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Short Communication

Radiocarbon Dating of Fossil Wood Remains Buried by the Piancabella Rock Glacier, Blenio Valley (Ticino, Southern Swiss Alps): Implications for Rock Glacier, Treeline and Climate History

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ABSTRACT

Fossil wood stem remains of larch (*Larix decidua*) found 1 m below the surface at the base of the front of the Piancabella rock glacier (46°27′02″N, 9°00′07″E, 2480 m a.s.l.) had a conventional age range of 845 ± 50 ^{14}C y BP (UZ-5545/ETH-34417), corresponding to a calibrated calendar age range of 1040–1280 AD (790 ± 120 cal BP) with a statistical probability of 95.4 per cent. Based on geomorphological, climatological and geophysical observations, we infer that (1) the treeline in the Medieval Warm Period was about 200 m higher than in the middle of the 20th century, which corresponds to a mean summer temperature as much as 1.2°C warmer than in AD 1950, and (2) that ice within this rock glacier is probably several centuries old and so predates recent climatic events such as the Little Ice Age.

KEY WORDS: Medieval Warm Period; permafrost; radiocarbon dating; rock glacier; Swiss Alps; treeline

INTRODUCTION

Radiocarbon dating is of great importance in alpine environments for investigating the origin of complex landforms as well as for inferring landscape history and evolution from sets of dated landforms of different origins. For example, the interpretation of such landscape historical data gives information on the velocity of processes, and therefore, the sensitivity of alpine environments to climate change.

Due to the cold climatic conditions of the alpine periglacial belt, however, it is often difficult to find datable organic material that allows the relative morpho-stratigraphical sequence of periglacial landforms to be established. The only materials suitable for ^{14}C chronology are peat-enriched layers, buried humic horizons and seeds, pollen, mosses or other organic remains embedded within ice in a rock glacier. In the EuropeanQ2 Alps, ^{14}C dating of soils and moss buried by a rock glacier has been discussed, for example, by Calderoni *et al*. (1998), Haeberli *et al*. (1999) and Dramis *et al*. (2003). Tree overriding and burial by advancing rock glaciers is known only in the North American cordillera (e.g. Shroder and Giardino, 1988; Carter *et al*., 1999), whereas systematic collection of glacially deformed fossil wood exposed in front of retreating tongues of Alpine glaciers is well documented (e.g. Hormes *et al*., 2006; Jörin *et al*., 2006). Apart from glaciological information, climatic change in the central and southern Swiss Alps during the late Holocene has also been derived from botanical and zoological proxies (e.g. Burga and Perret, 1998; Tinner and Theurillat, 2003; and references therein) and from changes in solifluction and landslide activity (e.g. Frenzel, 1993; Dapples *et al*., 2003).

This paper presents the results of radiocarbon dating of fossil wood stem remains of larch (*Larix decidua*) found at the front of the Piancabella rock glacier in September 2005 within the framework of geomorphological and geophysical investigations of the Late-glacial and Holocene glacier/permafrost evolution in the southern Swiss Alps (see Scapozza and Reynard, 2007; Scapozza, 2008). The site and

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the findings are described in their geomorphological context, the findings are examined in relation to the regional late Holocene climatological history and finally, the late Holocene dynamics of the Piancabella rock glacier are discussed.

GEOGRAPHICAL, GEOMORPHOLOGICAL AND ENVIRONMENTAL SETTINGS

The eight fossil *L. decidua* stem remains were found at a depth of 1 m below the surface at the front of the Piancabella rock glacier (46°27′02″N, 9°00′07″E), located at an elevation of 2480 m a.s.l. in the Sceru Valley (Figure 1). The Sceru Valley is an east-facing glacial cirque situated between 2000 and 2787 m a.s.l. in the eastern part of the Blenio Valley (Lepontine Alps of the Ticino, southern Switzerland). The morphology, hydrology and Late-glacial and Holocene glacier/permafrost history of the Sceru Valley were studied by Zeller (1964), Scapozza (2008) and Scapozza *et al*. (2008). The morphology is characterised by the presence of several rock glaciers with different degrees of activity, talus slopes and Late-glacial moraines (Figure 1C). At 2500 m a.s.l., the calculated mean annual precipitation is about 2300 mm/yr, whereas the extrapolated mean annual air temperature is about −1°C (Scapozza, 2008). According to Eggenberg (1995), the timberline in the Blenio Valley is, on average, at 2050 m a.s.l. Considering that in natural conditions, the treeline and/or the krummholz line has an altitudinal extension of 100–150 m above the timberline (Burga and Perret, 2001), it is situated between 2150 and 2200 m a.s.l. (Landolt and Aeschimann, 2005). This estimation is corroborated by the highest elevations reached by the trees in the area, as seen on the Swiss National topographical maps and in the field.

