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ICE CAVES AND THE CAUSES OF SUBTERRANEAN ICE.*

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I. DESCRIPTIVE AND EXPLANATORY.

Terminology.—The term “ice cave” refers to a rock cavern containing ice. It does not refer to a hole or tunnel, cut by the hand of man into a glacier, such as those one sees at Grindelwald or Chamonix. I make this statement, because on mentioning ice caves in conversation I have repeatedly been asked whether I meant those tunnels. The Germans use a term similar to ours, *Eishöhle*, while the French and Swiss use the word *glacière*, the feminine of

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glacier, which they also apply to artificial ice houses, speaking of ice caves as *glacières naturelles*, and of ice houses as *glacières artificielles*. The term *glacière* seems to me the most accurate in use in any language, and, if it were not too late to do so, it would be an advantage to use it, especially as we have adopted the term *glacier* from the same part of the world. In my opinion, the term "ice cave" should especially apply to the hollows in the ice at the lower end of glaciers, whence the glacier waters make their exit. The Hon. George N. Curzon uses the term, apparently in this sense, in a sketch published in the *Geographical Journal* in connection with his recent journey to the Pamirs, and in the account in the same publication of the visit of the English Training Squadron to Spitzbergen, in 1895, the term was applied to a natural tunnel found in a glacier.

Glaciers.—Ice enduring all the year round is found in three principal forms: glaciers, ice gorges and ice caves. Glaciers are formed, to speak in general terms, from the winter snows which have fallen from the skies, and, by their own weight, and melting and regelation, have accumulated into a mass of ice, causing the phenomenon known as a glacier. Glaciers depend, therefore, practically on the annual snowfall and a low temperature for their existence.

Ice Gorges.—Ice gorges or ice gullies show kinship to both glaciers and ice caves. They occur in fissures or ravines, at an altitude below the general snow line of the district, where the winter snow is sufficiently protected from the sun to endure either as snow or ice through the summer months. In some cases the surface ice and snow melts away, while underneath boulders, at the bottom of fissures, ice still remains. For instance, I have found lumps of ice in King's Ravine, on Mount Adams, in the White Mountains, late in September, among the big boulders which form such a trying path for the traveller. In such gullies, however, we have something resembling rather miniature glaciers than ice caves, in that gullies receive the accretion to their ice directly from the winter snows. Some of the reasons for their endurance are similar, however, to those which apply to ice caves, in that they receive little if any of the direct

rays of the sun, and are also scarcely exposed to any hot winds. It is almost a self-evident proposition that the ice in such gullies is formed in the same manner as the ice of glaciers, or the ice on ponds and rivers, by the cold of winter and the melting of the snows; and when ice is found remaining under boulders in such localities, it is simply that the snow water has run to the lowest level and there congealed. For convenience these gullies may be divided into two classes:

(1) The ordinary open ravines, of which a fine example occurs in the Shawangunk Mountains in New York State.

(2) The ice under boulders, such as we find in King's Ravine.

Ice Sheets.—A subterranean ice sheet covered with lava is reported from Mount Etna, and probably similar sheets also occur in Iceland. Sir Charles Lyell accounts for the one on Etna by the explanation that there must have been a great snow bank in existence at the time of an eruption of the volcano, and the lava stream must have flowed over the snow, which, in course of time, turned to solid ice underneath.

Wind-Holes.—In many parts of the world we find what are known as cold-current caves, or blowing holes, or wind-holes. These are pipes or holes, and in general they are found in more or less broken limestone rocks. In most cases a cool air pours forth from them in summer, while the cold air pours into them in winter, the draught being then reversed. In some cases, however, the operation is said to take place in the opposite way. De Saussure made an experiment in connection with the first kind of these holes, showing what is probably the cause of the cooling of the air current. He passed a current of air through a glass tube, an inch in diameter, filled with moistened stones, and found that the air current which entered with a temperature of 22.5°C ., came out with a temperature of 18.75°C ., that is, with a loss of 3.75° of heat. As in limestone caverns there would generally be moisture on some of the rock surfaces on which air currents would pass, it is doubtless the evaporation from these surfaces which lowers the temperature of the air cur-

