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Glacier fluctuation and vegetation history during the Holocene at the largest glacier of the Eastern Alps (Pasterze Glacier, Austria): New insight based on recent peat findings

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Summary

The spatial extent of Pasterze Glacier (47°05'N, 12°44'E, 17.5 km²), the largest glacier of the Eastern Alps located in the National Park Hohe Tauern, oscillated substantially during the Holocene. Precise knowledge of periods of smaller and larger glacier extent compared to present is still far from being complete. Ongoing global warming and its effects on the cryosphere reveal previously glaciated terrain and its underlying minerogenic and biogenic sediments. In this study four larger compressed peat pieces from the proglacial area of Pasterze Glacier found in June 2007 have been radiocarbon dated and palynologically analysed. The peat analyses indicate that Pasterze Glacier was substantially smaller compared to today at least at 3370–2200 cal BC and 1940–1430 cal BC. Remarkable is the fact that the largest peat piece covers a time span of about 900 years. The pollen flora is dominated by spruce (*Picea*) and corresponds with the well known composition during the Middle and Late Holocene at this elevation. The pollen content of one peat piece reflects the human impact on the vegetation of the higher altitudes during the Bronze Age. Our results allow a deeper insight into the vegetation history, climate and glacier history and the bog ecology during the Late Holocene in central Austria. Some of the results have been also used for educational purpose at the Hohe Tauern National Park visitor centre in Mittersill, Austria, for the "time wheel Pasterze" (Zeitrad Pasterze).

Keywords

Pasterze Glacier, Holocene, Palynology, 14C-dating, glacier changes, Hohe Tauern National Park.

Introduction and study site

Knowledge regarding the regional climate and its effects on vegetation and glaciation in Central Austria during the Holocene is still far from being complete. In general, a retreating glacier allows the colonisation of the deglaciated proglacial area by vegetation during a long-lasting warmer and drier period. In contrasts, an advancing glacier during a cooler and wetter period buries and hence potentially preserves the organic material such as peat pieces or wood fragments. Ongoing global warming and its effects on the cryosphere reveal previously glaciated terrain and its underlying minerogenic and biogenic sediments allowing deciphering past glacier and vegetation and hence climatic history.

A number of fragments of prehistoric biogenic material (pieces of *Pinus cembra, Larix decidua* and compressed peat) were found in particular during the 1990s at the proglacial sandur of Pasterze Glacier (47°05'N, 12°44'E, 17.5 km²), the largest glacier in the Eastern Alps (Fig. 1). The material was subsequently studied by colleagues in Salzburg (Slupetzky 1993, Slupetzky et al. 1998) and Innsbruck (Nicolussi & Patzelt 2000a, 2000b). These earlier publications focused on radiocarbon and dendrochronological analyses and less on palynological investigations (*cf.* Fig. 3).

After a remarkable break in peat findings for several years at this glacier, relatively large peat pieces were found in autumn 2006 and in particular during summer 2007. The temporal break in findings for several years might suggest that the new findings belong to a different sediment stratum as the ones found previously. Results and interpretations are presented here.

