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The Cryosphere Discussions

Brief communication: Tritium concentration and age of firn accumulation in ice caves of Mt. Olympos (Greece)

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Abstract. Firn from an ice cave in the highest mountain of Greece, Mt. Olympos, was sampled and analysed to determine the tritium content in order to estimate rates of accumulation and to date the ice plug. The presence of a sharp raise of tritium content because of the nuclear testing era was expected to be preserved into ice beds. This peak did not appear in the analysed samples providing an age estimation of less than 50 years. It is suggested that the rate of melting is responsible for the absence of older firn layers.

1 Introduction

Ice caves or caves hosting perennial ice accumulations (Persoiu and Lauritzen, 2017) in Greece are scattered throughout the country's latitude. In total, 76 records of ice caves in Greece have been processed according to Luetscher and Jeannin (2004) classification scheme and examined according to their morphology and distribution by Lazaridis et al. (2018). In Mt. Olympos, which is the highest mountain of the country, all the ice caves are classified as 'static with firn', where 'static' is interpreted as single entrance caves that form single down-sloping conduits. Ice of these caves, particularly the ones on the Eastern slopes of Olympus, have been exploited for years between the end of 19th centuries and the post WWII years, to provide ice columns to villages and town at the foothills of the mountain and across the southwestern Greek Macedonia.

In order to determine how old is the firn accumulation in these caves, measurements of the concentration of tritium in the ice were applied at the Christaki Pothole in Mt. Olympos. Tritium is a hydrogen isotope that decays emitting beta particles of very low energy (Emax ~18.6 keV) with a half-life of 12.33 y. Tritium is produced in the upper atmosphere by the interaction of cosmic rays with the atoms of the atmosphere. This mechanism introduces tritium into the water cycle by the form of tritiated water and the normal concentration of tritium in precipitation is found to be 5-10 TU (Tritium Units, 1TU = 0.118 Bq/L). During late '50s and early '60s nuclear era, hydrogen bomb detonations introduced huge amounts of tritium into the atmosphere, resulting to a sharp peak of tritium concentration in precipitation all over the world, especially in the northern hemisphere resulting in tritium concentrations up to 6,000 TU in Canada (Cauquoin et al., 2016) since 1953 and in Austria

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since 1961. In Greece, a maximum of 3,550 TU was observed in 1963. These peaks of tritium in the precipitation of these years (early 60s), is expected to be preserved in ice columns, if they have not melted since then.

2 Cave description and geological setting

The cave under investigation (Fig. 1; and supplementary information) is located on the NW slope of the mountain (N40.06898 E22.31350) at an altitude of 2,350 m, very close to the Christaki refuge. The sampling cave is included in the list of ice caves in Greece under the name Christaki Pothole (Lazaridis et al., 2018). The first descent in the cave is about ten meters and continues with an inclined floor to the west. Most of the cave is covered by an ice plug that overlies limestone gravels and small blocks. The ice plug consists of accumulated firn and snow. When surveyed, it was 1.5 m thick below the entrance and progressively goes thicker to the west, reaching about 4.5 m of thickness. Due to this ice plug any possible continuation of the cave to the west, becomes inaccessible. The cave is hosted in the Cretaceous crystalline limestones with dolomite interferences (Latsoudas and Sonis, 1985). The limestone sequence has a total thickness of about 2,650 m and is consisted of limestones that gradually reduce their composition to dolomite. While the eastern slopes of Olympos are affected by the maritime air masses, the western slopes act as a barrier to the hot and humid gas masses coming from the west, which increases the amount of precipitation on these slopes. The amount of precipitation in combination with the high altitude, leads to a high average annual snowfall.

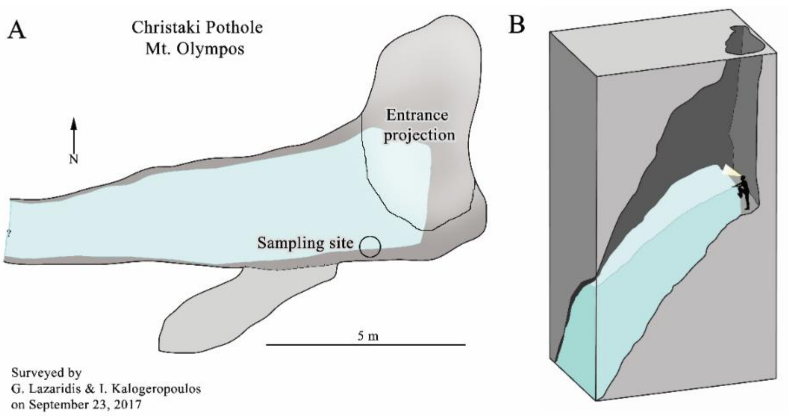

Figure 1. Location of the sampled cave Christaki Pothole; Ground-plan with the sampling site depicted and 3d representation of the cave.

3 Sampling and methods

On 23rd of September 2017, forty-one (41) ice samples were collected from the Christaki Pothole. Each sample was collected from a section of ~2 m high, with a portable cup drill of 5cm diameter and about 2-3 cm depth, resulting in samples of 30 to 40 cm^3, in 5cm intervals and spanning from the top of the ice column to the cave floor. Samples with odd numbering were chosen to be measured for tritium. Measurements were performed at the Archaeometry Center of the University of Ioannina.