rents. These wind-holes do not seem to necessitate the presence of ice. I have examined five of them myself, and in no case was there any ice visible. Whether there was any ice within the mountain I cannot, of course, say. At Seelisberg, on the Lake of Lucerne, the peasants have built little stone houses over the rocks whence these currents issue, and use these houses for keeping their provisions during the heats of summer. In all the wind-holes I have seen the cool air was pouring out.

Ice Caves.—Ice caves differ greatly from ice gullies. The greatest divergence is that there is a roof. This means that the ice is formed directly in the cave itself, and is not, except perhaps near the entrance, solidified snow, but genuine subterranean ice. The roof, while not admitting the winter snow, is, however, a protection against warm summer rains, and, of course, entirely cuts off radiation from the sky. If, therefore, it keeps out some cold, it also acts as a protector against heat. It may be noticed here that there is a strong resemblance between natural ice caves and artificial ice houses, a resemblance implied in their French appellation, *glacière*, and, in fact, it is hardly too much to look on ice caves as natural ice houses.

Kinds of Ice Caves.—Ice caves proper vary greatly in their positions, shapes and sizes. They may be divided into three main kinds :

(1) Those at or near the base of cliffs, entering directly into the mountain with a down slope. This class is found in limestone and in volcanic rocks. Examples : The Kolowratshöhle, Dobsina, Roth in the Eifel.

(2) Those at or near the base of cliffs, where a long passageway exists before the ice cave proper is reached. All I know of in this class are in limestone rock. Examples : Demenyfálva, the Frauenmauer.

(3) Those where a large pit opens into the ground, and the ice cave is found at the bottom opening into the pit. These are in limestone. Examples : Chaux-les-Passavant and la Genollière.

Ice Caves with Wind-Holes.—In two or three cases there are ice caves in connection with wind-holes ; that is, there

is first a large ice cave, at the rear of which is a fissure from which a draught comes. One of these is near Cluses in Savoy, and Professor Thury states that along the line of the draught he found the ice in August more melted than elsewhere in the cave. Another of these ice caves with a wind-hole is in Washington Territory, and is the largest ice cave so far reported in the United States.

Mines and Freezing Wells.—Subterranean ice is also found in certain places in connection with man's handiwork. It is reported as forming in some few mines in Europe and America. In some wells, also, in the New England States, abnormally low temperatures have been observed, and for four or five months of the winter the surface of the water is frozen so thick as to render these wells useless.

Geographical Distribution.—Ice caves proper are found in various parts of Europe, Asia and America, mostly in the smaller ranges or in the outliers of the snowy ranges, generally in limestone and occasionally in basaltic formations. There are a good many in the Jura, a few in Switzerland, a few in the Italian Alps, a number in the Eastern Alps, in Tyrol, Steiermark and Carinthia. There are some in Hungary, several in Russia, one in Iceland, one on the Peak of Teneriffe, several in Siberia, one in Kondooz in Central Asia, one in Japan, and one in Korea. I have heard, so far, of twenty-nine places where subterranean ice is reported as occurring in North America, two of which are in Pennsylvania. Professors Schwalbe and Fugger give lists which mention over 200 places where subterranean ice is said to occur. However, these lists are not claimed by the authors themselves to be accurate.

Dimensions.—The dimensions of ice caves vary greatly. Some are very large, some very small. The measures of the cave at Dobsina, in the Carpathians, are given as follows: Height of roof above ice floor, 10 to 11 meters; length, 120 meters; breadth, 35 to 60 meters; and surface about 4,644 square meters. The Frauenmauer Cave, in Eastern Tyrol, has an ice floor about 50 meters long by about 7 wide. The ice cave near Frain, on the contrary, is so small that one can only crawl in some 2 or 3 meters, and this at the expense

of soiling one's clothing. In fact, ice caves vary in size between great halls and small tunnels, in which one cannot stand up straight.

