# 4TH INTERNATIONAL WORKSHOP ON ICE CAVES

June 5 - 11th, 2010, Obertraun, Austria

# Abstract volume

Compilation: C. Spötl, M. Luetscher, P. Rittig

# *Programme*

***Saturday, June 5, 2010***
Arrival and registration

***Sunday, June 6, 2010***
Pre-conference field excursion (A-1): Dachstein - Rieseneishöhle and Dachstein plateau
9:00 Departure from the conference centre (BSFZ), meeting at entrance of cave at 10:00, lunch at Schönbergalm, followed by hiking on the plateau (13:30-16:45)
17:30 Return at BSFZ
18:00 Dinner at BSFZ
19:30 Oral presentations (Plan & Spötl, Haupt)

***Monday, June 7, 2010***
9:00 Conference opening
9:40-12:00 Oral presentations (coffee break 10:00 – 10:40)
12:00-13:20 Lunch
13:20-14:00 Oral presentations
14:00-15:00 Poster speed session
15:30 Departure from the BSFZ: Hallstatt tour (B-1), ends at Restaurant Simony at ca. 18:00; departure from this Restaurant at 20:30

***Tuesday, June 8, 2010***
9:00-12:00 Oral presentations (coffee break 10:00 – 10:40)
12:00-13:20 Lunch
13:20-14:40 Oral presentations
15:15 Departure from the BSFZ to field excursion B-2: Dachstein - Mammuthöhle (meeting at the entrance at 16:00), return at BSFZ at ca. 20:00 (no dinner provided)

***Wednesday, June 9, 2010***
8:30 Departure from the BSFZ: bus to Eisriesenwelt (Werfen; field excursion B-3)
18:00 ca. return at BSFZ
18:00 Dinner at BSFZ

***Thursday, June 10, 2010***
9:00-12:00 Oral presentations
12:00-13:20 Lunch
13:45 Departure from the BSFZ: Koppenbrüllerhöhle (field excursion B-4), afterwards transfer with bus to cable car station and piano concert in Rieseneishöhle (together with participants from VÖH annual convention), Dinner
22:30 Return to BSFZ

***Friday, June 11, 2010***
Post-conference field excursion (Dachstein – Südwandhöhle, C-1)
8:30 Departure at BSFZ
20:00 ca. return at BSFZ

## *Contributions*

# *Thickness and internal structure of underground ice in a low-elevation cave in the Eastern Alps (Beilstein-Eishöhle, Hochschwab, Austria)*

***M. Behm, H. Hausmann, C. Weghofer***

*Institute of Geodesy and Geophysics, Vienna University of Technology, Austria*

Beilstein-Eishöhle (Beilstein ice cave) is situated at the western margin of the Hochschwab-Massif in the Eastern Alps. Compared to other ice caves in the Alps, its elevation of 1330 m a.s.l. is relatively low. Beilstein-Eishöhle hosts extensive ice formations, including a 40 by 25 m wide surface. Since no second entrance to the cave exists, the ice formations result from trapped cold winter air which is conserved throughout the summer.

We used Ground Penetrating Radar (GPR) to investigate the ice. Antenna frequencies of 200 and 500 MHz provided excellent data and allowed to map both the thickness and internal structure of the ice. The maximum thickness is 11 m, which is considerably lower than earlier reports. Pronounced layering within the ice is also observed. We demonstrate that advanced mapping strategies (3D migration) are necessary to correctly delineate the strongly curved bedrock topography.

We further compare the radar data with results from three other ice caves and find remarkable differences in the reflection signature. The ice-ground transition from Beilstein-Eishöhle is much more reflective which could be attributed to an intermediate frozen sand layer in between ice and rock.

# *First data from a Pyrenean ice cave (A294 cave, Cotiella massif, Spain)*


## *Á. B. Ribas, C. S. Marcén*

*Departamento de Ciencias de la Tierra, Facultad de Ciencias, Universidad de Zaragoza, Spain*


A294 cave (UTM coord. 31T 0281171/ 4710349, 2238 m.a.s.l.) is located in the Cotiella massif (highest peak Cotiella, 2912 m.a.s.l.) in the Spanish central Pyrenees. The area is at the boundary of the Atlantic and Mediterranean climatic influences, with a peri-Mediterranean climate with some high mountain characteristics. Thus, the surroundings of the cave are snow covered at least six months per year, even though snowfalls last generally from September to May.

The cave is situated within a huge glacier cirque, nowadays ice-free. The predominant morphogenetic processes in the area are karst and periglaciarism, with an active rock glacier relatively close to the A294 cave. The whole cirque is rich in karren and dolines, many of which are entrances to a complex cave network, with several thousand meters of galleries and pits. Many of these caves have snow and ice deposits. Most of them are not perennial and are closely related to the winter snow accumulation and the summer temperature regime.

The studied cave has a relatively simple shape. The entrance is a shaft that leads to a ramp of ice, usually covered by snow. Then there is a room with the ice deposit at the bottom. The room is about 22 m high from the ice surface to the roof and 40 m wide.

Overlying the ice is a huge scree deposit that ends in an active protalus rampart morphology. In spite of the low temperatures inside the cave, no other periglacial morphologies have been observed.

The cave shows some cryo-karst features like speleothems (stalagmites, stalactites and a four meter high column that is not active every year) and a seasonal water pool on the ice surface that drains through a cryo-karst ravine. Along the ice-wall big karren and scallops can be seen.

Four temperature/relative humidity loggers have been installed at different points of the cave. Due to the cave morphology and the preliminary data (July to October) the cave can be classified as a static ice cave and so the data reflect its closed period. The average summer temperature around the ice block is 0.736ºC pointing out general ablation conditions during this season. Actually, during these three months there is a general melting of the ice, including the average 20 cm of new congelation ice formed during last winter.

The deposit is nearly 13 m thick, measured in an overhanging wall and the total volume is about 242 $m^3$. Its structure shows stratified ice with many debris layers. Due to this fact, several units can be distinguished. The kind of ice varies from congelation ice mainly covering the deposit to firn ice, which is the predominant kind of ice in the stratified section. Within the deposit, many plant remains can be seen, not always associated with the debris layers. Two of them gave calibrated radiocarbon ages of 5061 and 5476 years BP and so this may be one of the oldest ice cave deposits in Europe.

# *Some characteristics of ice and snow caves in Croatia*

***N. Buzjak* [1, 2]*, D. Paar* [3, 4]*, D. Bakšić* [3, 5]**

[1] *Faculty of Science, Department of Geography, University of Zagreb, Croatia*
[2] *Caving club Samobor, Croatia*
[3] *Speleological section Velebit, Croatia*
[4] *Faculty of Science, Department of Physics, University of Zagreb, Croatia*
[5] *Faculty of Forestry, University of Zagreb, Croatia*

Most of the caves and pits with ice and snow in Croatia are situated in Dinaric Karst Mountains (Gorski kotar area, Kapela Mt., Velebit Mt., Dinara Mt, Biokovo Mt.). Generally, the highest mountains parts (higher than 1500 m a.s.l.) have a humid boreal climate (Köppen's type Df) and the lower parts have a temperate humid climate (Cfb) highly modified by the relief (distribution of ridges and depressions suitable for retention of colder air even in lower altitudes below 1000 m a.s.l.). Mean annual temperature in the area 1000 m a.s.l. is about 5.5°C and in the highest parts around 3.5°C. The coldest months are January and February (mean annual temperature between -2 and -5°C) and the warmest one is July (12-16°C). Due to the position between Adriatic Sea and the Pannonian Basin there are important climate modifications. The most important ones are very high amounts of precipitation due to the vicinity of the Adriatic Sea, general atmospheric circulation, and a high relief. Annual precipitation varies from 2000 to 3900 mm/year. According to these data there are good conditions for the accumulation of ice and snow in caves and pits. In our presentation we will use data from Risnjak and Velebit Mt. area.

The Risnjak Mt. area is located in Gorski kotar in NW Croatia. There are 80 speleological features (mostly pits) developed in carbonate rocks of mostly Jurassic age. Most of them have occasional accumulation of snow fallen down from the surface and ice formed by freezing of drip water. According to meteorological data collected in the 105 m deep Nestasna jama (1335 m a.s.l.) air temperature in the summer at the bottom of the vertical passage filled with permanent ice was 0°C to 1°C with a very small amplitude during a one week measurement period.

The northern Velebit karst area is conducive to the formation of deep pits, three of these are deeper than 1 km: Lukina Jama - Trojama pit system (-1392 m), Slovačka Jama (-1320 m) and the Velebita Cave system (-1026 m). So far, more than 280 pits have been discovered in an area of 25 $km^2$. The area is composed of carbonate lithostratigraphic units ranging from the Middle Triassic to the Paleogene. Lukina jama is almost vertical from the entrance (1475 m a.s.l.) up to the depth of 550 m with one inclined snow shelf at a depth of 320 m. From 50 to 320 m, the deposits of snow and ice are on the walls, so the pit temperature in this part is 0°C. In deeper parts there is a positive temperature gradient up to 4°C at the bottom. Patkov Gušt pit is 553 m deep. The entrance is at 1450 m a.s.l. From the depth of 50 to 135 m there are thick deposits of snow and ice on the walls. At the depth of 105 m there is the narrowest passage part (2×1.5 m) which is occasionally completely filled with snow and ice. Below the depth of 130 m the pit widens. The walls are completely or partially covered by ice coating up to 300 m depth. Ice breaking and collapse was noticed in summer. Ledena jama in Lomska duliba is 536 m deep. It has a 42 m thick layer of ice starting at the depth of 62 m. Paž pit is 400 m deep. There is a negative temperature gradient in this pit in the summer from about 20°C near the entrance down to 0°C at the depth of 200 m. Down to the bottom the walls are partially covered by ice which is falling down to the hall where the temperature is 0°C. Most of the pits on Mt. Velebit have vertical entrances with temperatures close to 0°C down to about 100 m, so in many other pits we found ice and snow. On the other hand, in some of deepest pits in the same area – Slovačka jama, Velebita, Lubuška jama – there is no ice and snow, most likely because the entrance is not vertical. In the upper parts of these pits there is also a negative temperature gradient, but the minimum temperature is a few degrees above 0°C.

