining factor in the formations' spatial positioning (Racoviță & Viehmann, 1984). In addition, the isotopic composition analysis of successive ice layers taken from a stalagmite situated in the upper part of the "Biserica" indicated such small differences in the $\delta^{18}O$ and $\delta^{2}H$, that excludes the quantitatively prevalent presence of the condensation water (Șerban, 1970).

Morphology

As shown in Chapter 6, the intermittent thermocirculation in the Scărișoara Glacier Cave has as a direct consequence the fact that the air temperature in the glacial zone becomes positive during summer. Limited to a range with a medium value of 0.5°C, this warming is still sufficient to determine a seasonal evolution of all ice formations, with a winter development period and a summer partial melting period. Especially in the case of stalagmites, such an evolution affects not only their dimensions, but also their aspect, so that there are many absolutely characteristic morphological traits for each of the two seasons.

Morphodynamic phenomena recorded within the growth period

Bilateral symmetry stalagmites. Generally speaking, ice stalagmites appear as cylindrical columns, with radial symmetry and the dilated extremity in the shape of a club. Especially in the central area of the "Biserica", but also frequent in the two Reservations, there also are formations that divert from this classical configuration. Named "spectral stalagmites" by E. Racoviță (1927), they are noticed by an obvious bilateral symmetry. Their extremity is not club-headed, but more or less sharp and moved to a side from the longitudinal axis, always towards the "Sala Mare". In addition, not even the sides of these formations are alike: the one positioned on the direction of the head is more or less straight, vertical, while the opposite side is largely convex (Fig. 28).

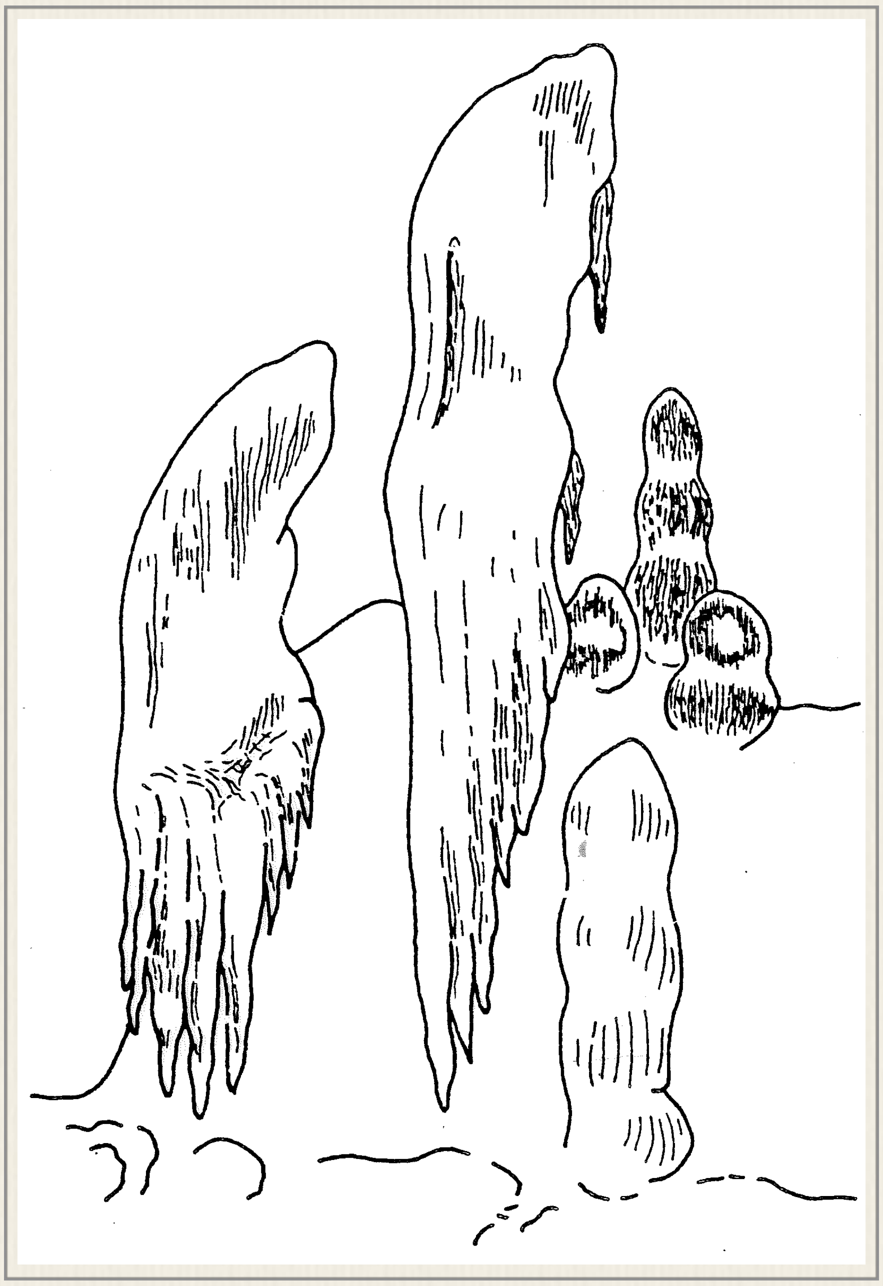

Fig. 28. – Stalagmite with bilateral symmetry (central area of "Biserica" (after E. Racoviță, 1927).

The genesis of such stalagmites is relatively easy to understand considering the fact that their symmetry plane is parallel to the direction in which the entering cold air flows, so with the direction on which the longitudinal thermal gradient is oriented. On the side exposed to this current, oriented towards "Sala Mare", the ice forms at a relatively lower temperature. As seen before, in these conditions the growth in height of the stalagmites is favored, fact that leads to the constitution of the head, while on the other side, protected from the direct cold air influence, the growth in diameter is favored, having as a result the formation of the convexity (Fig. 29A).

Such a mechanism proves to be in full concordance with the observations taken in the "Rezervația Mare", where the ice stalagmite field occupies a greater surface and where the existence of the "spectral" forms is more or less exceptional. In February 1965, for example, when the registered temperature in this sector was unusually low (–3.2°C, compared to an annual winter average of -0.9°C), all formations situated in the entrance neighborhood area had bilateral symmetry, while the ones in the distal half were all radial symmetry.

Characteristic to the winter growth phase, the bilateral symmetry may sometimes appear in the summer phase of stalagmite melting, too, as a consequence of the fact that the volume of ice lost through melting is greater in the side opposite to the direction in which the cold air circulates (Fig. 29B). In this case though, it is possible that the "spectral" form be accentuated by the intervention of the dripping water, which reaches the cave space having a higher temperature than during winter.

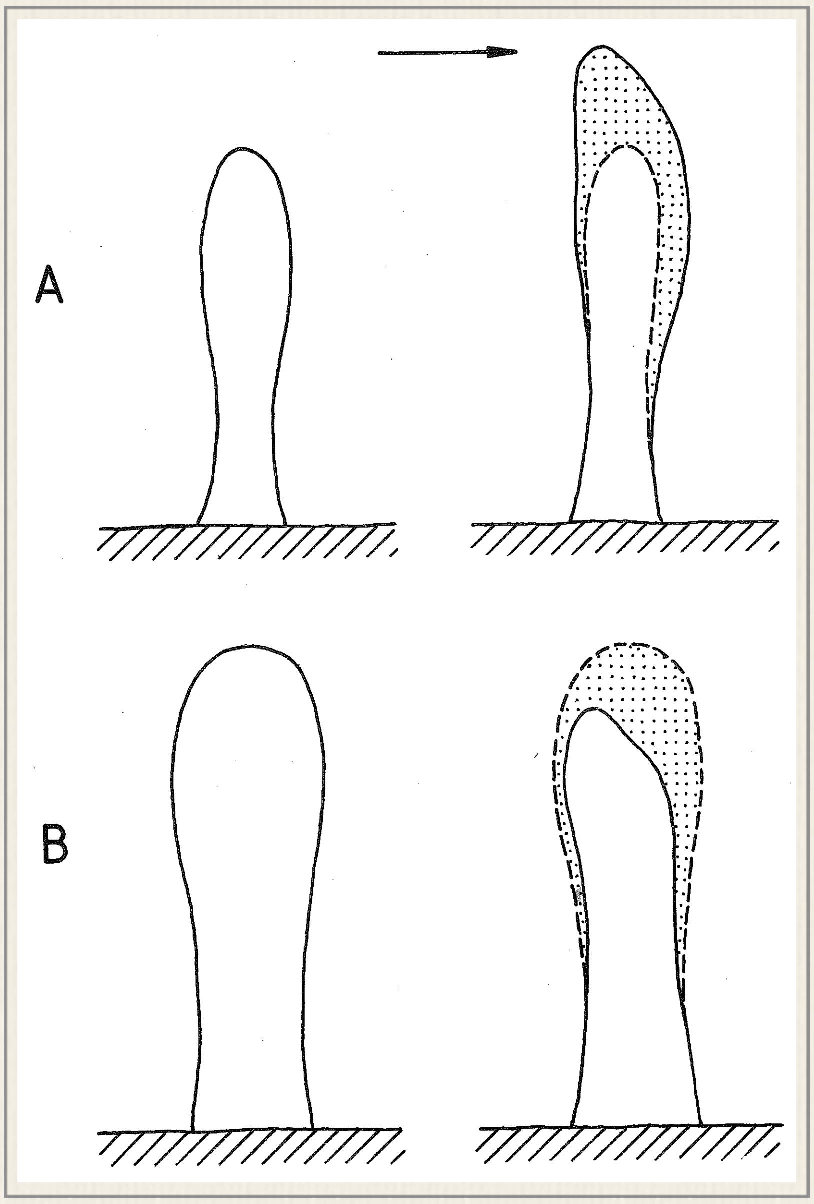

Fig. 29. – Diagram showing the formation of bilateral symmetry stalagmites by differentiated growth (A) and melting (B). The arrow indicates the thermal gradient's direction.

Solid and gaseous inclusions. No matter whether the water feeding the ice stalagmites originates from infiltration or condensation, it is always a more or less concentrated solution of calcium bicarbonate. As any crystallization process, the water freezing implies the purification of this solution, so that the calcium bicarbonate is eliminated from the crystalline network of the ice. Precipitating, it deposits as a white powder of fine granules of calcium carbonate at the surface of the stalagmites, conferring a certain opacity to the ice. If the dripping rate increases, this film can be easily washed away and the ice becomes transparent again.

At lower temperatures, when the freezing rate surpasses a certain limit, the calcium carbonate granules remain enclosed in the stalagmites, as solid autogenic inclusions (Schoumski, 1955).
A characteristic situation for this phenomenon was registered in February 1965 and January 1966, when in the "Biserica" the recorded temperatures were of -3.4°C and -4.6°C, respectively. In these conditions, most of the stalagmites had a particular aspect. The superior third of their length, thickened, consisted of new, slightly milky ice, but the tip was conical, completely opaque and much narrower than the ice below it (Fig. 30). This can only be due to an accelerated growth in height of the formations, and the enclosing of an unusually high quantity of calcium carbonate.

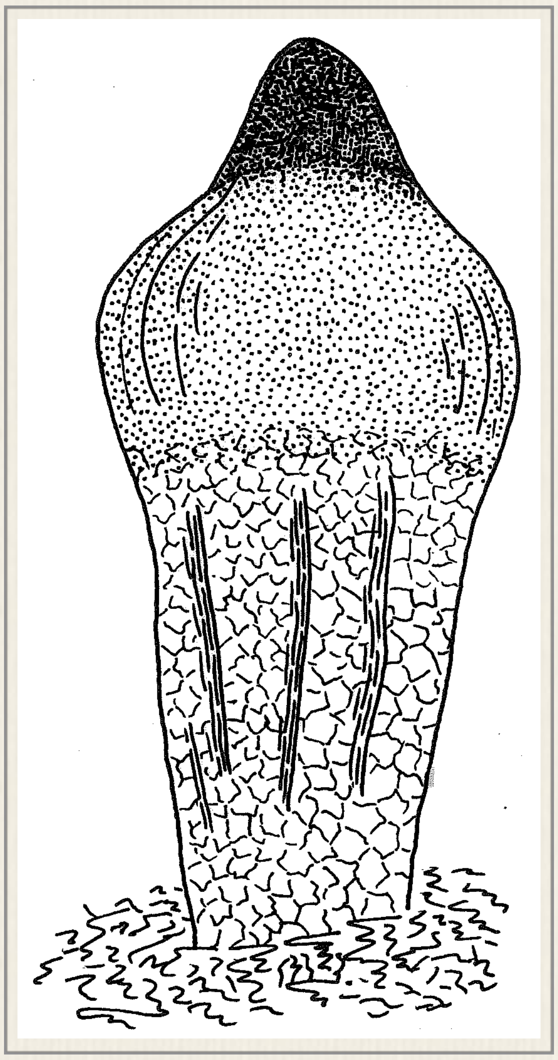

Fig. 30. – Stalagmite from „Biserica", having a conic tip formed of completely opaque ice (February 1965).

Sometimes, relatively opaque areas can be observed in the mass of the stalagmites, clearly delimited only in their superior part, and which mark the successive growth levels of the formations. As the existence of these opaque zones is not accompanied by morphological changes, we can presume that such stalagmites developed when the air temperature had moderate negative values, with slight fluctuations around the critical point under which the carbonate granules remain enclosed in the crystalline network. At the moment when the temperature surpassed this critical value, the calcite powder film deposited on the surface of the formations is washed away by the feeding water, so that the opaque areas remain clearly delimited under a layer of transparent ice.

In some cases, in the stalagmites' body, but especially at the level of their club-headed extremities, linear air enclosures can be observed. They are narrow and radial, parallel to the longitudinal axis of the ice monocrystals. They represent spaces that are created between the crystals during the melting, being covered with the first layer of new ice deposits.

The "thermoindicating" stalagmites. At the distal limit of the glacial zone, in each of the three rooms in which ice stalagmites grow, there are formations with an extremely characteristic morphology. They consist of a regular succession of dilated portions of perfectly transparent ice and narrow portions of opaque ice. According to the genetic mechanisms described above, the narrow portions should form at lower temperatures, when the growth in height predominates, while the dilated ones should form at relatively higher temperatures, which favor the columns' growth in diameter. This growth mechanism was confirmed by the daily measurements and observations performed on one such stalagmite in Rezervația Mare, between February 9th – March 23rd 1965. It could be observed that the three portions of opaque ice that formed until the end of the interval do correspond to decreases of the underground temperature, with minimum values of –3.0°C,–4.5°C, and –1.8°C, respectively (Fig. 31). One may conclude that ice stalagmites have this particular morphology when the air temperature oscillates repeatedly in a certain time period. This is the reason for which such formations were named "thermoindicating" stalagmites (Viehmann and Racoviță, 1968).

Most probably, when the amplitude of the thermal variations is greater, the radial symmetry of the dilated portions could be replaced by the bilateral symmetry that is characteristic to the "spectral" formations. Such a situation was registered in March1964, when at the base of the breakdown cone in "Catedrala" two stalagmites with very regular dilated and narrow portions were found. Their larger portions, though, were visibly asymmetrical (Fig. 32), the most prominent part being oriented towards "Sala Mare", opposite to the normal direction. The explanation for this anomaly is that the two stalagmites were placed in that area of the "Rezervația Mare" where part of the cold air current coming from the exterior reverses its direction.

Ice volatilization effects. The accentuated decrease of the relative air humidity the sometimes occurs during winter causes the loss of a certain ice volume by volatilization. This phenomenon is more obvious in "Biserica", but it was also noticed in "Rezervația Mica". Therefore, it affects the stalagmites positioned at a sufficiently short distance from the surface so that the masses

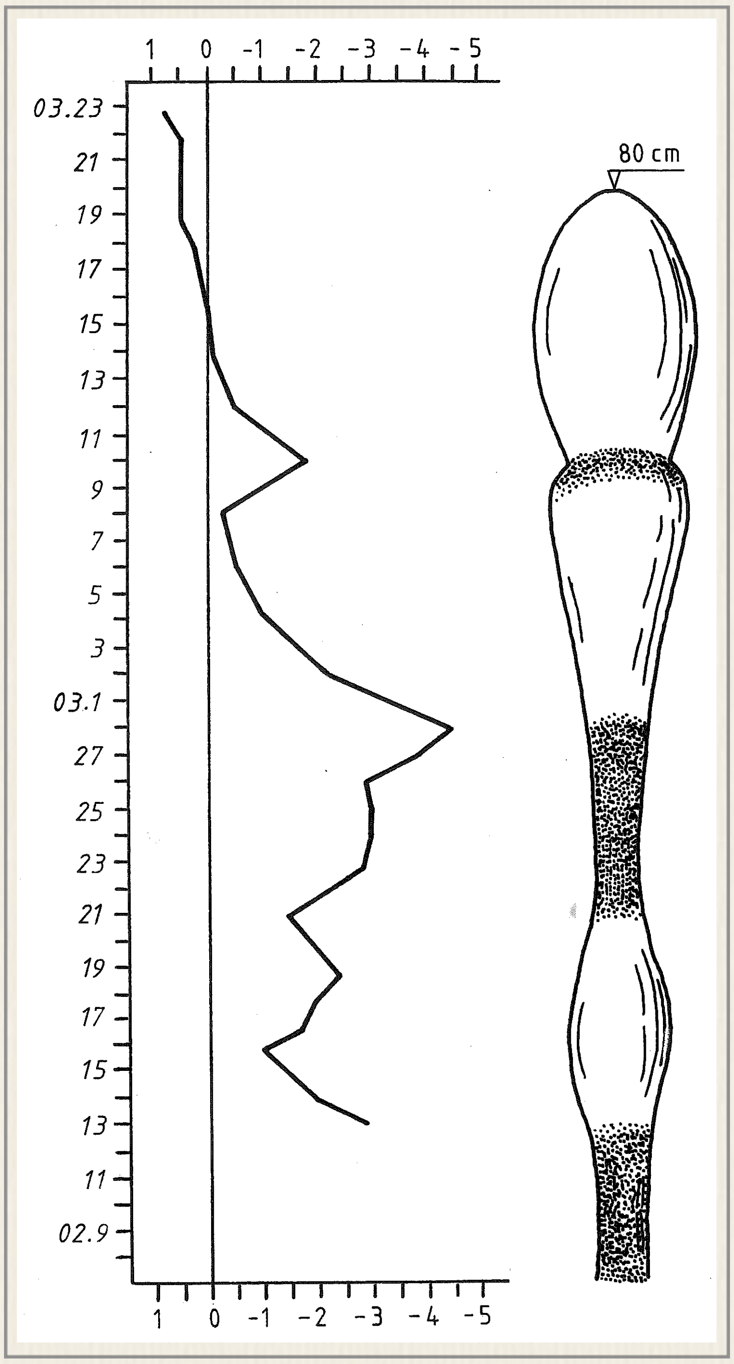

Fig. 31. – Air temperature variations during the formation of a "thermoindicating stalagmites" in Rezervaţia Mare (February 2nd – March 23rd 1965) (after Viehmann & Racoviţă, 1968).

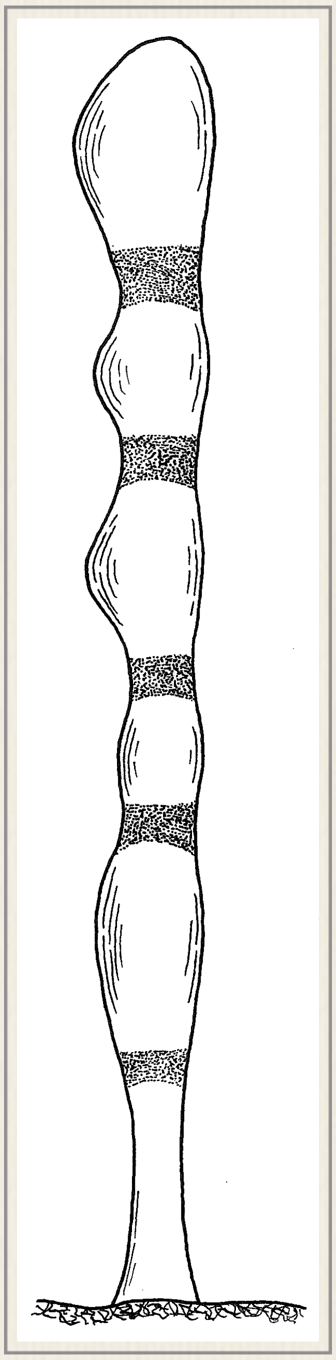

Fig. 32. – Thermoindicating stalagmite with bilateral symmetry in Rezervaţia Mare (March 1964).

of external air transported by thermocirculation do not reach a hygric equilibrium with the underground atmosphere.

The ice volatilization could be evidenced in experimental conditions. If a piece of paper is placed on the top of a stalagmite, in a short period of time the covered area will present a prominence, a "volatilization proof" of a few millimeters (Șerban et al., 1965). In natural conditions, the volatilization has several visible effects: the formation of a calcite powder layer, thicker than usual and completely dry; the alleviation or even the total disappearance of secondary outgrowths; and the formation (usually at the base of the columns) of areas in which the radial distribution of the monocrystals become visible after the superficial ice layer disappears. These areas may persist until the melting phase of the stalagmites (Fig. 33).

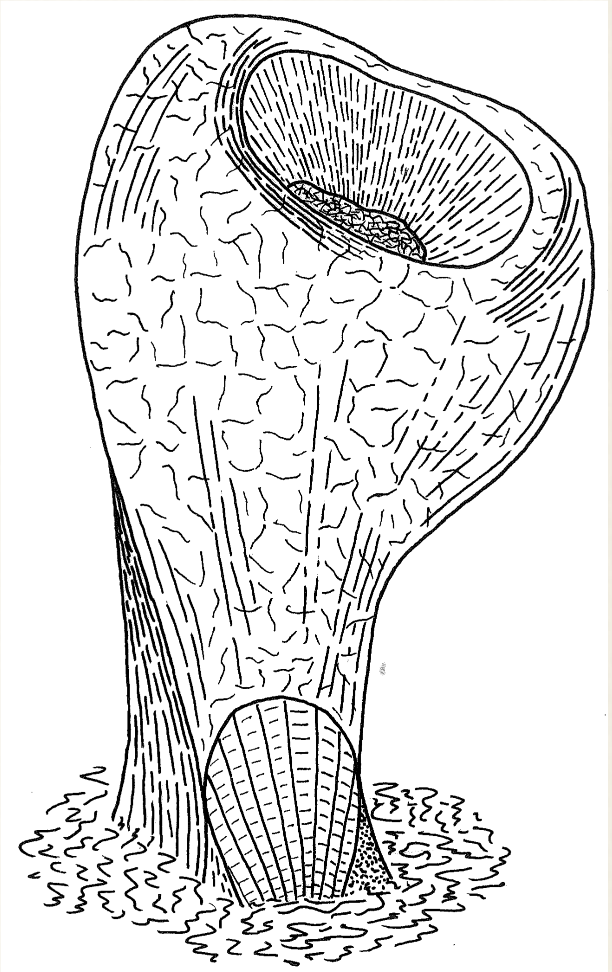

Fig. 33. – Stalagmite from „Biserica" in the melting phase, with a visible areolar structure, a well-developed apical cup, and with the base partially cut off by ice volatilization (October 1965).

