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The effect of Climate Change during the Lateglacial in the Hohen Tauern

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Abstract

Climate change and its impact on the Alpine landscape during the Lateglacial (~20.000-11.700 years) are reviewed with special focus on current research in the Hohen Tauern mountain chain (Eastern Alps) and surroundings. Based on three time slices (20-19 ka, 17-15 ka & 12 ka) the chronology of glacial, gravitational and periglacial processes with respect to climatic forcing is highlighted.

Keywords

Lateglacial, landscape, glacier, mass movement, rock glacier

Introduction

High mountain areas such as the Alps are one of the most climatically sensitive regions of the Earth. This is true not only with respect to modern climate change but also to paleoclimate change.

High resolution reconstructions of climate change at the global scale during the Lateglacial (~20 - 11.7 ka BP) are available from Greenland ice cores. In the case of the Eastern Alps data from e.g. peat bogs and lacustrine sediments provide useful proxies of temperature and precipitation changes during this time. However, major environmental changes in high mountain areas like glacier advances, alluvial aggradation, permafrost activity and mass movements (landslides, rock avalanches) are recorded - if at all - only indirectly.

Detailed geological mapping of sediments and morphological features in combination with various modern dating approaches (luminescence, surface exposure age and U/Th dating) leads to a chronology of landscape evolution during the Lateglacial in the Alps. Based on three time slices - 20,000-19,000, 17,000 -15,000 and ~ 12,000 years before present (BP) - the interaction of glacial, periglacial and gravitational processes in relation to changing climatic conditions is highlighted. Such geological findings promote our understanding of possible climate impact in an alpine environment.

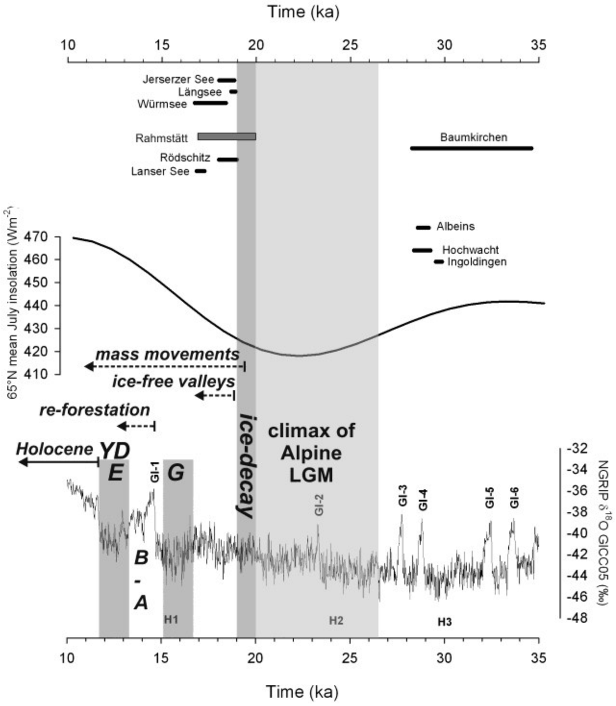

Figure 1: Diagram showing timing of climatic phases and processes (modified after STARNBERGER et al. 2011.) (A) Sites constraining the onset and termination of the LGM ice advance in the Eastern Alps and their foreland (for details see STARNBERGER et al. 2011). (B) 65°N mean July insolation (BERGER & LOUTRE, 1991). (C) NGRIP isotope record with numbered Greenland Interstadials (GI) and Heinrich (H) events (ANDERSEN et al., 2006). Important sites showing ice-free conditions in Alpine valleys are indicated. The climax phase of Alpine LGM is based on constraining data from the Tagliamento glacier area (MONEGATO et al. 2007). Abbreviations: E - Egesen, G - Gschnitz, B-A - Bølling - Allerød Interstadial, YD - Younger Dryas

The aim of this paper is to give a short overview of recent research in the Hohen Tauern mountain chain and its surrounding, with a special focus on the upper Salzach valley (Salzburg), Eastern Tyrol and Upper Carinthia.

