RADIOCARBON AGES FROM TWO ICE CAVES IN THE ITALIAN ALPS AND THE ROMANIAN CARPATHIANS AND THEIR SIGNIFICANCE

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Abstract

Some ice cores have been drilled from the perennial hypogean ice deposits found in the «Abisso sul Margine dell'Alto Bregai» ice cave in the Italian Alps and in the «Focul Viu» ice cave in the Romanian Carpathians. A wide range of analyses is being carried out both on the ice cores (ice crystallography, ice chemistry, stable isotopes ratios, pollen content, radiocarbon dating of organic remains) and on the local hypogean and epigean environment (cave and surface climatology, dendrochronology, morphology of the cave ice deposits). Even in caves lacking of readily dateable materials, it has been shown that the wealth of data gathered by the analyses listed above may suffice to set upper and lower bounds to the age of an hypogean ice deposit. In particular, considerations about the epigean environment at the time of ice accumulation can be useful in setting physical constraints to the ice formation process, e.g. by modelling the freezing of an hypogean ice deposit (recognized as lake ice from its textural and crystal fabric features) according to a «Stefan Problem»-like approach. The presence/absence of industrial-related chemical contributions is also important. Nevertheless, the availability of suitable organic samples, which for a vegetal remain cored XX m deep below the ice surface in the Romanian Focul Viu ice cave gave an age of 1790 ± 30 ^{14}C years BP, allows straightforward dating of the ice accumulation time. We believe that the dependence of this ice deposits on hypogean and epigean climate and their present fast mass reduction calls for further studies to be carried out in order to evaluate their suitability in paleoenvironmental and paleoclimatic studies.

Радиоуглеродные датировки льда из двух пещер в Итальянских Альпах и Румынских Карпатах и их значение

Было получено несколько ледяных кернов из многолетних гипогенных льдов из пещеры Abisso sul Margine dell'Alto Brega в Итальянских Альпах и из пещеры Focul Viu в Румынских Карпатах. Был выполнен широкий диапазон исследований как при обработке ледяных кернов (кристаллография и химия льда, соотношения стабильных изотопов, содержание пыльцы, радиоуглеродное датирование органических остатков) так и в местных гипогеных и эпигеных условиях (климатология пещеры и поверхности, дендрохронология, морфология пещерного льда). Показано, что даже при недостатке легко датируемых материалов в пещерах многочисленные данные, полученные из анализов, перечисленных выше, достаточно для того, чтобы установить верхнюю и нижнюю границы возраста гипогенных льдов. В частности, мнение об эпигенных условиях во время накопления льда может быть полезным для выявления граничных условий процесса формирования льда, например, при моделировании намораживания гипогенных льдов (по текстурным и кристаллическим особенностям определен как озерный лед) согласно задаче Стефана. Считается важным присутствие или отсутствие антропогенных химических отложений. Однако, хорошее качество органических образцов из растительных остатков, обнаруженных в скважине на глубине 20 м от поверхности льда в Румынской пещере Focul Viu дало возраст 1790 ± 30 ^{14}C лет назад, что позволяет прямо датировать время накопления льда. Мы считаем, что зависимость накопления этих льдов от гипогенного и эпигенного климатов и их современная быстрая деградация призывают к дальнейшим исследованиям оценки их пригодности к палеогеографическим и палеоклиматическим построениям.

Introduction

Ice caves are a widespread feature occurring in many mountain areas throughout the world. In Europe, they are a common feature of the high mountain karst in the Alps, but they are present from Sicily to the Pyrenees, from the Carpathians to the Urals to the Caucasus, and in the mountain ranges of northern Europe. Ice caves can be found not only in carbonatic rocks, but also in volcanic terrains, where they typically form inside ancient lava tubes. In general, cave ice deposits form wherever the hypogean environment shows favourable conditions in terms of temperature and snow or water availability (for a brief overview of several elements favourable to ice cave formation, and the concept of «cold content», see Mavlyudov, 1989).

