The interplay between air temperature and ice mass balance changes in Scărișoara Ice Cave, Romania.

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Introduction: Caves are natural traps for sediments (clastic sediments, guano, etc.), unique life environments, and valuable repositories (e.g., speleothems) for various forms of paleoclimatic and paleoenvironmental information since their deposits are protected from destructive processes acting on the surface. Recently, it was shown that perennial ice accumulations in caves could also host a wide range of paleo-proxies [1], [2], of which the most important one is the stable isotopic composition of water (i.e., ice).

The aim of this study is to present and explain the interplay between air temperature (both external and cave) and ice dynamics in Scărişoara Ice Cave (Romania) and its role in the genesis, accumulation, and preservation of the perennial ice block within it.

Study site: Scărişoara Ice Cave (700 m long, 105 m deep) is situated in the Apuseni Mountains (Fig. 1), at 1165 m above sea level; its entrance opens on the western wall of a circular shaft, 60 m in diameter and 47 m deep, the bottom of which is covered by perennial snow. Ice in the cave originated from freezing seepage water that accumulated to form one of the largest (>100.000 m^3) and oldest (>3000 years) underground glaciers in the world.

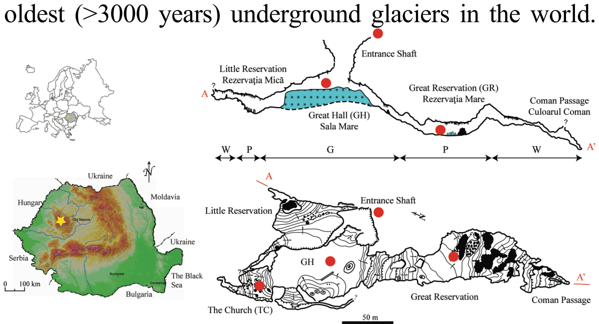

Fig. 1. Location map (the position of the cave is shown by the yellow star), plan view, and cross- section of Scărişoara Ice Cave, Romania (modified from [3]). On the cross-section, the three climatic zones of the cave are shown: G – glacial, P – periglacial, W – warm.

Methods: External air temperature (Tair) and precipitation amount were recorded on an hourly basis near the cave's entrance, between 1 October 2007 and 30 December 2009, using a HOBO Weather Station, with a measurement accuracy of ±0.2°C, 0.02°C resolution, and drifts less than 0.1°C/year. Rainfall amount has been recorded only when T was above 0°C, with a 0.1 mm resolution.

Cave air temperature was recorded on an hourly basis (over the same period as for the outside meteorological parameters), with Gemini TinyTag Plus dataloggers (0.5°C accuracy and 0.01°C resolution at 0°C), in three locations inside the cave (Fig. 1): the Great Hall (GH, ~10 m from the entrance shaft), the Great Reservation (GR, ~210 m from the entrance) and The Church (TC, ~120 m from the entrance). The locations have been chosen to reflect the thermal differences existing between the different parts of the cave: the GH is under the direct influence of external meteorological variations, while TC and GR are situated further away from it. Perennial ice is present in the GH and TC (the ice block itself and ice stalagmites and domes), whereas in the GR, the ice has a semi-perennial occurrence, in the form of ice stalagmites and ice crusts. In the inner sectors of the cave the air temperature is constant at +4.2°C [4].

Ice mass balance measurements were carried out on a monthly basis in the GH, by measuring the distance between the ice surface and the overhanging rock wall with a precision of 0.5 cm. In addition, observation on the ice melting and genesis processes were taken approximately every month.

Results and Discussions: Figure 2 shows the full record of air temperature changes in Scărişoara Ice Cave compared to the external ones. Three features of the temperature curves are noticeable: 1) in phase changes of air temperature in the cave and at the surface, as long as the later are below 0°C; 2) constant (~0°C) values of air temperature inside the cave when the external ones are above 0°C; and 3) decreasing amplitude of air temperature with increasing distance from the entrance.

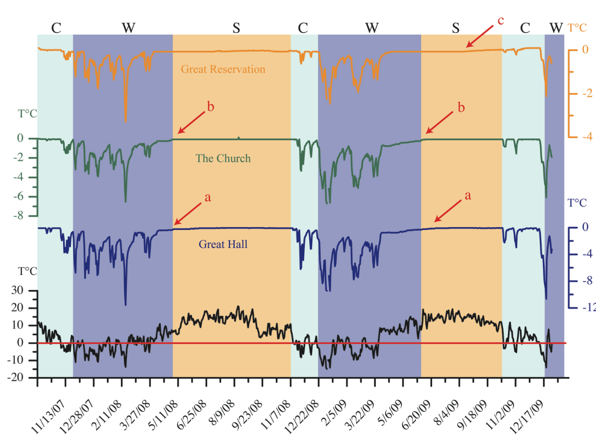

Fig. 2. Time series of daily air temperature in Scărişoara Ice Cave (C – cooling phase, W – winter phase, S – summer phase).

The maximum air temperatures in the GH and TC never exceed 0.1°C, whereas in the GR they reach 0.5°C. The minimum air temperatures follow a similar pattern, decreasing from -22.5°C outside the cave to -13.8 in the GH, -8.1°C in TC, and -3.6°in the GR. Thus, the amplitude variations inside the cave are given by the magnitude of air temperature drops below 0°C. In the inner, non-glaciated parts of the cave, the air temperature amplitude is ~0.5°C.

Geothermal heat and external climate are the main drivers of the cave's air temperature, but the ice forming and ablation processes modulate its spatial and temporal characteristics. During the winter season, cold air inflow leads to the overcooling of the cave atmosphere, walls, and ice formation, whereas in summer time, melting of ice acts as strong thermal sink, keeping the air temperature at 0°C. In autumn and winter, dynamic cooling of the cave atmosphere leads to ice build-up, whereas in summer, the causality is overturned, the cave air temperature being controlled by the melting ice. The existence of a net heat sink in the cave (melting ice in summer in this case), leads to the overcooling of the non-glaciated parts of the cave as well, a phenomenon that can hamper paleoclimatic reconstructions based on stable isotope studies in speleothems.

Extraterrestrial caves on other planets (e.g., lava tubes on Moon, Mars, etc.) may also host ice or other cave deposits. Understanding all aspects related to Earth's ice accumulation and preservation in caves (even when developing under deserts), their particular microclimate conditions and setting could ultimately have a paramount importance in deciphering the history of celestial bodies. Investigating minerals, microorganisms, or other materials trapped within ice in caves could give valuable clues in the formation of these galactic bodies.

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