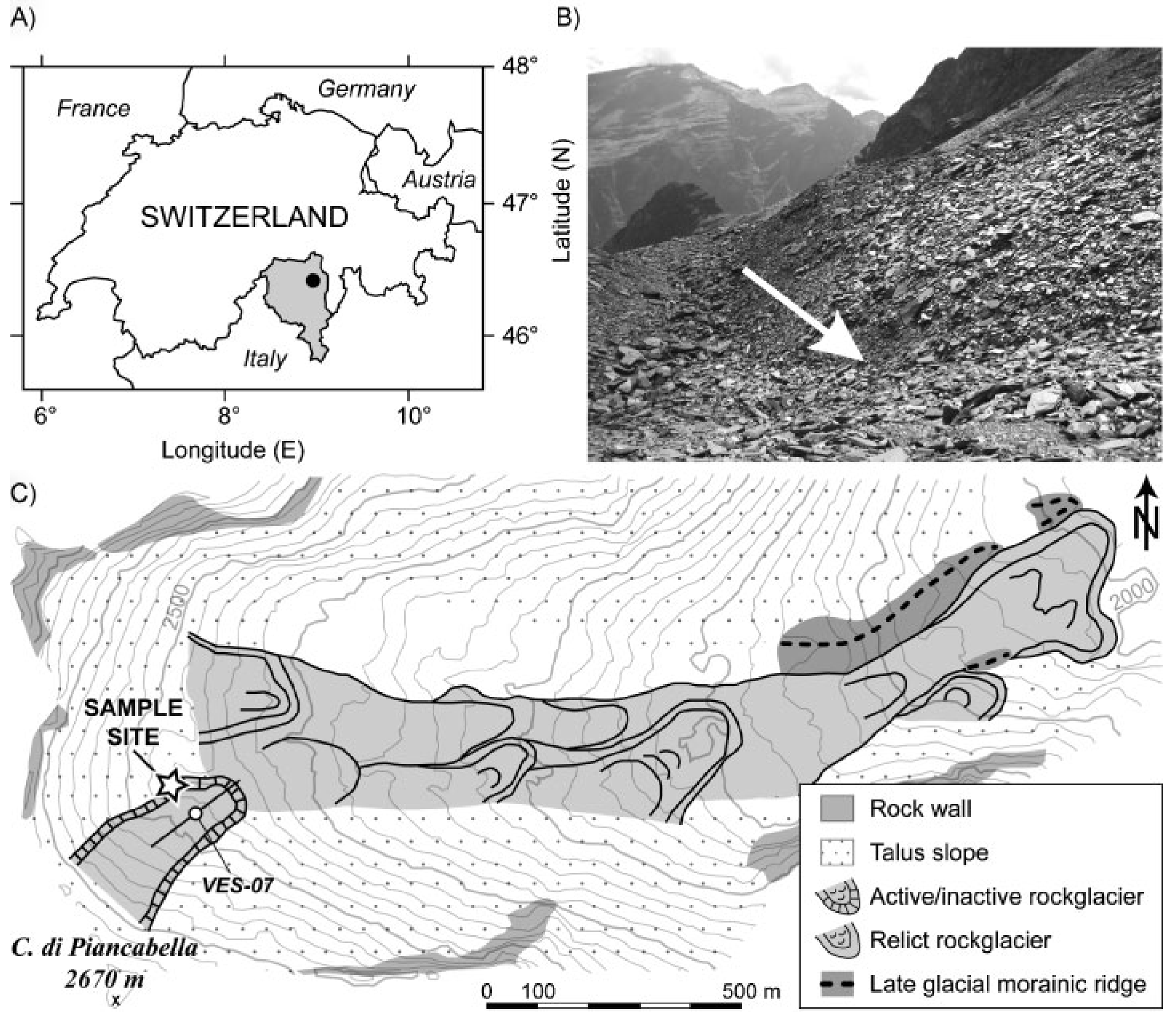

Figure 1 (A) Geographical location of the Piancabella rock glacier. (B) The Piancabella rock glacier. The arrow shows the location of the sample site. (C) Geomorphological map of the Sceru Valley showing the position of the Piancabella rock glacier and the location of the sample site. VES: Vertical electrical sounding.