Secondary formations. Especially in "Biserica", on the club heads of the stalagmites rounded, outgrowths of 1-3 cm appear quite frequently. They form through the practically instantaneous freezing of the water splashed when the drops that fall from the ceiling break on the head of the stalagmite. Sometimes, such outgrowths, also known as "*knolleneis*" in German, may have particular shapes. In February 1965, when the underground atmosphere temperature reached unusually low values, much smaller than usual outgrowths covered all active ice surfaces in this room, creating a rugged aspect. A month later, some of the columns had on their sides outgrowths up to 10 cm long, grown upwards and oblique and certainly formed through the same mechanism. They can therefore be considered similar to the famous "plate pile" shaped calcite stalagmites from the Aven Armand, France.

When winter temperatures are relatively high, therefore when the water drops flow down the stalagmites before freezing, longitudinal ice ridges and sometimes even stalactite type formations appear mostly on the side opposite to “Sala Mare” of the columns or stalagmitic massifs (Fig. 28).

Morphodynamic phenomena recorded within the melting period

Tilting of ice stalagmites. In “Biserica”, where many stalagmites reach over 5 m in height, some of the formations may curve under their own weight. First recorded by E. Racoviță (1927), this phenomenon is caused by the fact that, during summer, the ice plasticity increases due to the partial melting of the speleothems. Usually, the curving ends with the collapse; still, some stalagmites continue to tilt without breaking, until they lay on the floor.

The formation of the areolar network. One of the most characteristic and general morphological elements that appear in the summer period is that the crystalline structure of the ice becomes visible. This change has the following explanation. As melting takes place at temperatures just above the freezing point, it only affects the monocrystals’ boundaries that are in contact with the cave atmosphere. Consequently, each crystal will soon be surrounded by a fine water film that, having a different refringence than that of the ice, outlines the crystal’s shape. At the surface of the stalagmites many areas with more or less hexagonal shapes, corresponding to the superior faces of the individual crystals, can be observed (Fig. 33). This particular configuration is defined by the German authors as “*wabeneis*”, name coming from its great similarity to a honey comb.

Usually, when the areolar network forms, the so-called “Forel stripes” also appear. They represent the edges of the hexagonal plates that outline the elemental crystalline unit of the ice. These edges have also become visible on the monocrystals’ faces shaped as fine refringent ridges (Fig. 34).

Given the physical process that it originates from, the development of the areolar network is closely linked to the thermal conditions in which each stalagmite evolves, defined mainly by the vertical and horizontal gradients. As a general rule, the crystal’s shape first becomes visible on the upper part of the speleothems and on the side opposite to the direction in which the cold air current flows. In “Rezervația Mare”, where the stalagmite field covers a greater surface, this dependency is more striking, because the first speleothems that enter the melting phase are always the ones positioned further away from the “Sala Mare”.

As the dimensions of the hexagonal areas are determined by the size of the monocrystal, these areas are as much greater as the crystals formed at a higher temperature, when water freezing rate was smaller. Such differences manifest, on one hand, along one stalagmite, the dimensions of the areas increasing progressively from the base towards the top of the ice formation. On the other hand, they are linked to the position of each group of stalagmites, the smallest areas being found in “Biserica” and the greatest ones in the two reserves. On one formation from “Rezervația Mică”, in April 1966, they measured over 15 cm in diameter.

The association between the areolar network and the Forel stripes can sometimes lead to unusual configurations. In “Rezervația Mică” again, in July 1965, one of the stalagmites presented a band with small anastomosis stripes, clearly delimited and set perpendicularly on the room’s longitudinal axis. The two faces separated by this band were mostly covered by a regular areolar network, with normal stripes inside each area, but in their upper third part only stripes in radial position were visible (Fig. 34).

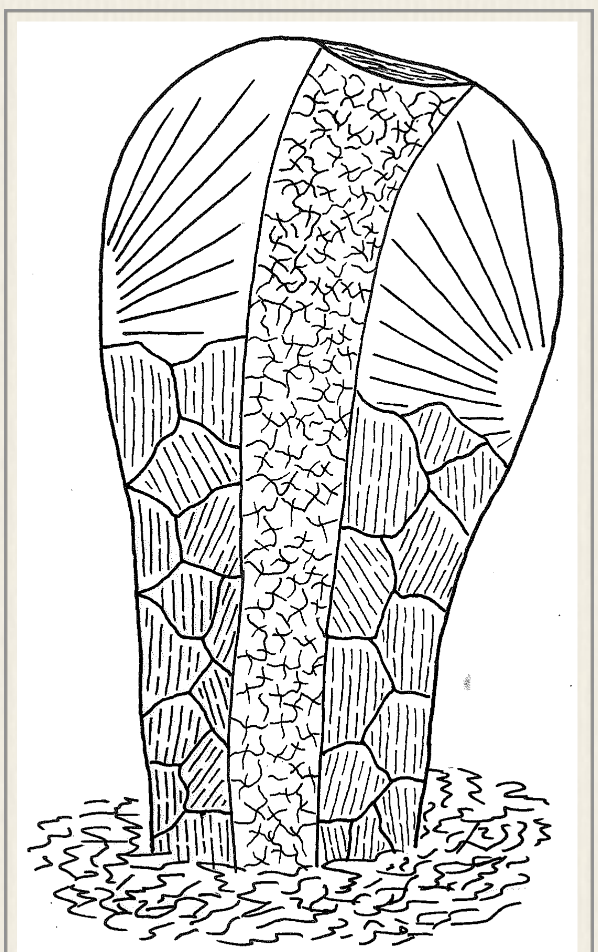

Fig. 34. – Stalagmite from Rezervaţia Mică during the melting phase(July 1965).

Superficial at the beginning, the areolar network also develops in depth, through the more and more accentuated enlargement of the areas between the crystals. This way, in the second part of the summer period, their extremities remain isolated and more or less prominent, forming an extremely characteristic outline. In the deep sectors of the cave, though, the melting leads to the disorganization of the whole crystalline edifice. This is because of the creation of large spaces, empty or filled with water, in the mass of the stalagmite, causing the ice to lose most of its transparency. Because of this, many of the ice formations located close to the limit of the glacial zone, and especially the seasonal ones, collapse before melting entirely.

When the thermal conditions in which the stalagmites regeneration starts are favorable, the newly formed ice may cover the areolar network before the complete closing of the spaces between the crystals, so that it remains visible in the formation's body for a time period.

Apical cups. Reaching the cave space at a positive temperature, the water drops do not freeze anymore, but produce an even more accentuated melting of the ice than the one determined by the underground atmosphere warming. The result is the creation on the top of the stalagmites of deeper and deeper circular excavations, named by Racoviță (1927) ”apical cups”. In “Biserica”, these excavations' depth doesn't surpass 10-15 cm (Fig. 33). In the two reserves, the apical cups are deeper and may transform themselves in tubes that end up piercing the stalagmites from top to the base and favoring their breakdown.

In the “Biserica”, the evolution of the apical cups has two detail particularities. The first consists in the fact that in more advanced melting phases the dripping creates a more visible outline of the ice crystals inside these excavations. At the bottom of the cups one may even find crystals or fragments of crystals completely detached from the walls. The second one manifests when the transition to the stalagmites growing phase is progressive. In such conditions the new ice first fills the cups, forming on the stalagmites' apex a plane, perfectly horizontal surface.

The ice crystals

As we have seen, speleothems formed from the freezing of dripping or flowing water appear to be similar to those of calcite. By contrast, speleothems formed from freezing water vapor have no counterparts among the other cave minerals (White, 1976). They form and disappear equally as fast.

Sometimes, moist, warm air enters the cave and sublimates as hoarfrost on the walls and ceilings. Over some parts of the year (late summer and beginning of autumn), the hoar builds up to such an extent that some of it overloads, breaks off, and falls to the floor. Alternatively, hoarfrost can be removed by ablation. Ice crystals composing these speleothems are tabular and hexagonal in outline (dihexagonal pyramidal class), and show great diversity in development.

Spectacular hexagonal plate-like ice crystals, singular or loosely connected, have been noticed through the years over large surfaces at the entrance to the Rezervația Mică, Rezervația Mare (left side), "Biserica", beyond the Eskimos, and in a few other locations. The size of these ice crystal platelets range from 1-2 cm to over 12 cm across during the winter and early springtime. Most of the ice crystals are transparent, but milky white or translucent varieties have also been observed.

There are approximately three distinct phases in the evolution of these ice crystal speleothems. Initially, isolated acicular (slender, needle-like) ice crystals must form. These continue to develop into parallel or divergent single bladed crystals. In the final stage of development, all these crystals join, forming long and complicated branching or tree-like aggregates, similar to Christmas garlands. In time (a few months), these aggregates can build up a crust that can exceed 20 cm in thickness.

These frost crystals were noticed not only over the cave ceiling and walls, but also over any object lying in the cave or even directly on the ice block. In this latter location, the crystals always have an acicular habit. The ice forming these crystals is whitish in appearance due to the entrapped air bubbles and is quite firmly attached to the receiving surface. Șerban et al. (1965) have experimentally grew such ice crystals on the surface of some glass plates disposed just above the ice block.

Some of these acicular (needle-like) ice crystals are produced by ice segregation at or just beneath the surface of a fresh impurity layer. This reflects a delicate balance between temperature, moisture, and impurity layer conditions. Direct cooling of the upper part of the ice block leads to the formation of these needle-like ice crystals, which grow upward in the direction of heat loss. These ice crystals can range in length from a few milli-meters to several centimeters. At times, this outward growth can lift small limestone pebbles or soil particles. The growth of the needle-like ice crystals is usually associated with cycles of freezing and thawing. Needle ice occurs widely in the Sala Mare whenever the temperature fluctuates near the freezing point.

Dynamics of ice speleothems

Seasonal dynamics

The ice in Scărișoara Glacier Cave is the direct consequence of the accumulation of external cold, winter air. The aerodynamic exchange interruption between the cave and the surface during summer determines, as already mentioned, a temporary melting, which affects all morphological types of speleothems. Therefore, the main element characterizing speleothem evolution is seasonal variation, occurring as periodic changes of speleothem masses and implicitly of their dimensions.

Measurements of the upper side of the glacier, of the height of stalag-mites in each of the three rooms, and of the extension of the glacial zone in Rezervația Mare were done monthly in order to establish the seasonal dynamics peculiarities of each speleothem type in each of the two multi-annual glaciological research cycles (1963-1968 and 1982-1992).

The level variations of the glacier were recorded in three locations in Sala Mare with ranging rods graded in millimeters: at the entrance (topoclimatic Station 5), at the center (Station 6), and close to the chimney on the northern side. The results are relative and express the differences between the level measured and the one at the beginning of each cycle. In addition, the possible vertical descent of the whole ice bloc was monitored between January 1966 and April 1968. The device used for this purpose is described in Fig. 35 and it can record millimetric variations. It was placed in the crevice at the western side of Sala Mare, before the entrance in “Biserica”.

The height of the stalagmites was measured using a portable centimeter-graded ranging rod provided with a gliding horizontal arm. Metal marks were planted at the base of each stalagmite to eliminate the level variations of the ice floor. Finally, only three stalagmites in “Biserica” and four in Rezervația Mare gave continuous series of data, due to natural breakdowns frequently occurring in the melting phase or to accidental breakdowns caused by tourists.

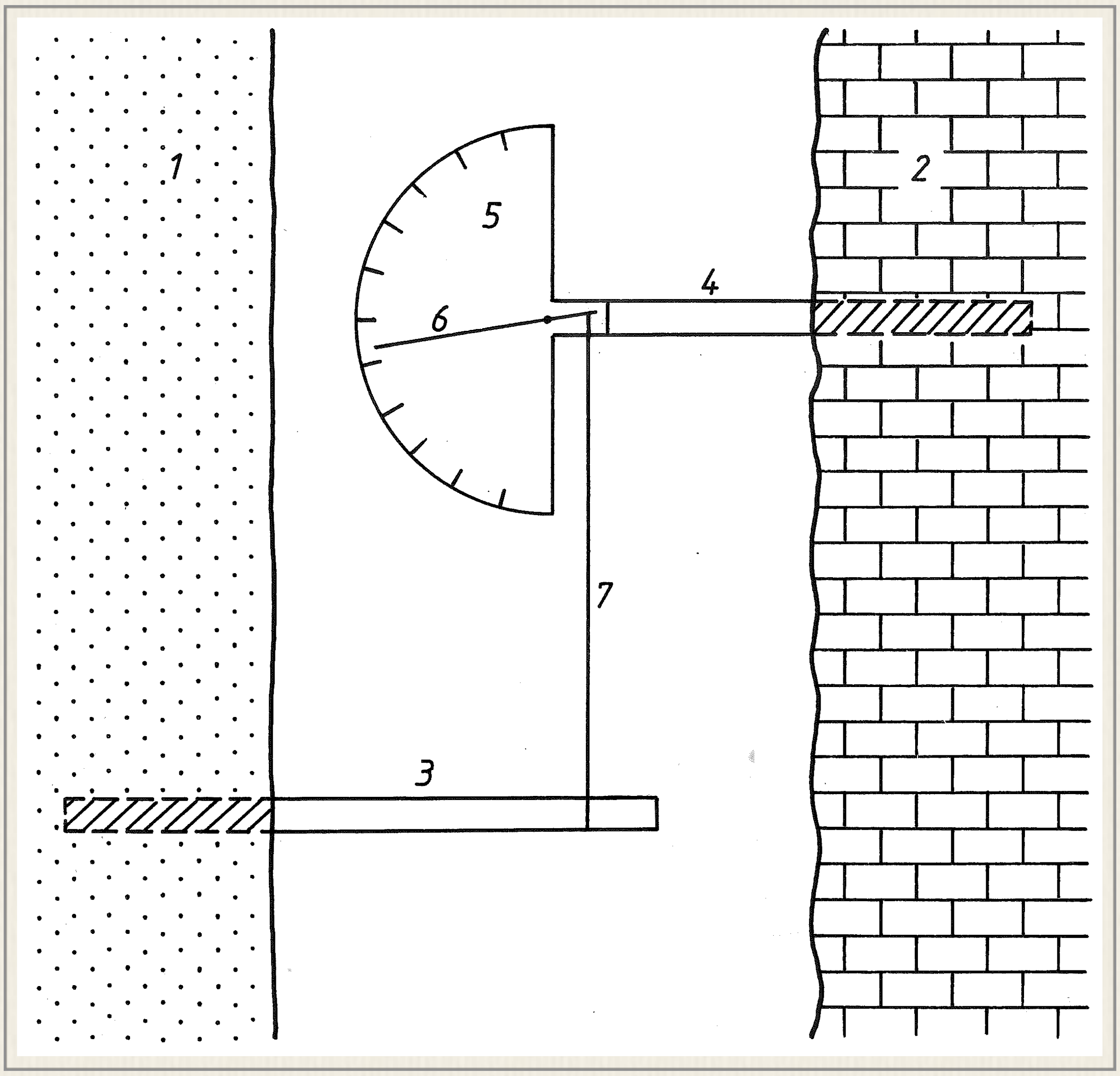

Fig. 35. – Scheme of the device placed in the southwestern crevice for recording the ice block's vertical movement. 1 = the block's side; 2 = the limestone wall; 3 and 4 = metal sticks thrust in the ice and bedrock; 5 = graded frame; 6 = pointer; 7 = metal wire.

The fluctuations of the glacial zone limit were registered by measuring the distance between a fixed mark and the monthly position of the last ice crusts on the cave floor. The measurements were taken along two alignments marked by plastic material bands, one in the central area of the room and the second one near the eastern wall.

The data obtained between 1982 and 1992 (Tables 7-10) confirms first a conclusion drawn from the analysis of the values recorded in the 1962-1968 cycle, that is, an obvious negative correlation exists between the amplitudes of the seasonal oscillations and the various morphological types of speleothems and their masses: the greater the speleothem masses, the smaller the oscillations (Racoviță & Crăciun, 1970). In fact, the annual average amplitudes calculated on the basis of these data are 8.0 cm for the floor of Sala Mare, 11.2 cm for the ice stalagmites in “Biserica”, 54 cm for the stalagmites in Rezervația Mare, and 16.3 cm for the extension of the glacial area. Such a correlation is normal considering that growth or melting of a certain ice volume determine dimensional changes of speleothems more important as their volume is greater. This volume is maximal for the ice block and minimal for the ice crusts on the floor at the limit of the glacial zone. A simple calculation shows that, taking the 8 cm amplitude of the ice block level variations reported to the 3,000 m^2 of the Sala Mare surface, and admitting that the ice volume deposited in winter is equal to the one melted during summer, these variations affect a volume of 120 m^3.

On the other hand, the amplitude of speleothem seasonal fluctuations is directly proportional with the minimum air temperature values and not with the thermal amplitudes, as one would expect. The reason is the fact that the warming of the underground atmosphere during summer is limited to the previously mentioned level of +0.5°C all over the glacial zone.

Another important aspect concerning seasonal variations is the time limit of each of the two phases creating one annual cycle, the winter growth and the summer melting. In this way, two observations need to be made.

First, concerning the ice stalagmites, the random variations that intervene in the feeding water drop frequency determine individual particularities in the speleothem dynamics from the same sector of the cave. Based on these particularities, two cyclic evolution types have been differentiated. One is the *closed evolution*, when at the end of an annual cycle the stalagmites return to the height they had at the beginning, and the other one is the *open evolution*, when stalagmite height at the end of the year is different from the initial one (Racoviță & Viehmann, 1966).

Second, the establishment of the average duration of the two seasonal phases is affected by the long-term tendencies that intervene in the ice speleothem dynamics, over which we comment in the next subchapter. Therefore, the monthly average values calculated from the multi-annual measurements of speleothem dimensions are not equivalent anymore, so it is necessary that the effect of these tendencies be eliminated. The simplest solution takes not account of the raw values, but of their diversion from the theoretical ordinate of the linear regression lines defining the long-term tendency for each speleothem. We must note though this operation is not necessary in the case of the glacial zone extension, because its oscillations lack an obvious tendency of regression or advancement (Racoviță, 1994). The average seasonal variation determined this way reveals noticeable differences between the morphological types of speleothems (Fig. 36).

Table 7

Level of the ice floor in Sala Mare (mean relative values in cm).

Month	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
I	–	5.0	4.7	1.4	6.5	10.0	19.4	15.6	11.6	7.9	5.4
II	–	5.1	4.4	0.9	6.6	9.7	18.9	15.0	12.2	7.1	5.1
III	–	7.7	4.1	0.4	7.3	9.8	18.9	15.2	11.9	7.2	6.2
IV	0.0	8.9	5.0	2.7	11.7	16.1	21.2	16.6	12.0	8.3	8.4
V	6.0	11.2	6.1	5.2	14.0	21.4	22.5	18.7	13.5	10.8	11.4
VI	11.9	11.2	6.7	9.7	14.9	22.5	23.7	18.9	13.3	13.3	12.7
VII	10.0	10.2	5.8	10.0	14.8	22.7	23.4	18.0	11.4	12.7	10.9
VIII	8.2	8.4	4.1	9.7	12.7	22.0	21.1	15.3	9.9	10.5	7.6
IX	6.9	6.9	3.2	8.7	11.6	21.0	19.5	13.2	8.0	7.3	6.4
X	5.6	5.7	2.6	7.6	10.6	19.4	17.5	12.5	7.4	5.3	5.5
XI	5.1	5.2	1.9	7.6	10.1	19.4	16.0	11.2	7.7	5.7	5.7
XII	5.6	5.1	1.5	7.4	10.0	19.4	15.7	11.0	7.9	5.2	7.4

Table 8
Height of stalagmites in the "Biserica" (mean ab solute values in cm).

Luna	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
I	–	144.3	147.7	146.5	168.7	176.5	185.2	193.6	201.7	208.0	209.2
II	–	149.0	144.7	153.3	173.3	181.8	188.9	198.9	202.9	208.7	209.2
III	–	155.3	146.3	155.3	177.3	187.2	190.6	201.4	204.9	212.4	213.0
IV	148.0	155.0	148.0	158.0	175.7	188.0	193.4	201.4	204.1	213.4	213.7
V	150.0	155.3	147.3	161.0	178.3	193.7	196.6	200.6	203.1	213.4	214.9
VI	149.7	155.7	147.3	161.3	178.7	190.3	196.3	199.9	202.8	213.1	214.6
VII	146.0	153.5	147.3	161.3	176.3	190.3	195.3	198.6	201.0	212.9	212.4
VIII	145.7	151.0	144.7	160.7	175.7	190.3	193.3	196.3	198.2	210.2	206.4
IX	145.2	149.3	142.7	159.7	174.7	187.7	192.0	194.5	196.4	206.0	215.7
X	143.8	148.0	141.0	158.3	170.3	186.7	190.8	191.7	195.4	207.8	213.0
XI	142.8	146.7	139.7	161.0	168.7	186.7	191.0	190.2	194.1	208.6	213.7
XII	142.0	146.3	141.3	163.0	171.2	186.0	191.8	201.7	198.3	208.9	216.0

Table 9
Height of stalagmites in Rezervaţia Mare (mean absolute values in cm).

Month	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
I	–	130.8	156.6	152.3	246.3	289.3	313.9	339.0	330.9	303.0	352.5
II	–	157.1	175.6	185.0	281.0	306.0	322.0	365.0	346.5	335.8	382.8
III	–	178.3	196.0	226.8	295.8	322.5	335.5	371.0	347.5	344.9	393.0
IV	162.3	179.5	203.0	246.8	298.3	326.8	342.8	369.5	349.4	349.5	393.5
V	163.9	179.0	203.3	248.0	302.5	329.3	341.8	366.8	346.8	349.3	394.0
VI	162.3	171.3	203.3	246.3	297.3	329.5	341.5	366.0	340.9	346.9	393.9
VII	160.5	167.3	202.8	245.5	294.5	324.3	338.8	355.0	334.5	343.5	391.0
VIII	158.1	163.3	196.5	245.5	287.8	323.8	332.3	344.5	308.3	333.5	381.8
IX	149.0	156.8	175.5	245.5	284.8	321.5	330.0	322.0	304.9	317.1	375.5
X	142.0	151.0	164.3	241.5	278.8	319.9	320.8	317.3	300.8	301.3	371.5
XI	136.9	142.6	153.3	237.8	276.5	313.3	312.5	305.5	290.8	301.0	361.8
XII	126.3	150.3	149.0	233.3	273.0	309.6	324.3	313.0	291.5	328.8	368.6

Table 10
Extension of the glacial zone in Rezervaţia Mare (mean relative values in m).