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Tritium measurements were conducted in a Liquid Scintillation Analyzer (TR/SL 3700 Tricarb, Perkin Elmer). Eight ml of each melted ice sample were added in a low-potassium borosilicate glass vial of 20 ml capacity and 12 ml of Ultima Gold LLT scintillation cocktail were added. The vial was closed and shaken to homogenize the solution and was measured for 1400 min typically. Background was also recorded at the same batch of samples.

4 Results and discussion

When extracted from the ice column the samples displayed indistinguishable ice layers and thus it was impossible to make a direct estimation of the age of the ice in the column. However, during processing the samples, it was revealed that almost every ice sample contained remains of dust and soil, as a result of the surface debris deposited during the yearly cycle of snow accumulation during winter and partial melting during summer. The ablation of the surface and the burden of each layer caused the incineration of the debris into the ice mass of each layer. Thus, it is suggested that the maximum layer thickness should not exceed that thickness corresponding to about 40 of annual firn accumulations in the ice column where the samples were collected. Since the ice column of the cave is thought to be accumulated for decades of years, it was assumed possible to find the above-mentioned peak of tritium raise in the atmosphere as an abrupt increase in the tritium concentration. Instead, tritium concentrations were found to vary only from 0.9 - 11 TU, which could be attributed to different initial tritium concentrations in snow fall. In comparison with tritium concentrations for selected years before the sampling year (2017), most of the tritium concentrations, corrected for decay, could be resulted from precipitation up to 50 years before sampling year, which corresponds to the calendar year 1967, when the annual mean tritium content was in the range of 130-230 TU (Fig. 2).

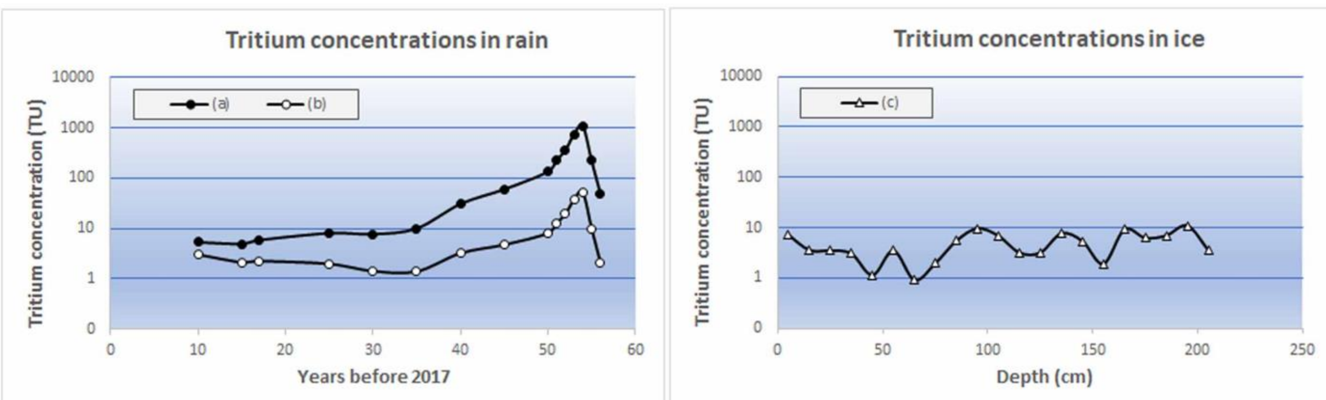

Figure 2. Tritium concentration: (a) Annual mean values of tritium in rain samples from various monitoring stations in Greece (GNIP, IAEA). (b) Annual mean tritium values of line (a) corrected for decay at the year of ice sampling (2017). (c) Tritium content in ice samples, of odd numbering, with depth, from the Christaki pothole.

This gives an upper limit of the possible age of the ice layers that were sampled during the campaign of September 2017. Considering that for this upper limit of 50 years for the ice layers age the corresponding mean thickness of each layer should be at least 4 cm y^{-1}; the result is in accordance with the presence of debris in almost each sample, as well as with findings in other ice caves. In Monlesi Ice cave, Switzerland, an annual accumulation rate 7-11 cm y^{-1} was estimated based on tritium and radon measurements (Luetscher et al., 2007) and in Ledena Pit, a croatian ice cave, an average accumulation rate of up to 12 cm y^{-1} during period of 1963-1995 was also estimated (Kern et al., 2008). However, these estimations do not date the time when the cave started to function as an ice cave nor to an event of total ice melting in the meanwhile. The ice surface that is in contact with the cave-walls and floor is melting in non-permafrost areas such as Greece. Thus, the results are rather indicative of a melting rate that cannot support the preservation of ice that is older than 50 years.

5 Conclusions

The Christaki Pothole provided a two meters thick succession of ice samples that display relatively low concentration of tritium, without any pattern of an abrupt increase that could correspond to the tritium peak due to hydrogen bomb detonations in early ’60s. This indicates that accumulated firn beds are younger than fifty years before 2017. The absence of earlier beds is suggested to be the result of melting rate at the bottom of the ice plug or may occur in ice beds that are not accessible due to the morphology of the Christaki pothole.

Data availability

All raw data are provided in the supplementary information.

Competing interests

The authors declare that they have no conflict of interest.

Author contribution

GL initiated the research; GL and KS organized field work and prepared the manuscript with inputs from all authors; KS analysed samples; GL and IK surveyed the cave and sampled the ice; LG, KS, IK did the field work; DD and KS collected information.

Acknowledgments

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