CHAPTER

# 5 DATING CAVE ICE DEPOSITS

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**CHAPTER OUTLINE**



## 5.1 INTRODUCTION

Why do we need to date cave ice? This question might be put by a person who sees in cave ice deposits only spectacular, glittering "decoration" in a weird, chilly "cellar." However, the importance of dating to scientists (paleoclimatologist or paleoenvironmental researchers) is obvious, because they would like to decipher the information about past subsurface and surface conditions encoded in the various environmental archives (chemical composition, pollen grains, macrofossils, etc.) to be found in cave ice deposits. If we want to place the changes found in these environmental archives, as analyzed along particular cave ice profiles, into a time frame and link them to well (or less well) known events from history of the Earth, and of humans on it, a numerical estimate of their age is essential. This dating procedure consists of two main tasks. Firstly, ages have to be assigned to certain levels (reference horizons) along the cave ice profile. Secondly, a model should be developed to assign an estimated age to the ice levels in between the reference horizons, and even out of their range, if needed. The first task is the focus of this chapter. The latter task, so-called age-depth modeling, is a general discipline, has no any specialty for cave ice profiles. However, it is necessary if the temporal fluctuations in any biological species, or chemical compound measured along any sediment sequence, are to be interpreted. If numerical age data have been assigned to a number of reference horizons in a cave ice sequence then

Ice Caves. https://doi.org/10.1016/B978-0-12-811739-2.00005-X

appropriate on-line (e.g., OxCal, Bronk Ramsey, 2008) or desktop (e.g., MOD-AGE, Hercman and Pawlak, 2012) tools are available for age-depth modeling.

It should be noted that there is no special age determination technique designed especially for cave ice deposits. The methods to be applied can be adapted from the usual toolbox of geochronology developed for other terrestrial sedimentary records (Walker, 2005; Rink and Thompson, 2015). Since the methods mentioned in the next few pages might be well-know from other studies not connected to cave ice, any detailed technical description is beyond the scope of this contribution and the theoretical background will be introduced as briefly as possible. However, some space will be devoted to special problems which might be regarded as unique to the cave ice environment.

It must be also kept in mind that any age determination must be interpreted in the context of stratigraphy which can show remarkable difference among cave ice profiles (Fig. 5.1).

## 5.2 DATING METHODS

### 5.2.1 DIRECT DATING—LAYER COUNTING

Cave ice deposits are usually layered. The clearly visible layered structure observed in the ice wall of Dobšiná Ice Cave inspired the earliest hypothesis on layer counting in cave ice sequences (Hanzlik and Ulrich, 1938).

The speleoglaciological processes, which can potentially create seasonal banding in cave ice, derived from firn and congelation ice, which are somewhat different. Firn layers are usually winter deposits and are usually capped with a relatively thinner layer of organic rich detritus, representing deposition during the snow free season. These pairs of layers taken together can be interpreted as annual. The layers of congelation ice typically consist of large, columnar ice crystals. The elongation of these columnar ice crystals belonging to the same layer is parallel and their size is also similar. The usual season of congelation ice development is spring, when water enters into the freezing cave environment. If erosion takes place in the season following this spring ice accumulation, organic and clastic material, and the potentially released cryominerals as well, can form a distinct seasonal marker in the sequence.

However, assuming that annual bands can be designated difference in the age between two levels can be ascertained by simply counting the number of annual bands between the given horizons. In this respect, therefore, the concept of dating by counting the layers of cave ice is similar to any other annually/seasonally layered sediment.

There are rather few published records available on layer counting in cave ice deposits. Counting of the visible layers, thought to be annual, in Ice Cave in Cemniak resulted in a figure of ~400 layers in the mid-1990s. The ~400 years age for that sequence roughly agreed with the palynological information (Rygielski et al., 1995), and no large discrepancy was observed between this and the radiometric results recently obtained from the same deposit (Hercman et al., 2010).

Based on the 4133 counted ice layers, the age of the Dobšiná Ice Cave has been estimated to have an age of ~5000 years (Droppa, 1960). This estimate, however, has not been confirmed by the recent radiocarbon ages derived from the deposit (Gradziński et al., 2016).

