RADIOCHEMICAL AND STRATIGRAPHIC ANALYSIS OF TWO ICE CORES FROM BORŢIG ICE CAVE, APUSENI MTS, ROMANIA

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Abstract: We have extracted two 2 metres long ice cores from Borţig Ice Cave on 11th and 12th of December 2005. We have observed ice layers with different physical properties within the cores. The core profile suggested that a less dense, grainy ice and a denser, transparent ice layer are coupling together and form one higher order stratigraphic unit. The tritium activity was measured on water melted from twenty samples of BA core using liquid scintillation technique. The results suggest that the position of the eminent tritium concentration from 1963 was between 81 and 102 cm below the ice surface at the drilling date. Following some calculation we predict that the position of the tritium peak is probably at 95 cm below the ice surface. In addition, we argue that the higher order startigraphic units represent the annual increment at the Borţig Ice Cave.

Finally, we have ascertained three periods since 1950 with different ice accumulation rates: 1 cm/a for 1992-2005; 2.8 cm/a for 1963 – 1992; even higher for 1953 – 1963 period.

Key words: cave ice drilling, tritium measurement, ice accumulation rates

INTRODUCTION

Validation of cave ice in paleoclimatological research is mainly criticised due to the episodically appearing multiannual negative mass balance periods (Racoviţa, Onac 2000). Not only the annual resolution is destructed during these periods, but previously deposited ice could also be destroyed creating long hiatuses in the stratigraphy.

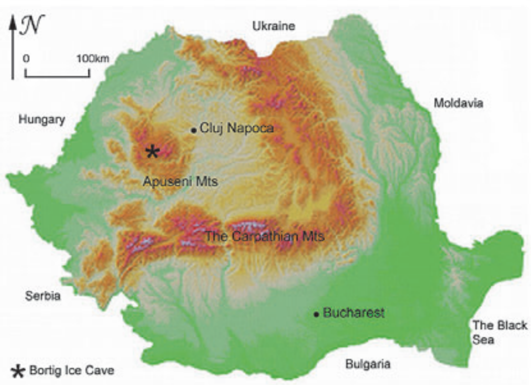

Fig. 1. Location of Borţig Ice Cave

Borţig Ice Cave (46.56 N 22.69 E; 1236 m a.s.l.) is the third largest ice cave of Romania (Fig. 1.). The main shaft has approximately 45 m depth down to the ice surface; the ice thickness is estimated to be at least 0 m (Fig. 2.) The cave contains 25 000 m³ of ice (Orghidan et al., 1984). In order to evaluate the palaeoclimatic significance of the ice accumulation in this cave, we started by surveying and estimating the age and ascertain the potential gaps of the upper ice layers in Borţig Ice Cave. In order to do so, we have chosen the anthropogenic bomb-peak of tritium (^3H) concentration as reference horizon, because

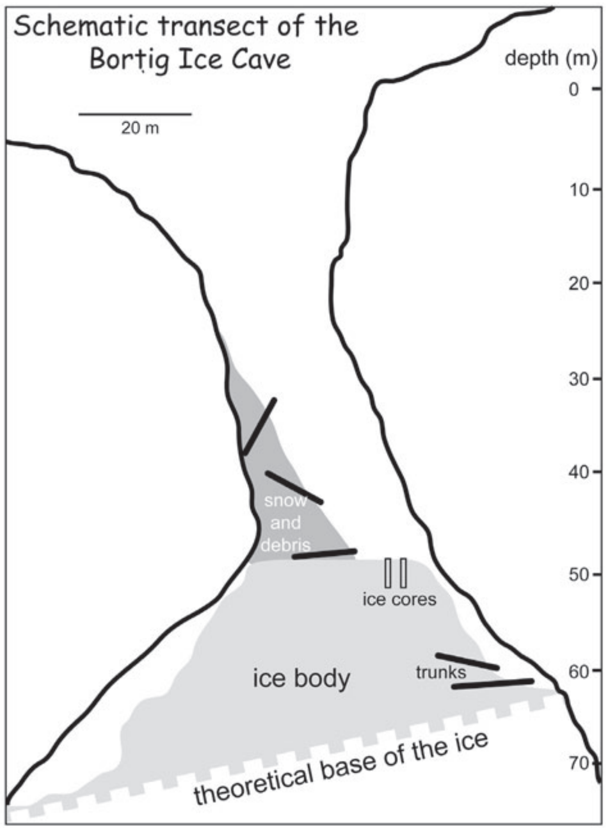

Fig. 2. Schematic transect of the Borţig Ice Cave. Approximate place of extracted cores are indicated. (Detailed mapping is in progress.)

it's well-known and distinct maximum in the atmospheric precipitation in June 1963 (followed by the "nuclear silence" on the Northern Hemisphere).

