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Rapid Communication

Ice-borne prehistoric finds in the Swiss Alps reflect Holocene glacier fluctuations

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ABSTRACT: During the hot summer of 2003, reduction of an ice field in the Swiss Alps (Schnidejoch) uncovered spectacular archaeological hunting gear, fur, leather and woollen clothing and tools from four distinct windows of time: Neolithic Age (4900 to 4450 cal. yr BP), early Bronze Age (4100–3650 cal. yr BP), Roman Age (1st–3rd century AD), and Medieval times (8–9th century AD and 14–15th century AD). Transalpine routes connecting northern Italy with the northern Alps during these slots is consistent with late Holocene maximum glacier retreat. The age cohorts of the artefacts are separated which is indicative of glacier advances when the route was difficult and not used for transit. The preservation of Neolithic leather indicates permanent ice cover at that site from ca. 4900 cal. yr BP until AD 2003, implying that the ice cover was smaller in 2003 than at any time during the last 5000 years. Current glacier retreat is unprecedented since at least that time. This is highly significant regarding the interpretation of the recent warming and the rapid loss of ice in the Alps. Copyright © 2007 John Wiley & Sons, Ltd.

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KEYWORDS: archaeology; glaciology; climate change; global warming; Switzerland.

Introduction

Recent data from systematic collection of glacially deformed fossil wood exposed in front of retreating tongues of Alpine glaciers suggest that glaciers were ‘smaller than the 1985 reference level’ for approximately 50% of the time during the last 10 000 years, i.e. the Holocene (Hormes *et al.*, 2001, 2006; Jörin *et al.*, 2006). Well documented are the glacier recessions of the Great Aletsch Glacier above the AD 2002 reference lines during the Bronze Age Optimum (1500–1100 BC), the Roman Age Optimum (200 BC–AD 100) and the Medieval Climate Optimum (Holzhauser *et al.*, 2005). Warmer than present summer temperatures during the early and mid-Holocene are documented from biological proxies in the western Swiss Alps (e.g. Wick and Tinner, 1997; Burga and Perret, 1998; Tinner and Theurillat, 2003; Heiri and Lotter, 2005; Lotter *et al.*, 2006; and references therein).

Receding Alpine glaciers are prime symbols of ‘Global Warming’. Thus the new results about the ‘Green Alps in the Past’ were perceived as a surprise and stimulated a public debate as to the degree to which the observed 20th century glacier retreat, in particular the most rapid ice decay of the past 20 years is unusual and unprecedented in the light of the Holocene history.

During the hot summer of 2003, Alpine glaciers lost a record amount of 2.5 m water equivalent of ice (Zemp, 2006), and exposed spectacular archaeological finds from the high alpine environments in an ice field at Schnidejoch (western Swiss Alps). This material sheds new light: (1) on the Neolithic presence in the high elevation Alpine areas, (2) on Bronze and Roman Age transalpine passages and, of particular interest in the context of this paper, (3) on the mid- and late Holocene glacier fluctuations and their interpretation in the light of the current glacier retreat. Our findings suggest that at the archaeological site this glacier was smaller in 2003 than at any time during the past 5000 years.

First we describe the site and the finds in their glaciological context. We put this in the context of the regional mid- and late Holocene environmental history, and compare the variability of Holocene glacial dynamics with the glacial retreat observed during the last decades and the most recent years. A detailed discussion of the archaeological material and the implications is presented elsewhere (Suter *et al.*, 2005).

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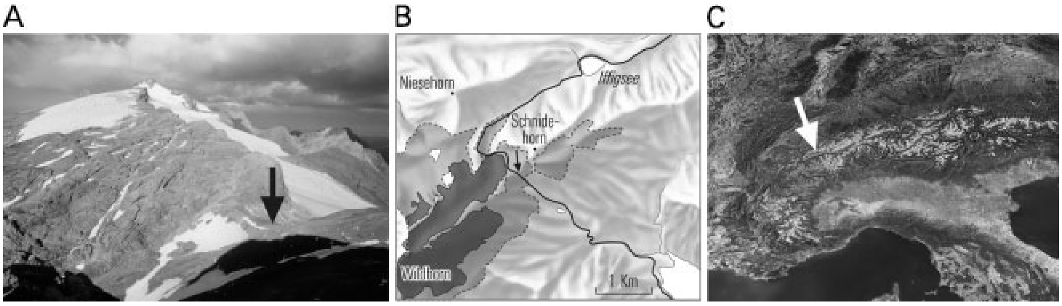