Finally, at the Monlesi Ice Cave, the stratigraphical age model (i.e., layer counting) underestimated the age of the basal ice when compared with the result of all other applied methods (Luetscher et al., 2007).

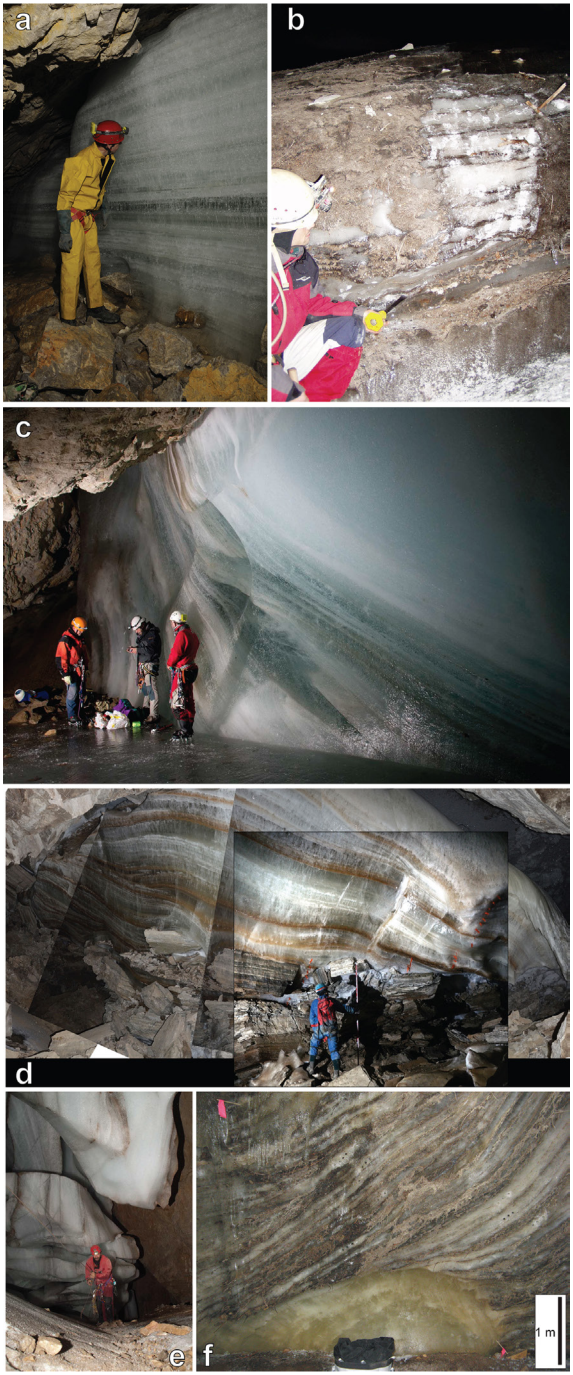


**FIG. 5.1**

Cave ice deposits with different stratigraphical complexity and different abundance of impurity horizons. (A) Ice Cave in Cemniak (Photo: Michał Gradziński, detailed description: Hercman et al., 2010), (B) Bortig Ice Cave (Photo: Balázs Nagy, detailed description: Kern et al., 2009), (C) Veronica Ice Cave (Photo: Manuel Gómez Lende, detailed description: Gómez-Lende, 2015), (D) Walkin-Ice Cave System (Photo: Greg Horne, detailed description: Chapter 15), (E) Hs4 ice block (Photo: Bernard Hivert, detailed description: Gómez-Lende, 2016), (F) Strickler Cavern (Photo: Jeff Munroe).

Special points: Detection of annual banding can be more difficult in congelation ice because congelation ice layers often represent sub-seasonal periods of active ice accumulation, associated, for instance, with specific recharge events. Layer counting is also a challenge in the case of mixed profiles consisting of both metamorphosed and congelation ice layers.

## 5.2.2 INDIRECT DATING

### *5.2.2.1 Mass turnover*

If the basal melting rate of an ice deposit seems to be constant (that is, seems to be forced predominantly by the geothermal heat flux) then the age of the deepest layer can be estimated as the ratio of the maximum ice thickness and the basal melting rate. The existence of a long-term balance between annual mean accumulation at the ice surface and basal melting is also a presumption.