Tritium-peak as marker horizon is a worldwide applied tool in ice core dating in the younger sections of the glacier cores (ex: Schwikowski et al. 1996, Ramirez et al. 2003). Horvatinčić (1996) performed four measurements on the 40 metres long ice-profile of the Ledenica Cave and assumed that the maximum tritium concentration is within the third metre below the surface.

Latter researches on different ice caves did not found material containing the salient tritium concentration (Kern et al. 2003, Leutscher 2005); however lower values give seldom opportunity for age estimation (Fórizs et al. 2004)

MATERIALS AND METHODS

Two ice cores were drilled in the ice block situated at the bottom of the entrance shaft of the Borţig Ice Cave (Fig. 2.) on 11th and 12th of December 2005.

The first core (BA) reached 209 cm depth below the actual ice surface and was sliced into twenty pieces. During the parting we made special efforts to develop segments representing equidistantly 10 cm long section of the profile, as during drilling the core was distorted.

The second core (BB) reached 197 cm depth below the ice surface. This core was separated into ninety-four sub-samples. In this case each sample represents about 2 cm long section of the real depth (the core being also distorted during drilling).

DRILLING STRATEGY AT THE BORŢIG ICE CAVE

Two drilling sites were chosen on the surface of the ice body. During the coring process we measured the length of the extracted core and the depth of the hole. The two values are differing. We recorded both values and after we calculated the deformation rate. Our aim was sampling for 10 cm long sections for BA core, and 2 cm long sections for BB core (according to the real depth). Consequently, we calculated how long section of the core might represent 10 cm and 2 cm real depth for BA and BB cores respectively. After that, we sliced the appropriate parts. If some material remained we made up the shortage from the appropriate section of the following core. We sliced the extracted cores on the spot and due to the raw estimation our final samples are not exactly 10 and 2 cm long but the mean section length is 10.2 and 1.97 cm for BA and BB core respectively. We stored and transported the sections from BA core in glass bottles. In order to ensure the air-proof closing of the caps, we applied plastic foil sealing below the cap onto the mount of the bottle. The smaller samples were stored and transported in plastic carriers.

TRITIUM MEASUREMENT

Tritium (^{3}H) is a radioactive hydrogen isotope with global occurrence and partly natural origin. Primarily it is produced by the cosmic radiation in the upper stratosphere. Tritium is a beta-decay isotope with a half-life of 12.34 years. In the last century nuclear weapon tests were important sources of anthropogenic tritium. The concentration of tritium drastically increased in the atmosphere and precipitation after the launch of thermonuclear weapon tests within a couple of years. Following commencement of the Nuclear Test Ban Treaty (so-called "nuclear silence") the above-ground thermonuclear detonations are forbidden and the tritium level of precipitation has been steadily decreasing. Owing to these events the most striking feature of the time series of tritium concentration in precipitation is the distinct peak in the summer of 1963. The vertex of observed tritium concentration within this year coincides with the summer months for the three most important northern hemispheric stations (Ottawa, Valentia and Vienna) concordantly.

Tritium activities were measured on water melted from twenty samples of BA core using liquid scintillation counting (LSC) technique. Water samples were distillated before LSC measurements to minimize quenching. 10 mL of distillated water sample was mixed with 12 mL of Ultima Gold LLT cocktail in a low-potassium glass vial and measured by a Tri-Carb 3170 TR/SL (Perkin Elmer) liquid scintillation counter in the lab of Institute of Nuclear Research (ATOMKI).

Measuring time was 1000 minute per sample, resulting 12 TU as detection limit (*tritium unit*, 1 TU is 0.1183 Bq/L) (Curie 1995). Results are published in tritium units, calculated for the date of measurement (2th of February in 2006).

We decided to extract two metres long cores from the ice body of the Borţig Ice Cave because on the basis of a theoretical growth curve of the ice cave we estimated that the upper two metres of the ice mass must cover the period at least from 1940. Anyway natural tritium content before this date surely decreased below the detection threshold due to the half-life of ^{3}H.

STRATIGRAPHY OF THE ICE CORE

Beside the radiochemical investigation we have also developed classical stratigraphic observations on the revealed ice profiles.