# *Fumarolic ice caves of Erebus Volcano, Antarctica*

***A. Curtis [1], N. Peters [2]***

*[1] New Mexico Tech, USA*
*[2] University Centre in Svalbard, Norway*

Ice caves formed by geothermal melting of ice and snow are widely distributed over the summit area of the active Erebus volcano, Antarctica. The origin and nature of the caves gives insight to possible features that may overlie active or recently active volcanoes beneath the Antarctic Ice Sheets. Many of the caves have overlying fumarolic ice towers formed where the geothermal gases are vented to the surface and freeze.

A program of mapping, cave atmosphere monitoring, and H and O isotope analyses of the ice towers was initiated during the 2009-2010 Antarctic summer to identify the formation and evolution of the caves and their relationship to the underlying geology. Results obtained include surveys, temperature records, and $CO_2$ concentration and anemometry. Seventeen monitoring systems are in operation, two of which are are telemetered and can be viewed in near real-time on the internet.

Observations to date suggest the caves are the result of a diffuse hydrothermal system covering the entire Erebus summit caldera area. With few exceptions, major cave rooms entered contain a vent emitting hot volcanic gases, usually 10 to 60°C with 1,000 to 20,000 ppmv $CO_2$, and greater than 95% humidity. Scalloped, anastomosing passages suggest warm air advection causes ice ablation and is important in cave formation.

# *Surprising dating results of bones and wood from the ice cave Schneeloch auf der Hinteralm, Styria*


## *E. Herrmann [1], E. Pucher [2], K. Nicolussi [3]*

[1] *Verband Österreichischer Höhlenforscher, Austria*
[2] *Naturhistorisches Museum Wien, Archäologisch-Zoologische Sammlung, Austria*
[3] *Institut für Geographie, Universität Innsbruck, Austria*


The Schneeloch (Austrian cave register no. 1851/7) is a huge snow-collecting shaft doline on the palaeosurface of the Schneealm Massif in northeastern Styria, formerly used by the nearby alpine pasture Hinteralm as a natural icebox. Recent research, lead by the Landesverein für Höhlenkunde in Wien und Niederösterreich, raised the total length of the cave to 721 m and the vertical extension to -68 m, and resulted in the exploration of the biggest cave room and ice body of this area.

The cave consists of two main parts: first, the entrance shaft doline with an extension of 70 x 20 m and its trisected continuation into the depth, and second, a 60 x 40 m wide cantilever cupola with the 10 m-high main chamber “Eishalle” in centre, surrounded by cramped crevices between the ceiling and collapsed roof portions. While the lower sections of the entrance doline are nearly completely filled with firn (in 2005 we made the first successful attempt to pass the 30 m-thick firn plug in one of the three partial shafts along its border crevices) the cupola-part contains massive bodies of layered ice. In 2006, ice covered about one third of the floor of the “Eishalle” and some side galleries with an overall extension of more than 400 $m^2$. A monitored rapid decrease of snow and ice fills within the short period of 2005-2009 could have been a consequence of climate warming, although a cyclic ice development forced by the cave morphology cannot be excluded.

The retreating ice body in the “Eishalle” released several tree trunks and bones of different animals, which turned out to be remains of different postglacial intervals. The first bone findings were identified as wisent (*Bison bison bonasus*) and elk (*Alces alces*), mixed with vertebrae of cattle (*Bos primigenius cf. taurus*), showing marks of modern slaughtering. A wisent femur was radiocarbon-dated to 2228 ±50 yr BP (400-280 cal yr BC, 2σ range). In this region, remnants of both, wisent, and elk frequently occur in caves with shaft entrances. In contrary, later collected bones of an ancient dwarfed cattle breed (“Bergschecken”) which were radiocarbon-dated in the hope for an early evidence of alpine transhumance, turned out to be recent in comparison to the previous descriptions of its spatial dispersion over time: the result was 242 ± 45 yr BP and the calibrated date (2σ range) shows three probability maxima, among which the period between 1490 and 1690 AD seems to be the most probable (56.8 %).

The tree trunks were encountered in a wide range of different conditions. Cross sections of two different spruce trunks were cut for dendrochronological dating, which was not successful yet and in one case caused by a too short tree-ring series. However, radiocarbon dating of a partly decayed sample yielded a surprisingly old result. Due to this result the spruce tree (length of tree-ring series: 202 yr) grew between c. 3100-2905 and 2900-2705 cal yr BC (2σ range). This does not only represent one of the oldest reported dates of wood found in alpine ice caves but suggests also long periods of continuous ice cover with possibly only short interruptions, because the trunk fell into the shaft doline nearly 5000 years ago.

## *The application of D.C. resistivity sounding in two Alpine ice caves*


***H. Hausmann [1], R. Supper [2], A. Ita [2], A. Römer [2], T. Mistelbauer [1]***

*[1] Institute of Geodesy and Geophysics, Vienna University of Technology, Austria*
*[2] Geological Survey of Austria, Vienna, Austria*



Alpine ice caves host up to several meter-thick ice fillings which may have recorded palaeoclimatic information. However, age, formation, and development of the ice are not fully understood and are subject to relatively recent investigations. Studies focused on D.C. resistivity measurements of glaciers and ice sheets concluded that temperate glaciers and cold glaciers/ice sheets can be differentiated by their specific resistivities. To characterize the ice and its formation some authors speculated that congelation ice, sedimentary ice, and metamorphic ice correspond to ice with low, high, and extreme resistivity values, respectively.

In this study we tested the applicability of D.C. soundings to underground ice in two Alpine ice caves (Dachstein-Mammut Cave and Beilsteineis Cave, Northern Calcareous Alps, Austria). Measurements of both ice fillings show very low currents (µA range) producing extreme high resistivity values in the order of MΩm. We discuss the potential conduction mechanism in relation to our observations and possible implications for similar studies of the cryosphere. We conclude that D.C. resistivity soundings are not applicable for the characterisation of ice fillings in caves.

# *Microclimatological survey of the Ice Gulch in the White Mountains, New Hampshire, USA*


## *D. Holmgren, A. Pflitsch*

*Workgroup of Cave & Subway Climatology, Department of Geography, Ruhr-University Bochum, Germany*


Due to their change from the ice-buildup phase to the ice-depletion phase during the year, ice caves, such as the Schellenberg ice cave in Bavaria, can be seen as an outstanding climate indicator for short-term and long-term changes of the climate of their respective region. Alongside the frequently well-known and often enlarged showcaves there are also so-called ice gulches, in which we can find ice-bearing parts during the whole year due to their extraordinary topography. The significant feature of these ice holes or little cave-like formations often situated in the talus pseudokarst is that the ice can persist at altitudes far below the summery snowline. During the fall of 2008 the Workgroup of Cave & Subway Climatology of the Department of Geography of the Ruhr-University Bochum started, in cooperation with the Mount Washington Observatory in NH (USA), a microclimatic analysis of a perennial ice carrying gulch in the White Mountains.

The so-called "Ice Gulch" is a gulch situated in the Appalachian Mountains of North America with an east-southeast alignment and an average hillside inclination of 14%. The site is located 16 km north of Mount Washington in NH on the eastern flank of Mt. Crescent at 605-770 m above sea level. Steep towering cliffs about 85-100 m high on the northeastern and southwestern side limit the insolation conditions throughout the year. Additionally, the width of the gulch – about 80 m - reduces insolation. The debris is made up of blocks of granite with an average diameter of about 0.6-1.5 m; in some places blocks can be found in the gulch with a diameter of up to 3 m. Every years new debris blocks fall into the Ice Gulch due to frost wedging.

One characteristic of the gulch is permanent ice between rocks of a former toppling at an altitude of just 670 m above sea level; in contrast, Mount Washington with an altitude of 1917 m is ice-free from May to September. The project's goal is a microclimatic analysis of this particular ecosystem addressing the following questions:

- Determination of the number of ice-bearing holes and caves

- Determination of the thickness of each single piece of ice during the ice minimum in fall and during the peak in spring

- Variability of the ice occurrence and ice capacity in relation to the weather conditions over a period of many years

- Analysis of the microclimate of the gulch, especially in the area of open voids, but also along the negative edges of vegetation, and in comparison with the weather conditions in the region.

Since October 2008 studies based on measurements of temperature loggers placed in various places within the gulch have been carried out. During times of potential ice minima and maxima thermal pictures of the blocks of granite and the bodies of ice were taken. From the middle of October 2008 and 2009, as well as from the beginning of June 2009 ice stock measurements on the bodies of ice were conducted to assess the extent and thickness at the times of the potential minima and maxima.