Month	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
I	–	13.75	15.60	16.65	15.50	17.15	12.25	15.65	14.20	15.35	16.55
II	–	16.45	16.55	17.10	16.55	17.70	8.50	15.30	13.55	16.65	16.55
III	–	15.25	16.15	17.50	15.75	18.30	15.30	14.00	9.25	16.10	16.15
IV	–	13.50	15.00	16.80	14.70	16.95	11.90	13.20	3.50	14.90	14.95
V	–	6.05	13.70	16.45	13.70	16.15	6.20	6.65	2.95	11.25	13.75
VI	–	5.25	5.50	15.50	9.75	14.75	5.10	5.90	1.65	6.50	13.45
VII	–	3.85	3.00	14.85	6.80	14.45	4.75	5.15	–3.00	3.40	9.85
VIII	–	–2.00	2.10	13.90	5.40	14.15	4.50	–2.00	–4.00	–2.75	6.25
IX	–	–2.60	–2.00	13.55	4.65	10.25	4.50	–2.75	–4.00	–2.75	2.60
X	–	–3.90	–3.00	9.15	0.50	9.50	3.50	–2.80	–4.00	2.95	0.25
XI	–	13.95	–3.00	8.65	4.65	8.00	4.30	–2.85	–3.50	16.55	2.95
XII	–	14.05	12.55	6.35	16.60	7.70	13.55	16.00	14.95	15.65	2.00

The upper side of the glacier reaches its maximum level in June and then progressively lowers until November. A slight increase that produces in December due to the underground atmosphere cooling is followed by a new decrease, that lasts until February (Fig. 36A), and which can only be the effect of a volatilization process.

The ice volatilization and sublimation phenomena affect stalagmites, lead to the formation of frost deposits on the walls of Sala Mare, and intervene as well in the seasonal dynamics of the ice floor level. Hygrometric and thermometric data recorded in the first research stage lead to the conclusion that the external winter air, cold and dry, determines the monthly volatilization of an ice layer 15 mm thick. Sublimation results in the monthly deposition of a 7 mm ice layer (Racoviță, 1967). These values are perfectly compatible with the structural and dynamic parameters of the ice block, because the thinnest layers in the ice cores are a few millimeters thick (Șerban et al., 1947), and the monthly level fluctuations are, in the best case, of a few centimeters (Table 7).

Although the glacier vertical movement is not obviously associated with speleothem seasonal dynamics, the measurements suggest that this process also implies seasonal variations. Șerban et al. (1948) supposed such a movement considering it is due to the slow and continuous melting of the glacier bottom influenced by the endogenous heat and by the pressure exerted by the ice weight. Data given by the device in the crevice on the southwestern side of Sala Mare entirely confirms this hypothesis, as it shows that in almost two and a half years the block descended 4.3 cm (Table 11). On the other hand, the same data shows that this movement is stronger in the second half of summer and during autumn. This suggests that the melting of the glacier bottom is mainly influenced by air currents circulating through voids similar to crevices that may exist under the ice massif.

Table 11

Vertical movement of the ice block flank (cumulated values in mm).

Month	1966	1967	1968
January	0.0	–24.6	–32.7
February	–0.2	–25.1	–36.0
March	–0.4	–25.4	–39.5
April	–0.8	–25.7	–43.1
May	–1.2	–25.7	
June	–1.9	–25.9	
July	–2.6	–27.5	
August	–5.7	–29.1	
September	–8.8	–30.5	
Octomber	–16.0	–31.9	
November	–23.2	–32.2	
December	–23.9	–32.4	

Stalagmite growth starts in December and continues until the end of spring, more precisely until May in “Biserica” and until April in Rezervația Mare (Fig. 36B and C). This is most probably because in “Biserica”, the water permanently dripping from the ceiling suppresses volatilization, while the thermo-hygrometric conditions from Rezervația Mare make impossible the ice ablation through volatilization from the very beginning.

The limit of the glacial zone starts advancing in November, when the air temperature becomes negative. The reason is that the ice crusts on the floor form when the vertical thermal gradient is null, that is the temperature is lower than at the height stalagmites usually reach. Very fast in the beginning, the advancing rate lowers because the formation of new crusts is replaced by the growth in volume of the already existing ones. As growth is always moderate, the crusts disappear easily through melting and their front begins to retreat in April (Fig. 36D).

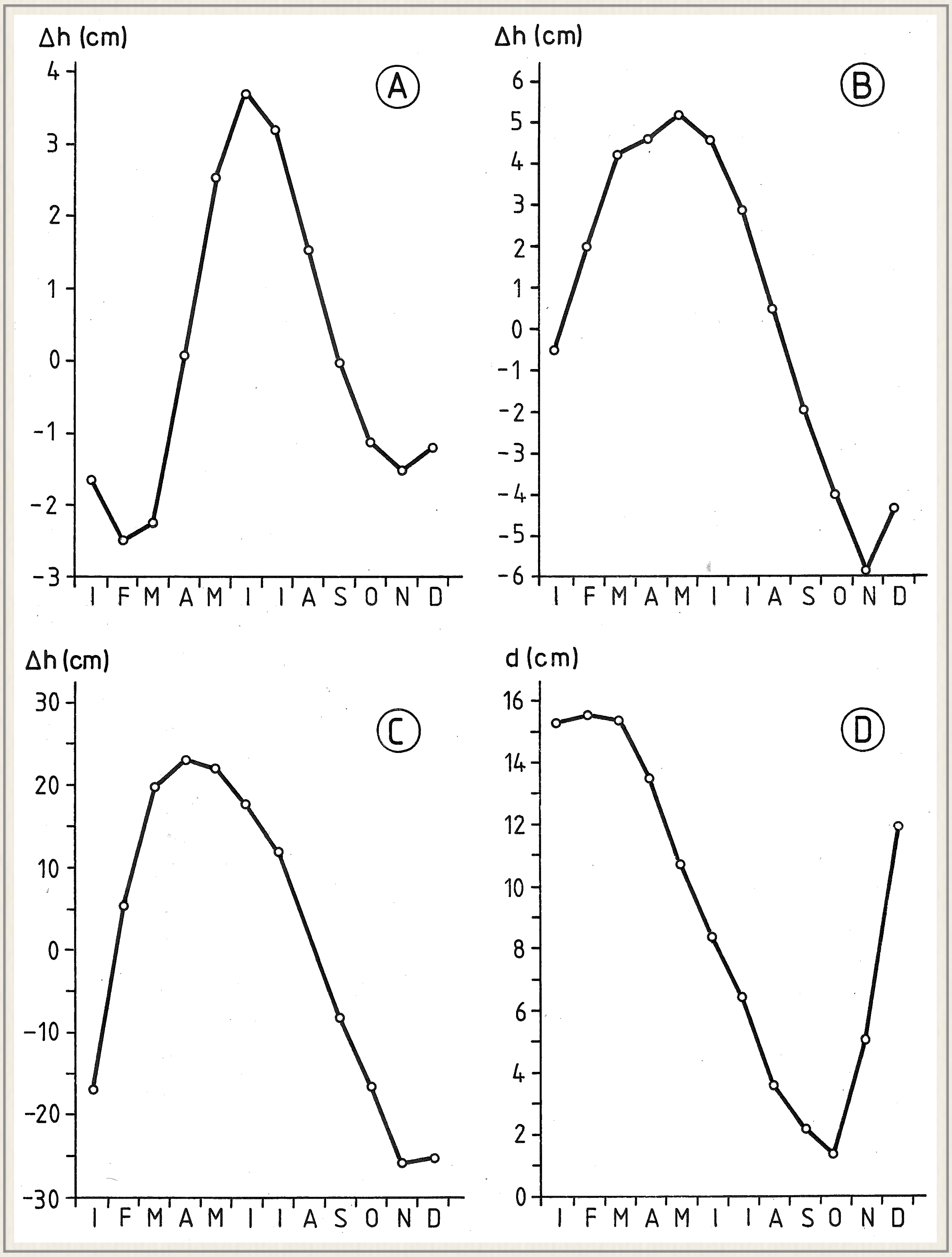

Fig. 36. – Seasonal mean variation of the morphological types of ice speleothems. A = glacier upper face; B = the stalagmites from „Biserica"; C = the stalagmites from Rezervaţia Mare; D = the limit of the crusts formed on the floor (see explanations in the text).

One can therefore conclude that, generally speaking, the most favorable conditions for the ice speleothem development are met either in winters when frost periods alternate with warmer ones, or in harsh winters abundant in precipitation and followed by early springs. That is, in all situations when outside meteorological evolution is able to create both low air temperature values and abundant percolation inside the cave. The summer decline of speleothems is determined strictly by the period when the external temperature remains positive but is completely independent from its absolute values.

Long-term dynamics

Șerban et al. (1967) compared the observations made by E. Racoviță (1927) with studies done after 1947 on the Sala Mare floor and on the ice stalagmites in "Biserica" and concluded that the glacier progressively decreased during four decades, whereas the stalagmites experienced a strong development. This was firstly confirmed by the statistical processing of the data from the first stage of glaciology research (Racoviță & Crăciun, 1970). Such a long-term tendency could then be generalized for all morphological types of ice speleothems (Racoviță et al., 1987, Racoviță & Șerban, 1991).

The data gathered up to now show that, beside seasonal variations, two other types of variations could be distinguished in speleothem dynamics. These are multi-annual periodic oscillations and multi-decade linear tendencies and are different in terms of both timescale and characteristics.

Multi-annual oscillations could be observed by analyzing the results of the measurements from the second research stage over the period of ten complete annual cycles (1982-1992) (Racoviță, 1994b).

During this period, the ice floor monthly average values (Table 7) reveal in the dynamics of the Sala Mare floor the existence of three periods with different tendencies: a lowering tendency until 1985, a raising tendency between 1985 and 1988, and a new lowering one until 1991 (Fig. 37A). The simplest way to determine the size of these tendencies is establishing the linear regression lines for each of the three data sequences. For the data introduced in the calculations to be coherent, it is necessary that these sequences consisted of a whole number of annual cycles and that these cycles always started with the winter phase (when the ice that melts in summer is formed). As mentioned in the analysis of the seasonal variations, the winter phase starts in this case in February.

The equations defining the regression lines are

$$h = -0.3235\, n + 9.73 \tag{46}$$

$$h = 0.49911\, n + 2.88 \tag{47}$$

and

$$h = -0.3312\, d + 21.31 \tag{48}$$

where *n* represents the order number of the months.

The quite similar absolute numeric values of the regression coefficient a in these equations (0.32, 0.49, and 0.33) show that the multi-annual tendencies have the same size order. The three periods can also be compared in terms of their time length, which is between three and four years.

In principle, multi-annual variations of the ice level should correspond to similar variations in the temperature evolution of the glacial zone. Taken as is, the temperature data registered in Sala Mare do not show any long-term tendency (Fig. 9), but their statistical processing offers a completely different result. The most appropriate analysis is the one that uses the Ballot-Besson method of adjusting chronological series. It consists of a progressive algebraic addition of the value deviations from their arithmetic mean. The succession of the so calculated sums S_i emphasizes all periodicities of the initial series (Șerban & Racoviță, 1991). The adjusted curve built upon the mean temperature values of the glacial zone also show the existence of multi-annual tendencies. They belong to the same three periods, but their direction is always contrary to that of the ice floor (Fig. 37B).

These findings suggest that multi-annual oscillations are mainly determined by the feedback type mechanisms interfering in the final stage of the glacier genesis, and not by external meteorological factors. No matter the topoclimatic type the cave belongs to, it can only contain a limited ice volume (Șerban et al., 1967). The progressive increase in the ice quantity is implicitly followed by the decrease of the available space for the external cold air accumulation, so that the conditions in which the new ice layers form become less and less favorable. Consequently, the most adequate theoretical model for the evolution of the ice deposit is given by an exponential saturation curve, with a not linear, but sinusoidal segment (Fig. 38). At the moment when the maximum ice volume is reached, the mutual dependence between the air and the space occupied by the ice massif acts like a self-adjustment mechanism, determining oscillations with an amplitude ΔV and a period P. Called *intrinsic oscillations* (Racoviță & Șerban, 1990), they regularly follow each other as long as the external climatic context remains constant.

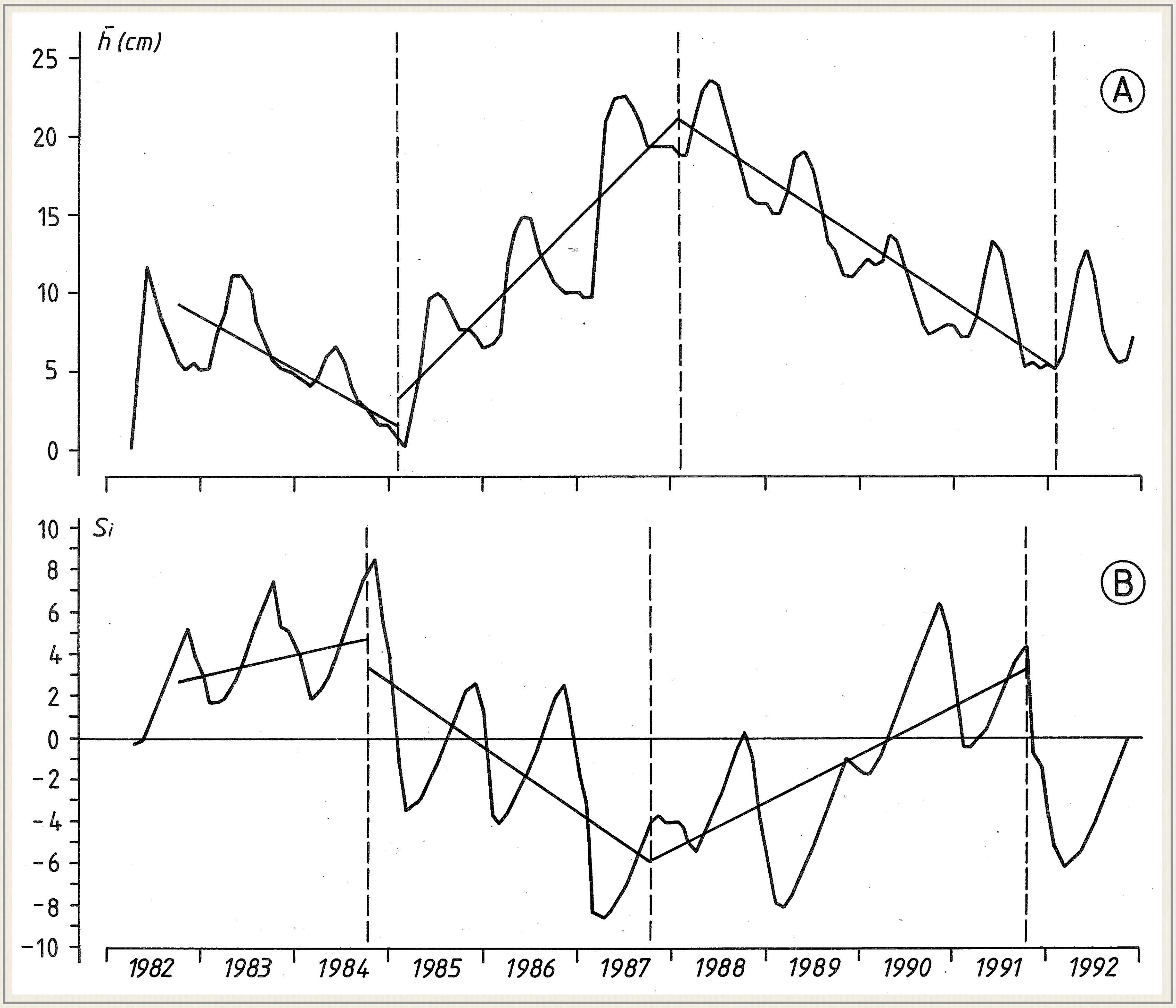

Fig. 37. – Multiannual variation of the ice floor level in Sala Mare (A) and the adjusted curve of the thermal variations in the glacial meroclimate (B).

Such an interpretation is in disagreement with two important facts. On the one hand, it is certain that, as we will soon see, the present volume of the glacier is significantly smaller than its maximum. On the other hand, as we already mentioned, the cave temperature variations closely reflect the external ones. The thermometric data processing using the Ballot-Besson method confirms that such a correlation also exists for a long-term period (Racoviță, 1994a). The only conclusion we can afford without any restraints is that the ice floor level fluctuations represent the direct result of the influences exerted by external meteorological factors over the cave topoclimate (Racoviță, 1994b).

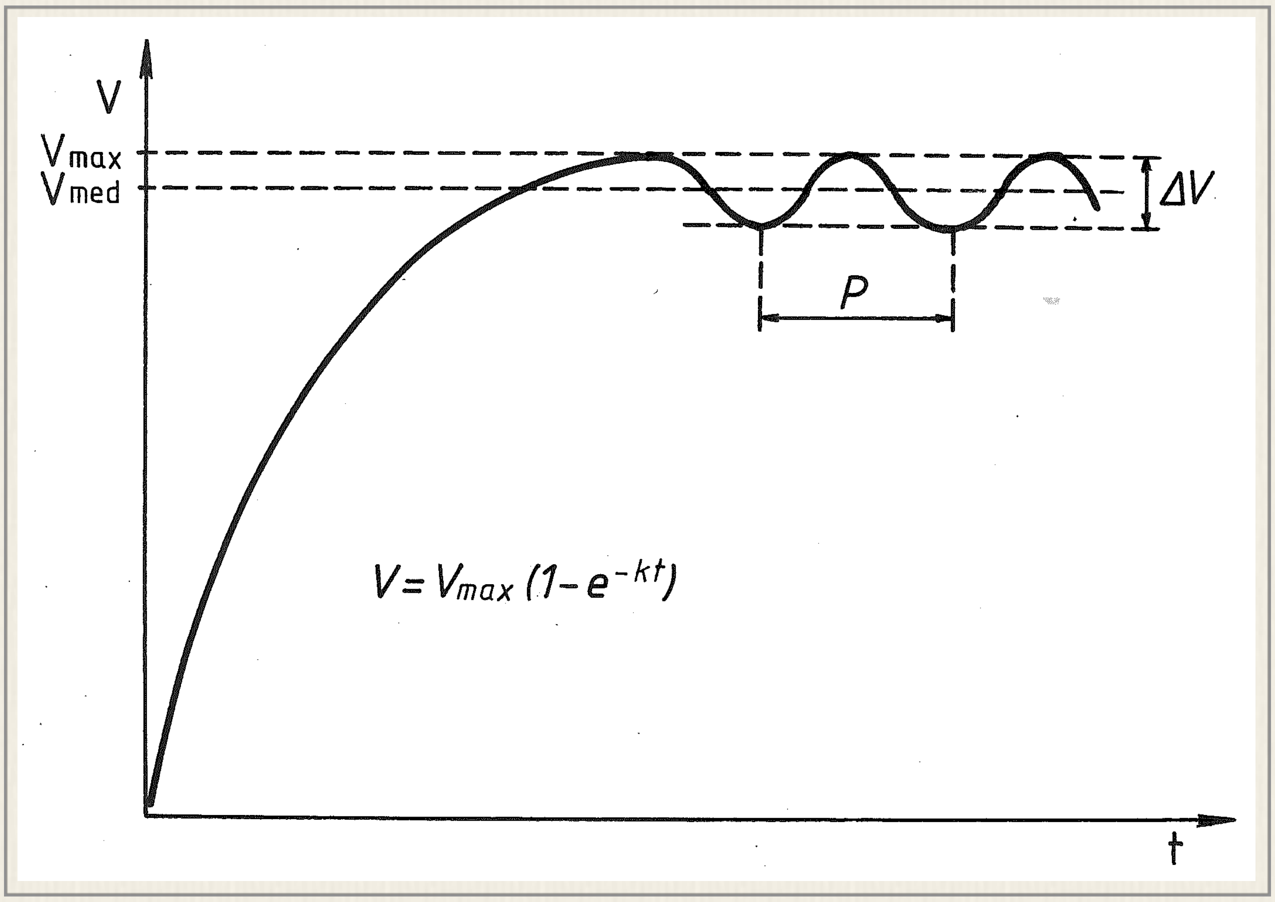

Fig. 38. – Theoretical model for the constitution of an underground perennial ice deposit. V_{max} = maximum volume occupied by ice; V_{med} = mean volume; ΔV = amplitude of intrinsic variations; P = these variations' period.

In the case of the ice stalagmites in "Biserica", the series of values of the 1982-1992 period suggest that this time interval could be divided into the same three periods with different tendencies (Fig. 39). The calculations of the partial regression lines confirm that, proceeding this way, the greatest values for the linear correlation coefficients are found. The equations of these lines are:

$$h = -0.2768\,n + 151.24 \qquad (49)$$

for the first period,

$$h = 1.2367\,n + 147.54 \qquad (50)$$

for the second one, and

$$h = 0.4471\, n + 188.09 \qquad (51)$$

for the third one.