Size of Entrances.—The entrances of ice caves vary also greatly as to their dimensions. As a rule they are small, that is, about the size of ordinary door-ways; but the entrance to the Schafloch, for instance, is about 10 meters wide by 7 meters high, while the entrance to Roth in the Eifel is not over 1 meter each way.

Drainage.—An important point in all ice caves is the need of some outlet for the surplus water at the lowest point of the cave, as otherwise the cave would soon be entirely filled. As the caves are always in either porous or broken rocks, the necessary drainage takes place through the cracks and fissures in the rocks.

Forms of Ice.—Almost all the forms assumed by underground ice are different from those visible in glacier or ice-berg. This is only what should be expected, as the ice is formed under such different conditions from those which obtain overground. There are no séracs or crevasses such as one sees *en route* to the Grand Mulets, for instance. The sharp angles and fractures visible on glaciers are absent. Almost all the lines are rounded. Unique forms of subterranean ice are those produced by the drip from roof or sides, that is, the forms of ice answering to the stalactites and stalagmites of limestone caves. They descend from the roof as icicles or rise from the floor as cones or pyramids. Sometimes the icicles reach to the floor, and, connecting with it, become regular columns; or sometimes columns issue from fissures in the sides in the shape of frozen water-falls.

At Dobsina the stalactites form grand ice pillars. They are from 8 to 11 meters in height, and from 2 to 3 meters in diameter. In some of the caves, as at Chaux-les-Passavant, the ice stalagmites take nearly the form of cones. There are some seven or eight of them, the tallest of which is at least 6 meters high, with a diameter at the bottom of 5 or 6 meters. Sometimes these cones are hollow, as is the case in a grand one at the Schafloch, some 6 meters or more in height.

The columns issuing from the sides of ice caves, for lack of a better name, I call fissure columns. They seem always to issue from a crack in the rock, and then sometimes stream over the rock. Sometimes they spring out far enough from the rock to be quite away from it. These fissure columns vary from about 2 to 7 meters in height, and at the base almost always spread out fan-shaped. Schwalbe speaks of these columns as "subterranean glaciers." Some are found in almost every ice cave; in one case—the Glacière de Chapuis—they form the special beauty of the cave, as there are some seven or eight of them, each perhaps 5 or 6 meters high, and about 1 meter in diameter, and spreading into fan-shape at their base.

The ice on the bottom of the caves of course takes its shape from the shape and angles of the floor of the caves. If the floor is level or nearly so, we find the ice in the shape of a sheet or floor. If the floor of the cave be sloping the ice will be found on more or less of a slope, sometimes becoming nearly or quite vertical, as an ice slope or ice wall, and distantly resembling the portions of glaciers called an ice fall, with the great difference, however, that there are no crevasses, not even tiny ones.* Holes we sometimes find, as at Haut d'Aviernoz, or runnels, as at the Kolowratshöhle, but these are entirely distinct from crevasses. On these ice walls or ice slopes, there is, in fact, no visible sign of anything that would lead to a suspicion of motion.

The holes, or runnels, just referred to are generally found at the lowest point of the ice floors and are almost certainly cut out by the melting water, to which they act as an exit. In fact, they form the drainage system in the ice. The holes are sometimes very deep. At Haut d'Aviernoz I looked down into one, which must have been many meters deep, and whose sides disappeared in darkness, no bottom being visible.

The drip produces also the exact opposite of cones, in the shape of ice basins. There are two splendid ones in the

* No observer seems as yet to have looked for any evidences of motion in subterranean ice.

Kolowratshöhle, each cut out in the floor by an extra strong drip from the roof at those spots. Such basins as these are not to be seen on glaciers.