The basal melting rate averaged from 5 years of measurements at three fixed points in the Monlesi Ice Cave resulted in a $8 \pm 2\,\mathrm{cm\,a^{-1}}$ rate of lowering. Given the 12 m thickness of the Monlesi glacier, complete mass turnover was estimated to take between 120 and 200 years (Luetscher et al., 2007).

The basal melting rate in the Dobšiná Ice Cave was estimated to *c.*$1\,\mathrm{cm\,a^{-1}}$ from the lowering of the entrance opening to the artificial Kapluka Cavity from 1.8 to 0.87 m over 100 years (Tulis and Novotný, 2003). The maximum ice thickness of the deposit is 26.5 m (Novotný and Tulis, 1996) so the estimated mass turnover time of the deepest ice layer in the Dobšiná Ice Cave is ~2650 years. A recent study, however, based on radiocarbon dates from bat remains taken from multiple levels of the deposit, suggested only *c.*1280 cal. year BP (c.AD 670) for the oldest ice at present exposed below dated samples (Gradziński et al., 2016). Inferred ice accumulation rates, however, exceed the basal melting rate, the discrepancy of which plausibly explains the overestimation of the mass turnover time in this cave.

Finally, based on multiannual instrumental observations, the basal melting rate was determined as $1.54\,\mathrm{cm\,a^{-1}}$ in the Scărişoara Ice Cave (Romania) (Perşoiu, 2005). Given the ~22 m maximum thickness of the Scărişoara glacier (Holmlund et al., 2005), the complete mass turnover can be estimated to take ~1430 years. In contrast to the case of Dobšiná Ice Cave, it is far below the estimation of an age-depth model based on numerous radiocarbon data (Perşoiu et al., 2017). The reverse relation between the estimated mass turnover time and the statistically estimated age suggest that the long-term ice accumulation rate is below the basal melting rate in this cave.

### *5.2.2.2 Dating the last ~100 years by anthropogenic and/or short-lived radionuclides*

Short-lived radionuclides are widely applied as dating tools and represent an objective control in age-accumulation models in various environments (Carroll and Lerche, 2003).

#### Tritium ($^{3}H$)

Among the aforementioned radiochemical tracers, tritium ($^{3}H$, $t_{1/2} = 12.32$ years) is probably the most frequently used one. Natural tritium is produced in the upper troposphere and lower stratosphere by the influence of cosmic radiation. However, a much greater amount was produced in the course of the atmospheric testing of thermonuclear weapons during the second half of the 20th century. Dispersion of the anthropogenic tritium into the atmosphere started in 1951. However, major deposition of anthropogenic tritium started only in 1953 in Europe. The maximum deposition peak in the Northern Hemisphere was in 1963, when the annual average of the tritium content in atmospheric precipitation was a thousand fold greater than natural occurrence. The maximum deposition in the Southern

Hemisphere was in 1965. Additional minor peaks worth also mentioning (e.g., Central Europe 1975) and can be considered as additional reference horizons in high resolution serial tritium measurement of cave ice sequence.

Tritium measurements have been applied quite frequently to constrain the chronology of cave ice sequences thought to preserve ice deposited over the past 50 years (Horvatinčić, 1996; Borsato et al., 2006; Luetscher et al., 2007; Kern et al, 2007a,b, 2011). Although tritium records were usually conforming to other age constraints, there are some exceptions (e.g., Pavuza and Mais, 1999; Fórizs et al., 2004).

The most complete tritium records, preserving detailed patterns of the characteristic changes of the atmospheric tritium concentration, have been presented from the upper 2.5 m section of the ice deposit of Grotta del Castelletto di Mezzo (Borsato et al., 2006) and from the Borţig Ice Cave (Kern et al., 2009). The excellent preservation of the high-resolution tritium record of the atmospheric precipitation have been confirmed by the replicated record measured in two parallel ice cores in the Borţig Ice Cave (Fig. 5.2).