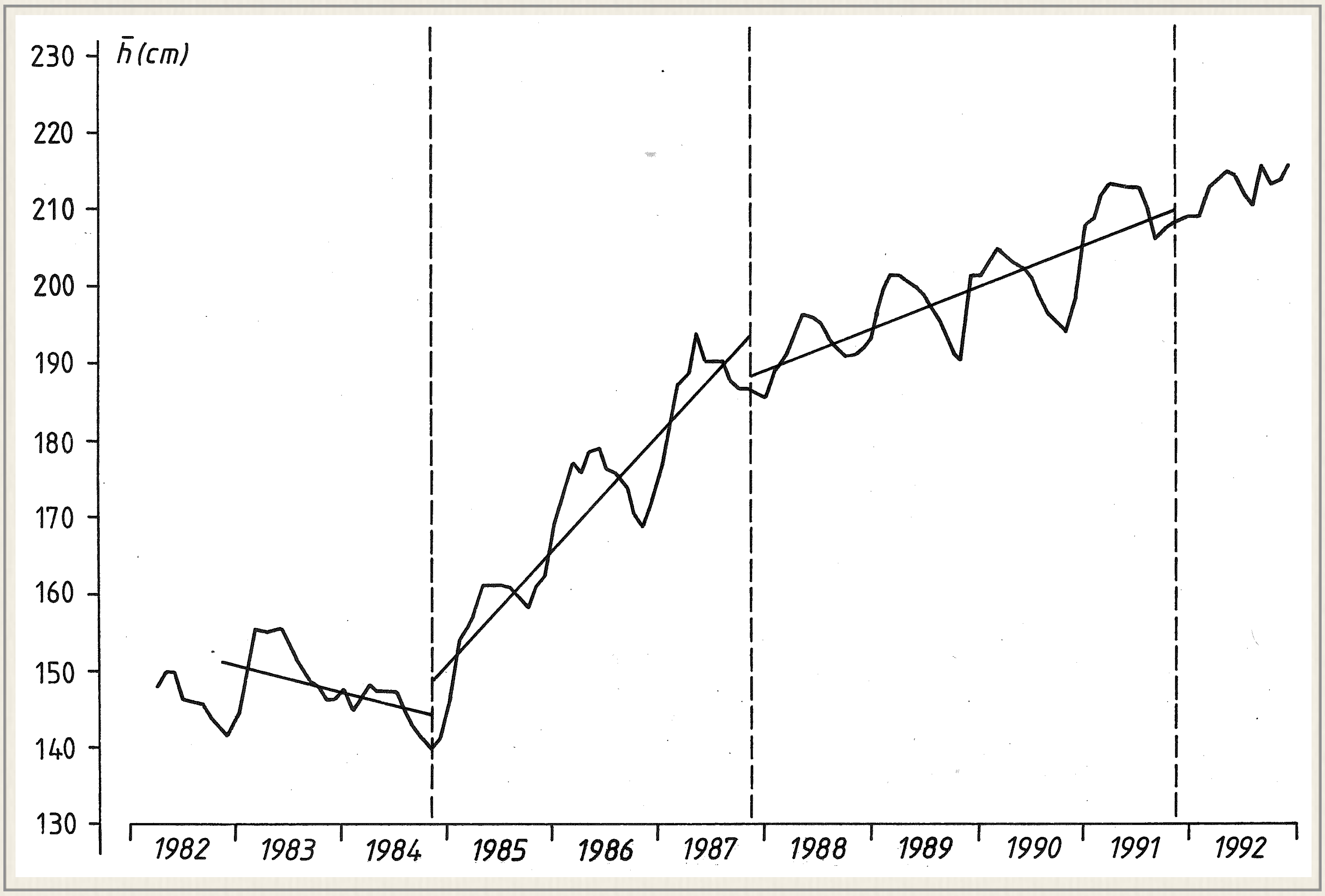

Fig. 39. – Multiannual variation of the height of stalagmites in „Biserica".

The similarities with the glacier dynamics end at this temporal limit of the multi-annual oscillations, because there are two very important differences that cannot be ignored. The first one concerns the positive the long-term tendency recorded in the period 1988 - 1991. The second one is that, the absolute numeric values of the regression coefficients are not equivalent, the one corresponding to the 1985-1987 period being noticeably greater (1.24). Therefore, unlike the case of the ice floor in Sala Mare, the stalagmites in "Biserica" have shown since 1985 a continuous but uneven increase, more emphasized in the first part of the interval.

The dynamics of the stalagmites in Rezervația Mare are similar to that of speleothems in "Biserica". They exhibit a rigorously identical separation of periods with distinct tendencies, but their particularities are mostly emphasized by the numeric expressions of the partial regression lines (Fig. 40). These expressions are:

$$h = 1.7184\, n + 146.49 \qquad (52)$$

$$h = 4.1232\, n + 191.37 \qquad (53)$$

and

$$h = -0.2561\, n + 337.56 \qquad (54),$$

respectively.

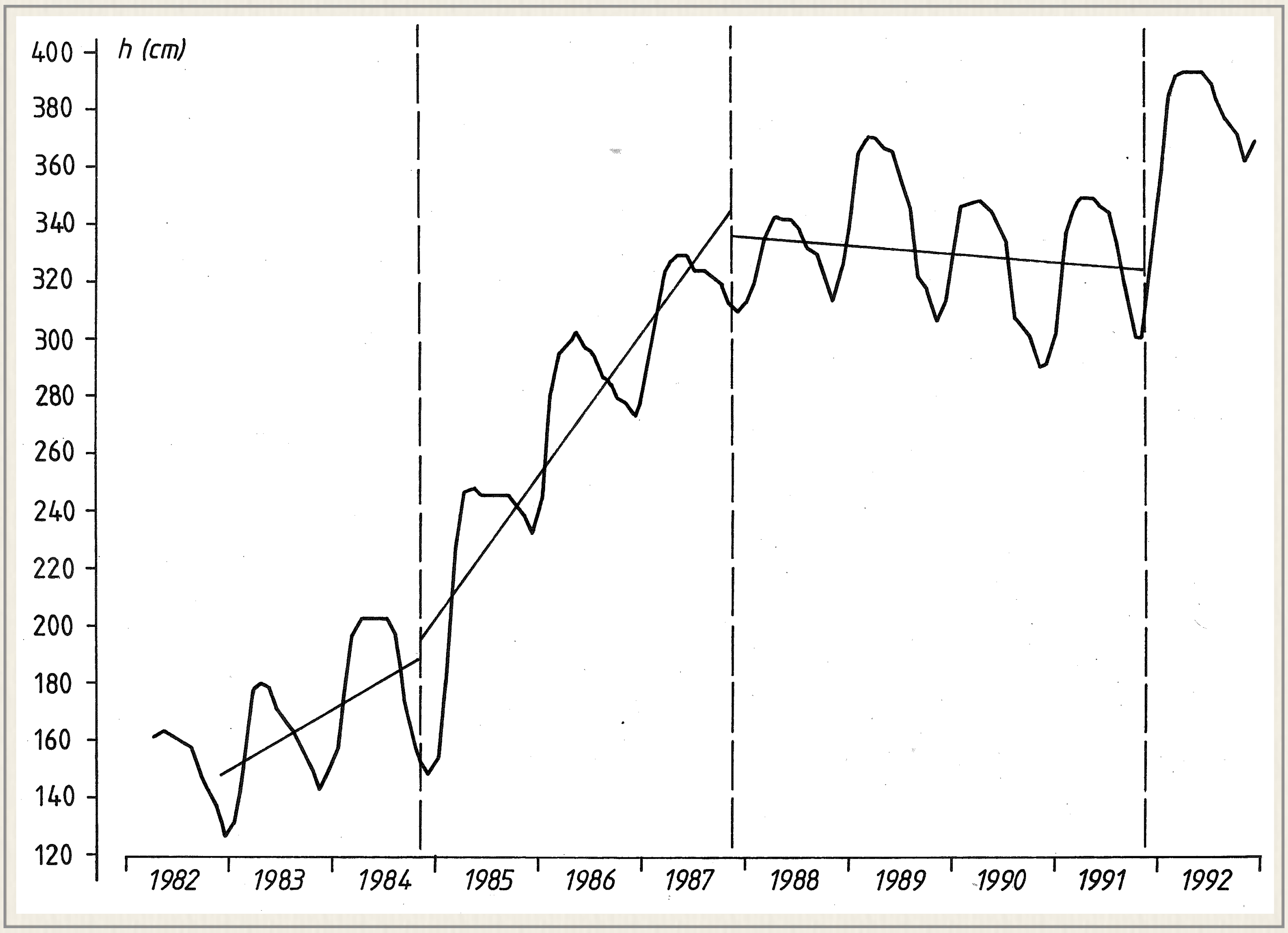

Fig. 40. – Multiannual variation of the height of stalagmites in Rezervaţia Mare.

They show that the positive trend was present only in the 1985 -1987 interval, this time with a greater growth rate. The first period has as original element a positive trend, and the last is characterized, like the ice block, by a negative trend, even if it is now less emphasized. On the other hand, with the exception of the last period, the absolute values of the regression coefficients are greater than those calculated for the stalagmites in "Biserica". This corresponds to the greater amplitude of the seasonal variations presented by these speleothems, the farthest away from the center of the underground glacier.

From the viewpoint of a long-term variation, the glacial zone extension in Rezervația Mare is a particular case. The plot of the data obtained through monthly measurements (Fig. 41A) does not offer any reason for distinguishing multi-annual oscillations, and the calculations confirm that the regression line obtained from these data is the one with the most significant linear correlation coefficient. Moreover, this line is almost horizontal, thus the regression coefficient has an extremely small value (a = –0.031). However, when applying the Ballot-Besson method to adjust the primary data, the configuration of this curve is completely different (Fig. 41B). It reveals the existence of some elements similar to those characterizing glacier dynamics, concerning both the limits of the periods with different trends and the trend direction. One may therefore conclude that the changes in the external meteorological context are at the origin of the multi-annual cyclic oscillations shown by the glacial zone limit (Șerban & Racoviță, 1991).

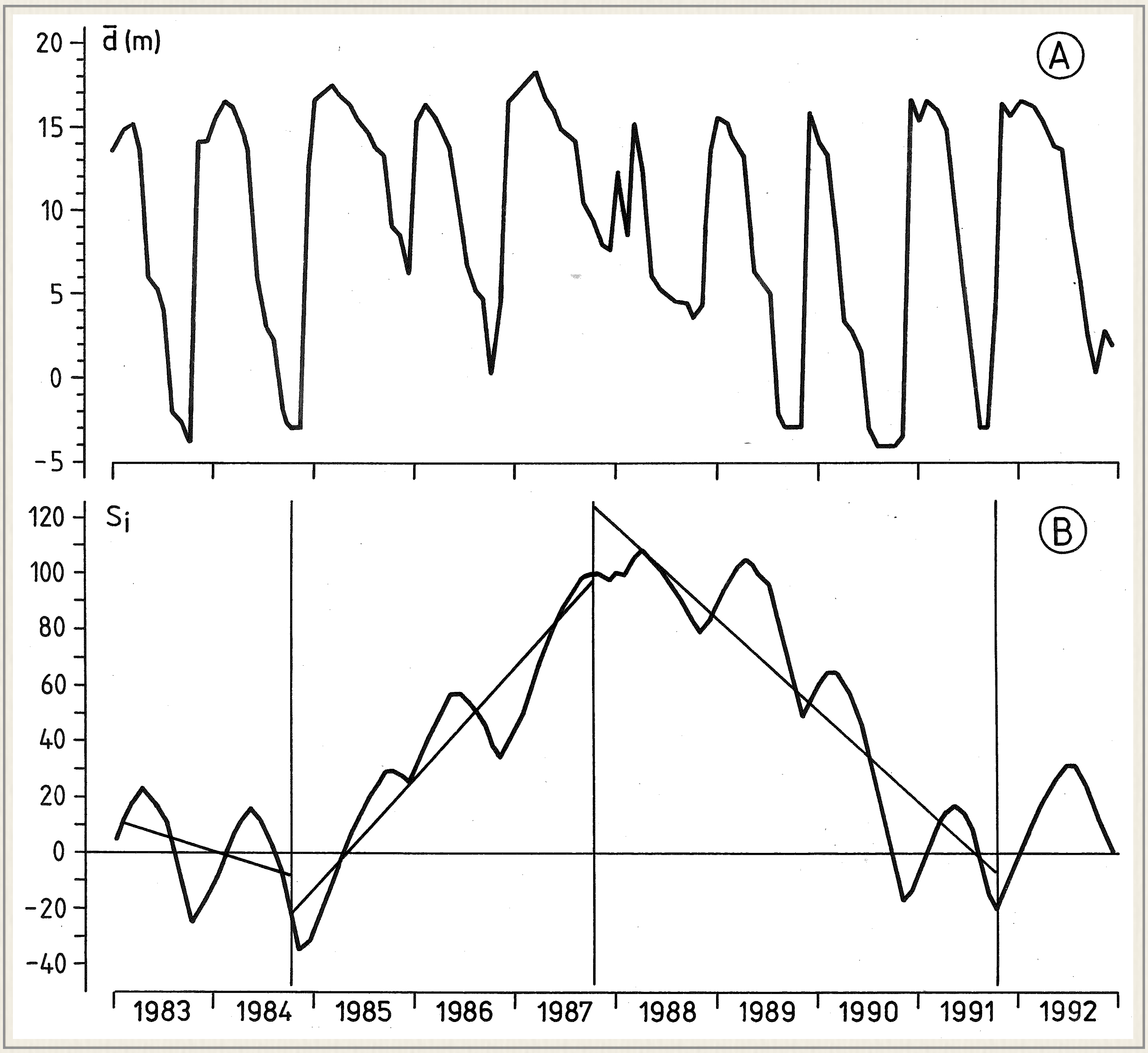

Fig. 41. – Multiannual variation of the glacial zone limit in Rezervația Mare.
A = raw mean values; B = adjusted curve.

The *multi-decade linear trends* were best emphasized by the comparative analysis of the data given by the systematic research made, especially between 1964 and 1992, and of the information recorded starting with 1921.

The first attempt of quantitative determination of such trends was made by Racoviță et al. (1987). It consisted in corroborating sets of monthly values registered in the intervals 1964-1968 and 1982-1985, concerning, on the one hand, the floor level in Sala Mare, and on the other hand the stalagmite heights in “Biserica”.

In the case of the ice floor, the fact that the level variations are expressed by relative values imposed the establishment of an absolute value of the reference level from which measurements were started in the second interval. This was possible due to a mark on the wall of the room, pointing the height of the ice floor in 1947. The reference level determined by some measurements taken from this mark was set to - 65 cm. Considering this difference and admitting a uniform decrease of the ice level, the linear interpolation between the two sets of monthly values leads to the equation:

$$h = -0.2297\, n - 0.94 \qquad (55)$$

The interpolation is direct for the ice stalagmites, because their height is expressed in absolute values and the same speleothems were measured in both intervals. The equation that defines the long-term trend is now:

$$h = 0.2275\, n + 93 \qquad (56)$$

The almost perfect equality between the regression coefficients of the two equations shows that, at least in the 1964-1985 period, the descent rate of the ice floor in Sala Mare was equal to the growth rate of the stalagmites in “Biserica”. Thus, the “phase contrast” phenomenon, that is the antagonism that appears as a specific element in the long-term dynamics of the two morphological types of speleothems, gets a first quantitative expression.

The analysis of the parameters defining this dynamics emphasizes another important aspect. It refers to the differences between the slope of the lines established for the entire 23-year interval and the ones corresponding to the speleothem variation in each of the two periods, respectively (Fig. 42). Because of this reason, the graphic correlation of the partial regression lines can only be done through curved lines. In the case of the ice floor, their convexity is oriented downwards and the inflection zone corresponds approximately to the year 1977. In the case of the ice stalagmites, the convexity is oriented upwards and the inflection appears earlier, in 1968-1969. This observation may confirm the hypothesis of Șerban et al. (1967), who stated that the multi-decade dynamics of the ice formations closely reproduces the elementary 11-year meteorological cycles.

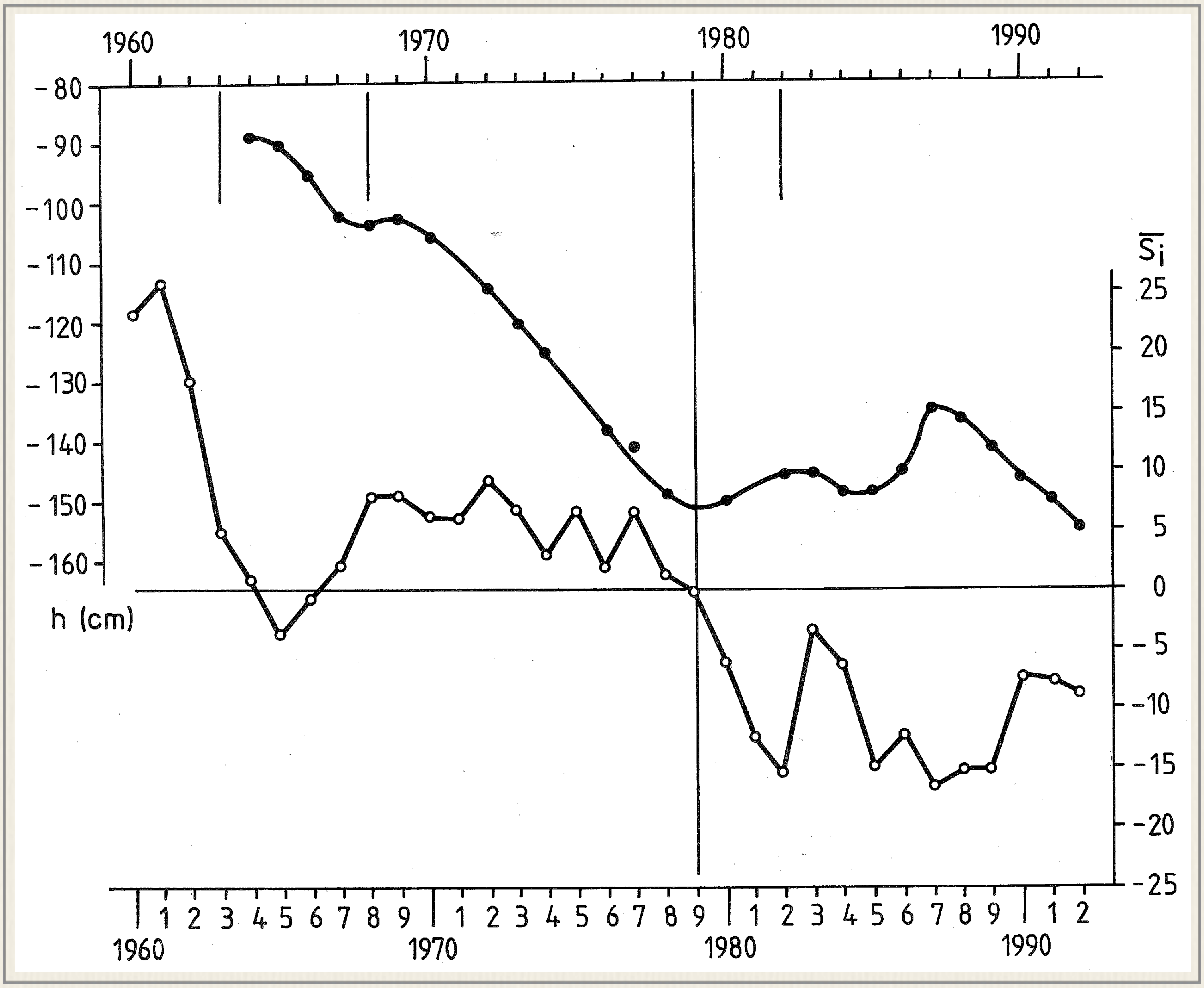

Fig. 42. – Evolution of the ice floor from Sala Mare (solid circles, left side ordinate) and adjusted curve of air temperature variations recorded at Băişoara meteorological station (open circles, right side ordinate) between 1960 and 1992.

The causes of the "phase contrast" phenomenon are still rather unclear. Basically, one may consider that through the lowering of the Sala Mare ice floor (thus the increase of the space where the cold air accumulates), the development conditions of the ice stalagmites would become more favorable, but this hypothesis is not confirmed by the temperature data. The mechanisms responsible for this phenomenon were found by analyzing the relative values of the speleothem seasonal variations, including the stalagmites in Rezervația Mare (Racoviță et al., 1987). Calculating the ratio between the sums of the monthly growths and decreases in each of the two time intervals (1964-1968 and 1982-1985), the values obtained for the ice level are subunitary, of 0.57 and 0.89 respectively. In contrast, the ratios for the stalagmites are greater than 1, the corresponding values being 1.51 and 1.31, respectively. On the other hand, the number of months when ice accumulates is in all cases smaller than that of the months with ice losses. Therefore, unlike the glacier, the growth trend of the stalagmites owes to the fact that the winter growth phase has a greater role in their dynamics than the summer lowering, even if the former is shorter in terms of time. The monthly mean values of ice depositions and losses clearly emphasize the particularities differentiating the speleothems (Fig. 43).

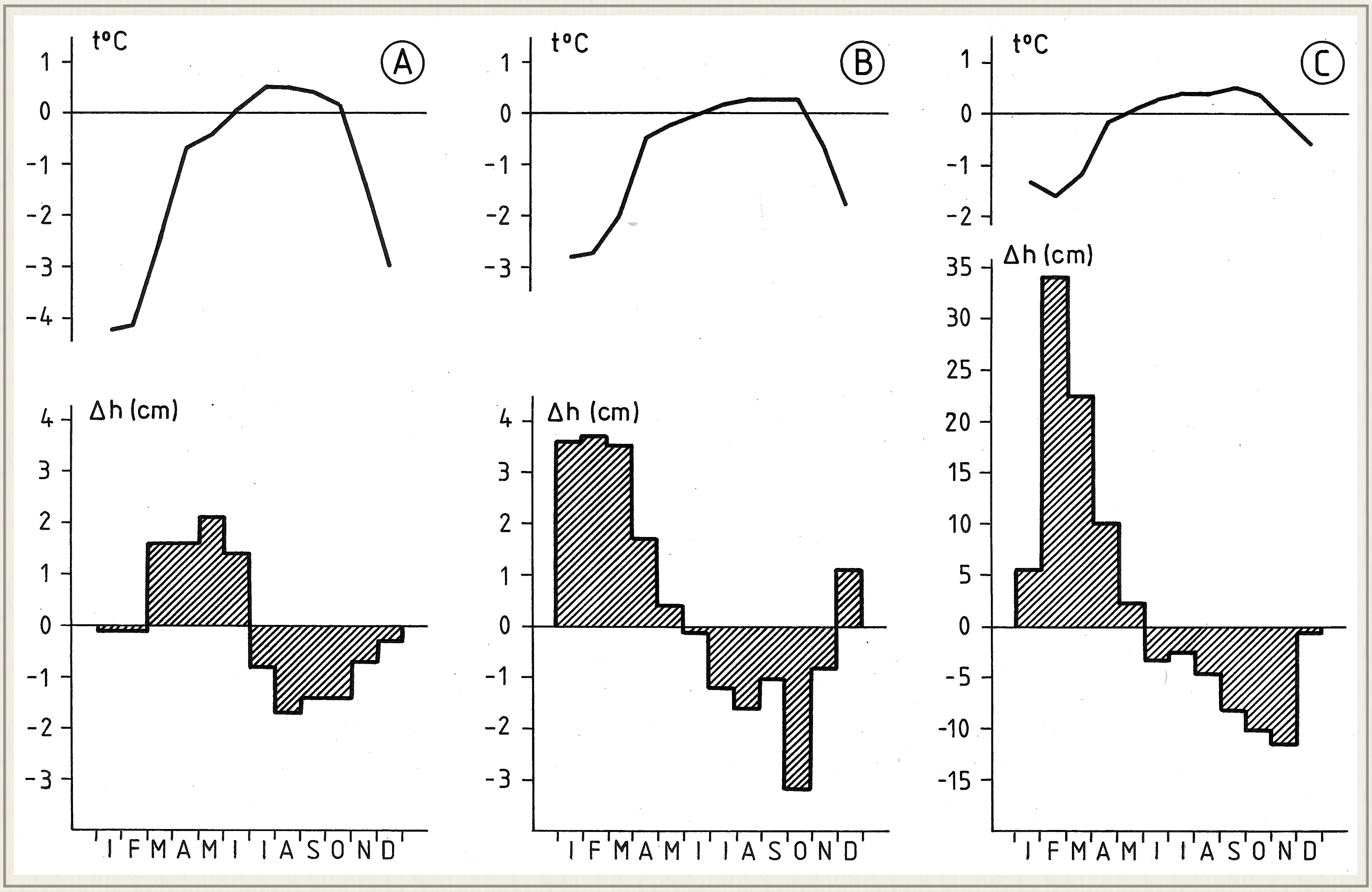

Fig. 43. – Mean monthly values of air temperature (above) and of growth and melting of ice speleothems (below). A = floor of Sala Mare; B = stalagmites from the „Biserica"; C = stalagmites from Rezervaţia Mare.