Several cave ice deposits show a distinct layering, usually marked either by ice crystallography or by dirt levels composed of mineral debris and, frequently, of organic remains. This suggested to investigate the suitability of these ice deposits as archives of proxy data for local paleoclimate and paleoenvironment studies. The presence of ice caves in mountain ranges near to densely populated areas, as is the case of the Alps and the Carpathians, further points to the possible importance of these deposits as high sensitivity recorders of man-induced signals. In order to correctly interpret the data obtained by studying these hypogean ice deposits, both the age and the genetic process responsible for ice accumulation must be determined.

While the genetic process can be investigated and identified by a range of methods, e.g. ice crystallography, ice chemistry, stable isotope composition, etc. (Citterio *et al*., 2005), the age of the ice is usually hard to determine without a radiometric dating method such as ^{14}C can be applied. Wood from the Eisgruben-Eishöhle ice cave (Austria) was dated to 2230 ± 110 e 5180 ± 130 radiocarbon years BP (Achleitner, 1995); both in the Focul Viu and Scărişoara ice caves (Romania) Kern *et al*. (2004) and Holmlund *et al*. (2005), respectively, sampled wood from the walls of the ice deposits and found it older than one thousand radiocarbon years BP. Common cautions must be exerted in avoiding collection of potentially contaminated samples, particularly to account for the possibility of the onset of bacterial activity on them, which would make the samples appear younger. On the other hand, special care must be paid to avoid dating of recycled samples (i.e., materials which underwent more than one cycle of burial in and exhumation from the ice), which would lead to overestimate the age of the ice. Radiocarbon samples which were buried in ice long time after the organism's death are another possible source of such errors. Snow accumulation in caves and lake ice freezing are two of the most important processes which, when cyclically repeating, can produce stratified deposits several metres or tenths of meters thick and characterized by a relatively simple stratigraphy (as opposed to ice flows produced by the repeated, «onion-like» superposition of frozen water films which can produce extremely complex deposits impossible to interpret when only a single vertical ice core is available).

The two hypogean ice deposits selected for this study each belong to one of these two types: the P50 deposit cored in the «Abisso sul Margine dell'Alto Bregai» in the Italian Aps is composed by lake ice, while the core from the «Focul Viu» cave in the Romanian Carpathians has been drilled in a deposit directly fed by snow entering in the cave.

Description of the investigated ice caves

The entrance to the ice cave Lo Lc 1650 «Abisso sul Margine dell'Alto Bregai» (Fig. 2) is located at an altitude of 2030 m on the northern slope of Grigna Settentrionale (Central Italian Alps), in the Moncodeno high altitude karst area. Field work started in 1999 and developed from a general survey of some caves known to host ice deposits to the drilling of two ice cores in the years 2000 and 2003, and to the set up of an automatic microclimatic station collecting data both from the surface and the hypogean environments down to a depth of 100 m from the cave entrance. The cave has been explored and surveyed in the past decades down to a depth of 192 metres below the entrance. Passages belong to the dominantly vertical infiltration zone of a karstic system decapitated by glacial exaration (Bini, Pellegrini, 1998). The cave begins with a 30 metres deep vertical shaft (P30) whose lowest part is filled by snow. Following to this shaft, an S-shaped meander leads to the shaft. The curved trend of this meander effectively prevents snow from reaching further down into the cave, while allowing air circulation to be active. At a depth of about 80 metres below the entrance, between the bottom of the P50 and the underlying P25 shaft, there is a stratified, clear ice deposit. Presently, this ice block shows a thickness of at least 15 metres and no accumulation process is active with the exception of some small and short-lived seasonal ice speleothems. In this paper we will refer to this deposit as the «P50 ice deposit», which has been the target for the ice coring and for most of our investigations. Through a tunnel in the ice deposit it is possible to reach the entrance of a 25 metres deep shaft (P25). The bottom of this shaft consists of ice, partially covered by rock debris, showing the same stratified ice facies of the P50 deposit. This is the top surface, and the only accessible part of the deepest ice body observed in the cave. Only one insect could ever be found in the ice from the P50 ice deposit, which has been dated by AMS (Atomic Mass Spectrometry) radiocarbon technique.