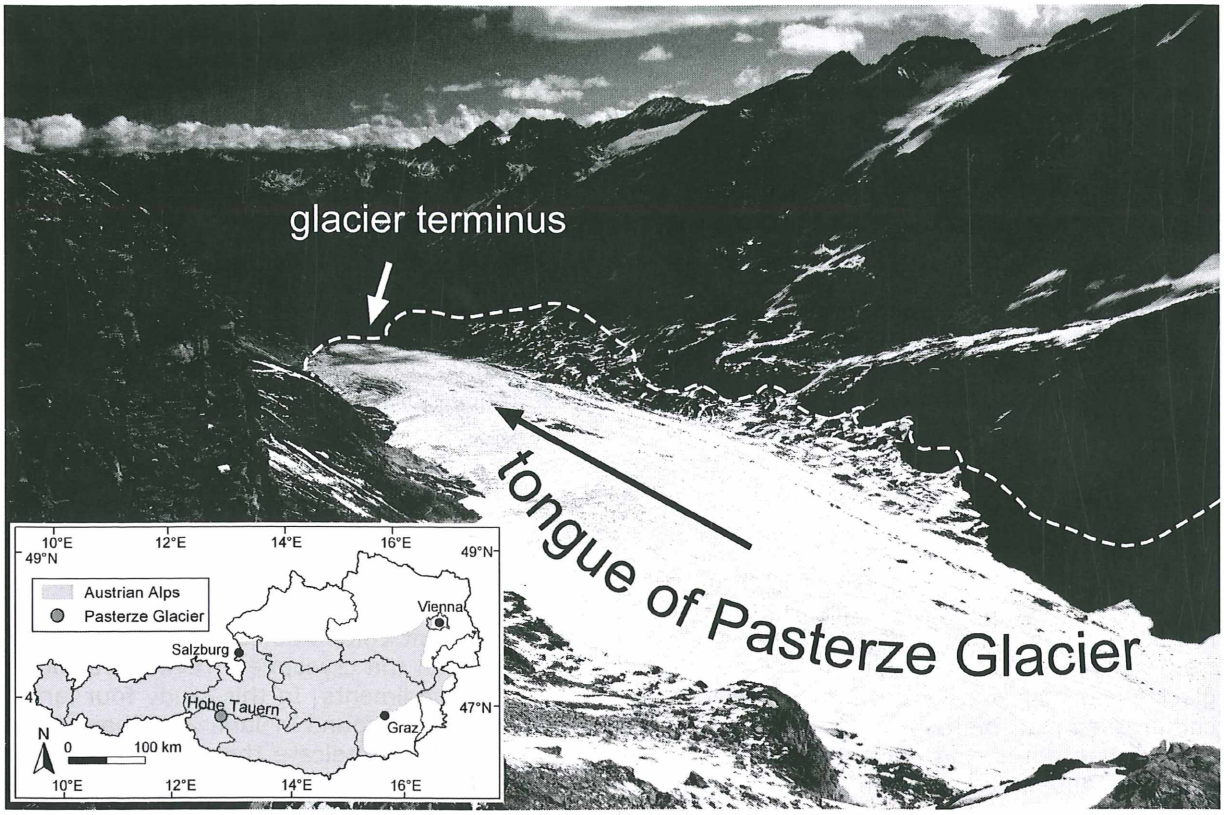

Figure 1: Location of Pasterze Glacier in within the Austrian Alps and a terrestrial view of its tongue and terminus in 2007. The four peat pieces discussed here have been found in the proglacial sandur close to the glacier terminus. The dashed line indicates the glacier margin at the debris-covered glacier part (Photograph kindly provided by P. Hadler).

Studied material and applied methods

Four large peat pieces were collected in summer 2007 in the proglacial sandur very close to the terminus of Pasterze Glacier (Figs. 1 and 2). The area itself was during that time a debris-covered dead ice body with numerous small depressions. The dead ice was presumably still connected to the main glacier but without any horizontal surface movement. The four peat pieces weighted between 1 and 12 kg. More importantly for the analysis was the thickness or c-axis of the compressed peat pieces which ranged between 5 and 13 cm (Table 1).