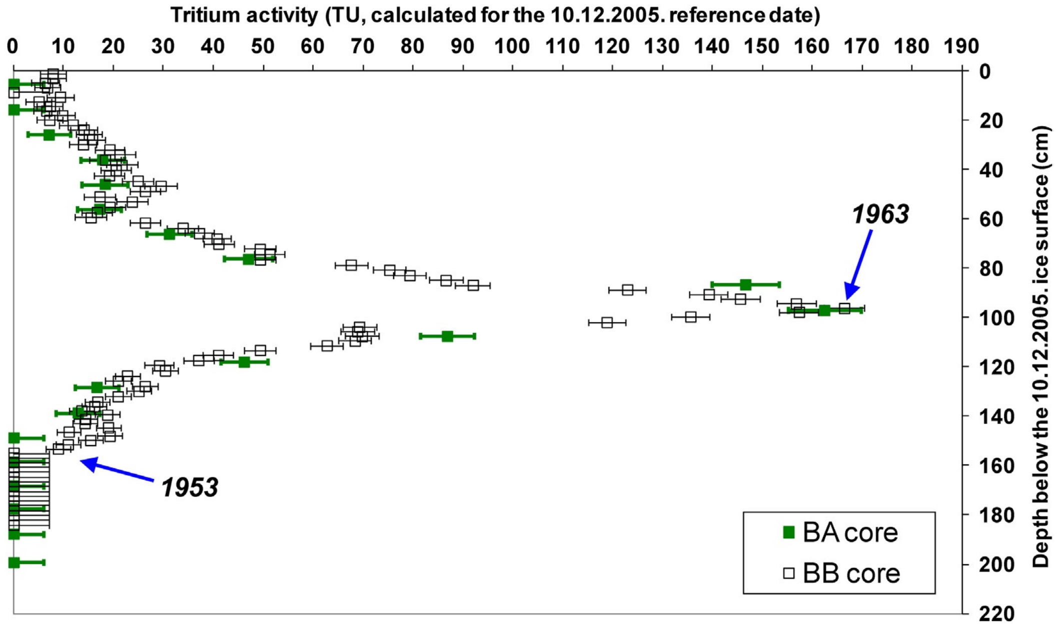


**FIG. 5.2**

Tritium depth profiles of parallel ice cores (*green squares*: BA, 10 cm sections: Kern et al., 2007a, *open squares*: BB, 2 cm sections: Kern et al., 2009) from Borţig Ice Cave. Assigned calendar dates based on the two most characteristic marker horizons, such as the start of atmospheric thermonuclear bomb tests (1953) when the anthropogenic tritium surplus appeared in the atmosphere and the sharp peak (1963) related to the sudden decrease of the anthropogenic emission following the Nuclear Test Ban Treaty, are indicated.

Special points: The method dates the water from which the ice layer was frozen. If the water supply was directly seasonal precipitation, then the age of the water equals the age of the deposition of the ice layer. However, if the origin of the water is the drip water from the karstic conduits, then a significant lag could exist between the date of precipitation event and the deposition of water originating from it as an ice layer in the ice cave due to the storage and travel time of the infiltrated water through the vadose zone (Kluge et al., 2010). This delay needs to be taken into account in a close analysis.

One must use the original tritium date if stable isotopes or water chemistry data are to be analyzed from the ice, as these parameters are very likely to coeval with the tritium age of the water.

The time scale of tritium dating theoretically can be extended by a few decades beyond the era of anthropogenic tritium emission. If the $^{3}H$-$^{3}He$ ingrowth method (detection limit ~0.1 TU; Palcsu et al., 2010) is applied, low levels of tritium content remained from the natural tritium activity (~5 TU in Central Europe) after decay, through 6–7 half-life tritium levels can still be detected.

## Radiocaesium ($^{137}$Cs) and Americium-241 ($^{241}$Am)

These technogenic radioisotopes can provide reliable radiometric marker horizons over the past half-century in undisturbed sedimentary sequences. Neither the radioactive caesium isotope ($t_{1/2}=30$ years), nor Americium-241 isotope ($t_{1/2}=432.2$ years), occur naturally in the environment. They have been produced and released by anthropogenic processes. Their most important global environmental source was the fallout from atmospheric thermonuclear weapon tests (from 1954 to 1963), which peaked in the early-1960s and declined rapidly in terms of intensity after the Nuclear Test Ban Treaty in 1963. Afterwards, the majority of Eurasia was affected by a subsequent deposition of $^{137}$Cs due to the accident at the Chernobyl Nuclear Power Plant (26 April 1986) (IAEA, 1991; De Cort et al., 1998). The magnitude of the Chernobyl Peak in the Eastern European sediments frequently exceeds the mid-1960s level. In case of areas affected by both fallout events, the presence of $^{241}$Am can help distinguish between the time markers, as this was exclusively related to the fallout from nuclear weapon tests (cf. Cambray et al., 1989).

