MINIMAL EXTENSION PHASES OF UNTERAARGLACIER (SWISS ALPS) DURING THE HOLOCENE BASED ON ^{14}C ANALYSIS OF WOOD

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ABSTRACT. Tree trunks and wood fragments in minerotrophic fen peat that accumulated as the result of a jökulhlaup in the outwash plain of Unteraarglacier were radiocarbon-dated using conventional ß-counting. Different pretreatment methods were tested on two wood samples to determine the reliability of our dates. We dated the wood compounds after extended acid-alkali-acid treatment, as well as extraction of cellulose and lignin. The results of the samples *Picea* (B-6687) and *Pinus cembra* (B-6699) show insignificant differences of $< 1\sigma$.

The ^{14}C dates represent retreat of Unteraarglacier due to warmer and/or drier phases in the Holocene compared to modern climate conditions. The glacier was at least several hundred meters smaller in extent than today *ca.* 8100–7670 BP, 6175–5780 BP, 4580–4300 BP, 4100–3600 BP and 3380–3200 BP. The ^{14}C dates suggest a *ca.* 2000-yr cyclicity of tree growth in the area covered by the present Unteraarglacier. The most intense warm and dry period occurred between 4100 BP (probably extending back to 4580 BP) and 3600 BP, with growth of fen peat between 3800 and 3600 BP attributed to wetter conditions.

INTRODUCTION

A prerequisite for predicting and modeling anthropogenic influences on the environment is the understanding of natural climate variability. Glacier fluctuations are one proxy signal of such variation.

In the summer of 1995, tree stems and disk-like rounded *Cyperaceae* fen peat fragments were found on the Unteraarglacier's outwash plain at an altitude of 1920 m asl.; these were clearly eroded from the glacier's bed and transported by an enormous jökulhlaup (glacier outburst flood) event in context with the actual retreat. A study of these samples may contribute to solving the following problems:

1. Dating of glacier extents that must have been smaller than today, because the stems and peat fragments have been eroded by the glacier. Parallel to a smaller glacier extension, the tree line must have been higher than today because no trees are now growing in the glacier's outwash plain and in its junction area. Thus, the samples studied provide clear evidence of an area formerly covered with vegetation.
2. Testing the conformity of ^{14}C dates of different wood components using chemical treatments.
3. Verifying Holocene climate changes reflected in glacier variations. Glacier recession phases represent higher annual-mean temperatures (*e.g.*, Wigley and Kelly 1990) and are applicable for comparison with other climate archives.
4. Verifying the amplitude of Holocene Unteraarglacier variations. The Little Ice Age maximum was reached in 1871 (Guttannen/Siegfriedatlas 1872; Unteraarglacier tongue 1879/80). This was much later than for most Alpine glaciers, due to the geometry of catchment basin.

Investigations into the fluctuations of Unteraarglacier were designed to evaluate the effectiveness of isolated components from wood as dating tools and glacier behavior as a climate signal.

Detailed knowledge of Holocene glacier fluctuations in high mountain areas can be gleaned from dated moraine sequences and historical records, especially maps (*e.g.*, Denton and Karlén 1973; Zumbühl and Holzhauser 1988; Gamper and Suter 1982; Patzelt and Bortenschlager 1973; Patzelt 1996). Due to the recent widespread retreat of Alpine glaciers, more information has become avail-

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able about glacier contraction phases in the Holocene (Porter and Orombelli 1985; Röthlisberger 1976; Röthlisberger *et al.* 1980; Schlüchter 1994; data also available from the World Glacier Monitoring Service[3]).

Location and Geology of the Study Area

The Unteraarglacier is situated in the Berner Oberland of Switzerland (46°34′N, 8°12′E) near Grimselpass; it is formed by the confluence of two glaciers, Lauteraar and Finsteraar. The equilibrium-line of the system is presently at 2800 m altitude (Gudmundsson 1994).

Reconstruction of the minimal extent of the Unteraarglacier during different Holocene phases is not possible based on the present samples, because they were not found *in situ*. The glacier tongue had to have been several hundred meters shorter than it is now. However, the complete disappearance of the Unteraarglacier is difficult to imagine and 6 km of ice remains today. The retreat was 1951 m between 1876 and 1995, with an average value of −16.9 m per year (data from World Glacier Monitoring Service).