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The Piancabella rock glacier has developed at the foot of the Cima di Piancabella (2670 m a.s.l.) from perennially frozen talus slopes located between 2650–2460 m a.s.l, as evidenced by geophysical and thermal measurements (Scapozza, 2008). The landform is a talus rock glacier, *sensu* Barsch (1996), north-east oriented and with a steep (about 35°) pebbly and sandy front. The rock glacier surface is made up exclusively of decimetre- to metre-size paragneissic blocks and is completely lacking in vascular plants. The lower part of the rock glacier is almost flat and presents several ridges and furrows. At 2500 m a.s.l. a sudden change of slope occurs, below which the rock glacier tongue is present. Morphological criteria and the temperature of water at the base of the front (ranging from 0.1 to 0.4°C) indicate that the Piancabella rock glacier is either active or inactive. Space-borne radar interferometry (SPRI) analysis, however, shows that the rock glacier is probably currently inactive (S. Mari, unpublished data).

A vertical electrical sounding (VES) carried out longitudinally on the centre of the rock glacier (VES-07 on Figure 1) shows the presence of a frozen layer (resistivity about 50 kΩm), at least 17 m thick, below a 4-m thick active layer (Figure 2). The resistive layer decreases in thickness and resistivity upslope of the break, as shown on a frequency–domain electromagnetic 2D resistivity profile carried out longitudinally on the centre of the rock glacier (Scapozza *et al*., 2008). The resistivity of the frozen layer may indicate that the ice/rock mixture within the Piancabella rock glacier is near 0°C and with a high content of unfrozen water, as suggested by self-potential measurements (Scapozza *et al*., 2008). This is not surprising for an inactive rock glacier situated close to the present lower limit of discontinuous permafrost.

SAMPLING AND RADIOCARBON DATING

Fossil *L. decidua* stems were found beneath 1 m of coarse blocky sediments at the base of the rock glacier's front, at 2480 m a.s.l., at the Swiss grid coordinates 720′050/145′630 (Figure 3A). In total, eight fragments of wood, of brown/grey colour, slightly jagged and in a good state of preservation, were found. They were covered with sand and silt. The longest wood stem is 36 cm long and 6 cm wide, whereas the other wood remains are less than 15 cm long and 3 cm wide (Figure 3B). It is important to note that the wood fragments do not result from a stump rooted *in situ*, which would have allowed us to state that the tree had grown at the spot where the wood fragments were found. Instead, we believe that the larch grew some metres above the location, at the only place where soil is present in the upper part of the Sceru Valley. A natural origin of the wood is probable as there are no indications that people transported the samples: there are no traces of wood-working, metal nails, fire places or other human artefacts in the sediment.

Wood analysis and species determination were carried out by Werner H. Schoch at the Laboratory of Quaternary Woods in Langnau (Switzerland) (ref. ANTO080418), whereas necessary preparation and pre-treatment of the sample material for radiocarbon dating were carried out by the ^{14}C Laboratory of the Department of Geography at the University of Zurich. Dating was done by AMS