Putting together all these elements, we reached the conclusion that the "phase contrast" phenomenon could be finally caused by the thermal conditions in which the different ice formations evolve. In the seasonal variation of the glacier level there is a noticeable period of time (from November to February) when no ice layers can form although the air temperature is negative. This is due to the volatilization process and to the absence of feeding water. The parallelism that exists between the air temperature and the amplitude of the monthly average growths of the stalagmites in "Biserica" and Rezervația Mare, also shows that these speleothems form only in a certain thermal interval. The most favorable conditions for the stalagmite growth in height are found in Rezervația Mare, and not in "Biserica".

The conclusions drawn from the analysis of the monthly-recorded data can be completed taking into account the observations done since 1923 on the evolution of the glacier surface.

In the description he made after visiting the cave in 1921-1923, E. Racoviță (1927) mentioned a 2 m high step on the northwestern side of Sala Mare, separating this room from what he called "Galeria" (later named Sala Mică). He also noted that the drop at the entrance in "Biserica" measured 5 m. The measurements taken in 1947 by Șerban et al. (1948) showed that the step in Sala Mică was only 0.5 m high and the drop between the ice floor in Sala Mare and the one in "Biserica" was 6 m. In 1951, when E. Balogh and I. Ujváry made the first topographic survey of the cave using a theodolite, the ice step no longer existed, while the drop at the entrance in "Biserica" increased to 7.72 m. This drop decreased to 7.17 m in 1965 (Rusu et al., 1970), but then increased again to 7.98 m in 1985.

Considering the 1947 data as a starting point, it is precisely known that the ice floor level lowered continuously to the present. Comparing its level to the mark on the limestone wall, one could register the variations of the glacier's upper part. The data leads to a linear model for the progressive lowering of the ice floor in Sala Mare (Fig. 44), defined by the equation:

$$h = -0.3275\, n - 6.64 \qquad (57)$$

Because this model is significant at a 1% threshold (the correlation coefficient r = 0.99), the model extension back to 1923 is justified, this operation leading to a positive level difference of 0.9 m compared with 1947. This result is not only credible, but also represents the only rational explanation for the fact that the old descriptions do not mention any opening in the northern side of Sala Mare (Racoviță, 1927; Jeannel & Racoviță, 1929). This opening is the actual entrance in Rezervația Mică, which must have been completely covered by the glacier at that time.

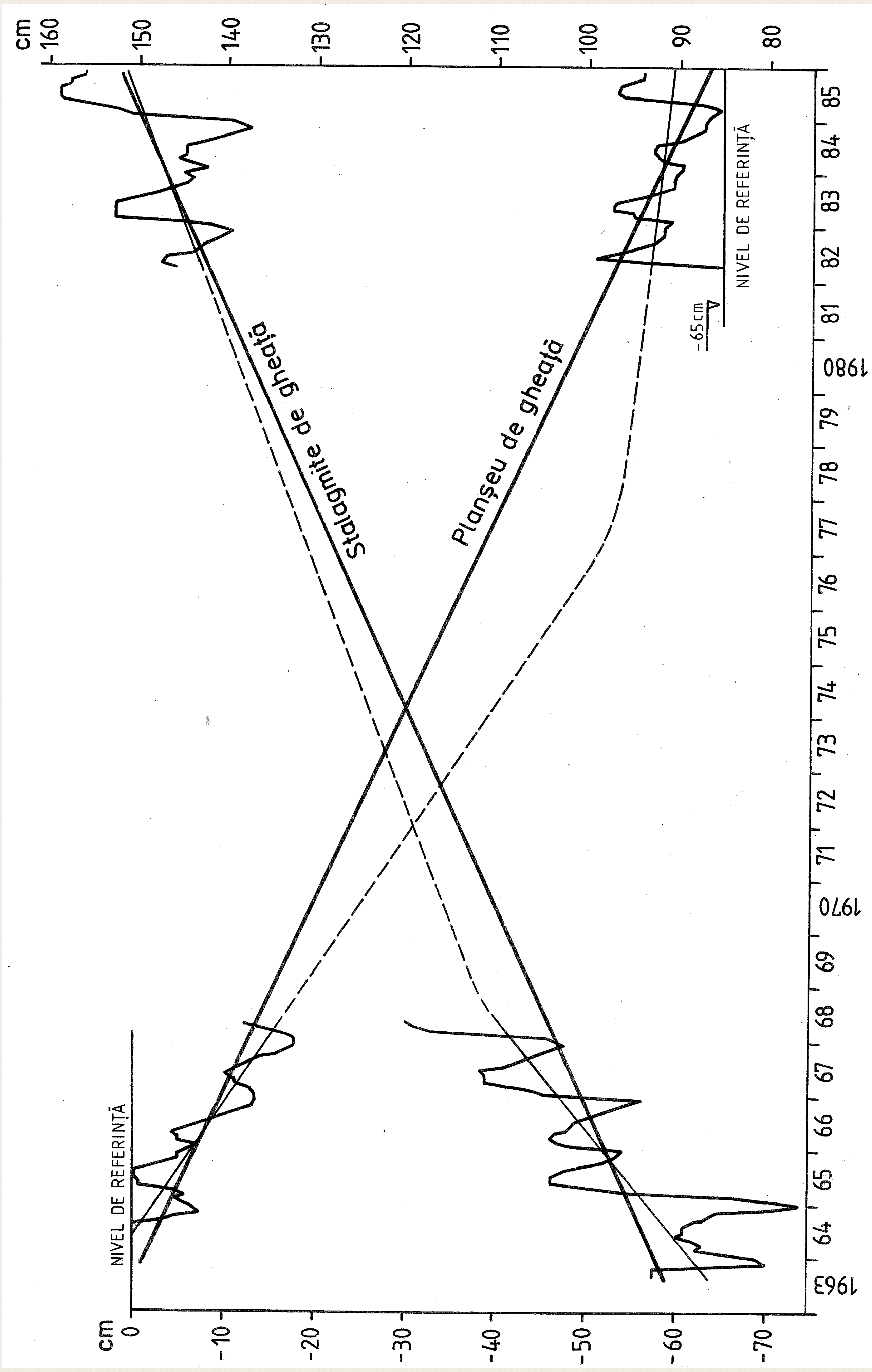

Fig. 44. – Relationship between seasonal variations of Sala Mare floor (left side ordinate) and of the stalagmites from „Biserica” (right side ordinate), recorded between 1963-1968 and 1982-1985.

In what concerns the ice floor level in Sala Mică, the same reconstitution shows that it increased between 1923 -1951 also following a linear function defined by the equation:

$$h = 0.2277\, n - 0.66. \qquad (58)$$

This equation is practically the same with the one established for the general lowering tendency of the ice floor in Sala Mare between 1964 and 1985. Similar to the "phase contrast" which opposes the dynamic phenomenon specific for the ice block and the one of the stalagmites, this antagonism confirms the hypothesis formulated by Șerban et al. (1967), that the various sectors of Sala Mare had different long term evolutions.

The last problem that must be analyzed is the fact that the absolute value of the regression coefficient from equation (57) is greater than that from equation (55). This means that the lowering rate of the glacier level between 1947 and 1985 was greater than the one for the 1964-1985 interval. One may suppose that the changes in the external meteorological conditions determined this difference. To verify this, the occasional measurements taken between 1968 and 1982 by I. Viehmann were used. These measurements were taken outside of the two research periods and they refer to the ice level in Sala Mare. Adding these data to the mean annual values from 1964-1968 and 1982-1992, a correct image of the ice floor level variations over those three decades is obtained. These variations must then be compared to an equivalent parameter of the external temperature evolution. The best one is given by the annual means, S_i, of the summed deviations, calculated for the temperatures recorded monthly at the meteorological station at Băişoara.

The two series of values put together (Fig. 45) show that the time interval considered includes two distinct parts, separated by the year 1979. Until then, the temperature curve is generally placed above the reference ordinate, thus showing the existence of a warm period, when the ice floor level progressively decreased for about 60 cm. After 1979, the decrease is replaced by the multi-annual variations formerly described, to which associates the growth trend which occurred until 1982. In its turn, the temperature curve shows an obvious cooling of the regional climate by passing below the reference ordinate, but still presenting the alternative oscillations that perfectly match the sequences identified in the ice speleothem dynamics.

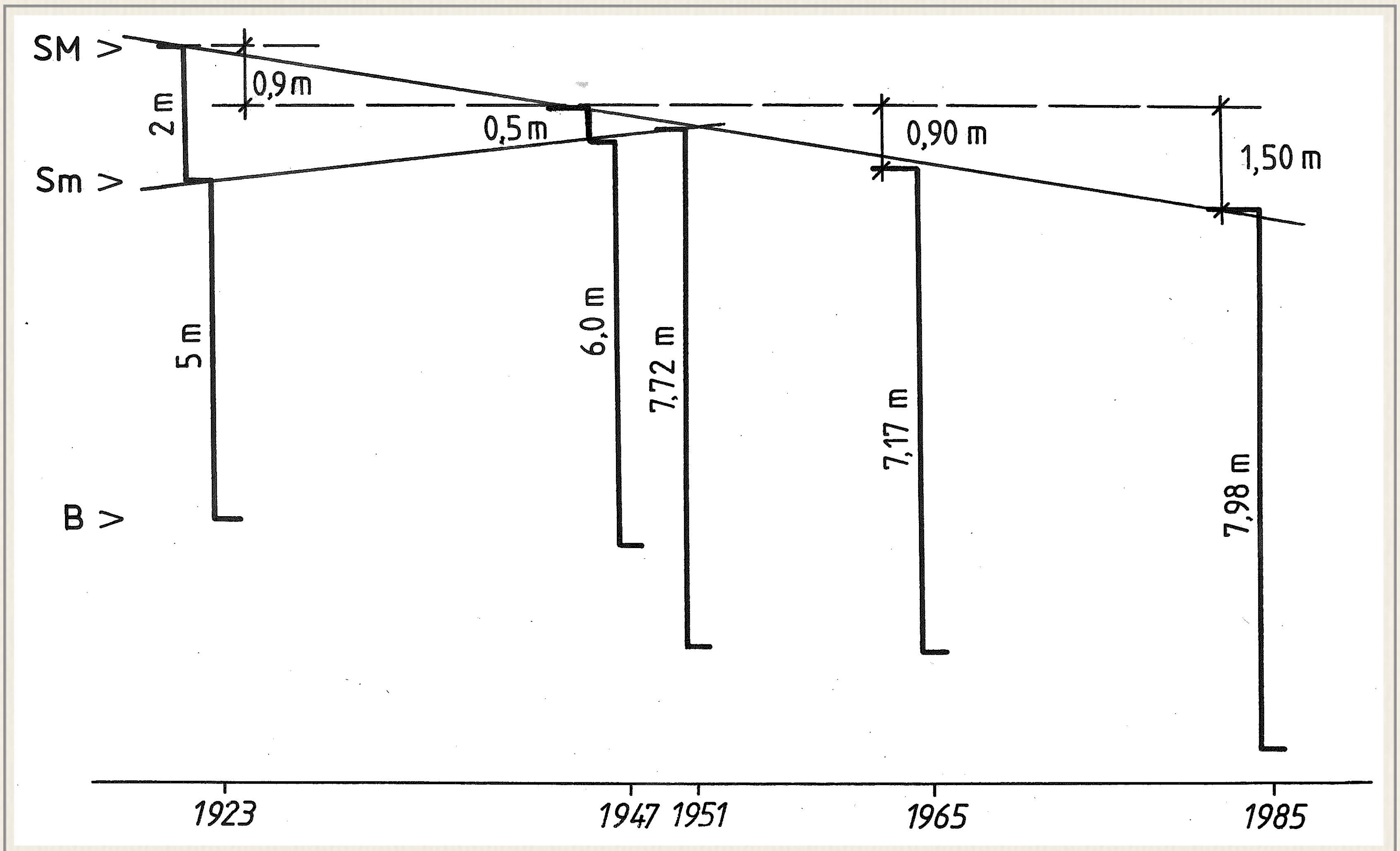

Fig. 45. – Diagram of level variations of the upper part of the glacier between 1923 and 1985 in Sala Mare (GH), Sala Mică (LH) and „Biserica" (C).

Such an obvious correlation between the long-term fluctuations of the temperature outside the cave and of the ice floor in Sala Mare proves that the various lowering rates of the ice floor level are caused by an important change in the meteorological context. In addition, it represents a new and remarkable expression of the fact that the long-term dynamics of the ice floor and of speleothems is mainly determined by the external influences over the cave topoclimate.

The palaeoclimatic information stored in the glacier

The glacier is in effect a peculiar paleoclimatic document, with all data yet gathered proving that its structure owes to the influence of the outside weather conditions. Thus, Scărișoara Glacier Cave preserves a stratigraphic section nearly 20 m high containing a record of the climatic conditions for at least three millennia.

Deciphering this information is extremely important, because it allows the reconstruction of the main events that occurred in the evolution of the regional climate and the formation of a long-term climatic prognosis, valid (at least) for the Apuseni Mountains. However, constructing a global model relating stratigraphic elements to climatic parameters is extremely difficult because such a model implies the intervention of numerous factors and complex interrelations.

First, the elementary stratigraphic unit, consisting of an ice layer and an impurity layer, does not always correspond to an entire year. Repeated observations have shown that during some winters, there are certain areas on the floor of Sala Mare where there is not an impurity layer under the new ice layer, but liquid water which forms a distinct ice layer when frozen, meaning that the possibility exists for several new ice layers to form during a single winter (Șerban et al., 1948).

Second, the primary stratigraphic succession is frequently altered by the presence of the distinct impurity layers, which formed in warmer periods when summer melting affects a whole set of layers. Therefore, it is really impossible to establish even an approximate number of primary layers forming such a set.

Third, the water forming the ice layers results from both percolation and partial ice melting, each possible origin causing variations in the isotopic composition of the ice. Interpreting such variations requires prior knowledge of the amount of each type of water, a parameter, which is far from constant. To this associates the variable effect induced by sublimation and volatilization on the isotopic content of the ice (Șerban et al., 1967).

Fourth, the statistical analysis of temperature data gathered in the winter reveals that the relation between the outside temperature and the cold meroclimate temperature is not linear, but parabolic. Moreover, this relation varies to a larger extent as the external temperature rises; thus, the underground temperature most favorable for ice formation may be related to temperature values ranging over several degrees (Racoviță, 1972).

The strongest impediment remains the fact that the most important stratigraphic sequence for the reconstruction of the palaeoclimate was lost by the lowering of the ice floor in Sala Mare between 1920 and 1980. Indeed, it is likely that almost 2.5 m of ice that disappeared during these six decades, including the layers formed while meteorological stations were recording complete data sets; thus, the possibility of establishing a direct correlation between stratigraphic elements and climate variations was seriously diminished. However, we cannot be certain of this. On the southern wall of Sala Mare there is a perfectly horizontal line below which the limestone color has a darker nuance and which was 383 cm above the ice floor in March, 1968. This line can only correspond to the top level of the glacier at the zenith of underground glaciation. But as we do not have any way to date this event, there is no possibility for an exact measurement corresponding to each stratigraphic sequence. This does not mean each sequence cannot be dated. The useful elements we have are the distinct impurity layers and periodic features that can be traced in the stratigraphic succession (Șerban & Racoviță, 1987; Racoviță & Șerban, 1990).

The first attempt to discern palaeoclimatic information from the glacier was done by Șerban et al. (1948). Examining the ice stratification visible in the entire natural section formed in the northern flank of the block, they noted three large layer sets, separated by thickness and colors of the impurity layers. The lower and upper sets comprise thinner and scarcer layers, composed of a clayey yellowish material and without coarse-grained elements. The median set contains visibly thicker and closer layers, with black earthy impurities and is very rich in vegetal remains (leaves, pine cones, branches, and even fragments of tree trunks). These substantial differences suggest that the upper and lower sets formed in colder, drier periods, while the median set corresponds to a significantly warmer and wetter period. The total thickness of the three layers is approximately the same in the entire glacier, and the pollen analysis (Pop & Ciobanu, 1950) showed that the ice layer at the base of the block is 3,000 years old. Therefore, each layer set corresponds to an interval of approximately 1,000 years. On this basis, Șerban et al. (1967) advanced the hypothesis that the median set formed at the same time with the Hystrian transgression of the Black Sea (Bleahu, 1963), that is, in the first millennium A.D.

More detailed studies were performed on two ice cores taken from the ice floor of Sala Mare in July, 1947, and September, 1960, the first 109.5 cm long and the second 42 cm long. The sampling times were separated by a 13-year interval, but the two cores were still considered a unitary stratigraphic sequence. The reconstruction based on micro-stratigraphic analysis led to the conclusion that this sequence represents the last 250 years prior to sampling and that, between approximately 1810 and 1850, the climate was marked by a rather strong cooling (Șerban et al., 1967). The same authors analyzed deuterium and ^{18}O ratios in a succession of 23 ice layers in the second core. Expressed in γd units (0.000001 g/ml) and with a somewhat large error when compared to absolute values (± 0.3 γd), the results were rather modest. They merely showed the existence of some variations in the isotopic composition of various layers with a certain periodicity of the minimal values (Fig. 46). However, these were too small to allow any paleoclimatic conclusions.

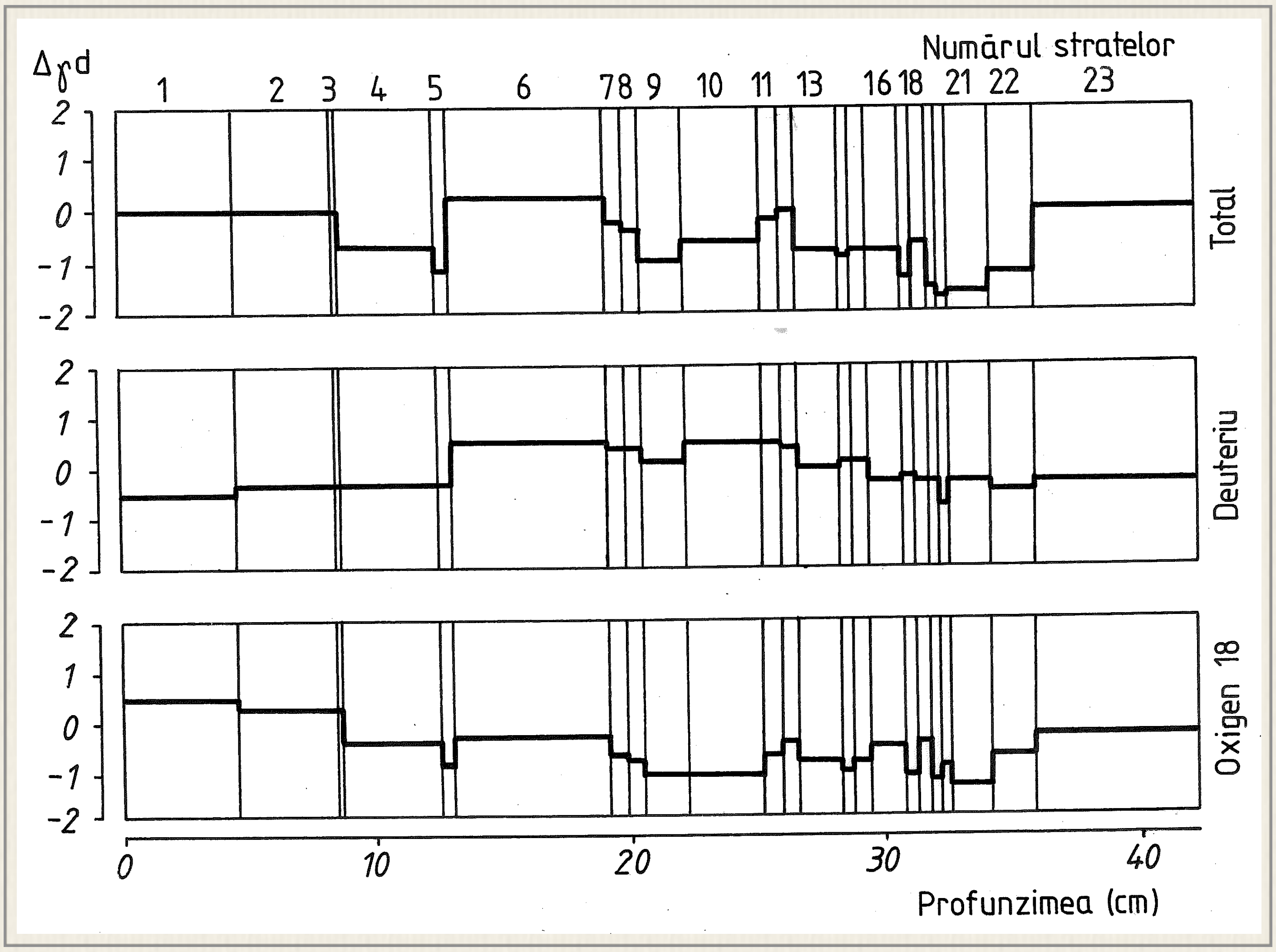

Fig. 46. – Variation of the isotopic composition of the ice layer succession in the core sampled in 1960 (after Şerban et al., 1967).

Racoviță (1972) also tentatively correlated the stratigraphic elements in the two cores with climate oscillations. His study was based in part on the marks of the main impurity layers and in part on the so-called *temperature coefficient*, defined as a synthetic expression of the meteorological peculiarities of each winter. This coefficient is deduced from the combination of other two parameters, called *average coefficient* and *intensity coefficient*. The first is equivalent with the ratio between the average of all the winters and the standard error. The second reflects other characteristic meteorological elements: the number of very cold days (with temperatures lower than –10°C), the number of frosty days and of those without thaw, and the average of extreme minimal temperatures of the three winter months (December, January, and February). The temperature coefficient ranges from 0 (the toughest winter) to 100 (the mildest winter), with 50 being the coefficient of a normal winter.