Reservoir effects hamper radiocarbon dating under certain conditions: bedrock lithology is one critical factor. The Unteraarglacier and its tributaries are situated in the Aarmassiv, a Variscan autochthon massif of the Swiss Alps. Mixed high-grade to anatectic metasedimentary gneisses, orthogneisses, chlorite schists and migmatitic gneisses, as well as ultramafic inclusions and amphibolites, are abundant in the Lauteraar- and Finsteraarglacier catchment area (Abrecht 1994). The Central Aar granite is the main geologic unit in the Unteraarglacier region.

Given this geological setting and the lack of fresh carbonaceous material at the surface of the Unteraarglacier region, reservoir effects are unlikely to be of concern here.

METHODS

The wood samples were deformed due to transportation in the glacier ice or due to erosive deformation of the glacier bed. The tree rings were compressed and the cell walls, in some cases, destroyed or wavelike. Pebbles and sand grains were sometimes found pressed into the wood. The anatomy of the wood was studied by microscope to determine the wood species (Table 1). The wood samples were air dried, cut with a mechanical saw and stored in distilled water. Slices were later cut with Gillette Super Silver razor blades. Afterwards the thin sections of wood were mounted into a glycerin:ethanol:deionized water (1:1:1) mixture on microslides for identification under the microscope (Schweingruber 1990). The wood macrofossils in the peat were handpicked and handled in the same way.

Chemical Pretreatment

To avoid contamination, ^{14}C dating is often based on chemically well defined compounds extracted from the wood. Subfossil wood consists mainly of lipids (waxes, fats), resins, sugars, hemicellulose, degraded lignin (30–60%) and altered cellulose (40–70%) (Killops and Killops 1993).

Zaitseva (1995) pointed out that lignin and lignoacids (alkali soluble, acid insoluble fraction) do not show significantly different ^{14}C age from *Larix* and *Pinus*. Obviously, species-independent dating is therefore possible. Our lignin extraction method is partially based on Zaitseva (1995). Olsson (1980) did experiments on *Pinus aristata* wood growing between 1835 and 1855. The most reliable

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dates, yielding reproducible values, were obtained from 1) the insoluble fraction after acid-alkali-acid treatment, 2) the insoluble components after treatment with NaOH, water, methanol and ethanol from heartwood, 3) the alkali insoluble fraction of sapwood and 4) holocellulose.

DeNiro (1981) described the D/H ratios after combustion in oxygen atmosphere using a Pekin-Elmer Model 180 spectrometer, concluding that the $NaClO_2$ method results in the purest cellulose. Hence we used oxidation by $NaClO_2$ to prepare the cellulose.

The outermost 5–10 tree rings of the wood samples were cut into small chips (<0.5 cm) before chemical treatment. The samples for lignin and cellulose were milled with a carbide mill.

The standard pretreatment at the Bern laboratory is based on, *e.g.*, the studies by Olsson (1980) and Mook and Streurman (1981) and has been extended by Steve Reese with one more alkali step to dissolve contaminants effectively. Hence, pretreatment at the Bern laboratory consists mostly of two acid and two alkali steps. Dilute solutions (4%) were used to avoid a high loss of sample material. A 4% solution of NaOH at a temperature of 25–80°C overnight was used to remove tannic acids, lignoacids *sensu* Zaitseva (1995) and infiltrated humic acids. Lipids such as waxes and fats were removed in a 4% HCl solution at a temperature of 80°C. In addition, sugars, infiltrated carbonate, hemicellulose, pentosanes, proteins, amino acids, amino sugars and possibly modern atmospheric CO_2 (dissolved during the alkali step) are removed by acid treatment. The extracts were separated from the residue and removed together with acid or alkali by washing with deionized water until a pH of 7 was reached. The insoluble residue consists mainly of lignin and cellulose, but residues of lipids, resins and celluloseacetate could have remained in the rest of the treated samples (DeNiro 1981).