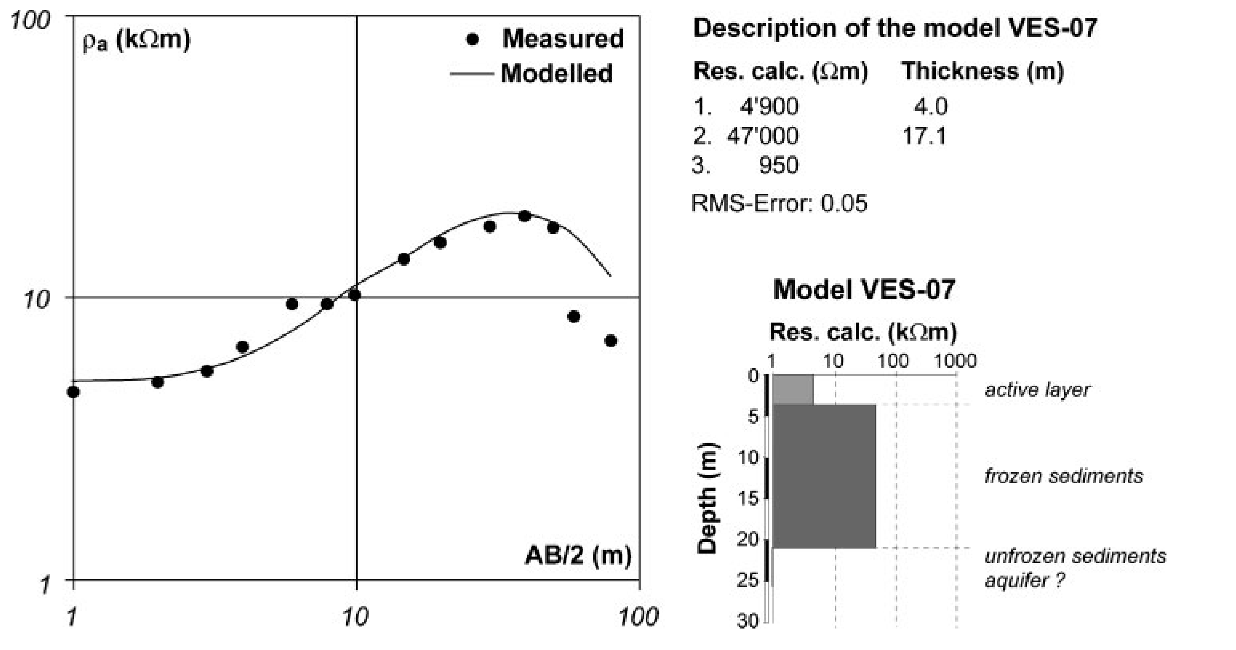

Figure 2 Curve and interpretation model of the VES-07 (vertical electrical sounding) carried out longitudinally on the centre of the rock glacier (see Figure 1 for the VES position).

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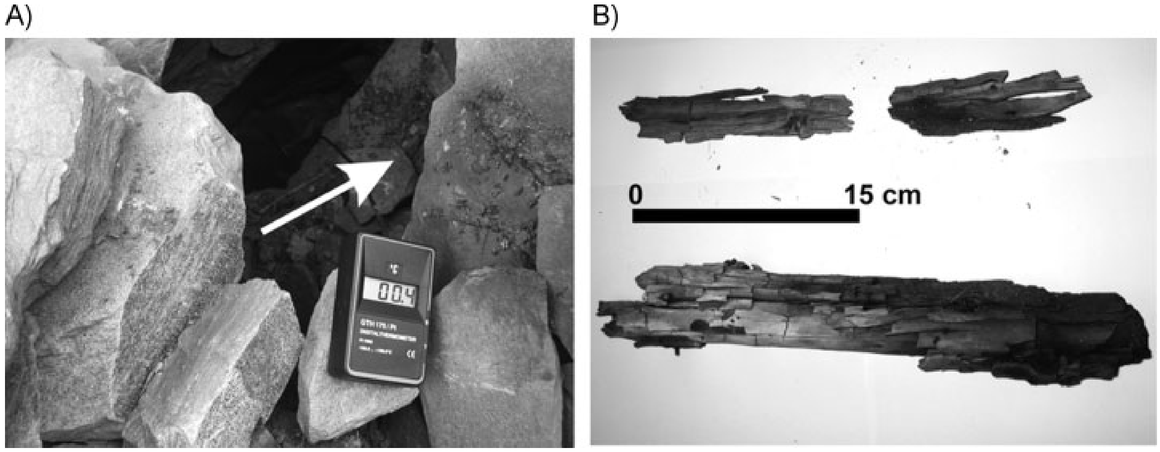

Figure 3 (A) Sample site. Fossil wood stem remains were found beneath 1 m of coarse blocky sediments (arrow). (B) Largest fragments of wood stem remains found.

(accelerator mass spectrometry) with the tandem accelerator of the Institute of Particle Physics at the Swiss Federal Institute of Technology Zurich (ETHZ) (ref. PIANCA2). Radiocarbon dating of the sample gave a mean conventional age of 845 ± 50 ^{14}C y BP (UZ-5545/ETH-34417). Calibration of the radiocarbon dating, performed with the software OxCal 3.10 (Bronk Ramsey, 2001) using the radiocarbon calibration curve IntCal04 (Reimer *et al.*, 2004), gave an age range of 1040–1280 cal AD (790 ± 120 cal BP) with a statistical probability of 95.4 per cent (Figure 4A).