Lakes and pools are to be found in ice caves. At Chaux-les-Passavant a pool of water, perhaps 30 centimeters in depth and 4 or 5 meters in diameter, lay at one place in August on the ice floor. The whole cave was damp and the ice in places decidedly slushy, in fact, all the signs pointed to a heavy thaw going on, and there could be no doubt that the pool was the result of this. In the Glacière de Chapuis, far underground, there are two adjoining caverns, one filled with water, the other with ice.

Again, in at least one case, the Kolowratshöhle, a lake sometimes forms on the ice floor in the spring, freezes over, and then runs off, leaving the marks of its passage in the shape of ice slabs reposing on the solid ice floor, as was the case on my visit to this cave in the middle of July, 1895.

I think there is no doubt that subterranean snow sometimes occurs, probably early in the year. A case of the kind occurring in Central France has been noticed in Monsieur Martel's book, "*Les Abimes*," and my brother and I, in a visit to the Dobsina cave early in July, before much thaw had set in, found in one spot of the cave a small sheet, perhaps 2 meters each way, of what, to look and touch, was genuine snow. I have little doubt that this was formed by the congealing, during their fall, of drops of water from the roof.

The ice in caves is sometimes found in a form or structure which is, I believe, of rare occurrence above ground. This is when it occurs in the shape known as prismatic ice. If you break off a lump from a column or icicle you will sometimes notice that it breaks into regular prisms. I have seen this prismatic ice a few times only. Browne speaks of it in his book as common. I am not sure that the phenomenon is as yet satisfactorily accounted for; the only thing I feel sure of is that it does not occur in ice of recent formation. Thury speaks of it as a form which is due to some change in ice which has already been formed for some time.

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TOP PHOTO. E. S. BALCH 1897

Color Effects.—The color effect of every ice cavern has a certain individuality. At the Kolowratshöhle the ice is beautifully transparent and of a pale ochre-greenish hue; the limestone rocks are streaked with iron, and thus have a reddish hue, while, owing to the entrance admitting plenty of daylight, the effect is only semi-subterranean. At the Schafloch it is the exact opposite of this; the ice is so completely away from daylight that black is the predominating note, the ice itself looking a dark gray. Again, at Chaux-les-Passavant plenty of daylight is admitted; the rocks are a yellowish-brown, while the ice is white and blue. At Dobšina, on the contrary, thanks to the electric light, white is the predominating note, in certain places and corners dulled into grayness by rock or shadow.

II. CAUSE OF THE FORMATION OF ICE.

The cause of the formation of the ice is practically the most intricate thing to understand and explain about ice caves. Numerous explanations have been offered on the subject, and many theories formulated, some of which are absolutely untenable. The great cause, as far as I can see, is simply the cold of winter, which re-forms anew each year the ice which has been destroyed by the heat of the preceding summer. Before elaborating the winter's-cold theory, I wish to mention two or three theories which cannot possibly be accepted in connection with the facts.

Glacial Period.—A suggestion to account for the ice, which seems to occur to many persons when they first hear of ice caves, is that the ice is a remnant of the glacial period. This theory is quite untenable. The great cave of Chaux-les-Passavant was entirely cleared of its ice in 1727 by the Duc de Lévi for the use of the Army of the Saone. In 1743 the ice was formed again. At Szilize, every year, the ice has almost completely disappeared by November, and the cave is free; but in April or May the floor is again covered with ice, and columns and icicles have formed on the roof and sides. At La Genollière, the cave is used by the people of the neighboring chalets through the spring and early summer to help in the operation of butter-making; by the mid-

dle or the end of August it has entirely disappeared, but is found formed afresh every spring. Too many examples of the complete melting away of the ice every year can be cited to permit any doubt on this point; ice caves are not connected with a glacial period.