Lignin ($(C_8H_{17}O_6)_n$) is a high-molecular-weight polyphenolic compound, insoluble in water and acid, forming the network around the cellulose fibers (Römpp 1992; Killops and Killops 1993). To remove cellulose, the hemicellulose must be removed first by a standard acid treatment. Then cellulose is converted into celluloseacetate by boiling with 3% H_2SO_4 + HCl and afterwards stored for 1 h in 72% H_2SO_4 + HCl at a temperature of 25°C (Zaitseva 1995; Römpp 1992). Treatment with cyclohexane and ethanol 2:1 in a soxhlet extraction apparatus removes the celluloseacetate as well as resins and waxes. After this pretreatment a standard treatment with one alkali and one acid step followed.

Cellulose ($(C_6H_{10}O_5)_n$) is a polysaccharide insoluble in water; it is the main compound in cell walls and provides a rigid layer around the cell membranes. First the waxes, celluloseacetate, and resins were dissolved during a soxhlet extraction with cyclohexane + ethanol 2:1. The second step was an acid step. To destroy the lignin, 30 g $NaClO_2$ + 1 mL 37% HCl were added to 50 g milled wood stored in 0.8 L deionized water at a temperature of 75°C. The oxidation step with $NaClO_2$ was repeated until the sample clearly showed a white color. The destroyed substances were removed by means of an alkali step and a final acid step.

Between all chemical steps the samples are washed with deionized water until a pH of 7 is reached.

Radiocarbon Measurement

In the underground laboratory of Climate and Environmental Physics at the University of Bern, the low-level gas proportional counting technique is used by converting carbon dioxide into methane (*e.g.*, Polach and Stipp 1967). All samples were counted for 4200 min, except samples B-6703, B-6706 (4080 min), B-6687 standard, B-6691, B-6701 (4140 min). ^{14}C ages are reported either as uncalibrated BP or cal BP; if corrected and calibrated it is done according to the methods outlined for OxCal by Bronk Ramsey (1995).

RESULTS AND DISCUSSION

The results of comparative investigations of different treatment methods on two wood samples were very encouraging (Table 1). The difference for the *Picea* sample (B-6687) amounts to only 90 ^{14}C yr (4520–4430 BP, 1σ). The ^{14}C ages of *Pinus cembra* (B-6699) extend over a range of only 75 yr (3980–3905 BP, 1σ).

These results show no significant difference between the different chemical treatment methods. (Bear in mind, however, that the wood samples were preserved under chemically favorable conditions under the glacier.)

The dates obtained cluster in the time windows 8.1–7.7 kyr BP, 6.2–5.8 kyr BP, 4.5–4.3 kyr BP, 4.1–3.6 kyr BP and 3.4–3.2 kyr BP (Fig. 1, Table 1).