To my knowledge, there has been only one attempt to search for the mentioned $^{137}$Cs reference horizons in a cave ice deposit. Ten samples were analyzed from a 2 m long cave ice core from Ledena Pecina (Montenegro) and no meaningful results were obtained, despite the fact that parallel tritium measurements argued for modern water above ~0.9 m in the core (Kern et al., 2007b). It is highly probable that the $^{137}$Cs was absorbed by organic materials during the infiltration process (e.g., in the topsoil).

Special points: More promising conditions for the application of these anthropogenic radionuclides might occur when the cave ice originates from direct deposition of atmospheric precipitation. If the main water supply is seepage water then the $^{137}$Cs contained in the fallen precipitation is prone be absorption by organic materials during the infiltration process (e.g., in the topsoil).

## Radiolead ($^{210}$Pb)

Fallout-based $^{210}$Pb is one of the most important means of dating recent (<150 years) sediments (Appleby, 2001, 2008). This method is based on the escape of gaseous $^{222}$Rn from the lithosphere into the atmosphere. This radioactive radon isotope decays to $^{210}$Pb. This radioactive lead ($t_{1/2}=22.3$ years) is removed by precipitation from the atmosphere and deposited into sediments where it subsequently decays to the stable $^{206}$Pb isotope. A general decrease of $^{210}$Pb was observed with depth, but anomalously elevated $^{210}$Pb activities were recorded from some ice samples which contained debris in Monlesi Ice Cave (Luetscher et al., 2007). It is a warning sign that soil-derived debris probably corrupts the application of the $^{210}$Pb method for dating ice samples with a high content of clastic sediments. However, estimates based on $^{210}$Pb analyses from clear ice samples in Monlesi Ice Cave gave results comparable to those from other methods (Luetscher et al., 2007), thus warranting further application.

### 5.2.2.3 Radiocarbon ($^{14}C$)

Radiocarbon analysis is a well-known Quaternary dating method, and this is the technique most frequently applied to the dating cave ice sequences, too. The principle can be summarized as follows: living organisms absorb traces of $^{14}C$ during their uptake through the food chain and via metabolic processes. This provides a supply of $^{14}C$ that compensates for the decay of the existing $^{14}C$ in the organism, establishing an equilibrium between the $^{14}C$ concentration in living organisms and that of the atmosphere.

When the organism dies, this supply is cut off, and the $^{14}C$ concentration of the organism starts to decrease due to radioactive decay.

There are two principal measurement methods. Decay counting involves measuring $^{14}C$ using either gas proportional or liquid scintillation counters, and accelerator mass spectrometry (AMS). The reader is referred to the literature dedicated to this theme to get insight into the analytical details or to sample specific pretreatments (Taylor et al., 1992; Hua, 2009).

A widely known difference between these methods which is of great practical importance is in the quantity of material required for dating. While 0.1–2 mg of carbon is sufficient for AMS, 0.5–2 g or more of carbon is required for the radiometric method (Jull and Burr, 2006; Molnár et al., 2013).

Probably $^{14}C$ dating of organic macroremains is the most often applied approach in cave ice deposits. Usually vegetal macroremains are analyzed (e.g., Achleitner, 1995; Horvatinčić, 1996; Fórizs et al., 2004; Holmlund et al., 2005; Maggi et al., 2008; Sancho et al., 2012; Spötl et al., 2014). However, occasionally insect (Citterio et al., 2005; Hercman et al., 2010) or other animal remains (Dickfoss et al., 1997; Yonge and MacDonald, 1999; Gradziński et al., 2016) have been also analyzed.

An interesting approach has been published on ice core derived samples from Eisreisenwelt (May et al., 2011). Although radiocarbon dating on small particulate organic matter separated from the cave ice samples rendered inconclusive, probably due to a background contamination introduced by the applied antifreeze drilling liquid, a crude estimate of a basal ice age in the order of several thousand years could be provided. Despite the modest success, an updated version of this technique probably has more potential (Kern et al., 2016), since the analogue method for surface ice cores has been considerably developed recently (Uglietti et al., 2016).