Figure 1 Picture (A) showing Schnidejoch (arrow, 46° 22′ N/7° 23′ W/2756 m) with the saddle and Tungel glacier. (B) Map showing the passage across Schnidejoch (black line) and the extent of Tungel glacier AD 1850 (inside dotted line) and AD 1980 (dark shaded). (C) Satellite map of the greater Alpine region with the location of Schnidejoch

The geographical and glaciological setting

The archaeological material was found near and within a small ice field at Schnidejoch pass (46° 22′ 20″ N/7° 22′ 40″ W/ 2756 m) in the western Swiss Alps (Fig. 1). The small NW sloping ice field used to be a part of the Tungel glacier but is now disconnected. During most of the 20th century, the ice field was close to the equilibrium line altitude (ELA), which is at 2700–2800 m and rose rapidly by 70 m $10\,yr^{-1}$ with the increasing warming trend of the late 20th century (data from nearby Griesglacier 1962–2000; World Glacier Monitoring System (WGMS)). Thus the mass balance at the archaeological site is at the most critical elevation to respond without delay to interannual climate fluctuations. Today, the site is clearly below the ELA. The thin ice is rapidly disintegrating and exposes archaeological finds. Glaciologically speaking, this is very different from changes at Alpine glacier tongues, where typical response lags vary depending on the size and geometry of the glacier between 21 and 67 years (for glaciers considered here; Jörin *et al.* 2006). In consequence, these glacier tongues are in equilibrium with the climate of the early 1980s and have not yet 'seen' the most recent warm decades.

The finds are located in and around the remaining ice that is located in a depression 60 m west of the pass. At present, this ice body is isolated from the Tungel glacier further to the NW (Figs 1(B) and Fig. 2). The potential accumulation area upslope of this ice body is very small, and ice flow at the site and dislocation of the finds was minimal, with easy transit across the Schnidejoch saddle. The trail leads along a gentle slope north of the remaining isolated ice body down to the front of the Tungel glacier, and further down the currently ice-free valley, whereas growing ice from the Tungel glacier would close the valley approximately 1 km NW of the site and make the route in the lower part very difficult for transit.

The first exposed archaeological material was found by hikers in September 2003. Afterwards, the site was repeatedly monitored by the Archaeological Survey of Canton Bern. Organic archaeological material was found on the soil surface adjacent to the border of the ice or on the ice surface. Metal