The Gețarul Focul Viu is the second largest Romanian ice cave (Gețarul de la Scărişoara being the first one). It is located at an altitude of 1120 m in the Padiş karst area (Apuseni Mounts, Transilvania, Romania) and it hosts an ice block composed of layered ice which is directly fed by snow entering from a large collapse doline opening in the ceiling of the main room. On one side the nearly vertical ice wall is not in contact with the rock, allowing direct observation of the ice layering which is mainly marked by darker levels of ice enriched in mineral and organic particles. During wintertime snow entering from the partially collapsed vault accumulates forming a snow cone which only partially melts during the hypogean warm season. Part of the resulting meltwaters seep through the older snow and refreezes. In the more distal parts from the snow feed, bare ice is exposed to ablation. Several tree logs and various organic remains can be observed to partially emerge both from the top and the side of the ice block. Descending into the gap between ice and rock at the vertical northern side of the ice block it can be seen that some of these logs are present in the ice even below the surface. The thickness of the ice block as visible on this side wall is about 20 m, but the necessary presence of the collapsed rocks from the ceiling suggests the actual ice thickness could be lower in the central part of the ice block. A core we drilled in 2004 reached the bedrock, or an impossible to drill across rock debris accumulation, at the depth of about 8.5 m. Several organic samples (wood chips, branches, leaves) were separated during ice core processing and three of them have been dated by AMS radiocarbon technique.

Previous knowledge about the two ice deposits

Comparatively much more data are available for the P50 ice block of the «Abisso sul Margine dell'Alto Bregai» cave than for the one of the Focul Viu ice cave. Citterio et al. (in press, a) reports about the results of a multidisciplinary work carried out on the P50 deposit: ice crystallography showed the ice block was formed by the freezing of shallow lakes one on top of the other, while stable oxygen isotopes and chemical composition suggested the accumulation had took place during the late Holocene, in a comparatively low