Salts.—Another favorite suggestion, which cannot stand on an acquaintance with the facts, is that there must be salts in the rocks. An elaborate paper, giving this as the true cause of the ice in Chaux-les-Passavant, was published in 1712, by M. de Billerez, in the proceedings of the French Academy. He stated that the earth in the immediate neighborhood, and especially above the roof of the grotto, was full of nitrous or ammoniacal salts, and he suggested that this salt was disturbed by the heat of summer, and mingled with the water which penetrated by fissures into the cave. His observations have been absolutely disproved, and in no place have any such salts been found. Repeated experiments in letting lumps of cave ice melt in my mouth have convinced me personally that in all cases the water is exceedingly pure and sweet, and there can be no doubt that all, what might be called, chemical causes, must be entirely eliminated as possible cold-producers. The very first notice extant about ice caves, in the shape of a letter dated 1586, of Bénigne Poissenot, a Paris lawyer, about Chaux-les-Passavant, speaks of the deliciousness of the ice water.

Draughts.—The formation of subterranean ice is sometimes—in my opinion incorrectly—assigned to air currents or draughts. Cold caves fall into two divisions in regard to the movements of air—caves with and caves without draughts. The first are ice caves proper; the second wind-holes or cold-current caves. Professor Thury seems to have been the first to call attention to this fact, and he divided caves into static and dynamic caves. The wind-current caves have complicated the understanding of the whole problem, as some observers have assumed that the draughts were the cause of the ice. I think the facts all tend to disprove any such idea, as very few of the observed wind-holes contain any ice. In fact, it seems as if draughts tend entirely to melt, not to form, ice. The air in an ice cave is gener-

ally almost still. I do not remember ever feeling any movement of air in an ice cave proper. In the double cave of Chapuis one cavern is filled with ice and the air is quiet, while the other is filled by a little lake, over which there is a draught. The lake is, doubtless, the result of the draught, which probably melts the ice in summer, if, indeed, it does not prevent any from forming in winter. At the entrances of ice caves I have several times noticed faint movements of the cold air outwards, but this is never perceptible within the body of caves. One cannot exactly feel the air moving out, but by lighting a cigar the smoke may be seen slowly moving outwards. At the entrance of the Kolowratshöhle there was a faint outward current when I was there. The day was a hot one and quite windless, and as the cold cave air met the hot outside air it formed a faint cloud or mist just at the mouth of the cavern.

Evaporation and Atmosphere.—Closely connected with draughts are the evaporation or expansion of the air in caves, and by some persons these are assumed as the cause of the ice. From what I have observed myself, I should say that the dryness or moisture of the air is coincident with the state of freezing or thawing of the cave. If you penetrate into a large cave about the beginning of June, when everything is frozen up tight, you will find no drips nor mushy ice; the air will be relatively dry, and the sensation of cold not unpleasant. If you penetrate into that same cave about the end of August you will find drips coming from the roof, the ice soft, and the sensation of the air a penetrating, damp cold. Thury says that in the caves near Geneva he found in summer the air so saturated with moisture that it could scarcely take up any more. In his observations with a psychrometer in the Grand Cave de Montarquis in August, he found $\frac{92}{100}$ of relative moisture. Although from what I at present know, I am inclined to disbelieve in draughts, evaporation, or expansion causing ice to form, yet I think there is need for a great deal more observation on this point.

Capillary Theory.—Another theory which has found some acceptance is the so-called capillary theory; namely, that

bubbles of air, drawn into water, flowing down through fissures in the rock, are liable to a continually increasing pressure, compelling it to part with latent caloric, which is immediately absorbed from the water on being liberated in any cave or well or mine. There may be truth in this, and I have been assured that in some borings in Western mines ice has been formed by pressure; but if it applied to caves, I do not see why so many thousands of caves contain no ice, and especially why ice caves are never known in hot countries. If the theory were correct, we should, for instance, find ice in the caves of Yucatan, described by Mr. Mercer. Still, this theory is held by some scientific observers. The Hungarian doctor at Dobsina told me he believed in it, and Dr. Schwalbe, whose opinion is entitled to great respect on account of his many observations, thinks that the rocks in summer are a cooling factor, and, that some cold comes out from them.*