TABLE 1. Tree Stems and *Salix* Macrofossils (Fen Peat) of Unteraarglacier

Lab code (B-)	Sample material (pretreatment method)	Tree rings	Background (cpm / l)	CO$_2$ (mbar)	δ^{13}C (‰)	^{14}C age (yr BP)	Calibrated age* (cal BP, 2σ)
6691	*Picea / Larix* (standard)	40	0.840 ± 0.006	663	–26.1	8029 ± 33	8990–8674
6690	*Picea / Larix* (standard)	48	0.843 ± 0.009	858	–27.0	7973 ± 31	8980–8613
6686	*Picea* (standard)	76	0.843 ± 0.009	1001	–26.4	7972 ± 31	8950–8674
6692	*Picea / Larix* (standard)	12	0.843 ± 0.009	783	–25.2	7960 ± 31	8956–8602
6700	*Larix* sp. (standard)	90	0.843 ± 0.009	~850	–26.2	7702 ± 31	8545–8375
6704	*Pinus cembra* (standard)	80	1.296 ± 0.010	601	–26.4	6032 ± 36	6997–6784
6689	*Pinus cembra* (standard)	25	0.843 ± 0.009	827	–24.3	6032 ± 28	6990–6788
6842	*Pinus cembra* (lignin)	70	0.843 ± 0.009	780	–25.5	5804 ± 28	6718–6506
6687	*Picea* (lignin)	65	0.843 ± 0.009	1043	–25.6	4494 ± 26	5286–4995
6687	*Picea* (cellulose)	65	0.843 ± 0.009	872	–24.3	4471 ± 26	5284–4885
6687	*Picea* (standard)	65	0.843 ± 0.009	898	–26.0	4460 ± 30	5277–4878
6707	*Pinus cembra* (standard)	20	0.843 ± 0.009	777	–26.0	4340 ± 25	4981–4838
6703	*Picea* (standard)	60	0.843 ± 0.009	814	–27.0	4045 ± 25	4565–4422
6688	*Larix / Picea* (standard)	65	0.843 ± 0.009	796	–26.2	4039 ± 25	4562–4421
6702	*Picea* (standard)	170	0.843 ± 0.009	706	–25.5	3972 ± 25	4517–4313
6699	*Pinus cembra* (cellulose)	95	0.840 ± 0.006	625	–23.4	3954 ± 26	4509–4294
6699	*Pinus cembra* (standard)	95	0.840 ± 0.006	719	–25.1	3945 ± 26	4505–4286
6699	*Pinus cembra* (lignin)	95	0.843 ± 0.009	765	–25.1	3930 ± 25	4421–4277
6697	*Salix* sp. (standard)	--	0.843 ± 0.009	858	–27.3	3789 ± 25	4236–4007
6696	*Salix* sp. (standard)	--	0.843 ± 0.009	908	–26.7	3778 ± 25	4231–4001
6701	*Pinus cembra* (standard)	130	0.843 ± 0.009	768	–24.3	3761 ± 25	4227–3992
6619	Fen peat (bulk)	--	1.482 ± 0.023	603	–31.2	3730 ± 32	4137–3932
6705	*Salix* sp. (standard)	--	1.542 ± 0.010	494	–28.7	3694 ± 33	4134–3920
6618	*Salix* sp. stem (standard)	25	0.841 ± 0.013	1064	–27.7	3686 ± 27	4087–3923
6694	*Salix* sp. (standard)	--	0.843 ± 0.009	959	–27.8	3683 ± 24	4086–3923
6698	*Picea / Larix* (standard)	45	0.843 ± 0.009	808	–23.6	3656 ± 24	4078–3890
6693	*Picea* (standard)	100	0.843 ± 0.009	820	–27.0	3641 ± 24	4072–3867
6695	*Salix* sp. (standard)	--	1.296 ± 0.010	603	–23.6	3622 ± 31	4062–3836
6891	*Pinus cembra* (lignin)	80	0.843 ± 0.009	765	–27.2	3276 ± 24	3566–3407
6706	*Betula* (standard)	40	0.840 ± 0.006	721	–27.5	3227 ± 25	3470–3380

*The OxCal program by Bronk Ramsey (1995, based on Stuiver, Long and Kra 1993) was used for calibration of the ages

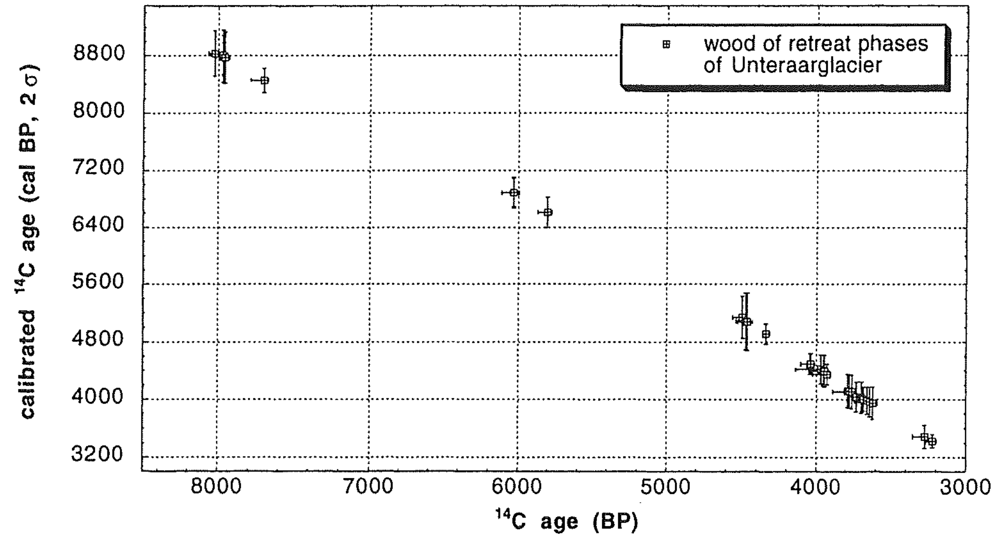

Fig. 1. ^{14}C ages (BP, including the number of tree rings and 1σ error) are fitted to their calibrated ages (cal BP), using the OxCal program (Bronk Ramsey 1995, based on Stuiver, Long and Kra 1993)