In October 2009 another gulch with a comparable ecosystem was added to the project. The Mahoosuc Notch is located a few kilometers northeast of the Ice Gulch and was also equipped with temperature sensors to add on to the previous researches and to offer additional hints to the understanding of this special environment.
Furthermore, this research is supposed to offer hints about climate change in New England.

# *Transformation processes of organ pipes gravitational sediments in different microclimatic zones of Kungur Ice cave*

***O. Kadebskaya, I. Tchaikovskiy***

*Mining Institute Ural Branch of Russian Academy of Sciences, Russia*

The article discusses the role of microclimate influence on the material constitution of deposition in Kungur Ice cave. Deposition of collapsed slide-rocks under “organ pipes” in different climatic zones were investigated. It was established that rock slide material is of identical composition, and it has different ways of transformation connected with the microclimate. In the cold zone negative temperatures «freeze» transformation processes in calcium and sulfate materials. The main process of mineral formation in this zone is cryogenic mineralization of sulfate and calcium water. The transition zone (with temperatures above 0°C and up to 3°C) is distinguished by the presence of authigenic calcium breccias and various gypsum forms in slide-rocks. In the warm zone complete dissolution of gypsum and partial dissolution of carbonate debris occurs. Later on, changes of palaeoclimatic conditions in the karst cavity can be identified by deposits bearing climatic markers.

# *Glaciochemical investigations on the subterranean ice deposit of Vukušić Ice Cave, Velebit Mountain, Croatia*

**Z. Kern [1], I. Fórizs [1], N. Horvatinčić [2], É. Széles [3], N. Bočić [3], B. Nagy [4], P. László [4]**

[1] *Institute for Geochemical Research, Hungarian Academy of Sciences, Hungary*
[2] *Laboratory for Measurements of Low-level Radioactivity, Ruđer Bošković Institute, Zagreb, Croatia*
[3] *Institute of Isotopes, Hungarian Academy of Sciences, Budapest, Hungary*
[4] *Department of Physical Geography, Eötvös Loránd University, Budapest, Hungary*

Vukušić Ice Cave (Vukušić snježnica, 44.8N, 14.98E 1490 m asl) is located near the Zavižan Peak in the north part of Velebit Mountain, Croatia. The thickness of its ice deposit is estimated to be more than 10 m. We investigated the perennial ice accumulations to evaluate the potential of the preserved glaciochemical signal for palaeoclimatological reconstructions.

Two drill cores (2.4 m and 26 cm long) were extracted from the ice deposit on 28.10.2008. The upper 2 m long segment of the 2.4 m long ice core was partitioned into 36 sections.

Tritium activities of the deepest 40 cm long section of the 2.4 m ice core and of the total section of the 26 cm ice core of the deposit were analysed using electrolytic enrichment. The results from the lower and upper samples are 1.8±0.5 and 9.9±0.6 TU, respectively. The tritium activity of the upper sample agrees with the mean tritium activity of the local (sub)recent precipitation. The tritium activity of the lower sample indicates a contribution of "modern" (post-1953) precipitation. This means that the ice accumulated from precipitation which fell around 1950-55, or the section is significantly older and "modern" water percolated and contaminated the deeper layers.

Four outcropping wood macro remains (branch, trunk) were sampled from the overhanging ice wall and one was penetrated by the drill at 1.4 m below the ice surface. The deepest sample (ca. 4.2 m below the surface) was radiocarbon-dated. The conventional date is 197±50 yr BP, and the calibrated age ranges are 1640-1690 (17.7%), 1730-1810 (39%) 1920-1960 AD (11.5%).

Stable isotopic data ($\delta^{18}O$ and $\delta D$) of the 36 cave ice samples range from -11.97‰ to -8.02‰ and from -82‰ to -53.1‰ (vs. VSMOW), respectively. This range and the derived isotopic waterline of cave ice agree reasonably well with the corresponding data of the local meteoric water line (Zavižan 44.82N, 14.98E, 1594 m asl.) collected over the period September 2000 – December 2003.

Concentrations of 45 elements were analysed using a double-focusing inductively coupled plasma sector-field mass spectrometer and 41 chemical species were above the detection limit at least in one sample out of the 36 analysed samples. Elevated concentrations were generally found in the uppermost sample which included the surface mud cover and in the sample above the intercalated wood where higher mud content was also observed. Fluctuations of concentrations along the profile are discussed for a few elements.

# *Isotope hydrological and geophysical studies on the perennial ice deposit of Saarhalle, Mammuthöhle, Dachstein, Austria*

**Z. Kern [1], I. Fórizs [1], M. Behm [2], H. Hausmann [2], M. Molnár [3], B. Nagy [4], R. Pavuza [5]**

[1] *Institute for Geochemical Research, Hungarian Academy of Sciences, Budapest, Hungary*
[2] *Institute of Geodesy and Geophysics, Vienna University of Technology, Austria*
[3] *Institute of Nuclear Research of the Hungarian Academy of Sciences, Hungary*
[4] *Department of Physical Geography, Eötvös Loránd University, Budapest, Hungary*
[5] *Department of Karst and Cave Science, Museum of Natural History, Vienna, Austria*

A 6.25 m long ice core was extracted from the ice deposit of Saarhalle, Mammuthöhle on 01.09.2009 using a manual drilling equipment. The main scopes of the research are (1) to survey the internal structure of the ice block, (2) to gain new and more detailed information about the origin of the water taking place in ice formation, and (3) to assess the potential of the perennial ice accumulation for future environmental studes. Ground penetrating radar (GPR) was employed to locate the site with maximum ice thickness.

The core was sectioned into 105 subsamples each representing a ca. 5 cm section of the deposit.

Tritium activities were measured on water melted from eight non-neighbouring samples of the upper 1.8 m, using a liquid scintillation counting (LSC) technique. Tritium activity has not reached the detection limit (8.5 TU) in each sample. These results suggest that water originated from the precipitation fallen in the 1960s is not present in the core. Since then the tritium content in precipitation had reached the ca. 5000 TU level, being still high (>100 TU) at the present time. Most probably the topmost layer of the Saarhalle ice block is older than 1953, the start of the anthropogenic tritium deposition. This is in accordance with the observations of regular ice level monitoring of Saarhalle, inasmuch as the ice surface is continuously decreasing since the start of the observations in 1996.

Stable isotope ratios of hydrogen and oxygen were measured using a Finnigan DeltaplusXP mass spectrometer in continuous flow mode. Final results are available for 79 samples for $\delta^{18}O$ and of 69 samples for $\delta D$. Stable isotopic data of the cave ice samples range from -12.95‰ to -9.50‰ and from -92.8‰ to -66.2‰ (vs. VSMOW) for $\delta^{18}O$ and $\delta D$, respectively. The derived equation of the isotopic waterline is $\delta D = 8.15 * \delta^{18}O + 11.17$. The isotopic range and the derived isotopic waterline of cave ice agree reasonably well with the precipitation data of the nearest GNIP stations at comparable elevations (e.g.m Klagenfurt, Hohenpeissenberg, Garmisch-Partenkirchen).

The GPR measurements from September 2009 are compared to previously (January 2007) derived data from the same location. We found significant differences which may be caused by an increased amount of melt water in the uppermost part of the ice deposit during the summer period. A pronounced layer within the ice in ca. 2-3 m depth correlates with the inclusion of liquid water as obtained directly from the drill core.

## *Svarthammarhola, a dynamic ice cave in northern Norway*

**S. Lauritzen [1], L. Baastad [1], J. Bjørlien [1], P. Holmlund [2]**
[1] *Department of Earth Science, Bergen University, Norway*
[2] *Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden*

Svarthammarhola, the largest natural cave room in Scandinavia and one of the lowest-altitude ice caves in Europe, is situated 275 m a.s.l. (ca N 67° 12'; E15° 30' ) close to Bodø, Norway. The cave has two main entrances at a Δh of 40 m, sufficient to drive thermal winds and support a perennial ice mass of some 4000 $m^2$. The ice has a stratigraphic thickness between 5 and 20 m and has a complicated cut-end-fill stratigraphy as exposed in a 13 m-tall ablation wall. Radiocarbon dating of plant debris at the base of the ice suggests that ice accumulation commenced after AD 1200. The cave was surveyed and an instrumental monitoring program was initiated in 2004. In early 2005 the ice mass was drilled, resulting in a continuous 5 m ice core.

Dating attempts were done by trace-element profiles and radiocarbon-dating of insect and plant fragments. Our results demonstrate that the ice mass is rapidly ablating, and since 2005 some 30-50 cm have been lost from the top surface, and paintmarks suggests that a total of 3 m might have been lost since about 1980. In any case, our observations suggest an accelerating ablation rate. Mapping of cryogenic carbonate powder revealed the possible maximum extent of the ice, which previously filled almost the whole passage. We have demonstrated that the main accumulation period of the ice is in fact during spring snowmelt, when surface meltwater enters a deeply undercooled cave. Ablation takes place during summer and fall. An ablation tunnel underneath the ice mass is basically created by an invading stream. Smaller, but still substantial changes beneath the ice mass can also be demonstrated from older cave maps and photographs. We have evidence that the ice is ablated also from its underside, as demonstrated by small ablation air vents at the base of the ice and basal temperatures above zero in a thermistor chain that was immersed and frozen into the drill hole. A new chamber, some 7 by 3 m, has emerged between rock and ice since 1993. Sub-ice air vents display high radon concentrations compared to the rest of the cave, suggesting a component of geothermally heated ground air. An attempt to correlate heavy metal profiles in the ice with known commencement of copper smelting in the area failed, and can be explained by the fact that this event was ablated away and was thus not recorded in the core. Huge cut-and-fill structures in the ice wall suggest episodes of heavy ablation as well as periods when this part of the cave was an ice lake. Thermal winds are driven by temperature differences, with maximum wind velocities at one entrance of 9-10 m $sec^{-1}$. Thermal winds are strongest in winter, and the system goes through oscillatory phases, "spring and fall inversions" between the summer and winter regimes. Data from a surface weather station above the cave suggest that a temperature difference of some 3-4°C is sufficient to drive (and reverse) thermal draught.