RESULTS

a) Core stratigraphy

We noticed ice layers with different physical properties within both ice cores. Generally, the cores show cyclic sequence of much and less dense ice layers (Fig. 3.).

Impurity layers scarcely appeared in the cores. We noticed two layers in BA core, a better and a less developed one, while only one appeared in BB core. The BB dust layer and the bigger BA dust layer settled almost at the same calculated depth (about 13 cm depth below the actual ice surface), suggesting a good correspondence. In addition, thirteen dense and thirteen grainy ice layers

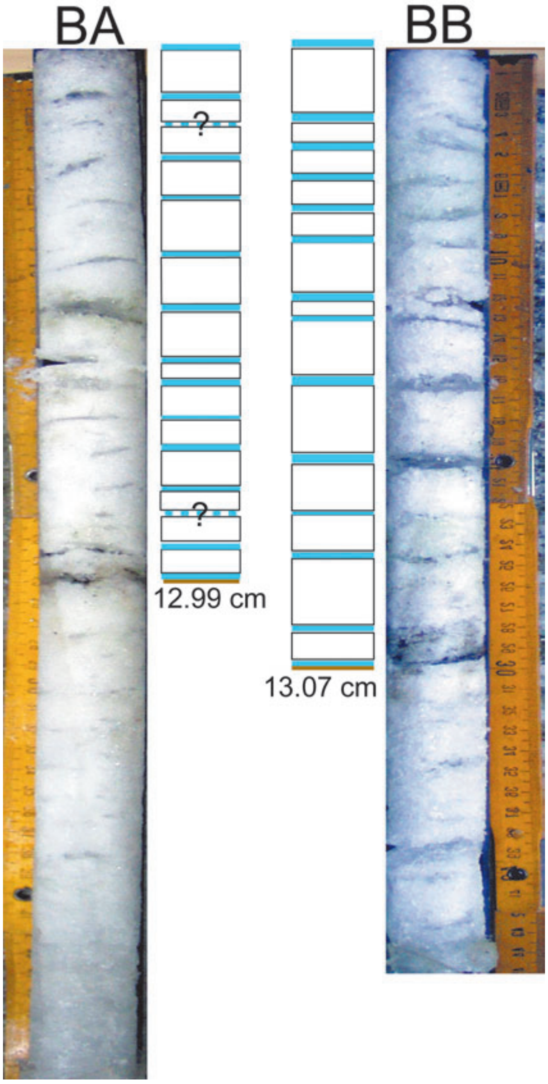

Fig. 3. BA1 and BB1 are the uppermost segments of the two ice cores. The ice layers with different physical properties are visible; moreover the drawings show the simplified stratigraphical sequences of the cores. The corresponding mud horizons are indicated

were distinguishable above the dust layer in BB core by layer counting during the image analysis of the uppermost segment while twelve-fourteen were in the BA core. The imprecise number in the BA core originates from the uncertainty of layer identification (the uncertain layers are indicated by question mark in Figure 3). Since BB core provided reliably countable layers we accepted them, and regarded the BB results as adequate results of layer counting.

The core profile suggested that a less dense, grainy ice and a denser, transparent ice layer coupling together and form onehigher order stratigraphic unit.

b) Tritium measurements

The highest tritium concentrations were found in section BA9 and BA10 (Tab. 1.) between 81 and 102 cm below actual ice surface. These results clearly suggest that the date of maximum tritium concentration of atmospheric precipitation could be joined with the depth of these two samples.

Table 1. Section boundaries with the corresponding tritium concentrations and measurement errors of the samples. Detection limit was 12 TU.

sample code	top of the sample (cm below the ice surface)	bottom of the sample (cm below the ice surface)	percepted activity (TU)	error (TU)
BA-1	0	10.31	<6.0	
BA-2	10.31	20.62	<6.0	
BA-3	20.62	30.74	7.0	±4.2
BA-4	30.74	40.74	17.8	±4.4
BA-5	40.74	50.74	18.3	±4.6
BA-6	50.74	60.9	17.2	±4.4
BA-7	60.9	71.05	31.1	±4.5
BA-8	71.05	81.21	47.0	±4.8
BA-9	81.21	91.68	146.6	±6.8
BA-10	91.68	102.15	162.4	±7.3
BA-11	102.15	112.62	86.8	±5.5
BA-12	112.62	122.96	46.1	±4.8
BA-13	122.96	133.27	16.6	±4.4
BA-14	133.27	143.58	12.9	±4.3
BA-15	143.58	153.5	<6.0	
BA-16	153.5	163.18	<6.0	
BA-17	163.18	172.87	<6.0	
BA-18	172.87	181.8	<6.0	
BA-19	181.8	193.36	<6.0	
BA-20	193.36	204.92	<6.0	