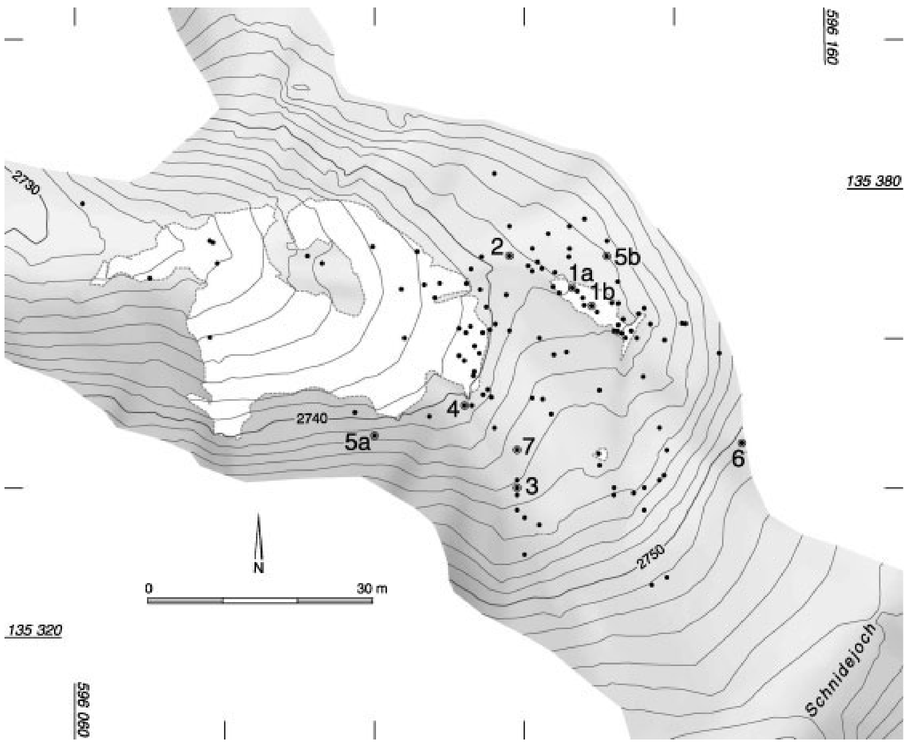

Figure 2 Map of the site showing the isolated relict ice field and ice patch on the NW slope of Schnidejoch and the locations of the finds 2004 and 2005. Numbers in the map refer to the artefacts in Fig. 3. Contour interval is 1 m

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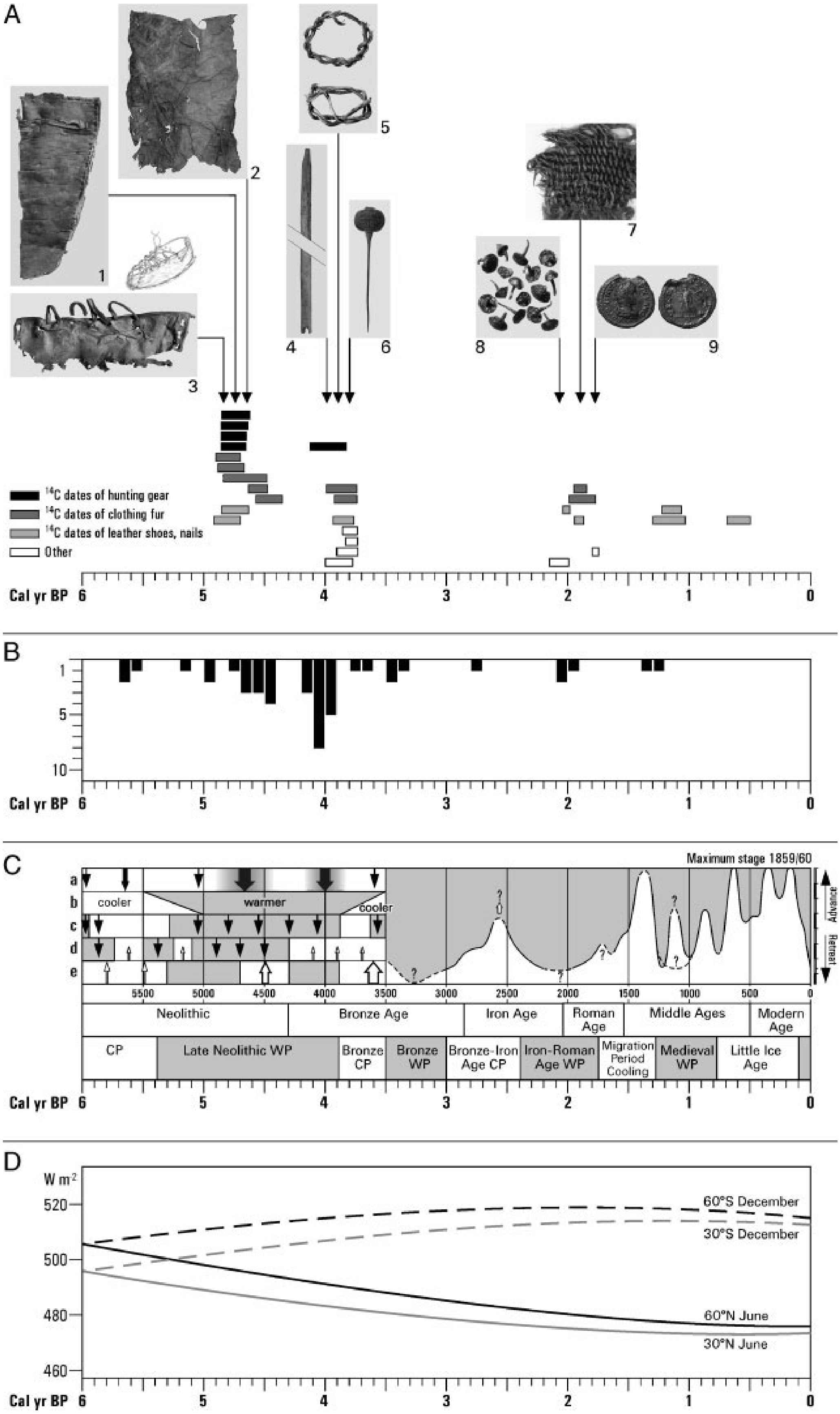

