Establishing past firn accumulation records from ice caves of the European Alps

Tanguy Racine[1], Christoph Spötl[1], Paula Reimer[2]

[1]Institute of Geology, University of Innsbruck,[2]Centre for Climate, the Environment and Chronology, Queen's University, Belfast.

Background

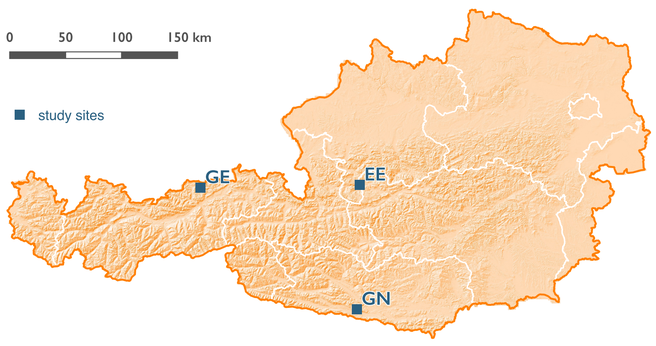
Ice caves are rock-hosted caves containing **perennial ice**. In many sag-type caves, winter snow accummulations accounting for several 100 m^3 are preserved underground in the form of firn. Ice in such caves is a proven climate archive (Stoffel et al., 2009; Munroe et al., 2018; Sancho et al., 2018) which can provide complementary insights in climate of the last 2 ka.

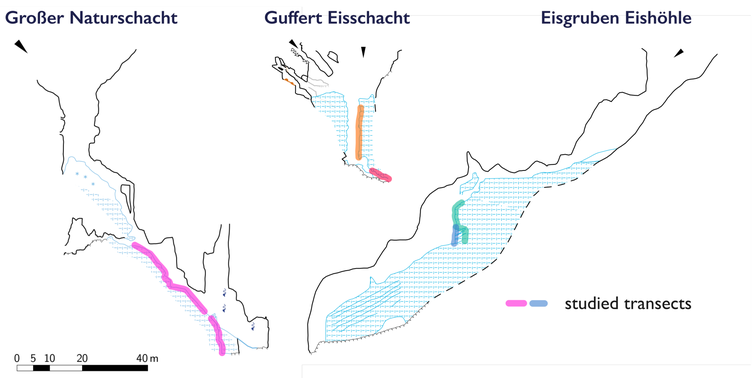
Objective

Establish radiometrically dated records of ice accumulation in alpine caves

Study Sites

Site	Region	Elevation
Großer Naturschacht (GN)	Carinthia, Dobratsch	1985 m
Eisgruben ice cave (EE)	Upper Austria, Sarstein	1720 m
Guffert ice cave (GE)	Tyrol, Rofan	1805 m





Elevation profiles of the caves, height/width ratio 1:1

Materials & Methods

→ Woody macrofossils (e.g. twigs) were sampled from the ice stratigraphy. Detailed stratigraphic logs, supplemented by annotated ice exposure sketches allow reconstruction of different deposition sequences.

→ Stratigraphic position of samples was recorded by laser-distance metre where possible, scaled photographs and measuring tape.

→ Wood samples were dated using radiocarbon AMS at the CHRONO Centre, Queen's University (Belfast,NI) and radiometric ages were calibrated against the IntCal13 curve (Reimer et al., 2013). Wherever possible, an age/depth model was produced with Oxcal (Ramsey, 2009), treating the ice deposition as Poisson process.