Finally, when large sets of organic remains are available from a certain ice cave, the temporal distribution of the remains, e.g., the aggregated probability distribution of the calibrated ages (Spötl et al., 2014), or, combined with the dendrochronologically constrained felling date of the larger trunks (see the next section and Stoffel et al., 2009), might indicate major halts in the ice accumulation.

Special points: A crucial prerequisite is the presence of a sufficient amount of organic carbon in the ice. This is an important prerequisite. The otherwise generally easily conducted radiocarbon dating is not feasible in some endogenic Alpine cave ice deposits due to the lack of a sufficient amount of organic carbon in the ice.

A potential source of error or uncertainty can be the spurious radiocarbon activity of the detritus feeding speleofauna, due to the consumption of aged organic litter. They can thus be $^{14}C$ depleted relative to atmosphere, and this will result in older than expected $^{14}C$ ages (Hatté and Jull, 2015). This, in turn, can introduce a shift in the radiocarbon age of the organism similar to that of the reservoir effect of aquatic organisms. To avoid this potential source of error, the superficial terrestrial organic remnants (the foliage and branches of trees and shrubs) is recommended for use in cave ice dating.

An additional factor that needs to be taken into account when a radiocarbon date is to be interpreted, is the potential residence time of the matter before it was deposited in the ice. For example, the decomposition rate of wood can be fairly different depending on species and environmental (e.g., climatic) conditions. It can range from a couple of years to a century. Hence, a piece of wood can be older by a few decades than the deposition date of the stratum where it was found. The decomposition rate of leaves or insects' corpus are much faster, hence, the best temporal agreement between the deposition date of a particular cave ice layer and captured organic matter can be expected from these kinds of remains (see also Section 5.3.1)

A related bias can be introduced when pieces of disintegrating larger trunks are deposited onto the ice surface. A radiocarbon date for these reworked wood fragments could again predate the actual age of the hosting ice layer.

Thick horizons rich in organic material are frequently observed, especially in firn deposits. These horizons usually originate from a longer erosion period and are an aggregate of mixtures of both current organics accumulated during the negative mass balance period and older material released during the erosion of the ice strata deposited before the erosion period. The radiocarbon result of a bulk sample from such a horizon will very likely give mixed results of these components, which can give an older age than the actual age of the negative mass balance period. Separating, again, only leaves, especially those in better condition, might help to avoid the reworked older material. Or, if multiple measurements are affordable, the distribution of single-sample $^{14}C$ results from such a thick organic horizon might reveal the age clusters of both the current and the reworked material.

#### 5.2.2.4 Dendrochronology

Some of the cave ice deposits enclose large quantities of woody macrofossils. Şerban and Racoviţa (1987) suggested first applying dendrochronology in the dating of ice layers in the Scărişoara's ice block.

In line with the general methodological rules of dendrochronology, the wide-narrow pattern of the sequence of tree-ring widths gained from a log trapped in cave ice is to be synchronized with the local/regional reference chronology, ideally with that of the same tree species as the analyzed sample (Speer, 2010). The procedure of this synchronization is called crossdating (Stokes and Smiley, 1996). The accuracy of the crossdating procedure is evaluated by different statistics. It is a fact well-known among dendrochronologists, though still worth mentioning, that samples consisting of only a few rings are useless for dendrochronological dating. The short sequence of tree rings is more prone to provide seemingly better statistics for a false position along the reference chronology than for the real date.

The first successful tree-ring based datings of cave ice-bound logs were presented from the St. Livres Ice Cave (Schlatter et al., 2003) and from the Focul Viu Ice Cave (Kern et al., 2004). However, these studies still neglected the use of startigraphical information. The ringwidth record of a larch log which emerged at the retreating edge of the ice deposits in the Ledena Jama pri Planini Viševnik (Slovenia) has been successfully synchronized to the local larch master chronology (Staut et al., 2016).