Figure 3 (A) ^{14}C dates (95% probability interval) of archaeological finds and a selection of artefacts from Schnidejoch: (1) casing for hunting gear, (2) leather leggings, (3) shoe, (4) arrow, (5) belts (made of twigs), (6) bronze needle, (7) wool (Roman *tunica*), (8) shoe nails and (9) coins. (B) Number of data points indicating Grimsel glacier shorter than present (i.e. 1985 reference level; data from Jörin *et al.* (2006)). (C) Compilation of glacier advances (light arrows), retreats (heavy arrows), cold/moist (CP, light) and warm/dry (WP, shaded) phases in the greater Alpine area: on the left 6000–3500 cal. yr BP, (a) Jörin *et al.*, 2006, (b) Trachsel, 2005 (compilation of 26 sites), (c) Hormes *et al.*, 2001, (d) Furrer, 2001, (e) Nicolussi and Patzelt, 2000; on the right 3500 cal. yr BP to present: Great Aletsch Glacier, Holzhauser *et al.*, 2005. (D) Milankovic forcing showing the greater insolation during mid-Holocene summers (June) at Northern Hemisphere mid-latitudes (Berger, 1978)

finds were scattered with a larger spread. The archaeological material is not stratified.

Results

The melting ice exposed spectacular archaeological material (Fig. 3). The late Neolithic assemblage (4900–4450 cal. yr BP) includes complete hunting gear with a case made of birch bark and lithic arrow heads inside, several arrows made of *Viburnum* sp. and the bow made of *Taxus baccata*. For the first time in Switzerland, Neolithic fur and leather cloth, leather leggings and shoes were found. In contrast to the Ice Man in the Austrian Alps, dated to 5300 cal. yr BP (e.g. Bortenschlager and Oeggl, 2000) no human body has been found.

Separated by a hiatus of 300–400 years, the second cohort of dates falls into the early Bronze Age (4100–3650 cal. yr BP). Finds include arrows made of *Corylus* wood, a bronze needle and belts made of twigs indicative for the use of pack animals.

Following a 1600 yr hiatus with no archaeological evidence, a third cluster of artefacts appears during the late Iron Age and Roman Age (2100–1600 cal. yr BP): a woollen belt of a Roman *tunica*, a leather fragment of a *carbatina*, more than 100 typologically precisely dated shoe nails span from the 1st to the 3rd century. According to the ^{14}C dates, a fragment of a leather shoe dates to the 8–9th century AD, and a repair kit of a medieval shoe to the 14–15th century.

Discussion and conclusion

The well-defined clusters of archaeological dates and the evidence of direct transalpine route passage during these windows of time is consistent with minimum glacier extensions as concluded from fossil trees exposed in the forefields of retreating glaciers (Fig. 3(B); Holzhauser *et al*., 2005; Jörin *et al*., 2006). This closely matches data from the glaciers in the Grimsel area, which belong to the same climatic regime of the north slope of the Western Alps, although somewhat enigmatic is the advance of the Lower Grindelwald Glacier during the 9th century AD (Holzhauser *et al*., 2005), when human presence at Schnidejoch is documented with two consistent ^{14}C dates of a medieval shoe. No archaeological evidence was found for the windows of glacier retreat around 3400 and 2800 cal. yr BP (Jörin *et al*., 2006).