Calculating this coefficient based on meteorological data recorded more or less continuously since 1757, and - before that date - on information taken from chronicles, Easton (1928) succeeded in classifying all the winters in the seven century interval between 1205 and 1916. However, as the values established by Easton are valid only for the climatic province of Western Europe, they cannot be used as is for Romania.

To overcome this inconvenience, a linear correlation between the temperature coefficient and the average temperatures of each winter between 1852 and 1916, the period for which there are registered thermometric data in Romania, was first established. This correlation is statistically significant at a 99% confidence level, which allows the temperature coefficient to be estimated from monthly average temperatures. Applying this linear function to temperature data furnished by the Cluj, Sibiu, and Bucharest stations occasionally results in temperature coefficients which have negative values surpassing Easton's scale. For this reason, it is necessary to also calculate a continentality coefficient, that is, a parameter to indicate the degree to which the severity of a winter is more pronounced in a climate with a continental character, as in Romania. Given that the average temperature of a normal winter is equal to the average temperature of winters from the whole interval considered, which is completely justified statistically, the continentality coefficient is given by the difference between the temperature coefficient of a normal winter (50) and the coefficient which, according to the equation of the regression line, corresponds to the arithmetic mean of winter temperatures recorded in Romania.

Mathematically, the algorithm leading to the continentality coefficient is expressed as:

– the equation of the regression line:

$$C_t = 10\,t + 15,$$

where C_t is the temperature coefficient and t the average temperature of winters in Western Europe;

– the general mean of winter temperatures in Romania: –2.1°C;

– the temperature coefficient corresponding to this value:

$$C_t = 10 \cdot (-2.1) + 15 = -6;$$

– the continentality coefficient:

$$C_c = 50 - (-6) = 56.$$

Comparing the two sets of temperature coefficients, that is, the values between 1852 and 1916 for Western Europe and Romania respectively, it may be seen that they do not indicate any major contradiction in the succession of winter types. In spite of the reserve initially expressed, Easton's data may be used in the reconstruction of the evolution of the climate in Romania for the entire 700-year interval represented.

As the values of the temperature coefficient are very heterogeneous, warming or cooling tendencies in the climate were highlighted through the statistical method of running average, which consists in replacing each value in the chronologic series with the arithmetic mean of a group of values (11 in this case), in which the respective value occupies the central position. Finally, the adjusted curve of the temperature coefficient variation may be compared to the stratigraphic structure of the two ice cores sampled from the Sala Mare ice floor.

The most significant indicators for correlation of the stratigraphic elements with climate oscillations are the distinct impurity layers and the positive oscillations of the temperature coefficient corresponding to warm periods. The core sampled in 1947 contains two thicker impurity layers, one of which is in the median zone and one of which at its base; the core extracted in 1960 also has two thick impurity layers, but the first is located at the top (Fig. 47A). This surficial layer clearly resulted from the melting that has led to the progressive lowering of the Sala Mare floor since 1947. It must therefore be associated with the first positive oscillation which appears in the graph of the temperature coefficients (Fig. 47B) and whose zenith occurred in 1955. Because the floor's lowering resulted in the removal of a 90 cm thick ice layer through 1965 (Fig. 44), it is obvious that most of the structure observed in the 1947 core is missing from the 1960 core. Chronologically, the second distinct impurity layer is therefore not the one from this latter core, but rather the first in the 1947 core; it may correspond to the warm period culminating in 1920. The third impurity layer must be common to both cores, because the lower layers in their structure could not form except in the only warm period immediately following, which took place at the beginning of the eighteenth century, with a maximum in 1705.

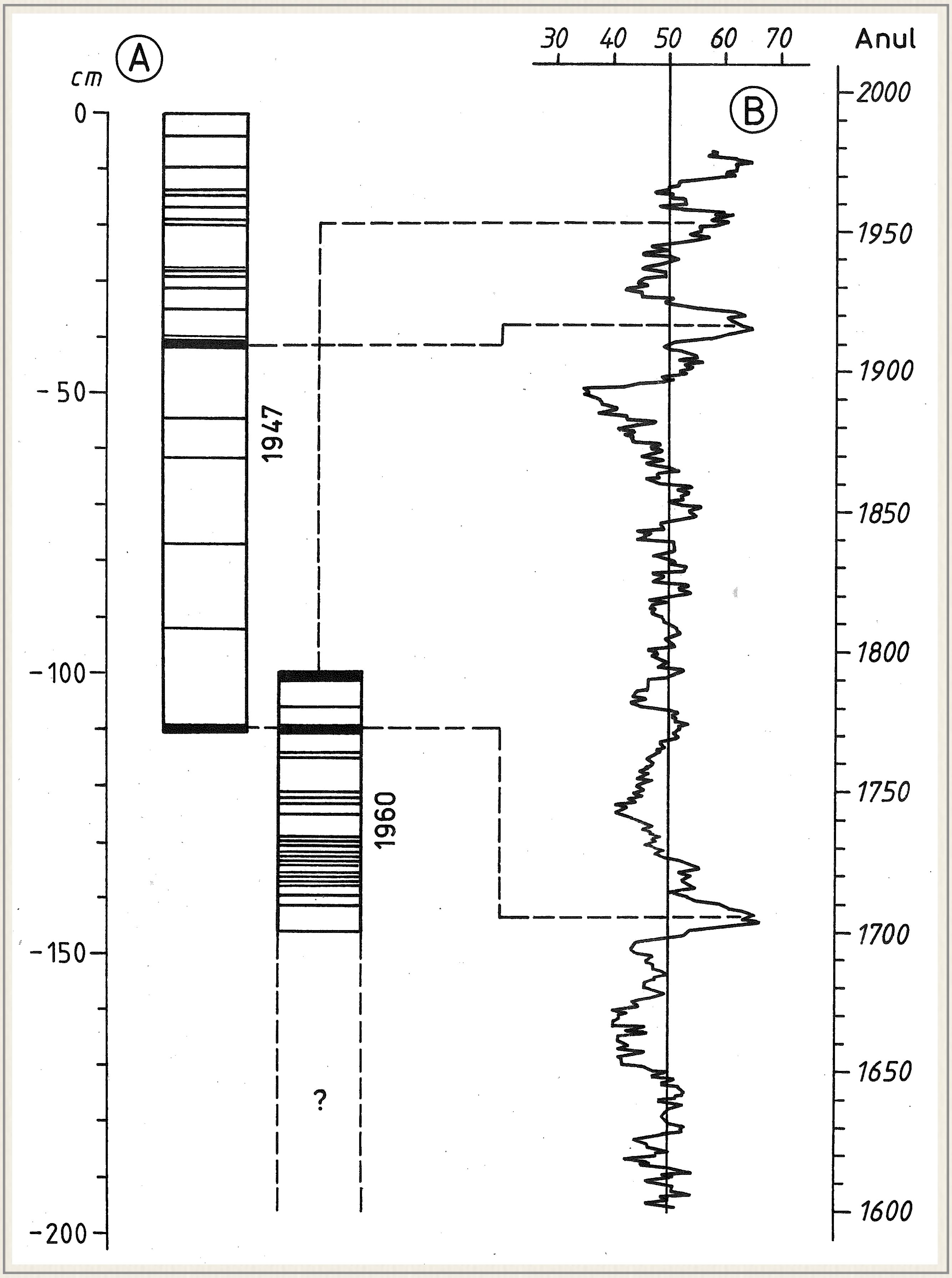

Fig. 47. – Correlation of the main impurity layers in the ice cores sampled in 1947 and 1960 (A) with the warming periods emphasized by the adjusted curve of the temperature coefficient variation (B) (Details in the text).

The same correlation of the core structures with climate oscillations show that the thick ice layers in the 1947 core were formed during the cold period which extended practically without interruption over the 18th and 19th centuries and which largely corresponds to the The "Little Ice Age" defined by American climatologists (Matthes, 1942).

Even if the current results are not entirely conclusive, they attest to the importance of the inherent value of the palaeoclimatic information in the stratigraphy of the Scărișoara Glacier. To realize that value, it is absolutely necessary to perform the most complex analyses possible, on cores sampled in different locations and on the entire thickness of the ice block, so the stratigraphic profile be studied in its entirety and in every aspect.

8

Carbonate speleothems

Mineralogy and morphology of speleothems

Summarized below is the basic mechanism of calcite deposition, which forms the various speleothems. The primary driving force behind this mechanism is the concentration (partial pressure) of carbon dioxide (CO_2) in water. The partial pressure of CO_2 increases as water travels from the atmosphere through the soil. Meteoric water is slightly acidified by atmospheric CO_2, however, the primary source of CO_2 is the decaying organic matter in soil. In this soil zone, the water usually acquires a partial pressure of CO_2 exceeding that of the cave atmosphere. The source of calcite is limestone dissolved at the soil/bedrock contact by CO_2 – enriched waters. As the water enters the cave, degassing of CO_2 occurs, causing the water to become supersaturated with calcite or aragonite. In turn, deposition occurs, precipitating calcite or aragonite in the form of various speleothems.

In Scărișoara Glacier Cave, the carbonate minerals calcite, aragonite, monohydrocalcite, and hydromagnesite are deposited as various speleothems from dripping, seeping, and pooling water. Calcite composes the majority of the speleothems. The other three carbonate minerals occurred only in one or a maximum of two types of speleothems.

Scărișoara Glacier Cave contains a variety of calcite speleothems. Many of these decorate the passages and chambers located within the warm mero-climate zone of the cave. These include calcite clusterites, cave pearls cor-raloids, rimstone dams (gours), draperies (with or without odontolithes), rafts, stalactites, stalagmites, columns, boxwork, and impressive flowstones.

Among these, cave pearls are the more outstanding, due to their unusual mechanism of formation (Viehmann, 1959, 1963, and 1967). Viehmann postulated that freezing of percolating water caused the separation of dissolved substances (calcite) in a cryptocrystalline form (lublinite). As the process continues, these cryptocrystals develop into micropearls.

The role of freezing in the formation of micropearls was confirmed when ice-wedges were found penetrating micropearl layers in Măgura Cave (Sighiștel Valley) (Viehmann, 1967). This suggests periglacial conditions within the cave, indicating severe ground cooling, exactly like the environment around the ice block.

If dripping water is also available, micropearls will develop further into classical cave pearls whose appearance varies with the shape of the nucleus fragment.

Viehmann (1963) has found and described the so-called *cave pearls conglomerate* in a few locations within the Rezervația Mare. This conglomerate formed when hundreds of cave pearls were welded together by calcitic cement. An explanation for the formation of this particular speleothem variety is interruption in the supply of dripping water. At a certain stage in the evolution of the cave pearls, the water dripping into the pool ceases, allowing cementation to take place slowly.

Aragonite is the second most common carbonate cave mineral after calcite. However, in the Scărișoara Cave it is not well represented, only being found in some stalactites, clusterites, and cave pearls (Bădău, 1984; Bodolea, 1992). In all of these occurrences, aragonite was identified by thin section examination using a polarizing microscope.

Aragonite and calcite coexist as alternating layers in most of the speleothems analyzed. All these samples exhibit pseudomorphism of calcite after aragonite (the initial internal structure was changed while the external form was preserved).

Patches of micron or millimeter-thick coatings, composed of white, finely crystalline material, were found covering the walls in a few of the sectors within the Rezervația Mică. X-ray diffraction and thin section examination showed these crusts to be composed of *monohydrocalcite*. Under a polarizing microscope, monohydrocalcite exhibits second to third order interference colors and moderate birefringence. In addition, when the crusts were stained with alizarid red-S (Friedman, 1959), the dark red color (a darker shade than that obtained when staining calcite or aragonite) confirmed the presence of monohydrocalcite.

Crusts composed of monohydrocalcite can only be found in a particular area of the periglacial sector of the cave where the temperature ranges from 0.3 and 3°C. In this area, monhydrocalcite occurs in the vicinity where small water droplets hit the ice stalagmite heads, ejecting onto the walls, forming a fine mist (aerosol) environment. Although no water chemistry data is available for this cave passage, the appearance of hydromagnesite and monohydrocalcite speleothems deposited in the same area indicates the likely presence of magnesium-rich solutions.

Worldwide, monohydrocalcite has been documented in relatively few caves (Hill & Forti, 1997). In Romania, it has been reported in only two caves (Humpleu and Lucia Mică), being identified in the composition of moonmilk (Onac & Ghergari, 1993).

The only explanation we have found for the presence of monohydrocalcite in Scărișoara Cave is the one proposed by Fischbeck & Müller (1971) and Fischbeck (1976). They assumed the following conditions for precipitation of monohydrocalcite: Mg/Ca ratio in solution higher then 1, solution temperature be lower than 20°C, and the presence of aerosols. All these conditions are met in Scărișoara Cave.

In "Palatul Sânzienelor" (upper part of the Rezervația Mică), patches of white mats of an earthy pasty mass (moonmilk-like speleothems) were collected from a side passage. The average size of these patches is about 1.5 cm. X-ray diffraction analysis of the samples revealed the presence of *hydromagnesite*.

Hydromagnesite is a common carbonate cave mineral, and its presence is not a surprise. However, currently it is the only magnesium carbonate mineral found in Scărișoara Glacier. We believe hydromagnesite was precipitated from magnesium-rich percolating solutions due to the degassing of carbon dioxide in passages located above the periglacial meroclimate zone.

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In addition to the minerals presented above, two other non-carbonate cave minerals were found in Scărișoara Glacier Cave. These are the phosphate minerals *hydroxylapatite* and *carbonate-hydroxylapatite* (dahllite). Both have been identified by means of X-ray diffraction analysis. Some of the diffraction patterns were tentatively ascribed to "crandalite", but as of yet the presence of this mineral is still uncertain (T. Tămaș, pers. comm.).

Hydroxylapatite and carbonate-hydroxylapatite were found in the lower part of Rezervația Mică. They form millimeter-size, gray to black dusty earthy-masses that covers both calcite crusts and limestone blocks on the floor. These minerals were derived from the reaction of calcite with bat guano that occurs near the sampling site.

Uranium-series dating of speleothems

Caves represent a particular sedimentation environment well protected from the effects of sub-aerial weathering processes. Therefore, sediments accumulated in caves potentially can record past climatic and environment changes. Scărișoara Glacier has yielded valuable information on past climatic changes. It contains an ice block and, in addition, is a relic cave perched above the present-day erosional base level. Age dating of this ice block has given several important time intervals in the evolution of the cave. Scărișoara Cave plays an essential role in understanding the speleogenesis of the entire cave system as discussed in Chapter 5. Uranium series dating, ^{14}C dating of wood fragments, and pollen analysis all contribute to this end.

Speleothems provide a sensitive tool for studying past climatic changes. Their growth (deposition of calcite) coincides with relatively warm and humid episodes, while breaks in calcite deposition correspond to cool or dry phases. To study this process, eight speleothems (four stalagmites and four fragments of flowstone) were collected from "Catedrala", Rezervația Mare, and Rezervația Mică in Scărișoara Cave. These samples were cut into thirteen sub-samples and dated by means of uranium-series dating ($^{230}Th/^{234}U$) using both α-particle (Onac & Lauritzen, 1996) and thermal ionization mass-spectrometry (TIMS) techniques (Table 12).

The sample age can be determined by the activity ratio of ^{234}U to its decay product ^{230}Th, providing the speleothems contain no clay or other insoluble detritus. Clay and insoluble material are known to be carriers of detrital thorium. This ratio can be calculated using standard algorithms (Ivanovich & Harmon, 1992).

Table 12
U-series dating results of speleothems from Scărișoara Cave.

Sample	U (ppm)	$^{230}Th/^{234}U$	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	Age (ka)	Corrected age (ka)
SC-1a	0.023	0.358 ±0.042	2.382 ±0.216	18	46.01 (6.72/-6.4)	43.00 (7.11/-6.8)
SC-1c	0.044	0.384 ±0.036	2.02 ±0.146	72	50.41 (6.06/-5.79)	
SC-3 (a)	0.035	0.214 ±0.021	1.758 ±0.152	22	25.77 (2.93/-2.87)	
SC-3 (b)	0.029	0.216 ±0.019	1.749 ±0.147	57	24.82 (1.12/-1.08)	
SC-4 base	0.039	0.129 ±0.015	2.404 ±0.13	>1000	14.83 (1.87/-1.85)	
SC-4 top	0.033	0.094 ±0.018	2.958 ±0.235	>1000	10.69 (2.17/-2.13)	
SC-5 base	0.102	0.672 ±0.007	0.976 ±0.002	215	126.3 (0.89/-0.91)	
SC-5 top	0.108	0.65 ±0.006	1.001 ±0.001	850	105.2 (0.67/-0.63)	
SC-6 base	0.133	0.677 ±0.007	0.977 ±0.002	725	124.9 (0.78/-0.781)	
SC-6 top	0.109	0.579 ±0.003	0.91 ±0.003	749	96.4 (0.56/-0.055)	
SC-7	0.055	1.164 ±0.079	1.78 ±0.095	217	>350	
SC-8	0.085	1.032 ±0.049	1.299 ±0.072	>1000	>350	
SC-9	0.037	1.075 ±0.041	1.387 ±0.051	>1000	>350	

A sample (SC) was taken from a 15-cm thick layer of flowstone found under some breakdown blocks located at the edge of the ice stalagmite field. Sample SC consists of yellowish-brown, porous, microcrystalline calcite. Both sub-samples extracted off the speleothem (SC-1a and SC-1c) gave dates of ca. 43 ka (top) and 50 ka (base) but with large standard errors.

Sample SC-3 is a 77 cm tall stalagmite, collected close to the entrance in the Galeria Coman. The stalagmite consists of dense, medium to large crystalline, milky white, banded calcite laminae. The sample was located on top of some collapse breakdown blocks and was actively growing at the time of sampling. For dating, two sub-samples were taken from its bottom. The resultant dates for both samples are reliable and reasonably precise at ca. 26 ka.

Stalagmite SC-4 (25 cm in height) was collected from approximately the same position and under the same settings as sample SC-3. The speleothem showed a pattern of thin gray opaque horizons separated by thick white opaque layers. Signs of corrosion (small pores) are evident in its central part. The base and top of the stalagmite gave reliable ages of 14.8 ka and 10.7 ka, respectively.

Within the same area of "Catedrala" two other small stalagmites (up to 15 cm each) were sampled and analyzed by means of TIMS. These two samples, SC-5 and SC-6, produced dates of extreme precision, showing that they grew entirely during the isotope stage 5 (Riss-Würm or Eemian interglacial). Growth of SC-5 commenced prior to 126.3 ka and halted after 105.2 ka. The age of the base of SC-6 was 124.9 ka, whereas the top of this stalagmite gave an age of 96.4 ka. Based on these ages, the growth periods of the two speleothems can be placed within the sub-stages 5e and 5c, respectively.

Two fragments of flowstone (SC-7, 8) were detached from the upper part of Rezervația Mică, and another (SC-9) from a small side passage within Rezervația Mare. The ages of all three samples were beyond the limit of the α-particle counting method (350 ka).

The results of the thirteen dates performed are shown in Table 12. Without exception all samples were low in uranium content, which was in part compensated for by using larger samples and prolonged counting times (when using the α-spectrometry method). The levels of detrital ^{230}Th contamination were acceptable, and only one date was corrected using $B_0 = 1.5$ in Schwarcz' (1980) equation. With all these precautions, some of the dates still have large analytical errors.

The most prominent paleoclimatic results obtained when analyzing the collective properties of the dates are:

- an active speleothem growth period sometime beyond 350 ka;
- the evidence for a gradual shift towards cooler or/and drier climate during sub-stages 5d and 5b when stalagmites SC-5 and SC-6 ceased their growth;
- the continuous growth of speleothems through the isotope stages 2 (Würm III or Late Weichselian) when the ice sheet was only 500 km away from Apuseni Mountains (Bowen, 1992). This confirms that this area of the Bihor Mountains was neither covered by alpine glaciers nor experienced enough severe permafrost conditions to suppress water percolation and hence speleothem growth.

The ages of the oldest two stalagmites that were found on top of the limestone breakdown, as well as those of the three flowstone fragments, dated to more than 350 ka. From these dates, it was estimated that Scărișoara Glacier Cave was formed during the Middle or even Lower Pleistocene period.

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Fossil trees and/or fragments of wood that may have been washed into the cave by stream flow or simply fell into the cave entrance are now trapped at different levels within the ice block. A piece of this wood was extracted from the middle part of the block in Rezervația Mică and dated by the conventional ^{14}C radiocarbon method.

The exact location of the sample, according to the stratigraphy of the ice block presented by Șerban et al. (1967), would be in the upper part of the median strata. These strata host a thick layer of impurities (10 m below the floor of Sala Mare). Dating of pollen grains provided additional clues to the climatic changes in the Scărișoara Cave. Along the base of the northern flank of the ice block, pollen analysis was performed on a 7.6-m long profile. The analysis showed that the lower part of the ice deposit was formed about 3,000 years ago, in the Postglacial Beech phase, during which the climate was colder and moister than in present time (Pop & Ciobanu, 1950). However, there are arguments that suggest the age of the ice block must be even greater (Șerban et al., 1967; Rusu et al., 1970). The true base of the ice is at least 5 m lower than the lowest limit of the analyzed profile. Since this thickness represents a third of the 15 m height of the northern flank of the block and assuming a linear growth of the ice, the age of the first ice layers could be as old as 4,000 years.

Assuming the age obtained from pollen analysis is accurate for the bottom of the ice block, the ^{14}C age of 1,110 ± 70 BP* obtained on the wood sample seems reasonable. This ^{14}C age is in good agreement with the stratigraphy and the general evolution trend of the ice block (Șerban et al., 1967). This preliminary date, while requiring support with further dating, does take into account a constant ice accumulation predicted through the saturation curve (the middle part of it) (Fig. 38). The constant accumulation rate held until the maximum volume of ice in the cave was reached.

* *The date was performed in the ^{14}C Laboratory of the Catholic University of Louvain, Belgium.*

9

Cave fauna

Apart from its exceptional glaciologic and paleoclimatic value, Scărișoara Glacier Cave is very important from a biospeleologic standpoint, because the cold meroclimate in most of the cave determines limited existence conditions. From this reason, the fact that it is populated by certain species of arthropods was interpreted as one of the most eloquent examples of the capacities of troglobiont animals to live in extreme thermal conditions (Vandel, 1964).