The cave contains large amounts of rockfall, cryogenic scree, and laminated glacial silt. We are now systematically dating rockfall events using calcite crusts. Many large blocks show subaerial weathering that may have lasted since the last or previous interstadials. The cave is heavily used by uncontrolled tourism. The ice mass is ablating faster than it can be disturbed by man, but the large areas of previously intact subaerially weathered scree and glacial laminates are now almost completely demolished by trampling. A simple layout of preferred paths might have helped in the situation.

## *Climatic control on cave ice mass balance, Monlesi ice cave, Switzerland*


### *M. Luetscher [1, 2], F. Bourret*

*[1] Institute of Geology and Palaeontology, Innsbruck University, Austria*
*[2] Swiss Institute for Speleology and Karst Studies (SISKA), Switzerland*


It is increasingly accepted that fluctuations of subsurface ice mass balances depend directly on the hydrological and thermal regimes experienced by the cave during the winter half-year. While the comparison of historical survey data allows to identify long-term trends, sometimes covering several decades, only few studies actually link the subsurface ice-mass balance to meteorological forcing parameters. Such data are nonetheless indispensible to conceive predictive models of the evolution of cave-ice deposits under changing climatic conditions, or, more generally, to understand the development of sporadic permafrost occurrences.

Over the last decade, Monlesi ice cave (Jura Mts., Switzerland) has been studied extensively to delineate heat fluxes controlling the cave ice mass balance. Results allowed quantification of the energy balance over an annual cycle and point out the major role played by forced convection for the preservation of the cave ice deposit. Based on this model, we explore here the long-term evolution of the cave ice and its dependency on the synoptic meteorology. In particular, the study aims at determining if the North Atlantic Oscillation imparts on the formation of cave ice.

## *Glaciological and climatic studies of Moncodeno ice cave (Italy)*

***V. Maggi [1], S. Turri [2, 3], A. Bini [2], B. Stenni [4], R. Udisti [5]***

*[1] Environmental Sciences Dept., University of Milano-Bicocca, Italy*
*[2] Earth Sciences Dept., University of Milano, Italy*
*[3] Parco Regionale della Grigna Settentrionale, Lecco, Italy*
*[4] Geosciences Dept., University of Trieste, Italy*
*[5] Chemistry Dept., University of Florence, Italy*

Ice deposits in caves, as glaciers of mid latitudes, represent a promising archive for environmental and climate information. Ice cave deposits can be found at low altitude, below the snow line, because of the very conservative hypogean environment. These deposits are usually located deep in karstic areas, widespread throughout the world, and under optimal conditions they allow collecting natural and anthropogenic information on stratified ice deposits. Many Italian caves, mainly in the Alps, preserve ice deposits at great depth. In these environments, some glaciological, stratigraphical, climatic, and environmental studies were recently performed. In the Moncodeno area (Grigna Settentrionale, Lecco, Italy) ice caves were found about 1800 m a.s.l., close to one of the most industrialized areas of the world (Lombardy). In the LCLO1650 ice cave, more than 20 m of stratified ice deposits originated from water dripping were found at 80 m depth in a vertical shaft without direct contact to surface (2330 m a.s.l.). Stable isotope and major ions analyses from a shallow ice core were performed to understand the formation and evolution of this ice body and to compare it with data from ice core records of alpine glaciers.

## *Cave glaciation in the past*

***B. R. Mavlyudov***

*Institute of Geography RAS, Russia*

Using examples of all three main types of caves with permanent snow and ice formations (horizontal, descending, and vertical) cave glaciation dynamics during the past several centuries in different countries are discussed. Glaciation in all caves types has a very close connection with the outside climate and first of all with the air temperature without dependence on the cave location. As cave glaciation changed almost synchronously in all types of caves during the past several centuries it allows to conclude that in the past cave glaciation changed also synchronously. This opens favourable possibilities for cave glaciation modelling in the more distant past.

## *First results from an ice core drilled to bedrock in the Eisenriesenwelt cave, Austria*

***B. May [1], C. Spötl [2], D. Wagenbach [1], Y. Dublyansky [2]***

*[1] Institut für Umweltphysik, University Heidelberg, Germany*
*[2] Institut für Geologie und Paläontologie, University of Innsbruck, Austria*

Investigations into the genesis and dynamical properties of cave ice are essential for assessing the climate significance of these ice bodies. Aimed at tackling this open question in the framework of the AUSTRO*ICE*CAVES*2100 project we drilled an ice core through a horizontal, 7.1 m thick ice layer of the Eisenriesenwelt cave. In addition to the optical core inspections, quasi-continuous measurements comprised ice density, insoluble impurity contents, stable water isotope ($\delta D$, $\delta^{18}O$), and electrolytic conductivity profiles supplemented by specifically selected samples analysed for tritium and radiocarbon. Main features of the visible core stratigraphy are impurity horizons (mainly made up by cryogenic calcite precipitates) and a change of large, irregular air bubbles in the upper 4 m to small, spherical ones in the lower core section. This partition is also evident in the isotope profile (showing larger variability and a higher mean in the upper part) as well as in the total ion content (overall tending to decline in the lower section). Our attempts to constrain the maximum age of the ice via radiocarbon analyses of the particular organic impurities gave no reasonable results (percent modern carbon values are broadly independent of depth), which was most likely due to the extremely low organic matter content and possibly the use of organic drilling fluid. No tritium could be found above the actual natural level, though the bomb-derived fraction strongly peaked around 1963. This finding clearly indicates a significant net ice loss during recent times in accordance with documentary evidence. Referring to the detailed isotope and impurity depth profiles we will address the potential climate signals inherent to the investigated ice body including the prospect obtaining a useful chronology.

# *Rapid changes of the ice mass configuration in the Diablotins ice cave – Fribourg Prealps, Switzerland*


## *S. Morard [1], R. Delaloye [2], M. Bochud [3]*

*[1] Geography Unit, Department of Geosciences, University of Fribourg, Switzerland*
*[2] Geography Unit, Department of Geosciences, University of Fribourg, Switzerland*
*[3] Geology Unit, Department of Geosciences, University of Fribourg, Switzerland*
*[3] Spéléo-Club des Préalpes Fribourgeoises (SCPF), Switzerland*


Located at 2000 m.a.s.l. in the entrance zones of the very deep Gouffre des Diablotins (-652 m), the Diablotins ice cave is the most important massive ice volume known in the Fribourg Prealps (Switzerland). Most part of the ice (estimated to about 100 $m^3$) is encountered 10 m inside the lower entrance of the cave and extends discontinuously into a lower horizontal gallery for about 40 m until the intersection with a vertical well leading to the upper entrance 100 m above.

The particularity of this ice cave is founded in the rapid changes of the ice mass configuration observed during the last two decades and recorded in the archive of the SCPF. In 1983, the lower gallery was plugged by ice. However, in the summers of 1991 and 1992 the ice volume was very low, allowing intense explorations of the karstic network during these years. Since 1994 the ice mass has sharply increased making it difficult for speleological explorations, and in 1995 the lower gallery was plugged completely. Since then it has been impossible to reach again the intersection with the vertical well from the lower entrance. In 2005, important quantities of water was observed in the lower gallery and since 2007 cold airflow was again perceptible along the ice mass. In June 2009 ice continuously plugs the gallery, but in fall 2009 it was possible to penetrate the ice cave beyond about 20 m to an intermediate room with a particular flat ice ceiling. Ice stalactites and clear ice with occasional bubbles and huge ice crystals point to the congelation origin of ice. Several ice ablation forms attributed to air circulation – such scallops, hollows and oval mound-shaped elevations – were also observed in the ice mass.

In order to better understand the processes occurring in this dynamical ice cave, the lower entrance was equipped in 2009 with several devices to measure airflow characteristics (temperature, humidity, velocity, and direction), rock temperature, and external air temperature. First results show that a chimney-effect ventilation system currently operates in the ice cave: the air flow direction reverses in the lower entrance when the external air temperature crosses a threshold of about +2°C. Important cooling and drying phases were thus recorded in early winter.

In addition to these direct measurements, winter meteorological conditions were reconstructed between 1980 and 2009 in order to estimate the causes of the rapid changes observed in the 1990s. Data were provided from nearby meteorological stations of the Meteoswiss network.

Assuming that the climate of the ice cave is mainly influenced by winter conditions and that air circulation plays a major role in its behavior, the analysis is based on three main hypotheses: (1) cold winters favor the refreezing of percolation water, (2) the level of relative humidity of air play an important role on the rate of ice sublimation when the external air is aspirated in the lower entrance, (3) snowy winters provide more percolation water for the formation of congelation ice during the period of snowmelt. The results of the reconstruction showed that the winters of 1989, 1990, 1992, and 1993 were mild, less snow-covered, and with dry air conditions. These years correspond to the low ice content period of the ice cave. In contrast, opposite meteorological conditions prevailed during the winters of 1994 and 1995, when a strong increase of the ice mass was observed.