DISCUSSION

In order to make a more precise estimation of the potential depth of the bomb-peak of tritium, we made some calculations, following the raw analyses. We used the dataset of monthly mean tritium content of precipitation from Ottawa and Vienna (GNIP/ISOHIS 2005 data base) as reference data for estimations. We calculated the present tritium concentration of the past precipitations using the equation of radioactive decay and the radioactive decay constant for tritium. Afterwards we dated our ice-sections applying three different assumptions, providing continuous and constant ice accumulation since 1963.

We calculated cases in which the exact position of the ice layer connected to the date of deposition of highest tritium concentration (June 1963), corresponds to 90, 95 or 100 cm depth below the actual ice surface. This assumption suggests 2.2, 2.3 or 2.4 cm/year average constant ice accumulation rates since 1963, respectively. The derived accumulation rates imply cca. 55, 53 or 50 months develop for a 10.2 cm (mean length of BA sections) long ice segment. We smoothed the time series of monthly (decayed corrected) tritium concentration series applying a non-weighted 55-, 53- and 50-months wide window. We plotted the values from cave ice core sections and the smoothed precipitation time series on the same age-scale (Fig. 4.).

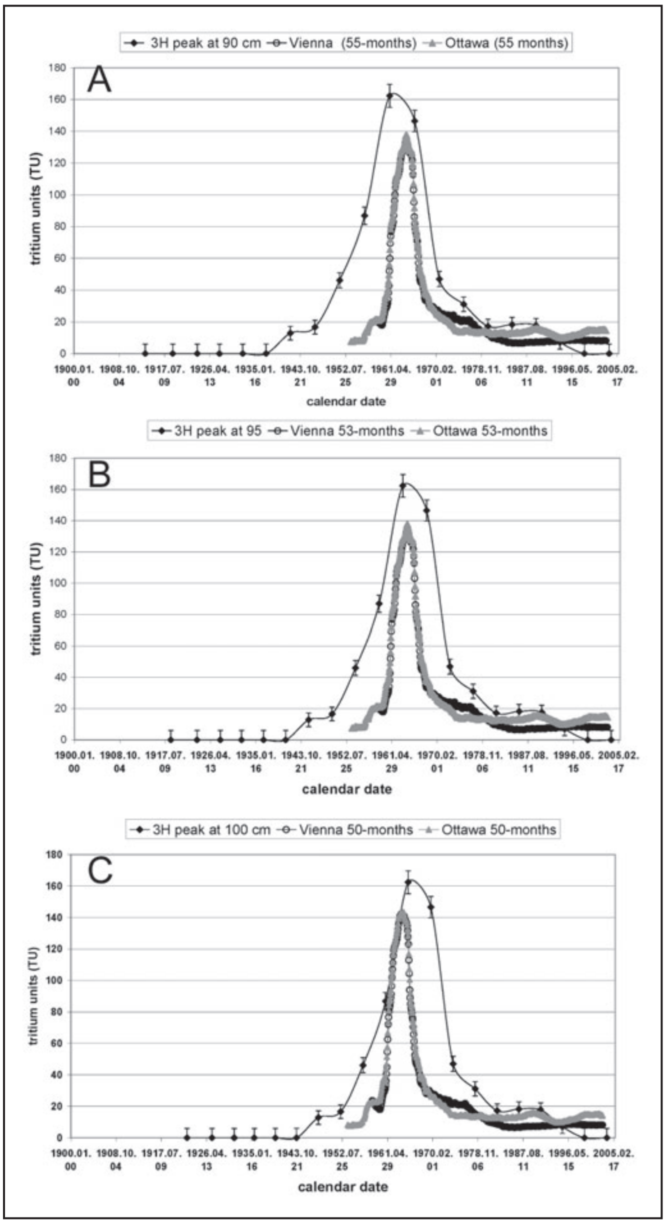

Fig. 4. Graphical comparisons between the tritium concentration characteristics of ice core samples at different estimated accumulation rates (graph A, B and C represents 2.2, 2.3 and 2.4 cm/year ice accumulation rates) and the corresponding smoothed monthly tritium data of the atmospheric precipitation.