In the light of the large number of dated artefacts (Fig. 3(A)), the separation of the age cohorts is noteworthy and reflects periods of glacial advance, i.e. times when the route was very difficult for transit. In particular the gap between the Neolithic and Early Bronze Age (4400–4200 cal. yr BP (2400–2200 BC) seems to be significant and suggests a (minor) glacial advance and cooling that is poorly documented in other climate archives of the greater Alpine region and the Swiss Plateau (Wick and Tinner, 1997; Tinner and Theurillat, 2003; Trachsel, 2005; Heiri and Lotter, 2005; Nicolussi *et al*., 2005; Jörin *et al*., 2006), but is consistent with a negative excursion of stalagmite $\delta^{18}O$ in the Spannagel cave (Austria) around 4200 cal. yr BP (Vollweiler *et al*., 2006). This cooling episode might have been sufficient to close the passage at Schnidejoch, which points to an interesting feature of Schnidejoch as a palaeoclimatic archive different from timberline changes or glacier tongue fluctuations, Schnidejoch is a binary and non-continuous archive ('open or closed'). It operates at a precisely defined and constant threshold (Equilibrium Line Altitude (ELA) at 2750 m) and responds immediately and most sensitively to small perturbations if climatology fluctuates around that threshold value. Interestingly the hiatus at Schnidejoch (2400–2100 BC) is also observed as an occupational gap in the Neolithic lakeshore sites in the Swiss Plateau (Magny, 2004; Suter *et al*., 2005; Arbogast *et al*., 2006), suggesting that transalpine passage and pile villages were both closely related to warm and dry climate.

The critical point in the context of this paper is that leather requires permanent embedding in ice in order to stay preserved and, as it is observed today, deteriorates very quickly if exposed at the surface. In consequence, the finds at Schnidejoch suggest permanent ice cover at that site for the last 5000 years, more specifically from ca. 3000 BC until AD 2003. At first glance our conclusion differs from the conclusions drawn from exposed trees in the forefields of melting glacier tongues (Jörin *et al*., 2006). However, the conclusions by Jörin *et al*. (2006; see also by Hormes *et al*., 2006) refer to the AD 1985 level:'glaciers in the Grimsel [and Alpine] area were smaller than at 1985 AD during several times for the last 5000 years'; while our conclusion reads: 'in the year of 2003 AD, the ice field at Schnidejoch has reached the smallest extent since the last 5000 years'.

This is not a contradiction. We argue that this difference is explained by the dissimilar response lags of the two types of archives compared: ice mass balance near the ELA (Schnidejoch) responds immediately to sub-decadal climate variations, while Alpine glacier tongues respond with a multi-decadal lag to climatology (20–60 years (Jörin *et al*., 2006); importantly this fact also applies to the study by Hormes *et al*. (2006)). Differences between the equilibrium states of fast and slowly responding climate archives are typically large during phases of rapid changes. Indeed while the ice field at Schnidejoch is in equilibrium with the state of the atmosphere of the most recent years, the glacier tongues have not yet fully responded to the excessively warm years of the last 15 years, when (1) solar radiation at the Earth's surface has increased owing to brightening of the atmosphere (globally $6.6\,W\,m^{-2}\,10\,yr^{-1}$ between 1992 and 2002, Swiss Plateau $7.2\,W\,m^{-2}\,10\,yr^{-1}$; Wild *et al*., 2005), (2) anthropogenic greenhouse forcing with related strong water vapour feedback enhanced the downward longwave radiation in Europe ($+1.18\,W\,m^{-1}\,yr^{-1}$, data 1995–2002; Philipona *et al*., 2005) which increased temperatures, and (3) negative trends in the specific mass balance of Alpine glaciers accelerated (Zemp, 2006).

Obviously the underlying mechanisms for the current ice retreat are very different from those during the mid-Holocene (6 kyr BP), when Milankovich forcing at 47° N alone accounted for $+25\,W\,m^{-2}$ (summer) and $-15\,W\,m^{-2}$ (winter; Berger, 1978) compared with today (Fig. 3(D)). Also the role of solar irradiance may have played a role (Holzhauser *et al*., 2005, and references therein).

Although the ecosystem response (in our case 'Green Alps') may be largely the same today compared with the pre-anthropogenic period, the underlying causes are fundamentally different. Furthermore, the use of precious glacial meltwater during the summer season is much more intense today, optimised and related to economic and societal gains or losses. The buffer for large variability and changes in resource availability has become very small, and vulnerability has increased. This is finally the critically important contribution to the public debate concerning the vanishing Alpine glaciers. Indeed, Schnidejoch shows that the state of the Alpine glaciers of today (year AD 2003) is very unusual and unprecedented in the light of at least the last 5000 years.

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