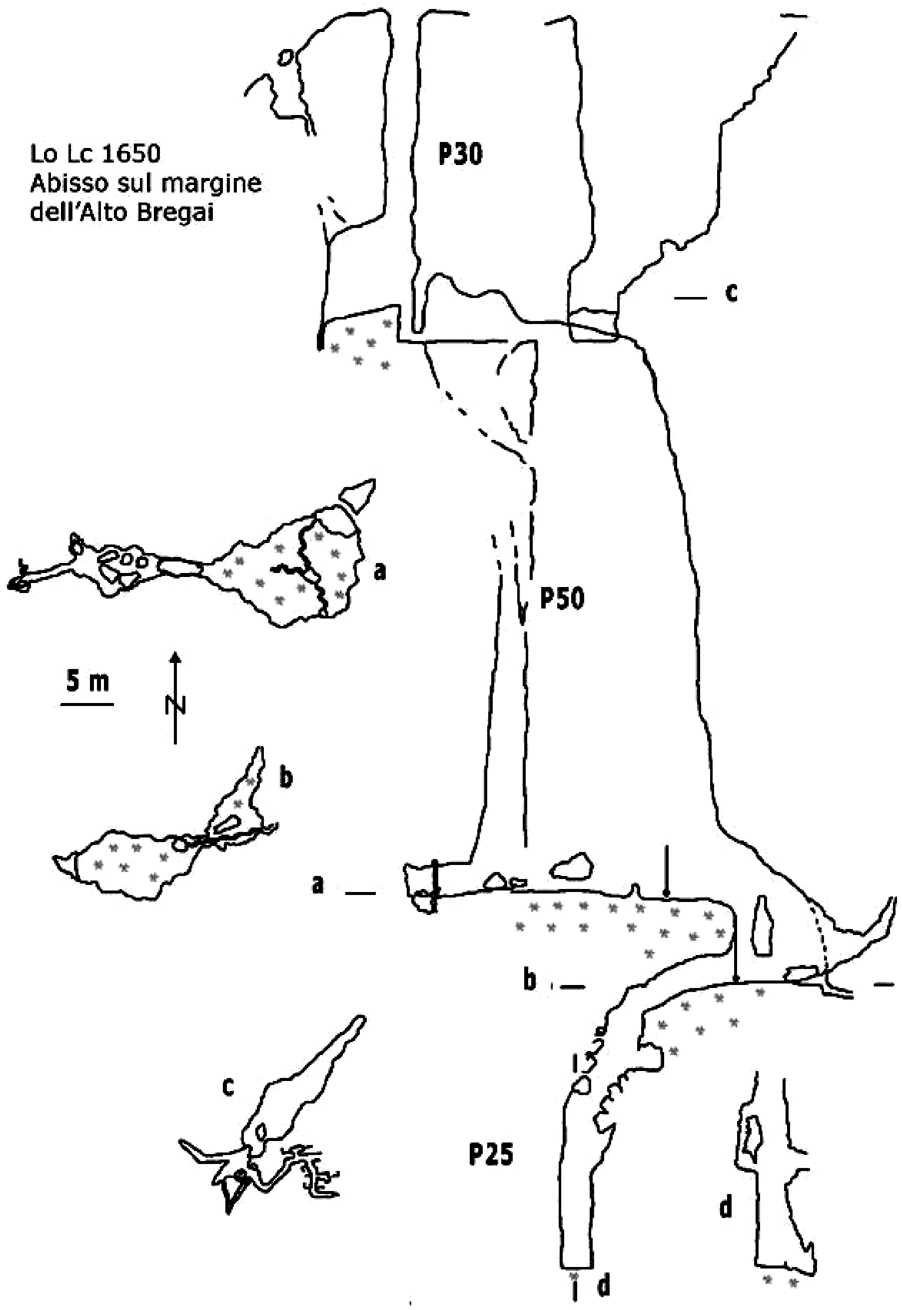

Fig. 1. Survey of the Lo Lc 1650 «Abisso sul Margine dell'Alto Bregai» ice cave (Italian Alps)

vegetation period and prior to the onset of major industrial-related chemical input in the atmosphere. By evaluating a «Stefan problem» - like simplified physical model, Turri et al. (in press) showed that the time required, under reasonable cave air temperatures, to freeze even the thickest observed stratum of ice is compatible with the duration of the yearly hypogean cold season as recorded by the aforementioned automatic monitoring station. Citterio et al. (in press, b) suggest some issues in refining the model by investigating the crystallographic and compositional trends found analysing an ice core, particularly when dealing with subtle compositional changes observed within one thick stratum from the ice core drilled in the year 2000, while at the deposit's thickness scale the superposition and intersection relations surveyed on the ice walls of the englacial tunnel crossing the P50 ice block allowed sketching a relative chronology of at least three accumulation and three ablation phases (Citterio et al., 2003).

Still, no organic sample was available for radiocarbon dating. As for the Focul Viu ice block, Kern et al. (2004) report about the results from an ice core drilled in the ice block. They found ages of 850 ± 50 BP at a -6.67 m depth in the ice core and 1230 ± 40 BP on a sample collected from the side of the ice deposit at a depth of -11.1 m. The samples were wood remains and a branch found in the ice. These findings, together with tritium and stable oxygen isotopes values, allowed them to discuss some hypotheses on long and short term accumulation rates and to suggest that several periods of accumulation and melting must have took place, and that they were responsible for the dust layers visible on the side of the ice block. Being these former results, and even the very fact of the field work execution, not publicly known at the time of planning of our research, initially our study was just aimed at understanding the genetic processes, the present dynamic and, if possible, the history of the ice block. Since the results by Kern et al. (2004) became available, our goals could be extended to evaluate the effects of lateral variability of the processes taking place during the accumulation-melting cycles, by dating new samples from a different core. Moreover, to understand the accumulation processes ice texture and crystal fabric studies are necessary. We thus cored a new, 8.5 m long ice core and carried it to the cold lab in Italy for further analyses.

AMS radiocarbon ages

The only organic sample known to-date from the P50 ice block in the "Abisso sul Margine dell'Alto Bregai" is an insect found in the 2003 ice core.