# *LEDs in ice-cave lightning equipment*

**J. Novomesky**

*COMLUX sro – Cave Lighting Systems, Slovakia*

The fast evolution of LEDs in the last 5 years suggests that they will be the light source of the next future. LEDs are energy-efficient, resistant to damage, safe, easy to control, maintenance-free, and have a longer life than previous types of lamps. But even if it is a good light, it is not the "miracle" light that many people hope for and its application should be very sensitive. Effective design, possible simple installation, control, and operation of LED cave lighting equipment (CLE) require a lot of technical knowledge and feeling for nature.

The latest generation of LEDs became suitable for use in ice CLE about 3 years ago. To avoid some of the mistakes that can happen from improper use of this new light source, this study reports some results of our experiments how to provide enough light in the cave without causing strange unnatural colours and the feeling of space deformation.

Experimentation of possible LED white light colours and comparison with previously used lamps suggest that it is necessary to suit the colour temperature of used LEDs (we can now choose between three basic white types) with the main colour of cave walls, to use only LEDs of the best quality with an efficiency above 50 lm/W and a colour rendering index better than 80, to avoid any violent experiments with the light effects and to install the proper quantity of light in the cave. Only this way is it possible to guarantee both, the best visual impression for the visitors and the high protection of caves ecosystem.

# *The mass- and energy balance of ice within the Eisriesenwelt cave (Austria)*

***F. Obleitner [1], C. Spötl [2]***
*[1] Institute of Meteorology and Geophysics, University of Innsbruck, Austria*
*[2] Institute of Geology and Palaeontology, University of Innsbruck, Austria*

Eisriesenwelt opens at the south-facing walls of Tennengebirge (Austria, 47°30N; 13°11E, 1641 m ASL) and is a famous show cave hosting one of the largest underground ice masses in the European Alps. We performed meteorological and glaciological measurements at the distal end of the perennial ice body covering two annual cycles. The data comprise long-wave radiances, vertical profiles of air temperature, humidity, wind speed, as well as ice and rock temperatures and surface height changes, respectively.

The measurement site is located in a widening about 700 m beyond the entrance and is characterized by a fairly horizontal and smooth ice surface. Local ice thickness is about 3m and the rock dome is about 15m above the surface. This provides a unique environment for studies on the conditions and processes determining the existence and development of the ice masses.

Annual free air atmospheric temperature reduced to the elevation of the cave entrance is +3°C while the cave measurement site experiences -0.4°C on average. Seasonal variability is weak as well as the temperature gradients towards the dome and within the ice. Average humidity is close to saturation (99.6%) with significantly lower values during winter when wind speeds are relatively high on the other hand (0.2 $ms^{-1}$). This meteorological background predetermines the mass and energy balance of the ice masses within the cave.

Currently, the ice surface lowers by about 4cm per year reflecting a negative mass balance. The main ablation period lasts from June until November, but there is also some loss during the winter months.

Analysis and preliminary modelling reveal that the development is mainly driven by energy input by net long-wave radiation and the turbulent heat fluxes. Thus, during summer the surface gains energy through sensible and latent heat fluxes both being directed towards the surface. During winter the gain through sensible heat flux is partly compensated by evaporation withdrawing energy and mass at the surface. Molecular heat conduction within the rock material provides energy to the ice from November until April, while withdrawing energy during summer.

Conductive heat fluxes within the ice generally play a minor role.

The measured data also demonstrate that these features are largely controlled by seasonal and short-term reversals of the cave circulation, which in turn are driven by thermally induced pressure changes modified by synoptic weather conditions.

# *Ice cave management - touristic and commercial aspects*


## *F. Oedl*

*Eisriesenwelt Ice Cave in Werfen, Salzburg, Austria*


Although there are pros and cons of running an ice cave in comparison with other caves (lacking ice) the touristic and commercial aspects are quite similar.

- Why open caves to the public?

Caves have – since about 100 years - an attractive (touristic) capacity to people all over the world. Some special feelings in caves like a little bit of scaring and danger, darkness and helplessness on one side and the beauty and all the fascinating sculptures which you do not find on the surface of the world on the other side are some of the reasons why common people are attracted to caves. And cavers want to show "their" cave to the public. To do this, you need money, people who spend their time, legal things to be allowed to run the cave etc, etc. In many cases regional political and official touristic institutes have the main interest and the financial background to open caves as an attraction of their region. Some caves are opened and are operated by idealistic teams and some by private organisations such as Eisriesenwelt. But there is no international "industry" or "global commercial networks" by running caves.

- Earning good money or spending on idealistic ideas?

If running a cave would be a secure way to make money, thousands of investors would have invested in caves. I do not know any cave in the world which has a performance that is strictly directed just do satisfy the investors! Most showcave operators hope to be able to pay the salaries of their employees and the necessary investments. Many showcaves need permanent supply by public institutions. If today's "world ideology" would rule the showcaves of the world, I think that more than 75% of them should be closed. I am sure that almost no cave in the world would have been opened if the initiators were not idealistic people and did not provide an enormous input by their own work and by spending quite a lot of freetime on their cave project.

If internationally known and highly visited caves have reached a level that allows an annual profit it depends on local circumstances and structures for what this profit is used. The development of technical things does not stop outside of caves! And the enormous risks are increasing worldwide. To prevent any accidents of the guests you must look forward and invest in many ways. So you are forced to spend a lot of money to stay on standards of time.

- (Ice) caves "in fight" with other touristic sights?

Every commercial operation tries to increase its business. So it is necessary to be in competition with other touristic sights. If the position of cave tourism should be securd or even extended it is my personal view that you must figure out the specific individualities and characters of caves themselves and you must provide manufactured elements such as "Disneyland" effects. I believe that the interests of public visitors in caves are mostly the pure impressions provided by nature!

## *Updated data on ice development in some Austrian caves*

**R. Pavuza**

*Department of Karst and Caves, Museum of Natural History Vienna, Austria*

Updated examples (since IWIC-II) of ongoing investigations in Austrian ice caves in the Dachstein-, Hochschwab- and Untersberg-Mountain Ranges are presented including ice-level, air-temperature, and further cave-climate measurements, as well as dating of organic remains within and below the cave ice.

In the investigated ventilated caves a roughly constant decline of ice levels could be observed during the past 15 years thus indicating a slightly progressive decline referring to the mass of the ice.

New $^{14}C$-data still indicate that most of the caves of this type experienced at least a minimum of ice levels during late Medieval times. In the investigated "static" ice caves a sometimes less significant, but still distinct loss of ice could be observed.

# *Multi-proxy climatic and environmental record for the last 1000 years in the western Carpathians, Romania*

***A. Perşoiu [1], B. Onac [2], A. Feurdean [3]***

[1] *Department of Geology, University of South Florida*
[2] *Department of Geology, University of South Florida*
[3] *School of Geography & Environment,Oxford University*

Scărişoara Ice Cave (Carpathian Mts., Romania) hosts Earth's largest cave ice block (>100.000 $m^3$, >30 m m thick), with a maximum age of more than 4000 yrs. The ice deposit consists of a sequence of annually laminated layers, each layer containing a couplet of clear ice and sediment strata (organic matter, calcite, soil, and pollen).

A complex research program has been initiated in 2003, which aims to reconstruct the climatic and environmental changes over the past ca. 2000 years, using the ice in Scărişoara cave as the main source of proxy-based data. The investigations include water stable isotopes measurements, pollen analyses, stratigraphic analyses, and radiocarbon dating. Stable isotope and stratigraphic analyses have been carried out on a 22.5 m ice core extracted from the main ice block inside the cave, while pollen was collected from a 15 m-high vertical ice exposure, due to very low concentrations in the ice core. Both the ice core and the ice-wall exposure were radiocarbon-dated. To independently support the ice block-derived results, a calcite stalagmite from the inner, non-glaciated part of the cave has been investigated as well.

Here we present the climatic and environmental history of the past ca. 1000 years, based on the above-mentioned data. Stable isotopes in ice and calcite show a peak of temperature at ca. 1050 AD, followed by a highly variable, but still warm period, lasting for ca. 250 years. After ca. 1350 AD, the climate became slightly cooler then the preceding period, with clearly marked cold periods around 1550 and 1816. The degree of air temperature variability was elevated both during the MWP (up to ca. 1350) and the LIA, but with higher amplitudes during the latter period. The coldest decade was between 1810 and 1820, whilst the warmest was around 1050. Due to intense melting over the last years the upper part of the ice record is disturbed, so that we do not have data for the past ca. 100 years. However, stable isotope measurements of recently deposited ice (2005-2008) yielded higher values than those from the MWP suggesting that the present-day warming is unprecedented in the last millennium.

The results from pollen analyses show the dominance of a forest ecosystem near the cave during the whole period of investigation, *i.e.* the last 1000 years. Between 1000-1500 AD, these forests were dominated by *Fagus sylvatica* with high amounts of *Picea abies, Carpinus betulus*, *Abies alba*, *Pinus, Quercus, Betula, Alnus,* and significant proportions of *Ulmus, Tilia,* and *Fraxinus*. From about 1500 AD onward these forests became dominated by *Picea abies* with only a small proportion of *Fagus sylvatica*, whilst most of the other tree species, notably warm-demanding deciduous species, became rare.