In graph A we experienced a latter, while in graph C an earlier date for the maximum concentration of the ice samples, than reality. The best coincidence between peaks of observed precipitation and calculated cave ice data is detectable in graph B.

In each graph, the relation between the smoothed precipitation and ice core tritium curves has two rather seriously unrealistic aspect. The period of ice core peak stretches for a wider time range; moreover, the absolute value of tritium activity from the cave ice overestimates the corresponding value of atmospheric precipitation.

Providing that the signal suffered a smoothing due to mobilization and mixture of the material during the regular annually melting season we can understand the wider peak range but in that case we would have to detect not higher but lower value for the cave ice tritium-peak according to this interpretation. So, at this stage, we have to reject the mixing process as the main cause of the discrepancy.

If 1963-peak is at 95 cm depth below the surface it suggests 5.65 year-old ice at 13 cm depth, where we found dust horizons in both cores. We counted 13 compact, transparent ice layers and 13 white, grainy ice layers above this mud horizon in the ice profiles as we mentioned before. We think these are not annual layers, because if 26 annual layers were above the 13 cm depth located mud horizon, then only 16 annual layers could be contributed down to the following 82 cm long section where previous calculation suppose the date of 1963AD. So the average annual growth rate would be 0.5 cm/yr for the upper 13 cm of the core and ten times higher (5.2 cm/a) for the remaining core. However, no such a significant change in the dominant layer thickness was observed. So, this strong and sharpen change in accumulation rate seems to be unreal. In addition, the two different kinds of ice layers are always nicely coupled. These observations force us to think that pairs of them, as a higher order stratigraphic unit might represent an annual increment.

We can correct the preliminary results taking into consideration that 13 annual bands are above the dust layer located at 13 cm depth. Repeating the calculation we get 2.8 cm/yr ice accumulation rate for the 1963 – 1992 period and 43-months moving average seems the appropriate smoothing for the Ottawa and Vienna time series. The cave ice tritium activity does not overestimate the calculated potential tritium activity of the precipitation at the bomb-peak anymore (Fig. 5.) and the curve of cave ice gets closer to the curve of the measured atmospheric precipitation after the peak. But the significant

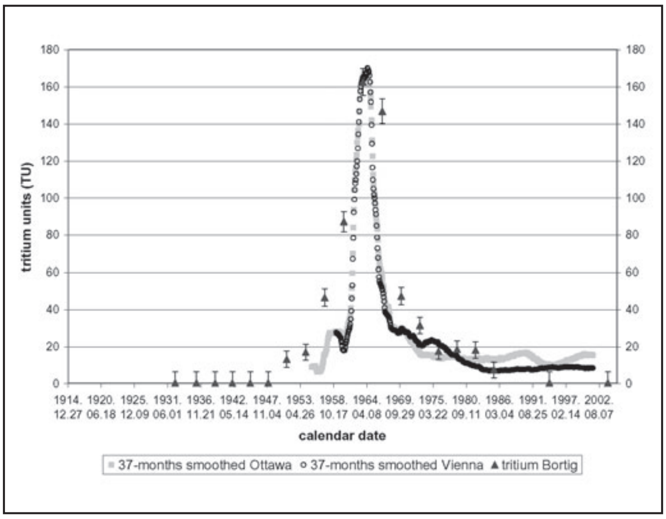

Fig. 5. The Figure 4 B results are corrected taking into consideration that ice above the 13 cm depth lying dust layer coincide with 1992. Hereafter the values of cave ice tritium concentration approach the observation-based atmospheric values. Moreover the highest value of cave ice does not overestimate the atmospheric values. The relationship has not improved significantly before the peak. It suggests that the accumulation was higher during the 1953 – 1963 decade that the following period.

difference maintains for the older period. We consider that the most probable interpretation is that the accumulation rate was even higher for the 1950's decade than we determined between 1963 and 1992.

CONCLUSION

- Ice cores from Borțig Ice Cave present annually layered ice for the second half of the 20th century.
- A grainy white layer and a compact transparent ice layer together form an one-year increment.
- Tritium measurement is a valuable tool for cave ice dating.
- Estimated ice accumulation rates in Borțig Ice Cave:
  – 1 cm/a between 1992 – 2005
  – 2.8 cm/a between 1963 – 1992
  – even higher between 1953 – 1963

We are sure that the results of BB core (with the five times finer resolution) will help the establishment of a more detailed reconstruction of the net mass balance changes of the floor ice of Borțig Ice Cave during the 20th century.

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