The most significant faunistic feature of the Scărișoara Glacier Cave is the severe biotope selection, which decided the structure of the terrestrial biocenosis. According to the present knowledge, it includes a restrained number of troglophile and troglobiont species, belonging to only three taxonomic groups: araneids (*Nesticus racovitzai* and *Troglohyphantes racovitzai*), springtails (*Oncopodura crassicornis*, *Onychiurus* spp., and *Tomocerus minor*) and Leptodirinae coleoptera (*Pholeuon* (s. str.) *proserpinae glaciale*). The first two groups are scarce, the biocenosis being dominated by coleopteres, the only ones forming large cave populations (Racoviță, 2000).

Ph. p. glaciale was firstly described from Scărișoara Glacier Cave (Jeannel, 1923). When it was found, the cave was not completely explored, so it could only be observed in the „Biserică", moving really slow on the limestone walls, rarely on the ice and there only during autumn, when air temperature slightly surpassed 0°C (Jeannel & Racoviță, 1929). Lacking any information concerning the effects of the winter on the biology of these insects, E. Racoviță (1927) only noted that, as long as they are not permanent, low temperatures do not prevent cave colonization. More categorical in his appreciation, Jeannel (1943) stated that the whole coleopteran life cycle must occur at a temperature of no more than 1°C.

The observations made after the discovery of the deeper halls proved that the normal insect habitat are calcitic sectors, where air temperature is positive for the whole year, and their presence in the frozen areas is only accidental. In fact, *Ph. p. glaciale* was never found again in the „Biserica" (Racoviță, 1969), most likely due to the increased tourist circulation in the last decades. Moreover, it was experimentally established that its optimal life temperature is 4.5°C (Șerban, pers. comm., 1968), comparable to the temperature of its normal natural environment. Therefore, there is no reason considering these insects are especially adapted to low temperatures.

The dynamics of cave coleopteran population

This conclusion was confirmed by a long-term demographic study between 1963 and 1968, the data gathered allowing a further identification of control factors of the cave population sizes (Racoviță, 1980). This study had in view the tracing of the number fluctuations shown by local populations in various speleic habitats, or „the groups of individuals", as stated by Delay (1975). It was done by the method of Cabidoche (1968), consisting in monthly estimates of the number of individuals concentrated around two long-term baits placed in „numbering stations". Two such stations were emplaced in the cave: the first in the periglacial sector of the Rezervația Mică, in a niche on the eastern side of the room, and the second in the calcitic sector of the Rezervația Mare, at the entrance in Coman Gallery.

As expected, the different thermal conditions in these two sectors of the cave determine significant specificities in the dynamics of the local populations.

At station I, the number of individuals varies with the air temperature. Very soon after the temperature rises above the critical 0°C value, the number of coleoptera grows progressively to summer maximum, but in autumn the population decreases and disappears entirely when the temperature gets below that value (Fig. 48). The dynamics of the local populations in the periglacial sector of the Rezervația Mică, as expressed synthetically by the curve of the monthly average number of individuals (Fig. 49), has therefore a clear seasonal character, with a summer phase of presence and a winter phase of absence of the coleopteres, which come regularly in term each annual cycle. Hence it results that, in conditions typical for periglacial meroclimate, the local population size is determined by the air temperature, that is, by a physical factor.

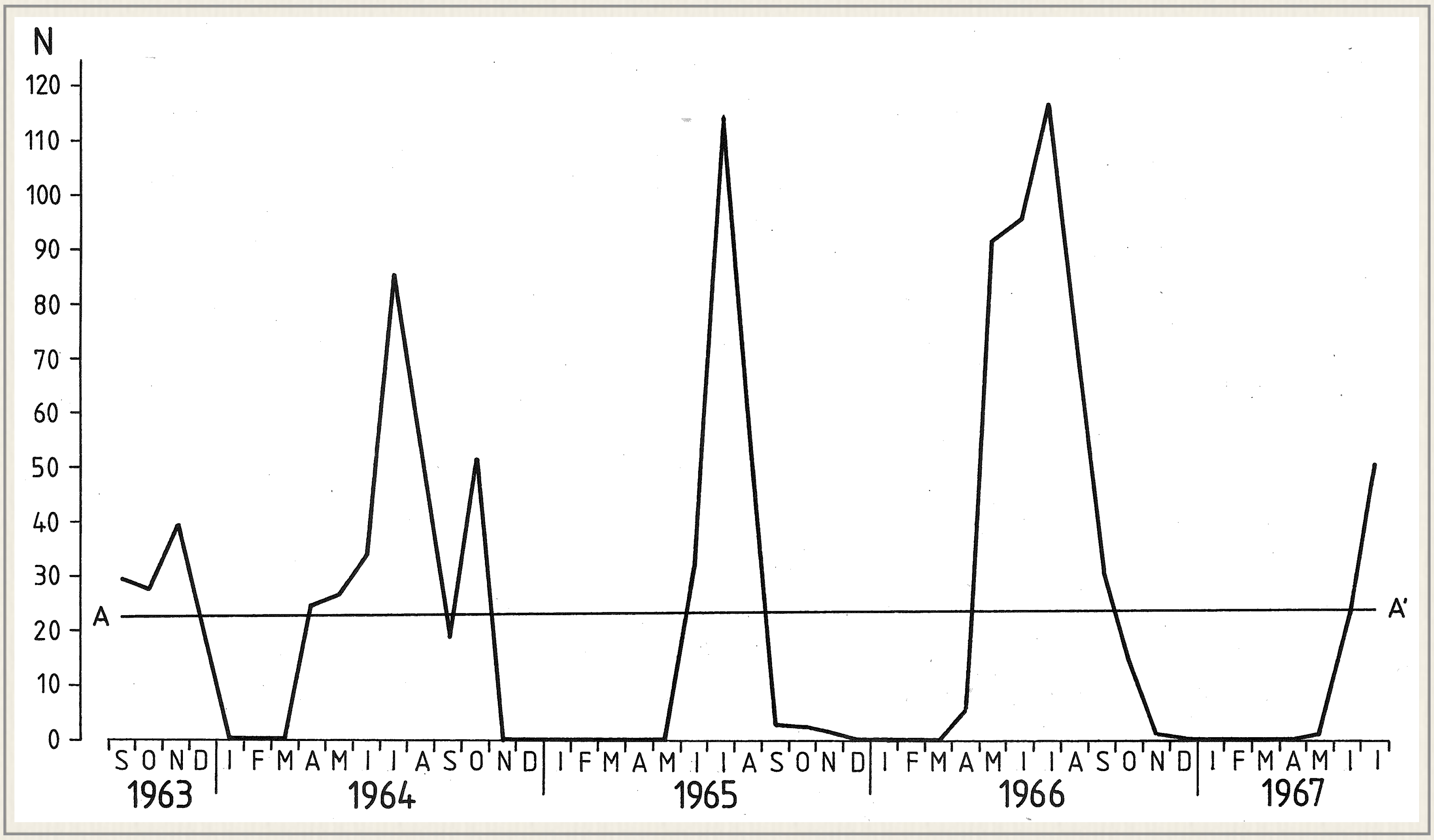

Fig. 48. – Variations in the number of Pholeuon proserpinae glaciale individuals in Rezervaţia Mică (Station I). A-A' = regression line.

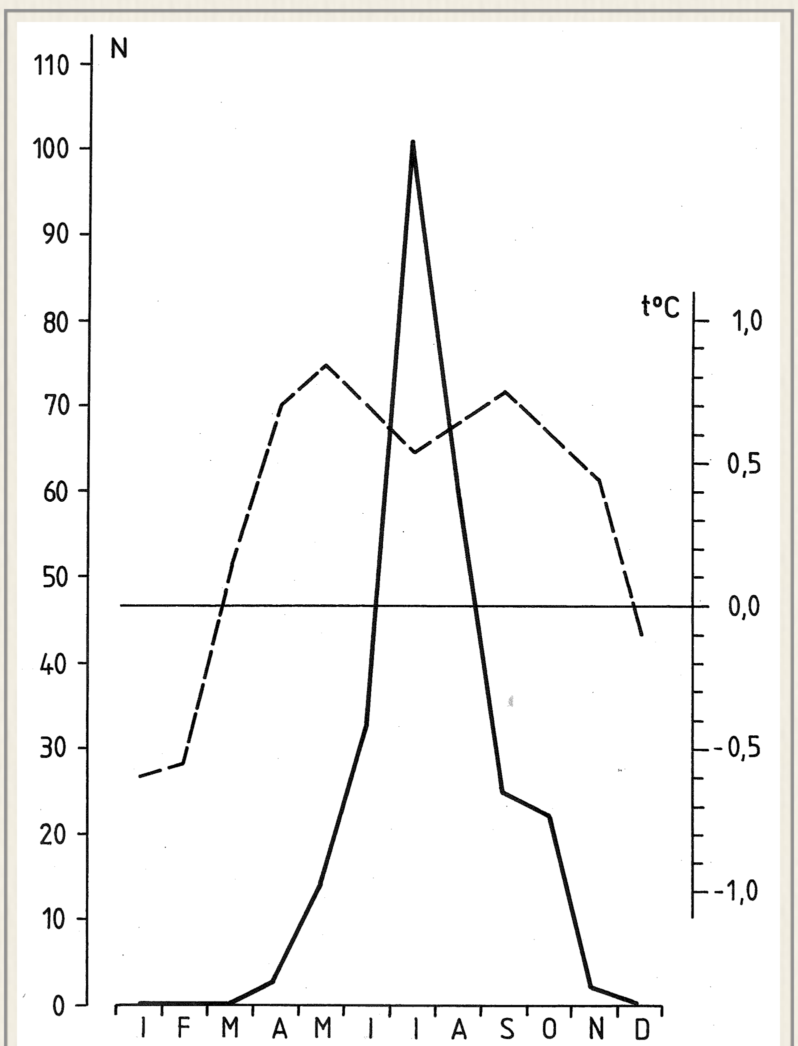

Fig. 49. – Mean monthly values of coleoptera numbers (continuous line) and of air temperature (dotted line) in Rezervaţia Mică.

At station II, the number fluctuations are completely different. The main difference is that the seasonal periodicity is less evident, being replaced by alternative increases and decreases of the number of individuals. The evidence of annual cycle is a strong number reduction during autumn (Fig. 50).

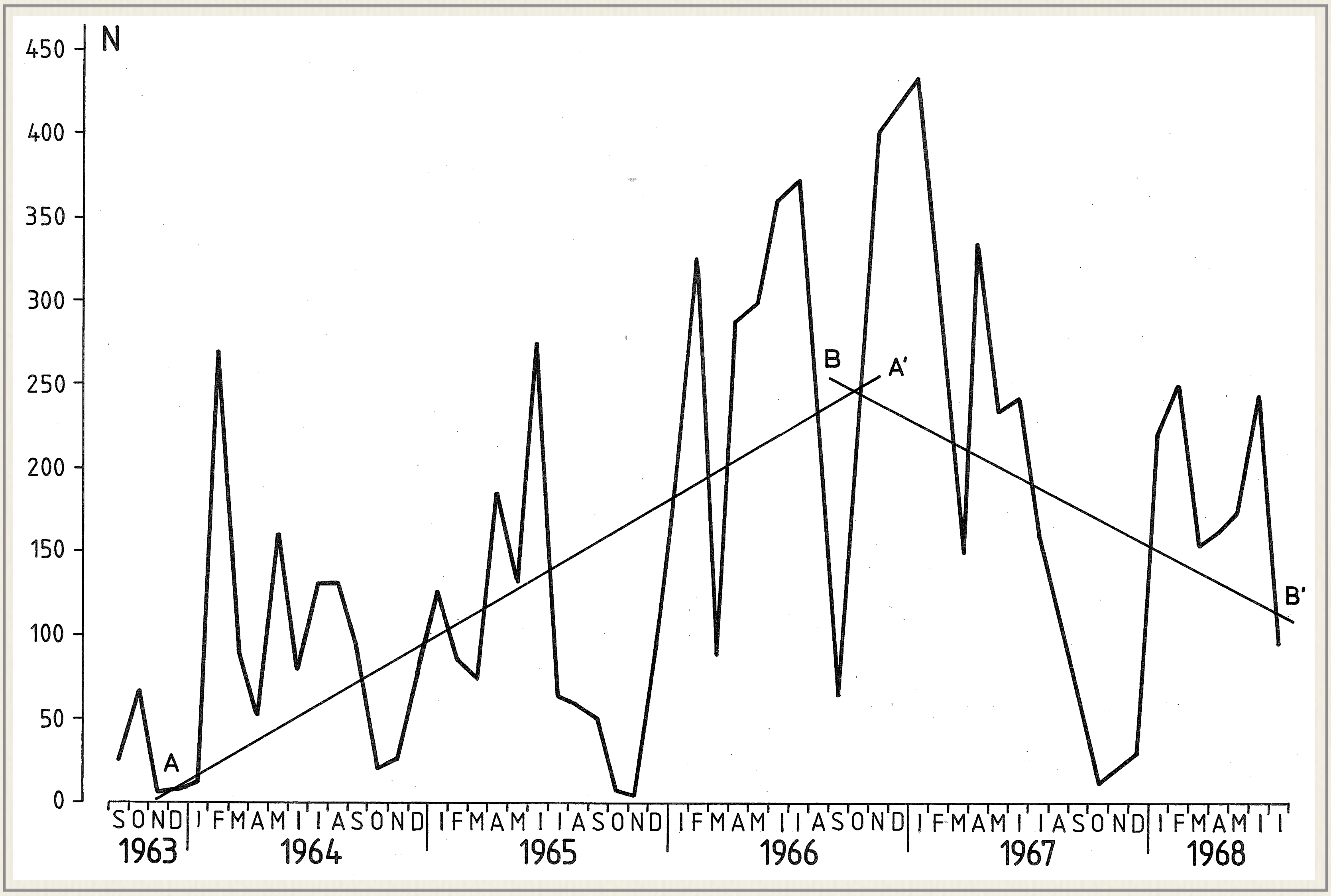

Fig. 50. – Variations in the number of Pholeuon proserpinae glaciale individuals in Galeria Coman (Station II). A-A' and B-B' = regression lines.

The factors influencing such apparently heterogeneous fluctuations may be easily identified if one considers the monthly average numbers of individuals (Fig. 51). Their variation shows that, besides the diminishing of the number of individuals in October and November, the population size presents clearly alternative oscillations, succeeding from January to July. The annual cycle also comprises two phases, but, as these no more correspond to the seasonal variations of air temperature, they are likely to have other cause.

The of saw-shaped curve, which is characteristic to the first of the two phases, suggests the possibility that the size of the local population during this time of the year is determined by a self- adjusting phenomenon, which may be controlled by biotic factors. According to MacArthur and Connel (1966), the

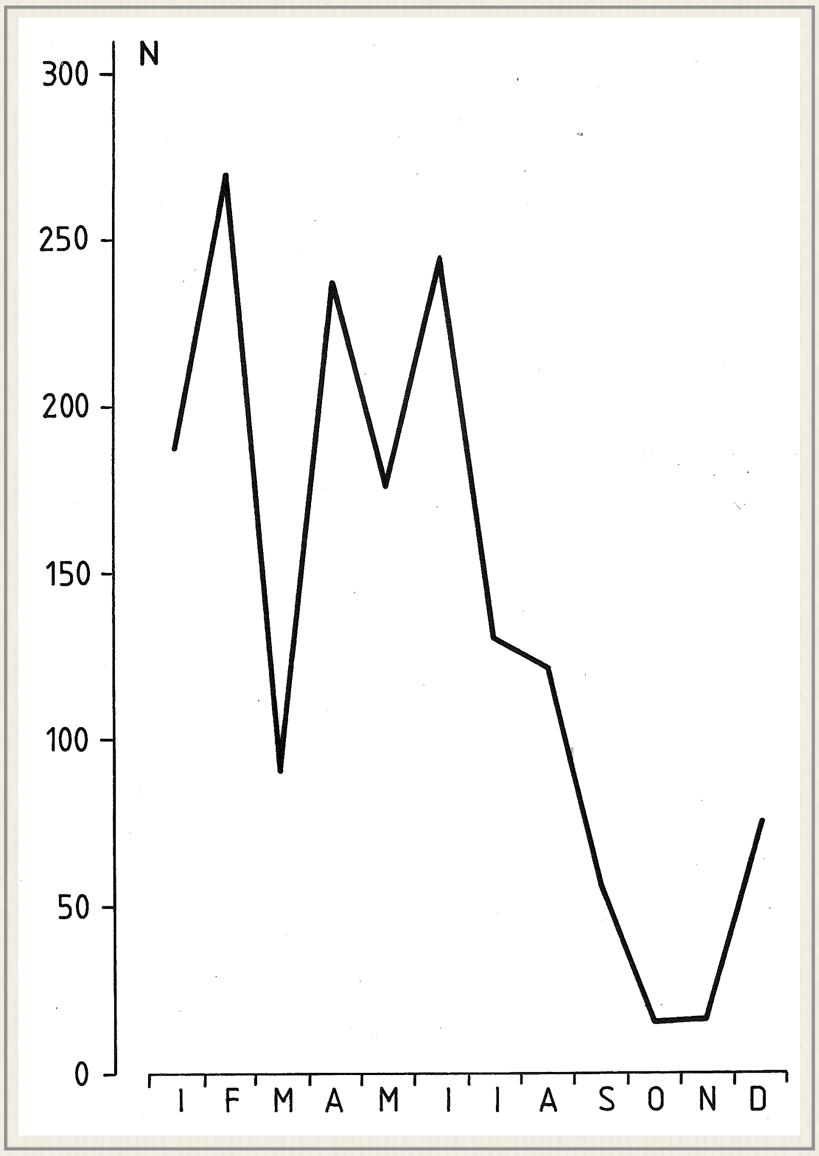

Fig. 51. – Mean monthly values of coleoptera numbers in Galeria Coman (mean values on the ordinate).

hypothesis applies if a statistically significant linear correlation exist between the absolute numbers of individuals in any month and the relative increase or decrease which follows (relative numbers). Such a correlation exists and is defined by the equation:

$$\Delta N = -1.86\, N + 352 \qquad (59)$$

This equation can be used to construct the mathematical model of the natural phenomenon. The parameter which gives the model oscillations similar those in the empirical data is the absolute value of the regression coefficient, which is the tangent of the α angle between the regression line and the axis of the abscissa (Racoviță, 1973). In this case, the regression coefficient has values between 1 and 2 ($a = 1.86$) and α ranges between 45° and 63°. Therefore, the theoretical model involves oscillations with progressively smaller amplitudes, which asymptotically approach a stable value of the number of individuals. Comparison of the natural and theoretical values shows there are not significant differences (Fig. 52), the stable value of the population size obtained theoretically (N_m = 189) agreeing quite well with the actual data (Ñ = 186). Thus, when the meroclimate in Coman Gallery is stable, the coleopteran density is controlled in the first part of the annual cycle by self-adjusting of the number of individuals.

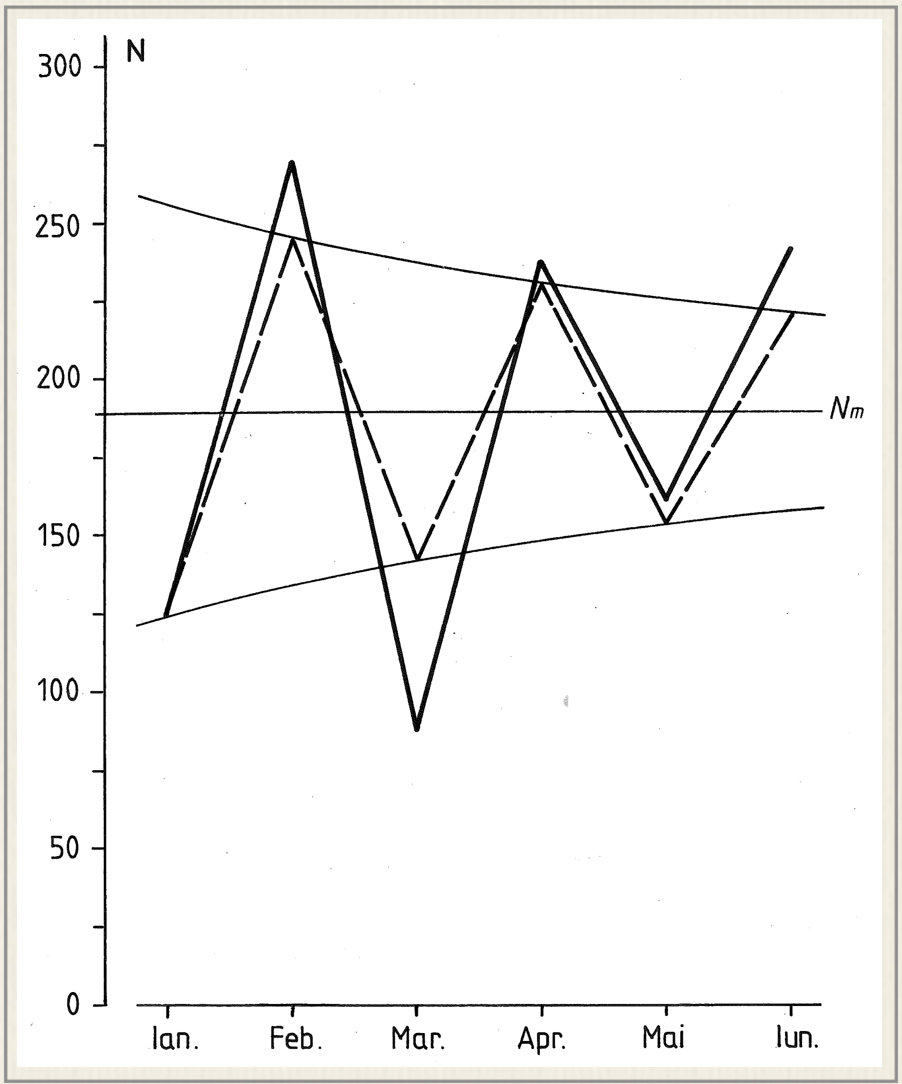

Fig. 52. – Comparative diagram between real numbers of individuals and the mathematical model of population size self-adjustment in the stability meroclimate. N_m = theoretical equilibrium value.

The reduction of the number of individuals during winter is most probably the result of seasonal reproductive reproductive maximum. This supposition is based on the observation that the decrease in the number of individuals is accompanied by a significant increase in the number of sexually immature adults in their first year after hatching. The proportion of immature adults represents 59% of the total in the age classes structure, while normal values are between 10 and 25% (Racoviță, 1970). If we accept the thesis of Jeannel (1943), according to which oviposition and larval development commonly occur in the fissure network of the limestone bedrock, it is normal that reaching the maximum of seasonal reproduction would lead to a selective decrease of the cave population and, implicitly a change in its age class structure, the dominant element being the sexually immature adults.