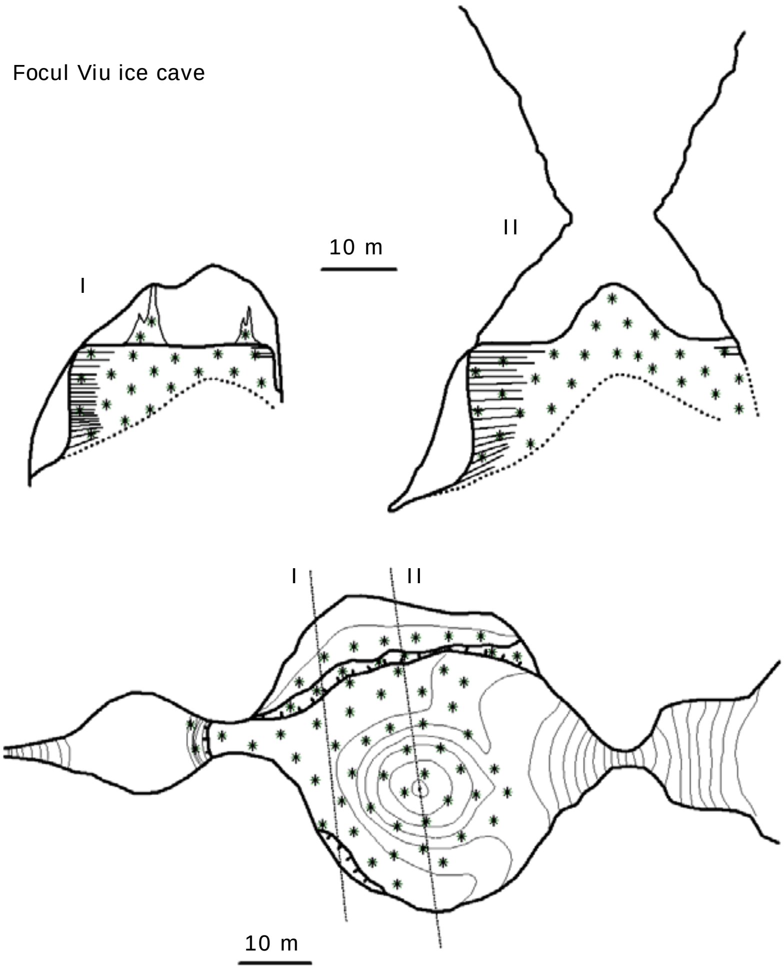

Fig. 2. Survey of the «Focul Viu» ice cave (Romanian Carpathians)

It has been identified as belonging to the gen. Oreonebria, which is still living at the surface in the area, particularly in the vicinity of snow patches (Sciaky, pers. Comm.). The body was found quite well preserved in the ice, the body parts linked by soft tissues being not connected anymore, yet their relative position having been basically preserved. This insect was sent to the Poznań Radiocarbon Laboratory for AMS radiocarbon age determination and it was found to have a radiocarbon age of 185 ± 30 years BP.

Organic material, mostly vegetal remains, is much more abundant in the Focul Viu ice core. Three samples have been sent to the same Laboratory for AMS radiocarbon age determination: a wood fragment from 183 cm below the ice surface, a leaf from the depth of 380 cm and another wood fragment found at 686 cm. Their radiocarbon ages are, respectively, 290 ± 30, 800 ± 30 and 1790 ± 30 years BP.

Discussion

Each of the said radiocarbon ages will need to be calibrated in order to obtain the respective ranges of calendar years they represent, as well as the calibration confidence levels will need to be taken into account when interpreting these data in view of the ice blocks evolution. Nevertheless, even by only considering the uncalibrated values, some interesting observations can be set forth. Beginning with the insect of the P50 ice block (whose radiocarbon age happens to fall in the middle of a wide plateau of the calibration curve), it is quite exciting to

Fig. 3 – The insect (gen. Oreonebria) found in the 2003 ice core from the P50 ice deposit of the «Abisso sul Margine dell'Alto Bregai» ice cave (please note that the abdomen is missing, having been cut in a separate sample). The small marks on the background are 1 mm

observe how the radiocarbon result fits with the qualitative hints derived from all the other methods. In facts, while confirming a late Holocene age (likely, the last part of the Little Ice Age prior to the beginning of large industrial emissions from the surrounding areas), the interpretation of the calibrated radiocarbon age itself can take advantage of the independently obtained knowledge of lacking industrial chemical content in excluding the most recent time intervals which may arise from the plateau of the calibration curve. Finally, the described good conditions of the specimen indicate that it was trapped by ice soon after the death and the transport inside the cave, thus making of it a reliable indicator of the age of the ice.