The age range for the larch sample corresponds to the end of the Medieval Warm Period (MWP) (c. AD 800–900 to AD 1250–1300), a complex climatic period with frequent and intense oscillations of temperature, preceding the Little Ice Age (LIA) cool period (e.g. Davis *et al.*, 2003; Mangini *et al.*, 2005; Büntgen *et al.*, 2006) (Figure 4C). According to the Great Aletsch glacier fluctuations reconstructed by Holzhauser *et al.* (2005) (Figure 4B), the period corresponds to a phase of general glacier recession in the north and in the south of the Alps, with frontal positions comparable to those in the late 20th century, or perhaps even further up-valley (Grove and Switsur, 1994).

DISCUSSION

Implications for Treeline and Climate History

If a natural (i.e. non-anthropogenic) origin is assumed for the fossil wood, the latter's position allows the minimum elevation of treeline to be inferred. The treeline is the upper limit of erect arborescent growth and it is sometimes difficult to differentiate it from the krummholz line, which is the upper limit of stunted scrub-like trees (Price, 1981). We consider it to be a minimum elevation because the samples were reworked. The maximum elevation attained by the treeline corresponds to mean summer temperature values of between 5.5 and 7.5°C and to a soil temperature of about 7°C (Körner, 1999; Paulsen, 2000).

Treeline positions do not respond instantaneously to climatic change or to anthropogenic perturbations: for example, today's treeline position (2150–2200 m a.s.l.) is a complex result of the environmental dynamics during the past 150 years. Lags of 50–150 years after climate warming are documented in both palaeoecological and modelling studies (e.g. Bugmann and Pfister, 2000). Considering this, we can estimate that the natural potential treeline for the middle of the 20th century was between 2250 and 2300 m a.s.l. In this case, the difference in elevation with the end of the MWP treeline inferred from the Piancabella rock glacier samples is about 200 m. With a local lapse rate of 0.62°C/100 m (Bouët, 1985), the difference in elevation of the treeline corresponds to a difference in temperature of 1.2°C compared to the mid-20th century (i.e. ~AD 1950). This lapse rate was verified experimentally for the Blenio Valley, and is representative for the estimation of temperatures with the altitude for all the Swiss Alps (J.-M. Fallot, unpublished data).

The same result is obtained if we consider the mean monthly temperatures at the treeline elevation. Currently, the mean monthly temperatures at the potential treeline (about 2300 m a.s.l.) during the growing season (between June and September) are between 5.2 and 7.5°C (Table 1), which is in the range of temperatures reported by Körner (1999) and Paulsen (2000) for the treeline maximum altitude. Considering that the wood samples were reworked, the treeline elevation at the end of the MWP must have been at about 2500 m a.s.l. At this altitude, tree growth was possible only if the mean summer temperature was about 1.2°C higher than today (assuming similar precipitation), as indicated by temperatures calculated for 2500 m a.s.l. (Table 1). It is possible that the regional 20th-century treeline elevation has been under-estimated because of important anthropogenic perturbations due to pasturage practices. For this reason, the difference in mean summer temperatures of 1.2°C between the end of the MWP and today must be considered as a maximum value. This is high compared to typical proposed differences between the warmest decades of the MWP and the 20th century of about 0.7–0.8°C (e.g. Büntgen *et al.*, 2006). However, it corresponds well with the