Based on the ^{14}C dating of the wood samples and the number of counted tree rings we can assume a first retreat with a smaller glacier extension than at present between 8100 and 7670 BP. Three *Picea/ Larix* samples of similar age are dated at 7973 ± 31, 7972 ± 31 and 7960 ± 31 BP. One *Larix* sp. sample (B-6700) is only slightly different at 7702 ± 31 BP (Table 1). The Unteraarglacier data confirm previous investigations such as the Holocene history of Swiss glaciers reported by Röthlisberger (1976) and Röthlisberger *et al.* (1980). They also ^{14}C-dated fossil soils and wood found in moraines. The results show similar glacier retreat phases at Gorner-, Zmutt- and Ferpècleglacier in the Alps of Wallis/Switzerland between 8160 ± 220 and 7550 ± 110 BP (Röthlisberger *et al.* 1980).

Dendroclimatological investigations on ^{14}C-dated floating chronologies demonstrated warm phases in the Swiss Alps between 7740 and 7685 BP as well as between 7610 and 7560 BP (Renner 1982: 157).

Blunier *et al.* (1995) pointed out in the GRIP ice core a relatively high (*ca.* 725 ppbv) methane concentration before 8200 yr ago (ice counted layers) and an abrupt fall at this time. This CH_4 dip has recently also been recognized in D47 and Byrd ice cores (Chappellaz *et al.* 1997; Alley *et al.* 1997). The GISP2 record shows a relatively stable optimum of $\delta^{18}O$ values between 9000 and 8500 yr ago. However, an abrupt fall also occurred at 8200 yr ago (Stuiver, Braziunas and Grootes 1995: 346 and Fig. 6). The fall in CH_4 concentration as well as $\delta^{18}O$ happened at around the same time as the alpine glaciers readvanced (*e.g.*, Röthlisberger 1976; Patzelt 1996).

Three *Pinus cembra* samples of Unteraarglacier were dated between 6030 and 5800 BP. This period of glacier contraction (6140–5780 BP, Table 1: counted tree rings included) is reported from other regions as well, based on ^{14}C dates of wood: the Mont Miné glacier and the Ferpècle glacier were smaller before 6020 ± 100 BP; the Allalinglacier was smaller than in the year 1920 before 5760 ± 120 BP (Röthlisberger *et al.* 1980). Even the glaciers of the Eastern Alps experienced a recession (Patzelt 1996); moreover, in Alaska in the St. Elias Mountains a glacier contraction occurred during 6175–5975 BP (Denton and Karlén 1973). At Alpe d'Essertse in the Central Swiss Alps, charcoal derived from *Pinus cembra* was found at 2380 m altitude (50–100 m above the recent timberline) and yielded a ^{14}C date of 6010 ± 70 BP (Tinner, Ammann and Germann 1996).

The $\delta^{18}O$ record of GISP2 shows slightly higher values relative to the average $\delta^{18}O$ in the time period 6997–6506 cal BP (*cf.* Table 1) (Stuiver, Braziunas and Grootes 1995: Fig. 6).

A warm period was documented with one *Picea* sample (4494–4471 BP with various pretreatment methods, B-6687) and one *Pinus cembra* sample (B-6707 = 4340 ± 25 BP). This climate change is also reflected in the CH_4 records of GRIP, GISP2, D47 and Byrd *ca.* 5000 yr ago (in comparison with our ^{14}C ages *ca.* 4500 BP), when CH_4 concentration increased from 35 ± 7 ppbv to 50 ± 3 ppbv (Chappellaz *et al.* 1997). At the same time (4600–4000 BP), a *Pinus cembra* forest developed in the outwash plain of Ferpècle glacier (Röthlisberger 1976). Using the dendroclimatological method, Renner (1982) identified a warm phase at 4395–4330 BP. The climate signals in the Western and Eastern Alps seem to be different, because the Ötztal ice man died in the Eastern Alps/South Tirol due to a cold phase beginning *ca.* 4535 ± 60 BP (ETH-8345.3, grass sample) (Bonani *et al.* 1994: 248). (Or the finding requires another interpretation if the Ötztal ice man does not indicate the beginning of a cold phase.)