A much advanced application of dendrochronology in cave ice study was presented for the St. Livres Ice Cave, Swiss Jura Mts (Stoffel et al., 2009). Combining radiocarbon data with dendrochronological analyses on 45 samples harvested from subfossil logs trapped in the cave ice, four major deposition gaps could be identified and dated to the fourteenth, fifteenth, mid-nineteenth, and late nineteenth centuries.

Special points: A potentially non-trivial antagonism is worth discussing briefly here in relation to tree-ring dating of cave ice captured trunks. The more rings the sample has, the greater the potential for dendrochronological dating. However, the more rings a sample has, in general, the greater its size, i.e., diameter of the trunk, tends to be larger, as well. This results in a strange paradox, as for larger sample, consisting of more rings, we could expect a more accurate chronological match from dendrochronological dating; however, the larger a sample, the less accurate will be the linking of the provided date to a fixed horizon into the sequence. In other words the accuracy of the more precise dendrochronological date can be biased by stratigraphical uncertainty. Two factors should be considered to minimize this uncertainty. Firstly, the date of the outermost ring of the dendrochronologically dated sample needs to be corrected for the potentially missing sapwood rings and by the potential residence time of the sample out of the cave. Secondly, the corrected date should refer to the level of the lowermost point of the trunk in the ice stratigraphy and not to the level of the mid-point of the sample.

## 5.3 SOME PRACTICAL ASPECT

### 5.3.1 SAMPLE SELECTION FOR RADIOCARBON DATING: THE BIGGER, THE BETTER?

When the ice accumulation is located relatively close to the cave entrance, organic material can settle onto the cave ice surface in various sizes, ranging from microscopic pollen grains to large trunks. Aggrading cave ice deposits will cover these remnants, though the required burial time will clearly depend on the height of the object measured perpendicularly to the ice surface, assuming uniform net accumulation over the cave ice surface. This means that thin/small objects can be buried quickly, for instance by the end of the following season, while a decade might be needed for a ~1 m diameter tree trunk to be completely covered by cave ice (Fig 5.3).

Smaller objects (e.g., leaf, cone) can be more suitable for radiocarbon dating because their smaller size provides a better confined reference level in the sequence, and their presumably shorter surface residence time (see Section 5.2.2.3) secures a closer coincidence between their radiocarbon date and their deposition onto the past ice surface. Both factors are valuable in reducing the uncertainty of a developing age-depth calibration in any cave ice profile.

### 5.3.2 A POTENTIAL METHOD—CRYOGENIC CAVE CARBONATE (CCC) LAYERS

Precipitation of cryogenic cave carbonate (hereafter CCC) proceeds at the freezing point and involves rapid or slow freezing of water, rapid or slow $CO_2$ outgassing from a solution, and locally, partial water evaporation. Depending on the freezing rate, and the thickness of the freezing water layer, either fine-grained (CCCfine), or coarsely crystalline (CCCcoarse) precipitation can be formed (for details see Chapter 6).

Lauriol and Clark (1993) approximated the age of two Arctic cave ice deposits based on the radiocarbon activity of their enclosed cryogenic powder. Derived age estimates were supported by independent $^{14}C$ dates on associated animal and plant remains. However, the validity of their assumptions, and the performance of the proposed calculation scheme, still remained untested for other cave ice deposits.

Larger aggregates of CCCcoarse have been successfully dated by the U-series technique, although these were rarely observed embedded in cave ice sequences. The occurrence of CCCfine is a usual phenomenon in sequences of congelation ice. CCCfine frequently forms quite thick interbedded layers in cave ice sequences, offering another potential for cave ice dating.

Hitherto, only one study has tested the suitability of fine-grain CCC for U-series dating. Analyzed samples from Eisriesenwelt (using TIMS in the Heidelberg lab) were too rich in $^{232}Th$ and, given its young age, could not be dated (Spötl, 2008).