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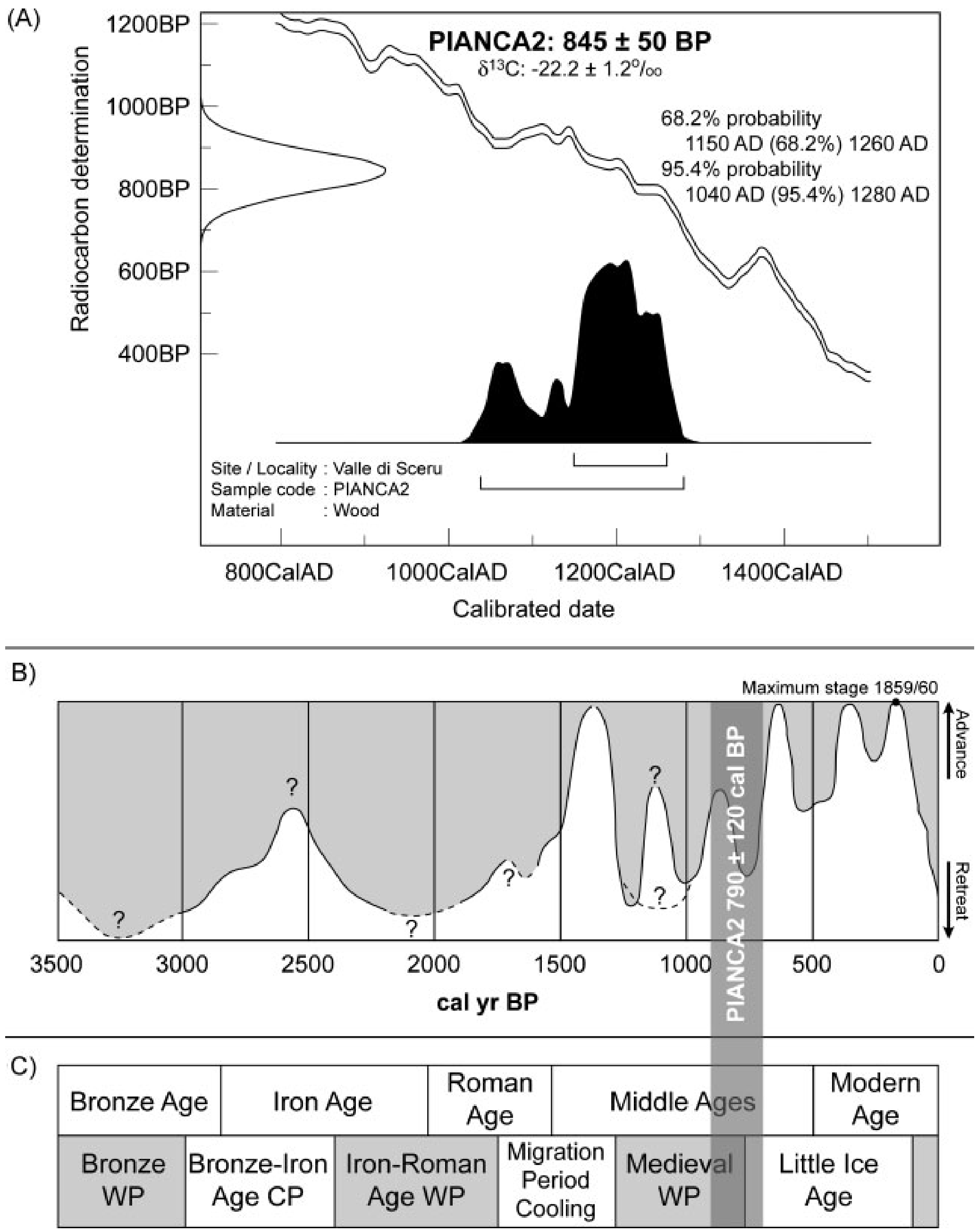

Figure 4 (A) Calibration of conventional ^{14}C age of wood sample PIANCA2, giving calibrated date ranges at 1σ (short horizontal bar) and 2σ (long bar) confidence levels: normally distributed ^{14}C ages are indicated at the ordinate. (B) Comparison of the radiocarbon age of sample PIANCA2 with the Great Aletsch glacier fluctuations in the last 3500 years established by Holzhauser *et al.* (2005). (C) Chronological and climatic framework of the Swiss Alps since the middle of the Bronze Age. Modified according to Grosjean *et al.* (2007). WP: Warm/dry period; CP: cold/moist period.

highest temperatures of the MWP reconstructed by Mangini *et al.* (2005) for an high-elevation cave system (2350–2500 m a.s.l.) in the central Alps of Austria from a $\delta^{18}O$ stalagmite record: temperature maxima during the end of the MWP that were on average about 1.7°C higher than the minima in the LIA and similar to present-day values, and with an absolute maxima for the MWP higher than the present-day temperature of 1.8 ± 0.3°C.