The most striking period of glacier recession of Unteraarglacier (Figs. 1 and 2, Table 1) is the period in the mid-Holocene between 4045 ± 25 and 3622 ± 31 BP. The greatest number of dated samples, 15 out of 25, cluster in this time period. Also, the climate was warm enough (and possibly with increased precipitation) for a *Cyperaceae* peat with *Salix* sp., *Alnus* (not yet dated) and *Betula* (not yet dated) species to arise in the period between 3789 ± 25 and 3622 ± 31 BP. The remarkable onset of peat growth could be attributed to a climate change at *ca.* 3800 BP with wetter conditions. Caulfield, O'Donnell and Mitchell (1998) pointed out that at 3800 BP in west Ireland the decline of pine growth also happens very quickly and peat growth is renewed.

Nowhere in the Alps have glacier advances been observed between *ca.* 4000 and 3600 BP (Gamper and Suter 1982). Indications of smaller glacier extensions than today have been found in the Wallis (Swiss Alps) between 4030 ± 250 BP and 3350 ± 80 BP (Röthlisberger *et al.* 1980: 43–44) and recently in the Berner Oberland at Stein- and Steinlimmiglaciers and in the Val Malenco, Italy at Lago di Musella *ca.* 4000 BP (Schlüchter 1994). Even the glaciers in Alaska were smaller *ca.* 4030–3300 BP (Denton and Karlén 1973). Using the dendroclimatological method, Renner (1982) identi-

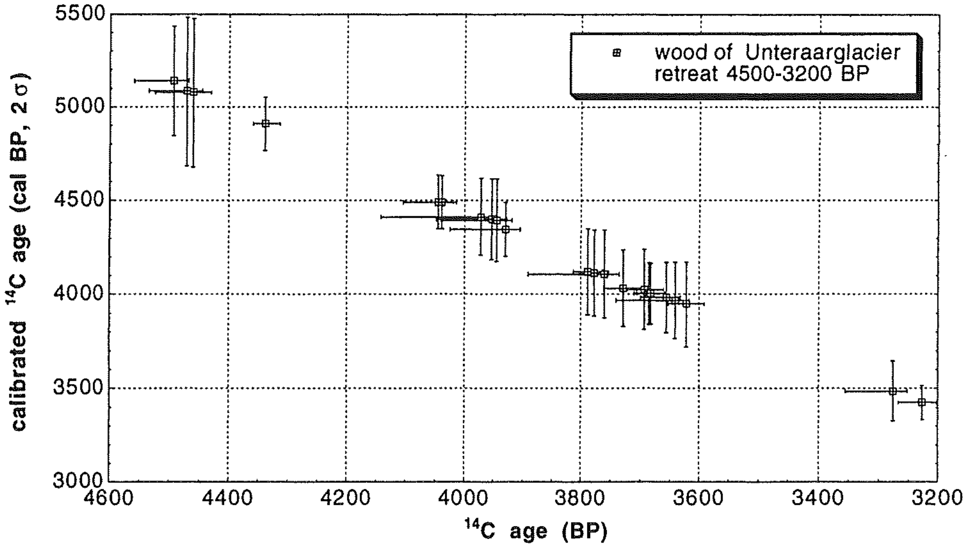

Fig. 2. Fitted ^{14}C ages as in Fig. 1

fied a higher-than-average warm period between 3740 and 3600 BP. Even the $\delta^{18}O$ values of GISP2 are high in the mid-Holocene (Stuiver, Braziunas and Grootes 1995: Fig. 6).