In conclusion, both the isotopic and the pollen record support the picture of highly variable climate over the past 1000 years, with a warm and relatively dry period (MWP) until ca. 1350, followed by a cooler and wetter period between ca. 1350 and 1850, in excellent agreement with other reconstructions for Central and Western Europe. Our results demonstrate the high paleoclimatic potential of perennial ice accumulations in caves and call for rapid action towards investigations in other ice caves, threatened by the currently rising temperatures.

# *Karst and ice caves in the Austrian Alps*


## *L. Plan [1], C. Spötl [2]*

[1] *Cave and Karst Department, Natural History Museum Vienna, Austria*
[2] *Institute of Geology and Palaeontology, University of Innsbruck, Austria*


The territory of Austria has an area of 84,000 km², of which about 22 % are represented by karstifiable rocks, and approximately 14,400 caves have been registered up to now. The Eastern Alps cover about two thirds of Austria and host almost all of the country's karst areas and caves.

The main geological units of the Eastern Alps stretch east-west. The Helvetic Units are restricted to the westernmost part of the country. Important carbonates are of Cretaceous age (Schratten Limestone) forming nice examples of folded alpine karst hosting caves up to a few kilometres long. The Northern Calcareous Alps stretch across the northern part of the Eastern Alps.

They are dominated by sequences of Middle (Wetterstein Formation) and Upper Triassic (Dachstein Fm.) carbonates that often reach a combined thickness of more than 2 km. They host the most important karst areas of the country and often form extensive karst massifs with a spectacular karst morphology. The middle and eastern part of the NCA are characterized by large karst plateaus reaching an elevation of up to almost 3000 m, while the deeply incised valleys separating them lie at ca. 500 to 700 m a.s.l. Most Austrian caves are developed in those areas. The most extensive cave systems may reach lengths of up to 130 km (Schönberg-Höhlensystem) and up to 1.6 km in vertical difference (Lamprechtsofen). 26 caves are longer than 10 km and 15 are deeper than 1 km. Often, these cave systems comprise several levels of conduits and mazes that developed in the Upper Miocene. They formed under (epi)phreatic conditions but are hydrologically inactive now as they lie far above the base level.

Later, vadose canyon-shaft-systems, which are still partly active, intersect the older sub-horizontal parts. Only in some cave systems a low lying hydrologically active epiphreatic level is accessible.

The areas with the highest elevations in Austria, reaching up to 3798 m, are the Central Alps. There, carbonates are present as marbles intercalated with schists and gneisses, as carbonate-bearing schists, and as low-grade metamorphic limestones and dolomites. Contact- or stripe karst settings are widespread. Outstanding caves are the 1145 m deep Feichtner-Schachthöhle developed in a thin, steeply dipping layer of calcareous schists. A comparable situation exists at the 10 km long Spannagelhöhle, where a 20 m-thick slab of marble is sandwiched between gneisses. Both caves are located near actively retreating glaciers.

Further important karst terrains hosting large caves (Lurhöhle, Drachenhöhle) are situated within low-grade metamorphic carbonates of the Grazer Paläozoikum. Although the Southern Calcareous Alps are dominated by limestone, caves are not as abundant as in the northern counterpart. Examples are the Obir Caves, being rich in speleothems, and the 4.5 km long and 690 m deep Klondike-Kloce-cave-system at the border to Italy.

Up to now only some dozens of caves have been attributed to a hypogene – mainly hydrothermal – genesis. Only at two locations, near Hieflau in Styria (Kraushöhle) and Bad Deutsch Altenburg in Lower Austria a sulphuric acid speleogenesis has been revealed.

# *Weichselian non-cryogenic and cryogenic calcites in former pools on ice within the Breitscheid-Erdbach Cave (Northern Hesse, Germany)*

***D. K. Richter, A. Immenhauser, P. Meissner, U. Schulte, I. Dorsten***

*Ruhr-University Bochum, Germany*

Local accumulations of small calcite crystals (< 1mm) and up to cm-sized calcite aggregates are present on the cave floor and on collapsed blocks in the Breitscheid-Erdbach Cave, Germany. The cave hostrock is composed of mid-Devonian Massenkalk and the thickness of the carbonates overlying the cave reaches 30 m. The following sub-types of calcitic speleo-particles are recognized: (a) crystal aggregates characterized by steep rhombohedra surfaces (age: 29.2 ka; Kempe, 2008); (b) moderately transparent to milky single crystals and crystal aggregates with non-planar (convex) rhombohedra surfaces, and (c) several sub-types of milky spherolites. Based on carbon and oxygen isotope data the following clusters are recognized:

Type (a) characterized by a $\delta^{13}C$ value of -6.9 to -7.2‰ and a $\delta^{18}O$ value of -6.9 to -7.3‰; type (b) with $\delta^{13}C$ values of -1.4 to -2.6‰ and $\delta^{18}O$ values of -11.8 to -13.6‰; type (c) with $\delta^{13}C$ values of +0.6 to -0.6‰ and $\delta^{18}O$ values of -14.4 to -18.0‰.

The exceptionally low oxygen isotope values of types (a) and (b) point to $CaCO_3$ precipitation under slowly freezing conditions in the cave (Zak et al., 2004; Richter & Niggemann, 2005).

The fact that different cryo-calcite types are present together points to transport and re-deposition after formation. Significant for the understanding of the processes involved is the fact that type (b) cryocalcites overgrow type (a) calcites (i.e. nuclei of type (a) calcites within type (b) calcites). The following model for the formation of these speleo-particles is proposed: (1) permafrost conditions during the Weichselian cold period; (2) during an interstadial the $0^oC$ isotherm reaches the Breitscheid-Erdbach Cave and an ice body forms in the cave; (3) cave pools form on the ice bodies during climate optima and calcite speleo-particles of non-cryogenic origin (type a) form in these pools; (4) with subsequently decreasing temperatures in the following stadial, the cave pools freeze and cryo-calcites of type (b) and (c) form; (5) during the next interstadial the ice bodies melt and meltwater transports and re-deposits speleo-particles (a) through (c) on the cave floor and collapse blocks.

# *Ichnusa Glacier: new evidence of perennial ice deposit in Steinugleflåget doline (Plura Valley - North Norway)*

***L. Sanna [1], S. Lauritzen [1], R. W. Stanton [2]***

*[1] GEO, Department of Earth Sciences, Bergen University, Norway*
*[2] Cave Diving Group of Great Britain*

Steinugleflåget doline is one the largest karst collapse in Norway, located in Plurdal (Mo i Rana, Nordland), a “classic” karst region on Caledonian marble hosting the >2.5 km long underground course of the Plura river.

In this fluviokarst area, a spectacular South-North oriented canyon fed by the Sprutfossen waterfall (resurgence of the active Jordbrugrotta cave) halts in front of rock threshold. The water reappears downstream from the Vauclusian spring of Plura (400 m a.s.l.) explored by cave divers during the last decade and revealed relatively shallow (< 30 m) and large North-South circular passages. Many of them appear to follow foliation and unloading fractures roughly parallel with the present land surface, but after a cave development of about 1000 m, a South-West oriented deep rift goes down beyond -112 m, halting the exploration. The underground river can be traced towards the river sinkhole in the form of two large collapse dolines, Trollkjerka and Steinugleflåget. The first one is a semicircular collapse opened as on the western side of the Plura canyon, without any cave conduit.

Steinugleflåget is a 100 m-diameter doline (almost at the same depth) with overhanging walls. First described by Oxaal in 1914, its entrance opens at an altitude of 450 m a.s.l., delimited by tensionally curved ring fractures and small graben structures that may penetrate deeper than 200 m below the present land surface. Its bottom, tilted towards North, is completely occupied by boulders. The underground river is accessible on the South side of the karst collapse through a small cave entrance that leads to deep fractures about 100 m below the surface rim of the depression.

A new, detailed survey of the depression has revealed the existence of an ice deposit below about 4-5 m thick choke on the North side of it, not evident from the outside investigation and which develops under the current doline floor.

A narrow descending passage beneath the blocks allows an easy access through an about 50 m-long tunnel developed between this ice body (called Ichnusa Glacier) and the marble rock, where a 5 m-thick succession of clear ice, locally with some boulders, is well exposed with stratigraphic continuity. The accumulation process seems to be represented only by some small seasonal ice speleothems. Air circulation and sublimation are active inside the cave conduit as shown by the large ablation scallops on the ice wall. Also large flaky ice crystals showing crystallographic faces are present both on ice and rock walls. Ice has been observed down to a depth of at least 7 m, where an unexplored shaft drains both ice-melt water and dripping related to rainfalls and seasonal snow melting.

And some years ago another unreported ice body was found by English divers at the base of a boulder choke at the end of the main line of the Plura passage, beyond the tunnel that descends to the West towards the deeper underwater part of the cave. From the cave survey this point is about 70 m North-East from the centre of the Steinugleflåget depression.

These discoveries open new interesting prospects: there is direct evidence that ice formed before the last stages of collapse evolution and the hypothesis is that the ice deposits are a single body which occupies the same level in the Plura karst system, unviable at the moment. Further research and explorations will help to understand more about this extraordinary ice karst environment.