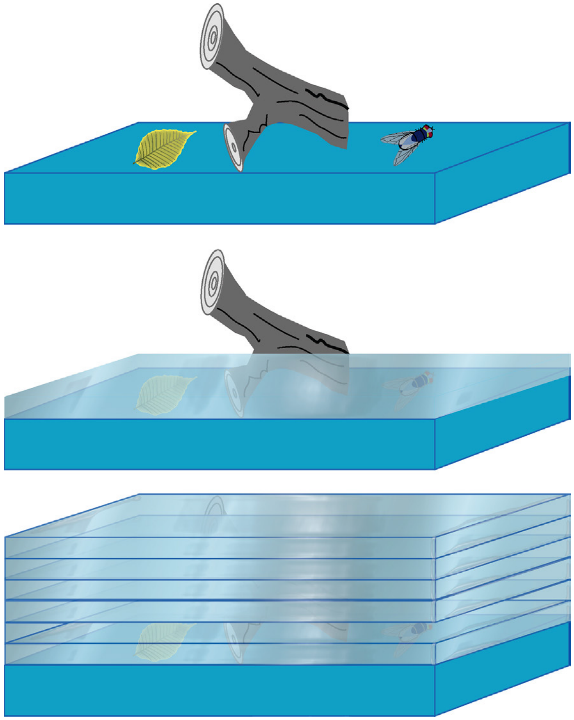

**FIG. 5.3**

Different burial conditions for small size (leaf, insect) samples and a large branch or trunk. Top: Deposition of different sized remains at the same time to the same ice surface. Middle: Subsequent season with a positive mass balance (i.e., net accumulation) is usually sufficient to cover the small size remains. Bottom: Much thicker deposition, laid down by a series of positive mass balance seasons (six in this example), should cover larger size remains. In addition, the larger size remains usually represent a less accurate position in the stratigraphy further complicating the utilization of their derived age estimates in age-depth modeling.

Despite this negative experience, however, careful pre-cleaning to remove potential clay contamination can help to get better results. Another potential problem could be the co-occurrence of microscopic host-rock particles in the CCC accumulation. The separation of CCCfine from host-rock particles is recommended since the old host-rock carbonate could bias the results towards a greater age.

## 5.4 CONCLUSION OR WHAT IS THE RECOMMENDED DATING STRATEGY IN CAVE ICE PROFILES?

Following the above overview, the conclusion cannot be anything other than that a uniform protocol is hardly recommended for the dating of every cave ice deposit. The peculiarities of the studied cave ice section have to be taken into account, and the dating strategy should be designed accordingly. Abundant organic material, for instance, provides a good opportunity for radiocarbon analysis, although a careful selection, focusing on small size and ephemeral samples (such as foliage, small branches, or insects) is recommended on account of their better defined stratigraphical position and shorter expected decomposition time. The conduct of a taxonomical analysis is also recommended before the radiometric dating because the species' ecological demand might contribute to the paleoenvironmental interpretation of the section enclosing the dated specimen, and $^{14}C$ results from a member of the potentially detritus feeding speleofauna could be less suitable for accurately dating the studied cave ice deposit. Individual samples collected from undisturbed stratigraphical locations near to the base of the cave ice deposit can provide useful information for the antiquity, i.e., the expected maximum age, of the deposit. If the temporal changes of the cave ice mass balance history should be detected (potentially betrayed by characteristic stratigraphical patterns), then a series of age determination is needed, obviously.

Tritium activity measurements can have the most potential to detect ice deposited from atmospheric precipitation after the early-1950s. The most characteristic changes of the atmospheric tritium concentration, such as the start of atmospheric thermonuclear bomb tests (1953) and the sharp peak (1963/1964) related to the sudden decrease of the anthropogenic emission following the Nuclear Test Ban Treaty, could provide distinct time markers in cave ice record. Radiocarbon analysis of surface derived ephemeral plant (e.g., foliage and small branch) and animal (e.g., insects) remains is currently the most potentially accurate dating approach for the older cave ice deposits.

Ideally, it is recommended that various methods be applied, and a series of dates be established, for any cave ice profile. The various dating methods could help to detect a systematic bias present in any particular technique. In addition, serial dating could help to detect outliers.

## ACKNOWLEDGEMENTS

Michał Gradziński, Chas Yonge, Greg Horne, Manuel Gómez Lende, and Jeff Munroe are acknowledged for their photo contribution in Fig. 5.1. Thanks to Christoph Spötl for sharing his experience on U-series dating of CCCfine. Thanks for support from the “Lendület” program of the Hungarian Academy of Sciences (LP2012-27/2012). This is contribution No.44 of *2 ka Palæoclimatology* Research Group.

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