There is a small remarkable gap between the ^{14}C ages *ca.* 4.3–4.1 kyr BP (Fig. 2). It could be interpreted as a gap in the numbers of retrieved wood samples, yet it could also represent glacier advance. Renner (1982) found indication of a climate depression at 4130–4070 BP based on density investigations of conifer latewood. But synchronous drier climate conditions are also registered in Western Ireland between 4600 and 3800 BP without a gap, based on ^{14}C dating of 44 pine samples in North Mayo (Caulfield, O'Donnell and Mitchell 1998), and in Northern Scotland between 4405 and 3815 BP (Gear and Huntley 1991). At Alpe d'Essertse in the Wallis, Switzerland the forest limit descended after 4700 BP (Tinner, Ammann and Germann 1996). Therefore we suggest that between 4.3 and 4.1 kyr BP there might be a gap in the amount of samples and the climate conditions were more favorable between *ca.* 4580 and 3600 BP.

There is little evidence in the literature for a warm period between 3380 and 3200 BP, but it exists at Unteraarglacier (Table 1, tree rings and ^{14}C dates + 1σ error). Only at Allalinglacier a buried soil of 3270 ± 135 BP indicates that the glacier had a smaller extension and afterwards the soil was buried due to a readvance (Röthlisberger *et al.* 1980). Dendroclimatological results also indicate warmer climate conditions between 3340 and 3175 BP (Renner 1982: 53).

The time intervals between ^{14}C date clusters of wood from Unteraarglacier are 2400–1800 yr, 2000–1700 yr, 1600–1400 yr, 346 yr and 295 yr (Table 1). The first three intervals suggest a *ca.* 2000-yr cyclicity.

The $\delta^{18}O$ record of the GISP2 ice core shows increases of $\delta^{18}O$ that are forced by spectral power density of the sun and oceanic thermohaline circulation near 3300, 1050, 550, 465, 314, 264, 242, 211, 155 and 120 yr (Stuiver, Braziunas and Grootes 1995). Also, studies of cosmogenic ^{14}C content in tree rings due to variations in solar activity found major anomalies with a 2000-yr periodicity (Stuiver and Reimer 1993; Dergachev and Chistyakov 1995). Finally, the 1374 ± 502 yr cycle found in North Atlantic deep sea cores (Bond *et al.* 1997) seems to coincide with Unteraarglacier, except for the peak of ice-rafted debris at 4200 BP. We would like to stimulate the discussion of whether any cycles from $\delta^{18}O$ records (Stuiver and Braziunas 1993; Stuiver, Braziunas and Grootes 1995) or ^{14}C content variations are reflected in the Unteraarglacier behavior.

CONCLUSION

The ^{14}C dates of a set of samples from Unteraarglacier, which reflect glacier contraction phases (8100–7670 BP, 6175–5780 BP, 4580–4300 BP, 4100–3600 BP and 3380–3200 BP) are comparable to several other Holocene climate archives:

1. Glaciers in the Swiss Alps and Alaska (Röthlisberger *et al.* 1980; Schlüchter 1994; Denton and Karlén 1973): recession phases are recorded 8160–7550 BP, 6020–5760 BP and 4030–3300 BP.
2. Dendroclimatological investigations (Renner 1982): warm phases in the Swiss Alps are noted during 7740–7685 BP, 7610–7560 BP, 4395–4330 BP and 3740–3600 BP.
3. The contraction of Unteraarglacier between 8029 and 7702 BP (8990–8375 cal BP, ±2 σ) coincides with high methane concentrations (*ca.* 725 ppbv) in the GRIP ice core (Blunier *et al.* 1995) and with a stable optimum in $\delta^{18}O$ values in the GISP2 ice core (Stuiver, Braziunas and Grootes 1995).
4. The contractions seem to reflect a 2000-yr periodicity that was also found in cosmogenically produced ^{14}C variations in tree rings by Fourier analysis (Dergachev and Chistyakov 1995).

5. However, the most conspicuous feature in our Holocene chronology oscillations of Unteraargletscher is the period between 4100 (probably extending back to 4580) and 3600 BP. A 500-yr (probably 980-yr) period of Holocene optimum climate conditions seems to be a striking event across the Northern Hemisphere (Swiss Alps, Alaska, West Ireland, Northern Scotland, $\delta^{18}O$ of GISP2). Whether this event is also existent in the mid-latitudes of the Southern Hemisphere and in the tropical regions has yet to be proven.

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