Implications for Rock Glacier History

The radiocarbon date and the inferred palaeotemperatures suggest that the Piancabella rock glacier probably became inactive towards the end of the MWP. If it is assumed that the wood remains were incorporated at their sampled location, their position at the front of the rock glacier and the small thickness of overlying sediments would show that the

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Table 1 Mean growing-season temperatures (°C) at the end of the Medieval Warm Period (T° 2500 m a.s.l.) and for the period between 1961 and 1990 (T° 2300 m a.s.l.) based on the MeteoSwiss climatic station of Comprovasco (575 m a.s.l., Blenio Valley). Data for T° Comprovasco (1961–90) by Meteo Swiss

	June	July	Aug.	Sept.	Mean
T° Comprovasco (1961–90)	16.1	18.4	17.6	14.6	16.7
T° 2500 m a.s.l.	4.0	6.3	5.9	4.2	5.1
T° 2300 m a.s.l.	5.2	7.5	7.1	5.3	6.3
ΔT° 2500–2300 m a.s.l.	1.2	1.2	1.2	1.1	1.2
LLR (500–1500 m a.s.l.)	0.63	0.63	0.61	0.49	0.59
LLR ($>$ 1500 m a.s.l.)	0.63	0.63	0.61	0.59	0.62

LLR: Local lapse rate (in °C/100 m) after Bouët (1985).

Piancabella rock glacier has not advanced since then. It appears probable that the wood stems were buried at or shortly after death. If the rock glacier front had been many metres higher upslope, the wood would have been exposed at the surface for several decades or centuries before being buried, causing its decomposition.

If the elevation of the treeline during the MWP corresponds to that of the lower limit of discontinuous permafrost, the wood remnants may indicate the beginning of permafrost degradation and consequently, the termination of rock glacier movement. This situation is similar to the history of inactivation of the Val Maone rock glacier in the Apennines, which was dated 780 ± 40 ^{14}C BP (BA145529), corresponding to a calibrated calendar age range of 1170–1290 AD with a statistical probability of 95.4 per cent (Giraudi, 2002). Apennine rock glacier ages have also been determined by dating soils, lacustrine deposits, tephra layers and loess deposits overlapping the rock glacier surface (Giraudi and Frezzotti, 1997; Giraudi, 2002; Dramis *et al*., 2003).

In a periglacial context, if climatic inactivation stops the aggradation of ice within a rock glacier, ice within the Piancabella rock glacier is probably several centuries old and therefore predates recent climatic events such as the LIA, as also indicated, for example, for the Murtèl-Corvatsch rock glacier in the eastern Swiss Alps (Haeberli *et al*., 1999).

It has been calculated by dating that rock glaciers within the Italian Alps resulted from cold episodes from 1000 to 5000 years BP (Dramis *et al*., 2003). Since these ages also indicate the timing of permafrost aggradation, an important phase of rock glacier development must have taken place between the end of the Younger Atlantic and the end of the LIA. However, the absence of ages older than 5000 BP in the Alps does not preclude the possibility of Early Holocene phases of permafrost aggradation (Dramis *et al*., 2003).

The Piancabella rock glacier, because of the phase of warmer air temperatures during the end of the MWP which likely corresponded to elevation of the lower limit of discontinuous permafrost, would have become inactive before the beginning of the LIA. It is difficult to determine if this behaviour is typical for rock glaciers situated close to the present regional lower limit of discontinuous permafrost (as are the Piancabella and the Val Maone rock glaciers). However, it is clear that, during the last millennium, the Piancabella rock glacier was the site of significant changes in dynamics, rheological properties and thermal conditions.

CONCLUSIONS

Two main conclusions can be drawn from observations, measurements and radiocarbon dating at the study site.

1. The ^{14}C age obtained from the Piancabella rock glacier and our observations show that the rock glacier probably became inactive during the end of the MWP. From a palaeoecological point of view, it seems likely that the treeline limit in the MWP was situated within the lower belt of discontinuous permafrost or close to its lower limit. Treeline was about 200 m higher than in the middle of the 20th century, which corresponds to a mean summer temperature as much as 1.2°C higher than in AD 1950.
2. Concerning the dynamics of the rock glacier, the ^{14}C date obtained can be interpreted as the minimum age for inactivity of the Piancabella rock glacier, which suggests that ice within this rock glacier is probably several centuries old and hence predates recent climatic events such as the LIA.

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