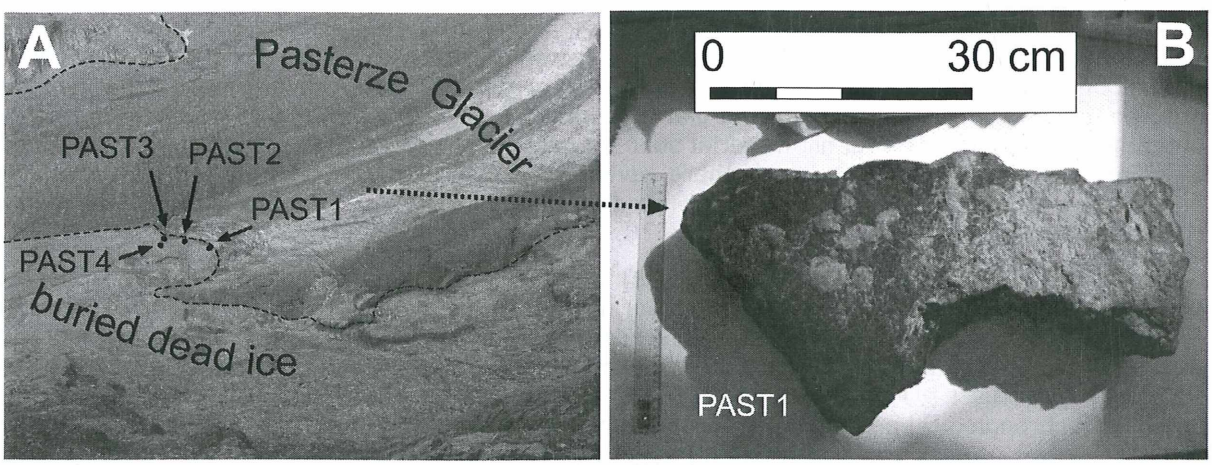

Figure 2: The four peat findings near the terminus of Pasterze Glacier on the 25th of June 2007: (A) locations of the peat findings PAST1 to PAST4. (B) The largest of the four studied peat pieces (PAST1) with a dimension of 56x29x13 cm and a weight of 12 kg (Photographs by A. Kellerer-Pirklbauer).

Table 1: Characteristics of the four studied peat pieces. For location of each finding refer to Fig. 2.

Peat piece	Weight (kg)	Size (cm) Length (*a*-axis)	Width (*b*-axis)	Thickness (*c*-axis)
PAST1	12	56	29	13
PAST2	12	44	43	11.5
PAST3	2	24	22	7
PAST4	1	18	12	5

All four peat samples were radiocarbon dated and palynologically analysed. Radiocarbon dating was carried out for six ^{14}C-samples by applying the AMS-method (VERA, Vienna). Both the upper and lower side of the two large pieces PAST1 and PAST2 were radiocarbon dated. Only one side (upper/lower?) of the two smaller pieces PAST3 and PAST4 were dated.

Palynological analyses were carried out by R. Drescher-Schneider applying conventional palynological routines. At three of the four peat findings (PAST1, 2 and 4) four samples of 0.5 cm³ of organic material were studied. The four samples were equally spaced over each thickness profile/*c*-axis (e.g. for PAST1: 0, 5, 10 and 13 cm. PAST3 had low pollen content.

Results

The six radiocarbon ages vary between 1630-1430 cal BC and 3090-3370 cal BC (Table 2), thus all peat findings belong to the Late Holocene, i.e. the Subboreal Chronozone (3780-800 cal. BC; Haas et al. 1998). The thickness profile/*c*-axis of the two larger peat findings cover time spans of 430 to 900 (PAST1: 3100-2200 cal BC) and, respectively, 100 to 510 (PAST2: 1940-1430 cal BC) years. The pollen conservation was sufficient in most samples for correct pollen designation. The pollen density varied substantially between samples but was sufficient (apart form PAST3) for pollen analysis. Pollen analytical results for PAST1, PAST2 and PAST4 (pollen diagram not shown) indicates for instance the dominance of spruce in all samples and the human impact on the vegetation in sample PAST2 during the Bronze Age.

Table 2: Radiocarbon datings of the four peat findings and description of the six dated samples (*cf.* Table 1).

Code-VERA	Lab-Nr.	14C-age ±1σ-error	Calibrated age	Sample origin (profile depth)	Position	Material
Pasterze 1	VERA-4439	4375±35 BP	3100-2900 cal BC (95.4%)	PAST1 13.0-13.5 cm	lower surface of peat finding	moss, 2 needle-heads, 2 *Carex* nutlets
Pasterze 2	VERA-4440	3855±35 BP	2470-2200 cal BC (95.4%)	PAST1 0.0-1.0 cm	upper surface of peat finding	moss, Cyperaceae-remains
Pasterze 3	VERA-4441	3260±40 BP	1630-1430 cal BC (95.4%)	PAST2 0.0-0.5 cm	upper surface of peat finding	moss, Cyperaceae-remains, small limb
Pasterze 4	VERA-4442	3515±35 BP	1940-1740 cal BC (95.4%)	PAST2 8.5-9.0 cm	lower surface of peat finding	different vege-tative remains.
Pasterze 5	VERA-4443	3310±40 BP	1690-1490 cal BC (95.4%)	PAST3 0.0-0.5 cm	tentatively upper surface of peat finding	moss, Cyperaceae-remains
Pasterze 6	VERA-4444	4530±35 BP	3370-3260 cal BC (34.0%) 3250-3090 cal BC (61.4%)	PAST4 0.0-0.5 cm	tentatively upper surface of peat finding	moss