# *Linkage of cave-ice formation to weather patterns inside and outside the cave Eisriesenwelt (Tennengebirge, Austria)*

**W. Schöner [1], G. Weyss [1], E. Mursch Radlgruber [2], F. Obleitner [3]**

[1] *Zentralanstalt für Meteorologie und Geodynamik – Climate Research Department, Austria*
[2] *Universität für Bodenkultur, Institute for Meteorology, Austria*
[3] *Universität Innsbruck, Institute for Meteorology and Geophysics, Austria*

In the frame of the project AUSTRO*ICE*CAVES*2100 the cave weather of ice cave Eisriesenwelt (Tennengebirge, Austrian Alps) was measured by two automatic weather stations and by energy-balance measurements at one station (see Obleitner & Spötl, this meeting) over the period 2007 to 2009. In order to investigate the linkage between the weather inside and outside the cave another automatic weather station was located outside the cave, close to its entrance. This weather station was equipped to measure air temperature, humidity, wind-speed, wind direction, and precipitation, the two stations inside the cave measured air temperature, humidity, wind speed and direction, and ice accumulation/ablation. To increase the information on spatial variability of ice accumulation/ablation in the cave ablation stakes were drilled at 6 locations with unregular readings throughout the project period. Although the environmental and logistic conditions (the cave is inaccessible during winter) resulted in data gaps, the data series are valuable to study patterns of cave meteorology inside and outside the cave as well as related effects on ice accumulation/ablation.

As Eisriesenwelt is used for touristic purposes, the circulation of cave air masses is artificially influenced during periods of cave-entrance closing in summer. In winter, however, a clear linkage between the weather outside and the circulation inside the cave was observed. In particular during weather patterns with approaching cold air masses outside the cave, these air masses enter the cave and increase wind speed with direction towards the inner part of the cave. At the same time cave air temperature significantly decreased. A clear offset in the onset of air movement from the entrance to the inner parts was measured. With increasing air temperature outside the cave the circulation weakens or even stops until the next approach of cold air.

Interpretation of ice accumulation/ablation measurements from stake readings is difficult because of several influencing factors which are not possible to quantify. Still, the measurements show clear ice ablation during summer for several stakes in close distance to the entrance. Accumulation of ice appears to happen between late autumn and spring. From the 3-year period of ice accumulation/ablation measurements in Eisriesenwelt no robust overall trends of ice-mass balance could be derived. Some stakes show a mass loss whereas others indicate a mass gain, but no clear spatio-temporal pattern emerged.

# *The thermal pattern of the Hundalm ice cave, Tyrol*

***C. Spötl [1], F. Obleitner [2]***
*[1] Institute of Geology and Palaeontology, University of Innsbruck, Austria*
*[2] Institute of Meteorology and Geophysics, University of Innsbruck, Austria*

Hundalm Eis- und Tropfsteinhöhle, the only ice-bearing show cave in western Austria, opens at 1520 m altitude on a NW-facing forested slope. The mean annual air temperature at this altitude is ca. 4°C. Developed along a N-S trending subvertical fault the cave consists of a large central chamber - containing massive ground ice - plus a few smaller ice-free chambers. Entry to the cave is possible via a ca. 28 m deep vertical shaft and a neighboring oblique shaft which opens a few meters below and was artificially widened in 1967 to allow for easy access of the tourists.

Despite its rather simple sag-like geometry the Hundalm ice cave shows both horizontal and vertical air temperature gradients which change seasonally. The former is reflected by the thinning and eventual absence of ground ice in N-S direction within a distance of only 30 m. The thickest ground ice (up to 4 m according to steam drilling, locally possibly up to 7 m thick) is present beneath the vertical shaft suggesting a genetic link between the two. The lowest seasonal air temperatures are also recorded at the base of this shaft (-12°C in winter). During summer the air temperature in the ice-bearing parts remains at the melting point, whereas the temperature at the southern end of this chamber rises asymptotically to +1°C until the end of autumn.

A series of temperature sensors installed along the vertical shaft revealed a stratified air column in surface in summer, whereby diurnal temperature variations only penetrate to a depth of ca. 10 m. Down to this depth the two shafts are interconnected allowing for air exchange with the outside atmosphere. Air in the lower parts of both shafts and in the cave proper is decoupled from the outside weather conditions during the warm season (no direct sunlight hits the middle and lower parts of the shafts). Once the outside temperature drops below 4°C descending cool air is recorded also in the deeper part of the shafts by rapid temperature decreases. This pattern leads to the winter regime whereby “old” cave air is replaced by very cold and dense, “fresh” winter air and the summer temperature profile in the shafts essentially reverses.

This cold air anomaly penetrates into the limestone walls of the cave and in-situ rock measurements in a subhorizontal borehole show negative temperatures in 1.3 m depth between December and May. The fact that summer temperatures inside the rock are positive is consistent with the presence (and apparent widening) of the fissure between the walls and the adjacent ground ice.

The cave’s ice reservoir, partly manipulated by the artificial introduction of snow during the winter, appears to decline since several years. In order to monitor the relationship between atmospheric parameters and cave ice-mass balance a weather station was installed outside the cave in May 2008, air temperature is being logged inside the cave, and ice-height measurements are performed since June 2007.

# *Bacterial life in ice and glacier caves*

***B. Standhartinger, B. Sattler, C. Wendlinger, R. Psenner***

*Institute of Ecology, University of Innsbruck, Austria*

The cryosphere reveals a variety of ice ecosystems which can serve as a repository, a refuge, or an oasis for microbial life. Ice caves and glacier caves are now recognized as habitats which require very specific adaptations from microbial communities. The living conditions in these caves are extreme but rather stable, e.g., permanently low temperatures, sometimes extreme chemical conditions, and darkness which excludes the possibility for autotrophic metabolism. The driving force for microbial inoculation is mainly transport by air currents or intrusion by melt water.

In this study a descriptive investigation has been done regarding the bacterial biodiversity and activity. Study sites were Grubsteinhöhle as an example of an alpine ice cave and two glacier caves in Antarctica (Dumar Cave at the Antarctic Peninsula) and Novolazarevskaja Cave (Queen Maud Land). The main difference between the alpine and the polar caves (except for the geographic location) is the stability of the caves itself – the two glacier caves are very dynamic due to constant changes of the ice body. Inside the caves various niches have been sampled including ice cores, sediments, and also air. Results revealed the highest diversity in Grubsteinhöhle which differed substantially from the ice samples of the glacier caves sampled in Antarctica. Moreover, the alpine air samples from within the cave showed very little similarity to the sequences retrieved from the ice. Bacterial activities and abundances showed surprisingly high numbers comparable to mesotrophic lakes.

# *Characterization of the englacial drainage system in Scott Turnerbreen, Svalbardm by speleological mapping and ground-penetrating radar*

***M. Temminghoff*** [1]***, D. Benn*** [2]***, A. Pflitsch*** [3]
[1] *University Centre in Svalbard (UNIS) Longyearbyen, Norway and Ruhr-Universität Bochum, Germany*
[2] *Dept. of Geology, The University Centre in Svalbard (UNIS), Longyearbyen, Norway*
[3] *Dept. of Geography, Ruhr-Universität Bochum, Germany*

In spring 2008 the englacial drainage system of the polythermal glacier Scott Turnerbreen in Svalbard was directly explored using speleological techniques. The storage and drainage characteristics are of fundamental importance for glacier dynamics.

Detailed maps and scale drawings were made to infer the englacial type that was discovered to be ´cut and closure´ which means that a supraglacial stream flowing over the glacier surface incised into the ice. For this to happen incision rates have to be higher that surface ablation rates which is favoured by high meltwater discharges and cool climatic conditions or a think debris cover. The incised canyon becomes isolated from the surface by drifting snow, rafted ice blocks or collapses of the roof. Continued incision allowed the channel to reach the glacier bed where a thick layer of till was found as well as basal crevasses which confirm that Scott Turnerbreen has surged.

In addition to direct exploration ground-penetrating radar (GPR) surveys were performed from the surface with the intention to locate and characterise the englacial channel, the bed and other inhomogeneities like debris bands or water bodies in the ice. The radar images were compared to the drawings of cross sections which were made inside the cave to judge the advantages and disadvantages of both methods.

Although ideas about the character and evolution of englacial drainage systems have been deeply influenced by the theoretical model developed by Shreve (1972), there is no evidence that this model provides a realistic picture of the actual glacial drainage systems.

´Cut and closure´ was identified as the dominant mechanism of englacial conduit formation on uncrevassed regions of polythermal glaciers.

# *Ice cave: experiment of the exploration in Russia*


## *E. Trofimova*

*Institute of Geography, Russian Academy of Sciences, Moscow, Russia*


Climatic conditions of Russia give rise to the wide-spread occurrence of ice caves. The first report about caves with ice lakes, situated in the Urievi Mountains in the Volga river valley, was published in 1689.

In the 18th century cave ice was marked in the Middle and Southern Ural (caverns Kungur, Kapova, Indersky, Ik), in the valley of Yenisei (Yeniseiskaya) and in the valley of Angara (Balaganskaya). With the exception of Kungur Ice Cave, mapped in 1703, the information about cave ice carried a descriptive character.

The 19th century is distinguished on the one hand by an enlargement of the geography of the ice caves: information about ice formation in underground cavities of the northern Ural, Eastern Sayan, in the middle part of the Lena valley and in the Aldan valley emerged. On the other hand, the measurements of external and cave temperatures were realized first in Ledyanaya Ice Cave. A hypothesis about the sublimation origin of cave ices was proposed from the Bolshaya Nizneudinskaya cavern. The “rising” and “descending” types of air circulation into karstic massifs, as well as the geographical conditions of ice formation in the caves on the globe were proposed.