References

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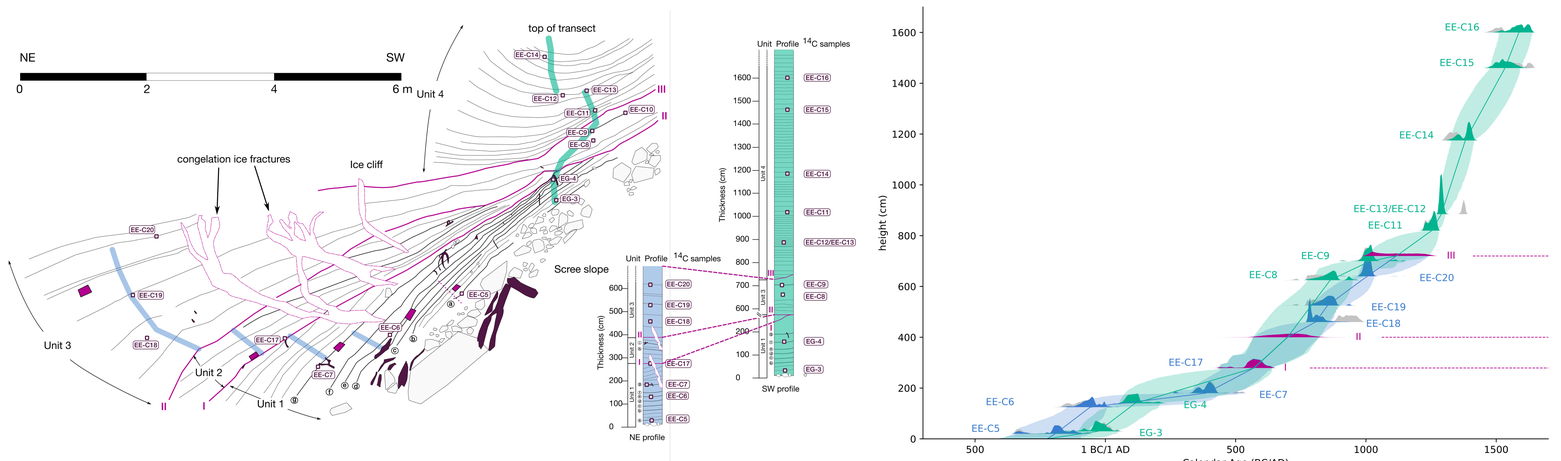
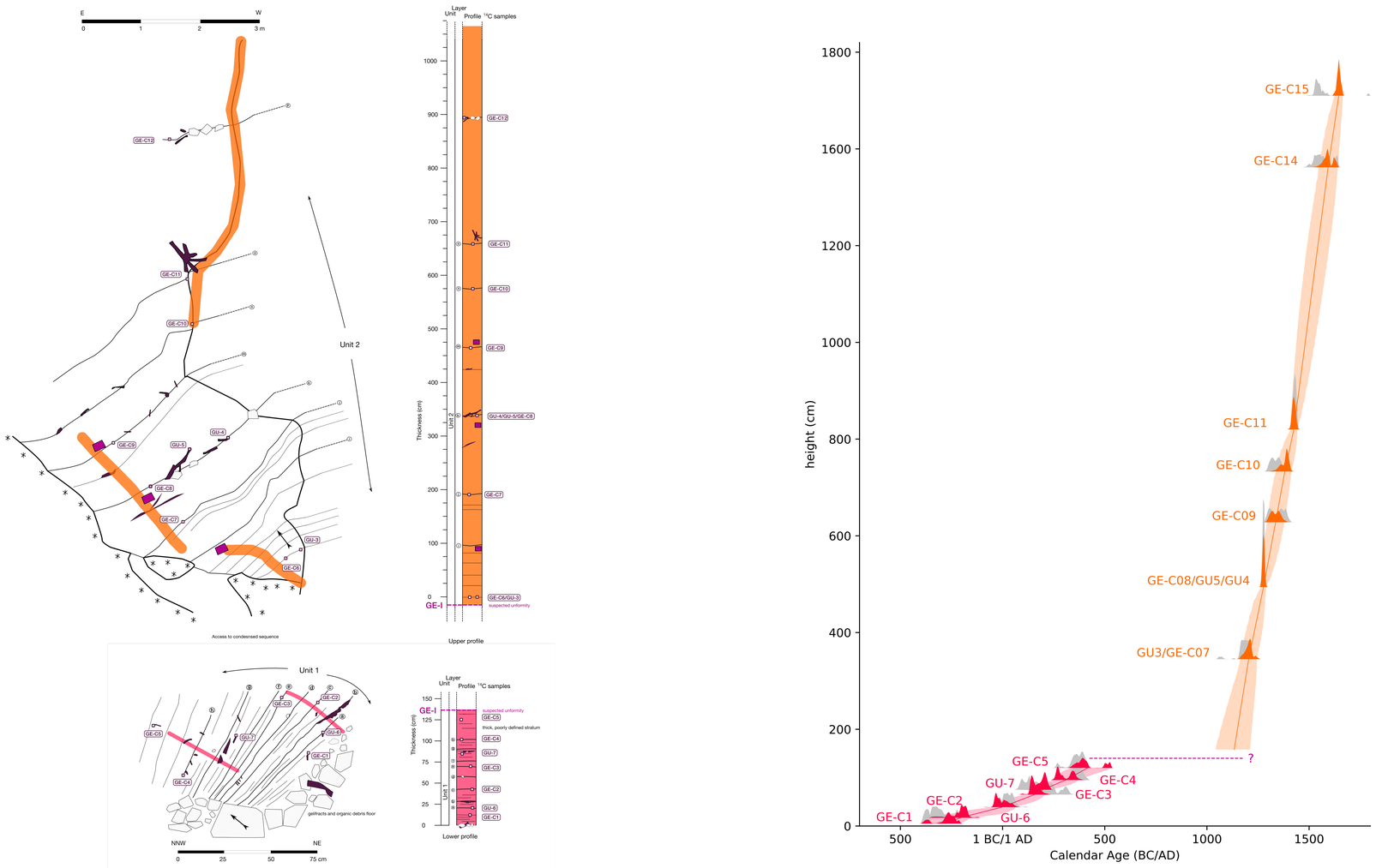
Stratigraphy and Age models