Summer Ice Formation Theory.—The theories just mentioned are advanced by well-educated persons, not necessarily scientists. The natives and peasants in the neighborhood of ice caves generally believe that the ice of caves is formed in summer and melts in winter. This belief I have met with everywhere—in the Eifel, Jura, Swiss Alps, Tyrolese Alps and Carpathians. Peasants and guides will tell you with absolute confidence: "The hotter the summer, the more ice there is." The hotel keeper at Eisenerz, near the Frauenmauer Cave, told me "many people had broken their heads" in trying to account for that cave freezing harder in August than in May. This belief is founded principally on the fact that the natives scarcely ever go to an ice cave except when some tourist takes them with him, and therefore they rarely see one in winter, and their opinion is, consequently, of no value. Thury tells a good story about this belief of the peasants. He visited the Grand Cave de Montarquis in midwinter. All the peasants told him there

*The capillary theory was first advanced by Mr. N. M. Lowe, of Boston, and published in the *Science Observer* for April, 1879. An admirable exposition of the theory by Mr. John Ritchie, Jr., was also published in the same number of the paper.

would be no use going, as there would be no ice in the cave. He tried to find even one peasant who had been to the cave in winter, but could not. He then visited it himself, and found it full of hard ice. On his return he told the peasants of his discovery. They were staggered at first. Finally one exclaimed: "It makes no difference; in genuine ice caves there is no ice in winter."

Still, there is an appearance of truth in the peasants' belief, and that is in the fact that the temperatures of ice caves, like that of other caves or that of cellars, are colder in summer than the outside air, and are warmer in winter than the outside air. Possessing neither reasoning powers nor thermometers, the peasants simply go a step further and say that the caves are cold in summer and hot in winter. In other words, from sheer ignorance, out of a true fact they make nonsense.

The extraordinary thing is that any number of writers—sometimes scientific men—in books and scientific papers, have accepted this belief of the peasants and tried to account for it. An attempt at explaining it dates back as far as 1686, in the Paris *Histoire de l'Academie Royale des Sciences*. It is found in a German book printed in 1689, then again in a French scientific journal in 1712. In the *London Philosophical Transactions*, in 1739, there is a long account in Latin about the cave of Szilize, in which the writer, a Hungarian *savant*, Mathias Bel, describes how, as soon as the warmth of spring comes, the cave begins to freeze, and, as the weather gets hotter, freezes the harder, until, in the dog days, icicles and columns grow with immense rapidity. But when the winter comes the ice all melts away, the cave becomes warm and pleasant, and the insects and the bats, and then the hares and foxes of the neighborhood come there in droves and live amicably together during the cold months. Several dozen writers in our century accept and repeat these statements as the truth. Sometimes the statements are repeated with, sometimes without, the hares and foxes, the latest repetitions occurring in 1861, 1876, and 1881.

Winter's Cold.—I now turn to the explanation which seems to me the true one, both because it is the simple and

obvious one, and because all the facts, as far as I have personally observed, entirely tally with it. This is the theory that the cold air of winter is the chief factor in producing the ice, and that it is through its means that certain caves are converted into what are practically natural ice houses. That the cold of winter produces the ice is hinted at by Gollut in 1592, by De Boz in 1726, and by Cossigny in 1743; it is elaborated into something like a theory by Prévost in 1789, and independently suggested by Townson in 1793; it is mentioned by Humboldt in 1814 and Deluc in 1822. Worked at afresh and elaborated into a theory by Thury in 1861 and Browne in 1865, it has received confirmation in our own time by the work of Professor Fugger and Captain Trouillet.