As for the three radiocarbon ages from the Focul Viu ice block, they are interesting under several respects. First, they are consistent with the hypothesis of a mostly snow-fed deposit growing with a roughly constant accumulation rate combined with compaction of the growing deposit (remember that this deposit is basically fed by snow accumulating in the cave).

However, this argument has to be taken with extreme caution, since a wealth of error sources can be playing a role, e.g.: we still have two few data points; the deposit shows distinct layering marked by dirt levels which may represent deposition gaps or even ablation episodes; despite they plot nicely with one another and against time (fig. 4), the analysed samples may still be reworked (see above) or anyhow not representative of the age of the ice they were taken out from. This last point is worth some more discussion: a large amount of wood and other vegetal remains is found in this as in many other caves, either enclosed in the ice or lying of the surface of the ice deposit; it is perfectly possible for wood to survive more than one cycle of burial in and exhumation from the ice, and this must be taken into account when selecting which sample to collect for radiocarbon dating. In the present study, we considered the dating also of well preserved leaves, which can usually give sample sizes well within the capability of the AMS technique. It is our belief that whenever it is possible, such «delicate» samples should be favoured with respect of wood, and that whenever wood is used, care should be paid at selecting the best preserved samples from a given depth, so as to minimize the risk to date much older wood. Furthermore, all the samples were taken from inside the ice core and handled in a controlled lab environment, thus minimizing the risk of contamination.

When comparing our results with findings by Kern *et al.* (2004), which used both a sample from their ice core and one branch from the ice deposit, a lower slope in the age vs. depth can be observed, which might indicate a higher accumulation rate at that location.

Conclusions

The radiocarbon dating of organic samples from cave ice at two ice caves has given meaningful and interesting data, which fit well with previous results from different techniques and are comparable with the few available published findings. The use of the AMS techniques is necessary when only very small samples are available, as was the case of the Italian cave, and when using delicate samples such as a leaf to avoid the risk of selecting recycled materials. The radiocarbon age of the insect collected from the P50 ice block from the «Abisso sul Margine dell'Alto Bregai» in the Alps was 185 ± 30 years BP, while the oldest sample from the «Focul Viu» Cave in the Carpathians gave a radiocarbon age of 1790 ± 30 years BP.

In spite of all the uncertainties connected with extracting samples from cave ice, we believe our results call for further investigations on both of these deposits, as well as for the radiocarbon dating of other samples (where available) from intermediate depths. In view of the potential role of ice caves in paleoenvironmental studies, and thus of the fundamental importance of reliable datings of cave ice deposits, we urge the researchers working on ice caves to consider performing such analyses whenever suitable samples are available.

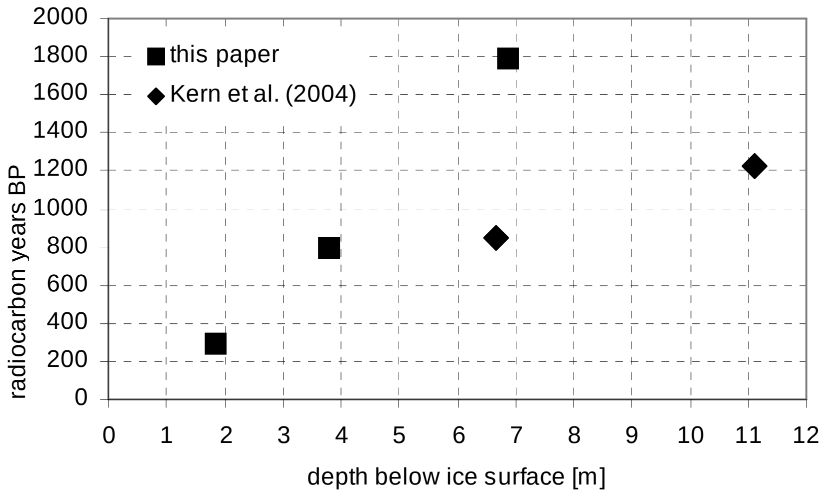

Fig. 4 – Plot of radiocarbon ages vs. depth from the surface of the Focul Viu ice deposit

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