Left: Sketch of the stratigraphic section at Eisgruben ice-cave. *Right:* Age/depth models of the highlighted transects, with their 95% confidence envelope. For each sample, likelihood (grey) and posterior (colour) probability density functions are also displayed



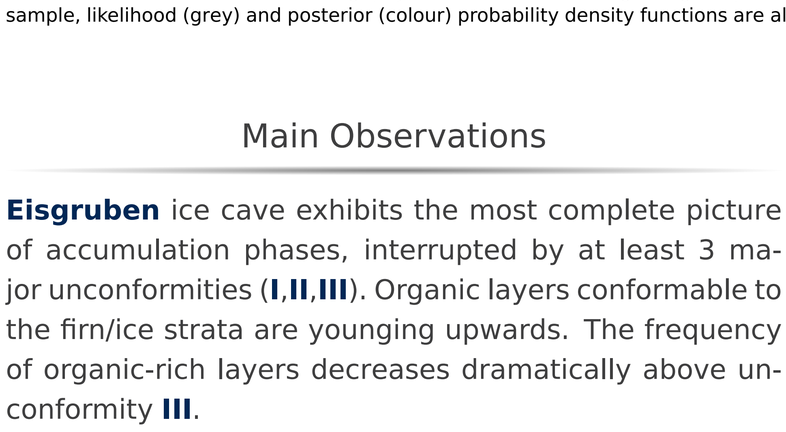
Left: Sketch section of the ice stratigaphy at Guffert ice-cave. *Right:* Age/depth models of the highlighted transects, with their 95% confidence envelope. For each sample, likelihood (grey) and posterior (colour) probability density functions are also displayed

Main Observations

Eisgruben ice cave exhibits the most complete picture of accumulation phases, interrupted by at least 3 major unconformities (**I**,**II**,**III**). Organic layers conformable to the firn/ice strata are younging upwards. The frequency of organic-rich layers decreases dramatically above unconformity **III**.

Guffert ice cave contains a condensed ice sequence at the base, separated from a thick firn/ice sequence of younger age. A 600 yr hiatus between the two sequences is apparent. At the surface of the cave, 18th Century ice is exposed. We speculate that the upper part of the cave filled up during the late Little Ice Age, but that ice is now lost..

At **Großer Naturschacht**, the dated wood samples suggest that the oldest ice currently accessible is younger than **300 yr** old. Not all samples are in stratigraphic order and the lower section likely represents a more recent remobilisation of firn by melting and refreezing.



Summary of accumulation record from the Eisgruben[a], Guffert[a] and Großer Naturschacht[b] ice-caves. [a] Apparent accumulation rate calculated from the respective age models. [b] Kernel density estimate of the ice building phase (Ramsey, 2017)

Key Results

Three broad ice accumulation periods in the past 2 ka are discerned in the ice cave record.

(1) 250 BC-500 AD, with apparent accumulation rates < 1 cm a^{-1}.

(2) 700-1000 AD only seen at Eisgruben (this study), between unconformities **I**,**II** and **III**. and Hundalm Eishöhle (Spötl et al., 2014).

(3) 1150-1850 AD exhibited in all three caves, with relatively high rates of accumulation generally > 3 cm a^{-1}, and up to 13 cm a^{-1} at Großer Naturschacht. Ice deposited during period 3 (broadly coincident with the Little Ice Age) constitutes the greater portion of ice in alpine caves. At Eisgruben and Guffert, no ice deposited post 1600-1700 is preserved. This is likely due to (1) the lack of accommodation space as well as (2) widespread ice loss.

Perspectives

This study highlights the potential of sag-type ice caves as archives of past winter precipitation. Major hiatuses will need to be replicated in other alpine caves and the established ice-cave records will be compared to and contrasted with constituents of the cryosphere.