Discussion and Interpretation

Our results show that PAST1 belongs predominantly to the warmer period between the Rotmoos II (Piora II) and the Löbben (=Tiefengletscher) oscillations (Fig. 3). PAST2 is related to the Löbben oscillation. PAST3 is related to a warmer period within the Löbben oscillation and PAST4 is connected to the Rotmoos II oscillation. The pollen flora of all analysed peat findings (PAST1, PAST2 and PAST4) conforms to the known flora composition of the Middle to Late Holocene dominated by spruce. The results further indicate that Pasterze Glacier was smaller compared to

today during the periods ~3370-2200 cal BC and ~1940-1430 cal BC. If one presumes that the development of a peat bog as well as a significant vegetation cover needs some decades to develop, we can conclude that a 2000 year long glacier unfavourable period existed between ~3370 and ~1430 cal BC in central Austria.

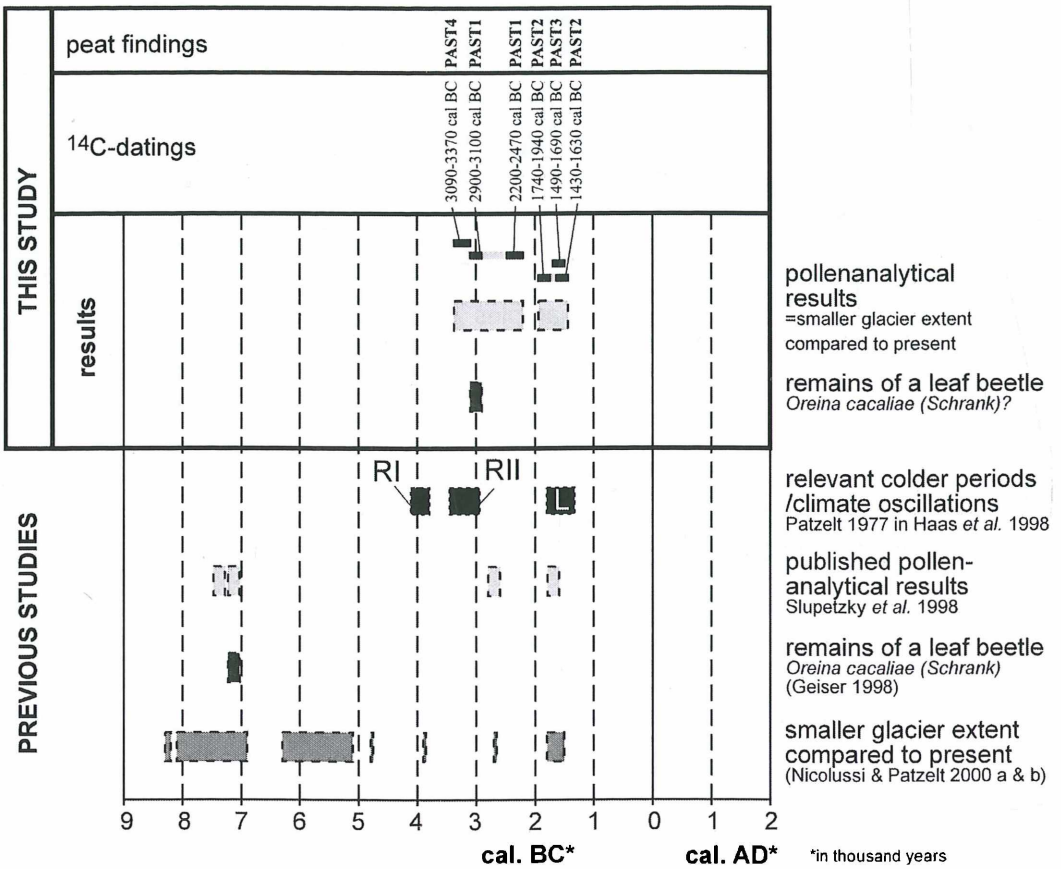

Figure 3: Results of this study and previous studies regarding the vegetation and glacier history at Pasterze Glacier. Parts of a newly found fossil leaf beetle are very similar to the ones studied earlier dated to 7280-7035 cal BC (*cf.* Fig. 4). Time spans of relevant colder periods during the Middle and Late Holocene are: Rotmoos I (=Piora I) ca. 4100-3780 cal BC., Rotmoos II (=Piora II) ca. 3450-2960 cal BC und Löbben (=Tiefengletscher) ca. 1800-1320 cal BC (after Haas *et al.* 1998, Fig. 4).