This ecological maximum, evident in the optimal conditions of the warm meroclimate in Rezervația Mare, may also be observed in the local population from the Rezervația Mică, although it is masked by the dominant influence of air temperature. The number of individuals decrease in Galeria Coman, long before the temperature drops below freezing; this means that the reproductive maximum occurs throughout the entire cave population simultaneously.

The different conditions from the two sectors of the cave influence the long-term trend of the local population size. In Rezervația Mică, the regression line of this trend is practically horizontal (Fig. 48, A-A'), meaning that the population size remains long-term constant. In Rezervația Mare, the population showed an obvious trend of increasing its number, which was maintained until the end of 1966 (Fig. 50, A-A') and became negative thereafter (Fig. 50, B-B'). This change is certainly the consequence of the fact that, monthly since 1967, 50% of the individuals concentrated in the counting stations were sampled to establish the population structure on sex and age classes. We conclude that, in normal conditions, the permanent presence of baits is a trophic stimulus determining an agglomeration of coleopterans in the cave, but this effect is cancelled when air temperature only allows a seasonal inhabitance.

A second demographic study undertaken between 1982 and 1986 but limited to the local population in Rezervația Mare led to the conclusion that for 20 years, no qualitative changes occurred in the dynamics of the coleopteran population along 20 years; the self-adjusting phase of the number of individuals and the autumn decrease in density still being its most characteristic features (Racoviță, 1987).

The fluctuations in the number of individuals recorded in the various habitats within the cave are controlled by the physical environment factors, especially by the air temperature in variable meroclimate conditions,especially air temperature in variable meroclimate conditions, and by kenotic factors – self-adjustment of density and ecological periodicity in the reproductive cycle – in stable meroclimatic conditions corresponding to the ecological optimum. Therefore, the dynamics of the *Pholeuon proserpinae glaciale* population in Scărișoara Glacier Cave fit to the model proposed by Dajoz (1974) for determining the size of natural populations.

As is now clearly established, all fluctuations in the number of individuals of the cave populations occur not as changes of the birth and mortality rates, but rather as alternative migrations of the insects between the cave and the fissure network (Delay, 1978; Racoviță, 1980). When the population size is controlled by physical factors, migration from the cave is determined by the alteration of life conditions, generally owing to the seasonal reversal of the subterranean circulation. If the population size is self-adjusted, alternative migrations are effective in keeping an optimal density both in caves and in the fissure network.

The fact that *Pholeuon proserpinae glaciale* lives in conditions at the limit of the ecological tolerance is of great importance. It rejects an idea dominating biospeleology for a long time, which states that caves act as refuges for species in their final evolution stages and have an adaptive potential so reduced they could not survive the great climate oscillations at the end of Triassic and at the beginning of Quaternary (Vandel, 1964). After the discovery of the subterranean superficial biotope (Juberthie et al., 1980), the existence of a dense coleopteran population in Scărișoara Glacier Cave suggested that the invasion of the underground domain is rather an active process, equivalent to the colonization of any free ecological niches. In this process are involved those species that have ecological affinities compatible with life conditions in caves by adaptation in transition environments (moss cover, humus, soil, and superficial subterranean biotope).

References

ANDRIEUX, C. (1970a) Contribution à l'étude du climat des cavités naturelles des massifs karstiques. II.– Aérodynamique souterraine. Ann. Spéléol., XXV (2): 491-529.

ANDRIEUX, C. (1970b) Contribution à l'étude du climat des cavités naturelles des massifs karstiques. III.– Evapo-condensation souterraine. Ann. Spéléol., XXV (3): 531-559.

ANDRIEUX, C. (1971) Contribution à l'étude du climat des cavités naturelles des massifs karstiques. V.– Les bilans climatiques. Ann. Spéléol., XXVI (2): 367-386.

ANDRIEUX, C. (1973) Etude du climat de la grotte du Pigailh (Ariège). Problèmes posés par le mécanisme des transferts thermiques. Ann. Spéléol., XXVIII (3): 361-374.

ANDRIEUX, C. (1974) Premiers résultats sur l'étude du climat de la salle des peintures de la galerie Clastre (Niaux – Ariège). Ann. Spéléol., XXIX (1): 3-26.

BALCH, E. S. (1900) Glacièrs or freezing Caverns. Allen, Lane & Scott, Philadelphia.

BALINTONI, I. (1997) Geotectonica terenurilor metamorfice din Romania. Editura Carpatica, Cluj-Napoca, 176 pp.

BĂDĂU, A. (1984) Remarques sur la structure microscopique de certaines perles de caverne. Theor. Appl. Karstol., 1: 51-57.

BLEAHU, M. (1963) Observații asupra evoluției zonei Histria în ultimele trei milenii. Probleme de Geografie, 9: 45-56.

BODOLEA, A. (1992) Mineralogy of speleothems in caves from Bihor Mountains. B. Sc. Thesis, "Babes-Bolyai" University, Cluj, 105 pp.

BORZA, AL. (1918) Gheţarul de la Scărişoara. Convorbiri ştiinţifice, Orăştie, An II, Nr. 8-9, 7 pp.
BUCUR, I. I., ONAC, B. P. (2000) New data concerning the age of the mesozoic limestone from Scărişoara (Bihor Mountains). Studia Univ. Babeş-Bolyai, Geologia, XLV (2): 13-20.
CABIDOCHE, M. (1968) Biocénose cavernicole de la Salle de la Verna (Gouffre de la Pierre Saint-Martin). Méthode d'étude en milieu naturel. Ann. Spéléol., 24 (1): 667-688.
CASTANY, G. (1967) Traité pratique des eaux souterraines. Dunot, Paris, 661 pp.
CHOPPY, J. (1982) Processus climatiques dans les vides souterrains. 1. Dynamique de l'air. Phénomènes karstiques, Spéléo-Club de Paris, 78 pp.
DAMM, P., LASCU, V., CIUBOTĂRESCU, C. (1999) Condiţionarea tectonică şi hidrogeologică a sistemelor hidrocarstice din Platoul Ocoale (Munţii Bihor). Speomond, 4: 14-18
DAVIS, W. M. (1930) Origin of limestone caverns. Geological Society of America Bulletin, 41: 475-628.
DECU, V., HERDLICKA, W., SUCIU, N. (1982) Mensuration indirecte de l'eau de condensation de deux grottes des Monts Mehedinţi (Carpates Méridionales). Implications écologiques de la condensation endokarstique. Trav. Inst. Spéol. „E. Racovitza", XXI: 43-52.
DAJOZ, R. (1974) Dynamique des populations. Masson, Paris, 301 pp.
DELAY, B. (1975) Etude quantitative de populations monospécifiques de coléoptères hypogés par la méthode des marquages et recaptures. Ann. Spéléol., 30 (1): 195-206.
DELAY, B. (1978) Milieu souterrain et ecophysiologie de la reproduction et du développement des coléoptères Bathysciinae hypogés. Mém. Biospéol., 5: 1-340.
DREVER J. I. (1997) The geochemistry of natural waters (3rd ed.), Prentice Hall, New Jersey, 436 pp.
EASTON, CH. (1928) Les hivers dans l'Europe occidentale. E. J. Brill, Leyde.
FISCHBECK, R. (1976) Mineralogie und Geochimie Carbonatischer Ablagerungen in Europäischen Höhlen, – ein Beotrag zur Bildung und Diagenese von Speleothemen. Neues Jahrbuch Miner. Abh., 126: 269-291.
FISCHBECK, R., MÜLLER, G. (1971) Monohydrocalcite, hydromagnesite, nesquehonite, dolomite, aragonite and calcite in speleothems of the Fränkische Schweiz, Western Germany. Contr. Mineral. and Petrol., 33: 87-92.

FORD, D. C. (1971) Geologic structure and a new explanation of limestone cavern genesis. Cave Res. Gp., G. B. Trans., 13 (2): 81-94.
FRENCH, H. M. (1996) The Periglacial Environment. Longman, Harlow, 2nd ed.
FRIEDMAN, G. M. (1959) Identification of carbonate minerals by staining methods. Jour. Sed. Petrology, 29 (1): 87-97.
GÈZE, B. (1953) La genèse des gouffres. I-er Congr. Intern. Spéléol., Paris, p. 11-23.
HILL, C. A., FORTI, P. (1997) Cave minerals of the world. National Speleological Society, Huntsville, Alabama, 463 pp., 2nd ed.
IANOVICI, V., BORCOȘ, M., BLEAHU, M., PATRULIUS, D., LUPU, M., DIMITRESCU, R., SAVU, H. (1976) Geologia Munților Apuseni. Editura Academiei R.S.R., București.
IVANOVICH, M., HARMON, R. S. (eds.) (1992) Uranium-series disequilibrium. Applications to Earth, Marine, and Environmental Sciences. Oxford University Press, Oxford, 910 pp., 2nd ed.
JEANNEL, R. (1923) Etude préliminaire des coléoptères aveugles du Bihor. Bull. Soc. Sc. Cluj, 1: 411-472
JEANNEL, R. (1943) Faune cavernicole des la France, avec une étude des conditions d'existence dans le domaine souterrain. P. Lechevallier, Paris, 334 pp.
JEANNEL, R., RACOVITZA, E. (1929) Enumération des grottes visitées, 1918-1927 (7e série). Arch. Zool. exp. gén., 68 (2): 293-608.
JUBERTHIE, C., DELAY, B., BOUILLON, M. (1980) Extension du milieu souterrain en zone non calcaire: description d'un nouveau milieu et de son peuplement par les coléoptères troglobies. Mém. Biospéol., 7: 77-93.
KYRLE, G. (1929) Beiträge zur Kenntins der Eiskeulen in Höhlen. Mitteilungen de Geograph. Gesellschaft in Wien, 72.
LOWE, J. J., WALKER, M. J. C. (1997) Reconstructing Quaternary Environments. Longman, Edinburgh, 446 pp., 2nd ed.
MACARTHUR, R. H., CONNEL, J. H. (1966) The biology of populations. New York, 230 pp.
MATTHES, F. E. (1942) Galciers. In: O. E. Meinzer (ed.), Hydrology. Dover Public., Inc., New York,:149-219.
ONAC, B. P. (2000) Mineralogical and uranium series dating studies in Scărișoara Glacier Cave (Bihor Mountains, Romania). Theor. Appl. Karstol., 13 (in press).

ONAC, B. P., GHERGARI, L. (1993) Moonmilk mineralogy in some Romanian and Norwegian caves. Cave Science, 20 (3): 107-111.
ONAC, B. P., LAURITZEN, S. E. (1996) The climate of the last 150,000 years recorded in speleothems: preliminary results from north-western Romania. Theor. Appl. Karstol., 9: 9-21.
ORĂȘEANU, I. (1996) Contributions to the hydrogeology of the karst areas of the Bihor-Vlădeasa Mountains (Romania). Theor. Appl. Karstol., 9: 185-214.
ORĂȘEANU, I. (2000) Contribuții la cunoașterea dinamicii sistemelor acvifere carstice din Munțiii Apuseni. Ph. D. Dissertation. University of Bucharest, 256 pp.
ORĂȘEANU, I., GAȘPAR, E., POP, I., TĂNASE, T. (1991) Tracers experiments in the karst area of Bihor Mountains (Romania). Theor. Appl. Karstol., 4: 159-172.
PETERS, K. F. (1861) Geologische und mineralogische Studien aus dem südöstilchen Ungarn, insbesondere aus der Umgegend von Rézbánya. Sitzung-Ber. Akad. Wiss. Wien, Math.– Naturwiss. Classe, 43, (1): 385-463.
POP, E., CIOBANU, I. (1950) Analize de polen în ghiața de la Scărișoara. Anal. Acad. Rom., Seria Geol., Geogr., Biol., III, (2): 23-52.
POP, M. (1947) Descoperirile de la Ghețarul de la Scărișoara. România, Revista Oficiului Național de Turism, București, 16: 14-16.
RACOVITZA, E. (1927) Observations sur la glacière naturelle dite „Ghețarul de la Scărișoara". Bull. Soc. Sci. Cluj, III: 75-108.
RACOVIȚĂ, G. (1967) Nouvelle contributions à l'étude du topoclimat de la grotte „Ghețarul de la Scărișoara". Ann. Spéléol., 22, (1): 757-786.
RACOVIȚĂ, G. (1969) Recherches sur l'écologie du Bathysciinae troglobionte Pholeuon proserpinae glaciale Jeann. 5 Int. Congr. Speleol., Stuttgart, 4, B 14: 1-6.
RACOVIȚĂ, G. (1970) La périodicité reproductive chez *Pholeuon proserpinae glaciale* Jeannel (Coleoptera, Bathysciinae). Livre du Centenaire „Emile G. Racovitza", 1868-1968, Ed. Academiei, București, p. 445-458.
RACOVIȚĂ, G. (1972) Sur la corrélation entre l'évolution du climat et la dynamique des dépôts de glace de la grotte de Scărișoara. Trav. Inst. Spéol. „E. Racovitza", XI: 373-392.
RACOVIȚĂ, G. (1973) Quelques significations de la variation numérique des populations de coléoptères cavernicoles. Trav. Inst. Spéol. „E. Racovitza", XII: 9-29.

RACOVIȚĂ, G. (1975) La classification topoclimatique des cavités souterraines. Trav. Inst. Spéol. „E. Racovitza”, XIV: 197-216.
RACOVIȚĂ, G. (1980) Etude écologique sur les Bathysciinae cavernicoles. Mém. Biospéol., VI: 1-199.
RACOVIȚĂ, G. (1984) Sur la structure méroclimatique des cavités souterraines. Theor. Appl. Karstol., 1: 123-130.
RACOVIȚĂ, G. (1987) Variation à longue échéance dans la dynamique d’une population troglobie. Studia Univ. „Babeș-Bolyai”, Seria Biol., 32 (1): 39-51.
RACOVIȚĂ, G. (1993) Modélisation mathématique des données dans les bilans topoclimatiques souterrains. Bull. Soc. géogr. Liège, 29: 115-118.
RACOVIȚĂ, G. (1994a) Bilan climatique de la grotte glacière de Scărișoara (Monts du Bihor, Roumanie), dressé sur dix années d’observations. Trav. Inst. Spéol. „E. Racovitza”, XXXIII: 107-158.
RACOVIȚĂ, G. (1994b) Eléments fondamentaux dans la dynamique des spéléothèmes de glace de la grotte de Scărișoara, en relation avec la météorologie externe. Theor. Appl. Karstol., 7: 133-148.
RACOVIȚĂ, G. (2000) Ice caves in temperate regions, In: H. Wilkens, D. C. Culver and B. Humphreys (eds.), Ecosystems of the World. Vol. 30, Subterranean Ecosystems, Elsevier Sciences, Amsterdam, p. 567-574.
RACOVIȚĂ, G., BOGHEAN, V., PETRESCU, M. (1993) Le bilan topoclimatique de la grotte de Cloșani (Monts Mehedinți, Roumanie). Theor. Appl. Karstol., 6: 7-86.
RACOVIȚĂ, G., BOGHEAN, V., SILVESTRU, E., PETRESCU, M. (1991) Etude thermométrique des substratums de la Grotte de Scărișoara. Trav. Inst. Spéol. „E. Racovitza”, XXX: 159-184.
RACOVIȚĂ, G., CRăCIUN, V. (1970) Considérations sur la variation saisonnière des formations de glace de la grotte „Ghețarul de la Scărișoara”. Livre du Centenaire „Emile G. Racovitza”, 1868-1968, Ed. Academiei, București, p. 587-616.
RACOVIȚĂ, G., CRĂCIUN, V. (1981) Etude topoclimatique de la grotte de Fața Apei. Trav. Inst. Spéol. „E. Racovitza”, XX: 157-178.
RACOVIȚĂ, G., ȘERBAN, M. (1990) Interprétation en vue d’une reconstitution paléoclimatique des particularités structurales et dynamiques du dépôt de glace pérenne de la Grotte de Scărișoara. Studia Univ. „Babeș-Bolyai”, Seria Geol., XXXV (2): 47-61.

RACOVIȚĂ, G., ȘERBAN, M., VIEHMANN, I. (1987) Tendances de long terme dans la dynamique des formations de glace de la Grotte de Scărișoara (Monts du Bihor). Theor. Appl. Karstol., 3: 143-164

RACOVIȚĂ G., VIEHMANN, I. (1966) Observații asupra dinamicii stalagmitelor de gheață din Ghețarul de la Scărișoara – Sala Biserica. Lucr. Inst. Speol. „E. Racoviță", V: 43-65.

RACOVIȚĂ, G., VIEHMANN, I. (1984) Sur le rôle de la condensation souterraine dans la genèse des stalagmites de glace. Trav. Inst. Spéol. „E. Racovitza", XXIII: 89-97.

RACOVIȚĂ, G., VIEHMANN, I. (1985) Etude de l'évapocondensation souterraine dans une grotte glacière. Theor. Appl. Karstol., 2: 123-130.

RUSU, T., COCEAN, P. (1992) Contribuții la studiul sistemului carstic Ocoale-Ghețar-Dobrești (Munții Bihorului). Studii și Cercetări de Geografie, XXXIX: 37-44.

RUSU, T., RACOVIȚĂ, G., COMAN, D. (1970) Contributions à l'étude du complexe karstique de Scărișoara. Ann. Spéléol., 25 (2): 383-408.

SCHMIDL, A. A. (1863) Das Bihar-Gebirge an der Grenze von Ungarn und Siebenbürgen. Verl. Förster u. Bartelmus, Wien, 442 pp.

SCHOUMSKYI, P. A. (1955) Principes de glaciologie structurale. La pétrographie de la glace comme méthode d'étude glaciologique. Ann. Centre d'études et de docum. paléontol., 22.

SCHWARCZ, H. P. (1980) Absolute age determination of archaeological sites by uranium dating of travertines. Archaeometry, 22 (1): 3-24.

SILVESTRU, E. (1989) Several considerations of the tectonics of the underground fossil glacier in the cave Ghețarul de la Scărișoara (Romania). Trav. Inst. Spéol. „E. Racovitza", XXVIII: 77-86.

SILVESTRU, E., BOGHEAN, V. (1992) Ultrasonic investigations on the underground fossil glacier in the cave Ghețarul de la Scărișoara. Trav. Inst. Spéol. „E. Racovitza", XXXI: 151-154.

SILVESTRU, E., GHERGARI, L. (1994) On the paleokarst in the cave Ghețarul de la Scărișoara (Bihor Mountains, Romania). Theor. Appl. Karstol., 7: 155-161.

ȘERBAN, M. (1970) Morphologie comparée des stalagmites de glace de la grotte de Scărișoara (Roumanie). Trav. Inst. Spéol. „E. Racovitza", IX: 35-60.

ȘERBAN, M., BLAGA, L., BLAGA, L., CHIFU, Al., CIOBOTARU, T. (1967) Contribuții la stratigrafia depozitelor de gheață din Ghețarul de la Scărișoara. Lucr. Inst. Speol. „E. Racoviță", VI: 107-140.

ȘERBAN, M., COMAN, D., GIVULESCU, R. (1948) Découvertes récentes et observations sur la glacière naturelle dite „Ghețarul de la Scărișoara”. Bull. Soc. Sci. Cluj, X: 174-210.
ȘERBAN, M., COMAN, D., VIEHMANN, I. (1957) Recherches spéologiques dans les Monts Apuseni (Roumanie). Ceskoslovensky Kras, 10 (1): 11-25.
ȘERBAN, M., RACOVIȚĂ, G. (1987) Sur l’information paléoclimatique comprise dans le dépôt souterrain de glace de la Grotte de Scărișoara (Monts du Bihor) et sa valorisation pour une prognose de long terme. Theor. Appl. Karstol., 3: 133-142.
ȘERBAN, M., RACOVIȚĂ, G. (1991) L’extension de la zone glacée dans la grotte de Scărișoara (Roumanie) – effet des oscillations météorologiques multiannuelles. Theor. Appl. Karstol., 4: 51-64.
TROMBE, F. (1952) Traité de Spéléologie. Payot, Paris.
VANDEL, A. (1964) Biospéologie, La biologie des animaux cavernicoles. Gauthier-Villars, Paris, 619 pp.
VASS, I. (1857) Eine Wanderung nach der Eishöhle bei Skerisora. Verh. u. Mitt. des sieb. für Naturwiss. zu Hermannstadt, VIII: 162-170.
VĂLENAȘ, L., BLEAHU, M., BRIJAN, P., HALASI, G. (1977) Inventarul speologic al Munților Bihor. Nymphaea, V: 209-335.
VĂLENAȘ, L., HALASI, G., CZAKO, L. (1982) La morphologie et l’hydrologie des conduits submergés du bassin de la vallée Gîrda Seacă (Monts Bihor). Nymphaea, X: 183-194.
VIEHMANN, I. (1958) Perlele de cavernă din Ghețarul de la Scărișoara. Com. Geol., Dări de Seamă ale Ședințelor, XLV: 283-295.
VIEHMANN, I. (1959) Un nouveau processus de genèse des perles de caverne. Ceskoslovensky Kras, 12: 1-9.
VIEHMANN, I. (1963) Un nou proces de geneză a perlelor de cavernă. Lucr. Inst. Speol. “E. Racoviță”, I-II: 295-303.
VIEHMANN, I. (1967) Noi contribuții la geneza perlelor de cavernă din peșterile cu gheață. Lucr. Inst. Speol. „E. Racoviță”, VI: 141-147.
VIEHMANN, I. (1969) Methoden für experimentelle Forschung im Studium der Eishöhlen. V Int. Kongr. Speläol., Stuttgart, 2, S 29: 1-3.
VIEHMANN, I. (1976) Dix ans de recherches périodiques dans une grotte de glace (la Grotte de Scărișoara, Roumanie). Proc. 6th Int. Congr. Speleol., Olomouc, 1973, 4: 323-326.

VIEHMANN, I. (1995) Vertical potholes on karst. Acta Carsologica, Ljubljana, XXIV: 535-541.
VIEHMANN, I., RACOVIȚĂ, G. (1968) Stalagmitele de gheață termoindicatoare. Dări de Seamă Comit. Geol., LIV: 353-363.
WHITE, W. B. (1976) Cave minerals and speleothems. In: Ford, T. D., Cullingford, C. H. D. (eds.), The science of speleology, Academic Press, London, p. 267-327.

“I think I have shown the great scientific interest presented by the Scărișoara Glacier Cave. Not taking into account the solution of the enigmas presented by the history of the glacier, numerous problems within all the branches of natural history may be thoroughly considered upon this occasion, with the help of periodical or continuous observations and by conceiving experiments“.

E. G. Racoviță (1927)

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