All my own observations have tended more and more to make me believe that the cold of winter is the cause of the ice, and to make my thought clearer I will put it in the form of two propositions. The first is:

The ice in caves is formed entirely by the cold of winter; the heat of summer tends to melt it. Owing to the sheltered position of cave ice, however, the summer heat reaches it with more difficulty than it reaches the snow and ice in the open, and cave ice, therefore, remains sometimes long after the ice in the surrounding country has disappeared.

The second is:

Two things are necessary for the formation of ice. The first is cold, the second is water. Therefore, to form ice in a cave, the cold air of winter must have access to it, and in some way water must be supplied to it.

Altitude and Latitudes.—The most important proof, to my mind, of the truth of these propositions, is the fact that no ice cave that I have heard of, is found in any latitude or below any altitude where ice and snow does not form for part of the year in the surrounding open country. None are reported from India or Africa, or, in fact, from any low-lying places in tropical latitudes. They are found mostly in middle latitudes, and only where during part of the year, at least, there is a cold season, that is, where, for some time, the thermometer stands below freezing point. Even in the middle latitudes they are in general at fairly high altitudes.

The Schafloch is at 1,780 meters ; Skerizora in Transylvania at 1,127 meters ; Dobsina at 1,100 meters ; the Glacière de Saint George at 1,208 meters. It is true, there is one cave in the sub-tropical latitude of Teneriffe, La Cueva de la Nieve ; but that is at an altitude of 3,300 meters, and where snow falls every year in the open on the Peak. Unless some cave is hereafter discovered in a region where there is no winter, I do not see how the imperative necessity of the presence of the cold air of winter for forming the supply of ice can be controverted.

Temperatures.—That the cold air of winter is the important factor in the production of cold seems to me also proved by the thermometric observations recorded in various caves by different observers. They all tell the same tale, that the temperatures vary with those of the outside air ; that they are lowest in winter and highest in summer. Here are the results of one year's observation at Dobsina in degrees centigrade :

January,	— 4·2	July,	+ 2·1
February,	— 3·4	August,	+ 3·8
March,	— 2·1	September,	+ 2·3
April,	— 1·2	October,	+ 0·2
May,	+ 0·9	November,	— 1·9
June,	+ 1·5	December,	— 3·2

Here are a year's observations at Frain :

January,	— 5	July,	+ 3 to + 5
February,	— 5 to — 2	August,	+ 5
March,	— 1 to 0	September,	+ 3 to + 6
April,	0	October,	+ 5
May,	+ 2 to + 5	November,	+ 5
June,	+ 3 to + 6	December,	0 to — 2

These figures seem to me to prove pretty conclusively that from about the first of November to the first of May we have—inside the ice caves—winter temperatures, that is, temperatures below freezing point ; and from about the first of May to the first of November we have summer temperatures, that is, temperatures above freezing point.

Positions of Entrance and Body of Caves.—A great and important factor in permitting the cold air to permeate, and remain in, a cave, is the actual form and position of the cave

and of the entrance. In all known cases, as far as I can learn, the main body of an ice cave is well below the level of the entrance, and even if the ice cave is sheltered against the wind, it is not sheltered against the cold air of winter. This is heavy, and by its own weight sinks well down to the bottom, freezing up, in course of time, all the moisture that may drip from the roof or that may come into the cave in the shape of melted snow or cold winter rain. The summer air, being warm and, therefore, light, can only enter the cave much more slowly to dislodge the winter air and destroy the ice, and before it accomplishes the latter, another winter's freeze reverses once more the conditions. This applies universally to the main body of the caves.