Findings related to animals which are commonly found in littorale areas of lakes and bogs indicate very humid ecological conditions during peat growth. The remains of a fossil leaf beetle, similar to a fossil beetle found earlier, belong presumably to the leaf beetle species *Oreina cacaliae* (Schrank) (Fig. 4). Therefore, our palynological and radiocarbondating results are relevant for three different aspects: (a) vegetation history, (b) climate and glacier history and (c) indications regarding the bog ecology.

Conclusion and Outlook

The results of this study allow a deeper insight into the vegetation history, climate and glacier history and the bog ecology during the Late Holocene in central Austria. It is for instance shown that Pasterze Glacier was substantially smaller compared to today at least at 3370–2200 cal BC and 1940–1430 cal BC, hence during a roughly two thousand year long period. Besides its scientific value the results presented here have been partly used for educational purpose at the Hohe Tauern National Park visitor centre in Mittersill, Austria, for the "time wheel Pasterze" (Zeitrad Pasterze).

Concluding analyses of the four peat findings presented here are currently in progress. These analyses are – amongst others – the analysis of tree parts embedded within the peat pieces (conclusions regarding the tree limit), two further radiocarbon datings (conclusions regarding the lower and upper surface of PAST3 and PAST4), analysis of macro remains and the analysis of animal remains (for more precise conclusions regarding the bog ecology).

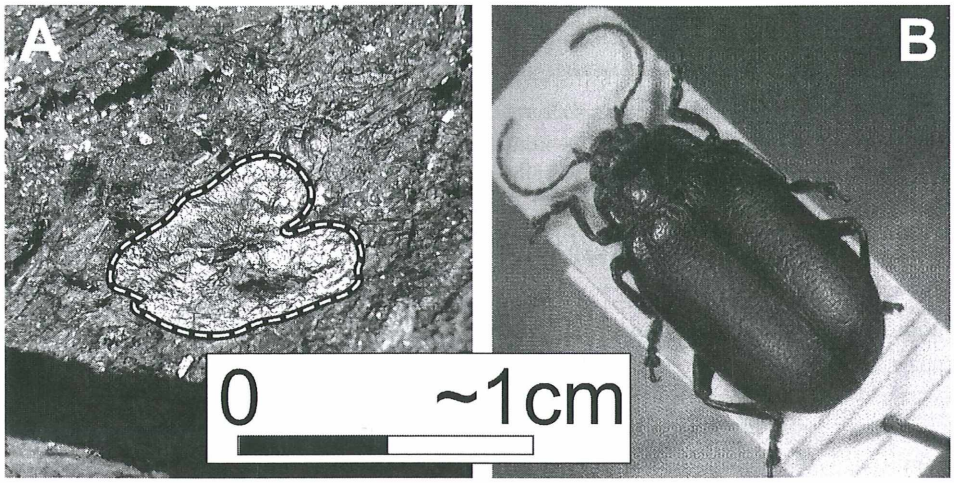

Figure 4: (A) Parts of a fossil leaf beetle (possibly of the species *Oreina cacaliae (Schrank)*(*cf.* Geiser 1998) found in PAST1 with an age of 3100-2900 cal BC. (B) Image of a recent specimen of an *Oreina cacaliae (Schrank)* taken from Geiser (1998).

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