In the 20th century the speleological movement in Russia emerged. This is the reason why a lot of new ice caves were discovered in different regions of the territories of Altai, Kuznetsky Alatau, Western Sayan, Klichkinsky… As a consequence of this, scientific groups studying ice caverns were formed in Moscow, Arhangelsks, Ufa, Irkutsk, Vladivostok, etc., and a lot of data about morphometric and morphological peculiarities of ice caves were published.

In this period the first classifications of the cave ice were elaborated by G.A. Maksimovich, N.A. Gvozdetsky, A.P. Shumsky, V.E. Dmitriev, based on the cave ice origin, its morphology, duration of cave ice existence, as well as the conditions of the origin of the coldness and accumulation of snow and ice in underground cavities. A theory of cave glaciation was proposed (B.R. Mavludov). Long-term observations of microclimate and dynamics of the ice in caverns of the Ural, Belomorsko-Kuloiskoe plateau, Kuznetsky Alatau and Lake Baikal started. As a result of these explorations the influence of both the global climatic changes and the anthropogenic factors on the state of cave ice was revealed.

Only in the 21th century the first experimental data loggers appeared in Russian ice caves: Kungur, Kapova and Pinezhsky. But, unfortunately, until now no reliable data of observations and no isotopic studies of cave ice in Russia are available. In general, the 21th century is characterized by an increase in the awareness of the problems of ice-cave protection, whereas Kungur Ice Cave remains the only excursional route to caves with perennial ice in Russia.

# *Kungur Ice Cave venting schedule*


## *N. Trushkova*

*Organization of the Russian Academy of Sciences Mining Institute Ural Branch RAS, Russia*



An air-depression survey has been conducted in the Kungur Ice cave over three years to analyze the air distribution and its motion. This work resulted in a venting schedule.

The schedule defines the order of interaction and controls governing the venting organization and follows the established procedure for the amount of air calculation, schemes and ways of venting. Measurements allowed to select the most appropriate regime to preserve the natural ice accumulations and to reduce anthropogenic heat in the cave, and also to estimate the through-put according to the season and venting regime.

# *Cave ice in the context of Alpine glacier archives*

**D. Wagenbach [1], C. Spötl [2]**

[1] *Institut für Umweltphysik, University Heidelberg, Germany*
[2] *Institut für Geologie und Paläontologie, University of Innsbruck, Austria*

The most obvious ice bodies in the Alps are the relatively large, temperated glaciers. For glaciological reasons the typical ages of these glaciers are limited to some centuries only. However, much older ice may exist in the highest Alpine summit ranges where the glaciers are non-temperated, frozen to bedrock, and thus possibly holding long-term records on past climate and environmental changes. Alpine cold ice bodies though of relatively small extent and being close to the melting point are found even at lower altitudes in form of miniature ice caps, quasi-static ice patches, rock glaciers, and cave ice. Except for the latter, some of these cryospheric features are known to exist since historical and pre-historical times. Presenting some key findings gained on the Alpine cold glacier ice repository provided by high altitude sedimentary glaciers and various low altitude ice bodies the prospect of Alpine cave ice in providing supplementary clues on past climate condition will be discussed.

# *Comparison of carbonate cave pearls from periglacial zones of Demänovská Ice Cave (Nízke Tatry Mts., Slovakia) and Scărişoara Ice Cave (Bihor Mts., Romania)*

***K. Žák [1], M. Orvošová [2], L. Vlček [3], M. Filippi [1], J. Rohovec [1], B. P. Onac [4, 5], A. Perşoiu [4]***

*[1] Institute of Geology, Academy of Sciences of the Czech Republic, Prague, Czech Repuiblic*
*[2] The Slovak Museum of Nature Protection and Speleology, Slovakia*
*[3] Slovak Caves Administration, Hodžova 11, SK 031 01 Liptovský Mikuláš, Slovakia*
*[4] Department of Geology, University of South Florida, Tampa, USA*
*[5] Department of Geology, "Babeş-Bolyai" University, Cluj/"Emil Racoviță" Institute of Speleology, Romania*

The Demänovská Ice Cave (DIC), Slovakia (main entrance at 840 m a.s.l.), and the Scărişoara Ice Cave (SIC), Romania (entrance at 1165 m a.s.l.) are both located in the temperate zone, with a mean annual temperature above 0 °C. Ice blocks developed in both caves due to specific cave morphology, with a large entrance followed by vertical or downward sloping cave passages, into which the dense, cold winter air sinks and remains trapped.

In the periglacial zone (PZ) of both caves, remarkable accumulations of rounded carbonate cave pearls and micro-pearls occur. These ice-cave pearls differ in many aspects from "regular" types of cave pearls known from non-glaciated caves. The pearls of the DIC and SIC form extensive accumulations, commonly containing thousands of pearls, located typically on the surface of limestone scree. The ice-cave pearls occur at sites where stagnant liquid water cannot accumulate, since any liquid water either rapidly disappears in the talus, or flows away on inclined surfaces. Compared to regular cave pearls the ice-cave ones show a higher porosity (up to several tens of a percent), a less distinct concentric layering, and a larger size and shape variability (polygonal pearls and aggregates of pearls are common).

Pearls of the SIC were studied by I. Viehmann (several papers published 1958–1993). He considered that the pearls of the SIC are formed by accumulation of fine-grained cryogenic carbonate powder in the PZ of the cave. The cryogenic powder was interpreted to be formed by expulsion of the dissolved carbonate from karst water during the formation of cave ice. He supposed that pearls are formed by mechanical accumulation of cryogenic powder, which was washed from the surface of the ice mass during periods of melting. Temperature oscillations in the PZ were considered to be the crucial process necessary for keeping individual pearls separated, due to their seasonal movement under the influence of waxing and waning ice. Pearls in the PZ of the DIC were first noted by F. E. Brückmann (a letter dated from December 1, 1728; published in Wolfenbüttel, Germany in 1749). The locality was later repeatedly mentioned in the literature but never studied in detail.

Pearls of the DIC and SIC were subjected to a comparative petrographic and geochemical study. The chemical composition of pearls dissolved in 2% $HNO_3$ was studied by ICP-OES. In most cases the pearls show higher contents of major (Mg, Mn, Fe, Sr) and some minor elements, as compared to speleothems from ice-free cave sections. The C and O stable isotope values of pearls from both ice caves are practically identical. In the $\delta^{13}C$ vs. $\delta^{18}O$ diagram, data for the pearls plot between the data cluster for normal speleothems from the non-iced part of the caves, and the data cluster of cryogenic powdery calcite collected directly on the surface of the ice blocks, the latter being more enriched in $^{13}C$ due to strong kinetic fractionation processes during its formation. This difference in isotopic composition between the calcite formed during rapid water freezing on the surface of the ice block and pearls contradicts the previously proposed mechanism of pearl formation by simple mechanical accumulation of cryogenic powder. Alternatively, we suggest that the pearls form in the PZ with seasonal temperature oscillations around 0 °C.

Cave pearls forming extensive accumulations in the PZ of ice caves can be considered as one of the "regular" types of secondary cave carbonate formed in ice caves located in the temperate climatic zone. Since repeated water freezing represents a *conditio sine qua non* for the formation of this specific type of cave pearls, we propose the term ‘cryogenic cave pearls’ for them.

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# *Assessment of cave climate and its interactions with karst geomorphology*

***K. J. Vinod***

*Columbia Institute of Engineering & Technology, USA*

Caves, along with other natural features come under conservation and management regimes on the basis of their heritage significance. Chhuikhadan is a recently discovered interesting vertical cave developed in dolomite rocks and having only one upper entrance. The carbonate massif is characterized by the almost complete lack of surface water flow during most of the year and by an important well developed underground and active drainage network. Chhuikhadan is characterised by a succession of some vertical shafts that allow to access a vadose meandering canyon excavated along a normal fault. The cave has a development of 1.0 km and a depth of 110 m.

The aim of the work is to define the importance of condensation processes on the hydrogeological balance of this karst system and to analyse its possible interaction with speleogenetical processes. The cave climate also has an influence on cave morphology, because the evaporation-condensation processes which can be triggered by fluctuations around the equilibrium are able to continuously wet the walls with unsaturated water. The dissolution induced by the condensation is strongly isotropic then very different from that due to water fluxes, and then characteristic morphologies, like the extraction of less soluble rock from the matrix, can result. These observations will allow to collect important information and to stimulate interesting discussions concerning the feeding of the karst aquifer not only by infiltration but also by condensation.

## *Ice formation in the dry part of Ordinskaya cave and some mineralogical characteristics of its underwater part*

***U. Zhakova***

*Natural Science Institute of Perm State University, Perm, Russia*

The underwater Ordinsky cave is located in the Kazakovsky mountain 1.5 km northwest of Orda (the Perm region), in the interfluve of the Iren river and its inflow, the Kungur river.

The total length of known galleries is over 4,600 m. At present it is the longest underwater cave in the world in sulphate rock (plotted by D. Osipov et al., 2007). The ice formations of the dry part of Ordinskaya cave are very famous, too. The author investigated the ice formations in the Glacial Palace grotto of the cave which include stalactites and stalagmites. The ice cover of the lake was also studied. The chemical constituents of the ice are sulfate, calcium, and are pretty much the same as the lake water with prevalent $SO_4^{2-}$, $Ca^{2+}$, and $HCO^{3-}$ ions.

In this paper a boron mineral from the underwater part of the Ordinsky cave is also described; already found in the period of the cave discovery (1997) it has not yet been studied.