In all but two known cases there is a steady drop from the entrance of an ice cave to the ice. These exceptions are the Posselthöhle and the Frauenmauerhöhle, in which you first ascend gradually a short distance before the drop to the main ice begins. Both these caves are at high altitudes and well sheltered. In the Frauenmauer you have to walk through a gallery for about 30 meters, ascending in that distance perhaps 3 meters, when the slope is suddenly reversed and you then have a down grade. At the highest point, last July, I found quite a large mass of ice, enough to fill, perhaps, a couple of ice carts. But as, in ascending to the cave, I had crossed the remains of two snow avalanches, it does not seem very remarkable that better sheltered subterranean ice should remain, even if higher than the entrance of the cave. I, therefore, should not feel surprised at any time to hear of an ice cave being found with the body of the cave higher than the entrance; but this would be either at a very high altitude or in a very high latitude.*

The position of the entrance is very important. In almost all cases it has a northerly exposure, and is sheltered against

* Since this paper has gone through the press, I have heard of a cave, "Amarnath," in the Himalayas, where the floor is said to slant upwards to the back wall. Two blocks of ice, which last through the year within the cave, are worshipped by the Hindus under the names of Siva and Ganesh, probably as re-incarnations.

entering winds. If these two conditions do not exist the ice supply surely suffers. Sometimes the entrance is more or less tortuous. In some cases it is protected by a fringe of trees. Again, in one kind of ice cave there is first a great pit, at the bottom and on one side of which we find the ice cave proper. In one case at least, the Geldloch on the Ötscher, the entrance is due south, and as a consequence the ice in the front of the cave, solid about the end of June, becomes a lake about August, and then cuts off access to the rear of the cave. In the case of the Kolowratshöhle the entrance is badly sheltered against the wind, and this undoubtedly affects the supply in summer, and causes more rapid melting there than in some other cases.

Time of Formation of Ice.—As already mentioned, cold and water are the necessary requisites for the formation of ice, and the time and method of formation were approximately explained by Thury. His winter excursions caused him to accept as proved that part of the mountaineers' belief which holds that there is no ice formed in caves in winter. He says: "In winter the cold is not wanting, but if there is no spring emptying into the cave, water is absent, and then no ice is formed. It is in the spring, at the time of the first melting of the snows, that the ice must be formed. Then water at 0° C. flows on the surface, and penetrates by the fissures of the rock and by the great openings into the interior of the chilled cavern, which receives besides the freezing night air. The grotto then makes its yearly provision of ice, which could do nothing more than diminish during the entire duration of the hot season."

Dr. Terlanday recently published a paper about the Cave of Szilize, in which he asserts that ice does not form there in winter, but that the ice first forms in the winter in the upper part of rock fissures, and that in the spring, at the time of an increase of temperature, this fissure ice is brought to the melting point by the successive entering of heat into the earth, and this water then arrives at the cave, where it aids the formation of icicles. This theory about fissure ice is probably in so far correct, that the ice in the upper parts of fissures, near the surface of the ground, melts before the

ice in the lower parts of fissures. The drip would then naturally run into the cave, and as long as the temperature of the cave was below freezing point would help to form cave ice.

But this theory does not take sufficiently into account surface thaws. Thury's theory is very good and true enough in many respects, but it does not go far enough. The observations of Professor Fugger, and especially those of Captain Trouillet, make certain the fact that ice begins to form in a cave as soon as the temperature of the cave has sunk below freezing point, whenever, from any cause, water gets into the cave. This will occur whenever there is a thaw outside at any time during the course of the winter; and it is probably entirely correct to assert that ice is formed intermittently in caves all through the winter months.

In conclusion, I wish to say that I look on this paper as in the nature of a *preliminary report* only. I have collected a great deal more information about ice caves, which I hope to publish before long. The whole subject is as yet by no means exhausted, and further observations may bring forth valuable results, and I wish I might now see American scientists give more attention to the ice caves of our own continent.

RECENT ADVANCES IN THE STUDY OF THE RESINS.*

BY HENRY TRIMBLE.

HISTORY.

The earliest knowledge of the resins was probably derived from frankincense and myrrh; it is possible, by certain paintings on the walls of the ancient temple of Dayr el Báhri, in Upper Egypt, to recognize that they were important articles of traffic seventeen centuries before Christ; they were associated with such important commodities as

* Abstract of a lecture delivered before the Franklin Institute, December 4, 1896.