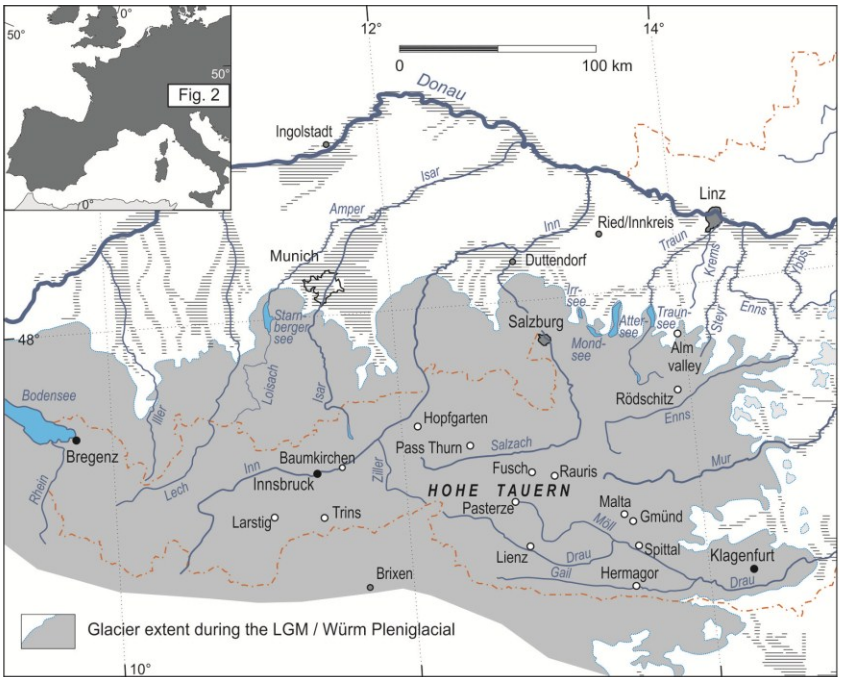

Figure 2: Map of the Quaternary landscape of Austria with the limit of the Last Glacial Maximum (LGM / Würm Pleniglacial)and key locations mentioned in the text.

The Termination of the Last Glacial Maximum - phase of ice-decay 20,000-19,000 years

Today, ice-decay at Austria's biggest glacier, the Pasterze, appears to be gigantic compared to the loss of volume of 50 percent and more since the last glacier highstand around the year 1850 (Lieb & Slupetzky 2011). The picture of a stagnant glacier tongue and isolated buried ice serves as a modern analogue of the situation after the Last Glacial Maximum (LGM) when the big network of valley glaciers spanning most parts of the Alps decayed and eventually vanished.

At the climax of the Würm Pleniglacial (the regional expression of the LGM) valleys of the Hohen Tauern and adjecent regions where filled with up to 2500 m thick glaciers and annual temperatures in the Northern foreland where lowered by 10-12°C (Frenzel et al. 1992) compared to modern conditions. Ice flow occurred across todays' watersheds (transfluence passes) like the Pass Thurn (Salzburg) independent of the current drainage system. The global maximum ice extension was due to a decrease of summer insolation (Fig. 1) linked to variations in the Earth's orbit (Hays et al. 1976) generally referred to as the "Milankovic Theory". On the other hand a slight increase in summer insolation caused the beginning of the Last Termination (Termination I) of the LGM.

Due to the geometry of the LGM valley glacier network in the Alps with a gentle slope from the centers of the glaciation to the Alpine foreland, a slight rise of the equilibrium line caused by orbital changes led to a sudden increase of the glacier's ablation area at the expense of its accumulation area. In addition the shift in mass balance of the glaciers initiated a positive feedback. The sudden appearance of huge quantities of melt water along the margin and on the surface, partly transferred via moulins (sink holes) to the glacier bed, accelerated ice-decay. Short-lived ice-dammed lakes were formed where calving ice fronts collapsed and produced icebergs. Finally, the ongoing reduction of ice thickness in relation to the water depth of lakes in the glacial environment led to the floating of ice and thus to the rapid collapse of glaciers. Today, up to 100 m thick ice-marginal terraces (kame terraces; Fig. 3) located hundreds of meters above the modern valley floors document the downwasting of the glacier network. Hollows, so called kettle-holes, within relatively even terrace slopes were formed by the melting of a mass of buried ice (Fig. 3). The most impressive examples of such features are found in the area of Spittal (Drau vally) and Gmünd (Carinthia; Reitner 2005, Pestal et al. 2006, Schuster et al. 2006) and in Hopfgarten (Northern Tyrol, Reitner 2007a).

The warming and ice-decay was interrupted by at least one cold spell as indicated by advances of small glaciers which reacted to short climatic deteriorations (Reitner 2007a). Most glaciers did not reach a balance with climate, as terminal moraines are missing. Till deposited by tributary glaciers on top of Kame terrace sediments are a wide spread phenomenon in the Alps like e.g. at Lienz (Eastern Tyrol; Reitner 2003a & 2003b).

The only direct dating, in this case by luminescence dating of ice-marginal deposits from Rahmstätt / Hopfgarten in Northern Tyrol (Klasen et al. 2007) gives an age of 19 ± 2 ka. ^{14}C - datings of organic material from peat base layers (see compilation in van Husen 2000 & Reitner 2007a) show already ice-free conditions in the major valleys around 19 - 18.5 ka thus providing further age controls for this phase of ice decay (Fig.1).

With the beginning of ice-decay gravitational processes on different scales were initiated due to the failure of slopes which were oversteepened by glacial erosion during the LGM (Reitner et. al. 1993). The ^{36}Cl exposure dating of a rock avalanche deposit in the Alm valley (van Husen et al. 2007) provides an age of around 19,000 years showing that slope instabilities started together with the downwasting of glaciers when no vegetation was able to stabilise slopes.

A modern re-investigation of a bog located in a tension gap near Hermagor (Reitner et. al. 1993) provides a calibrated ^{14}C date of around 17.000 as the minimum age for the onset of early mass movements (Reitner & Drescher-Schneider, in prep.) at this location.

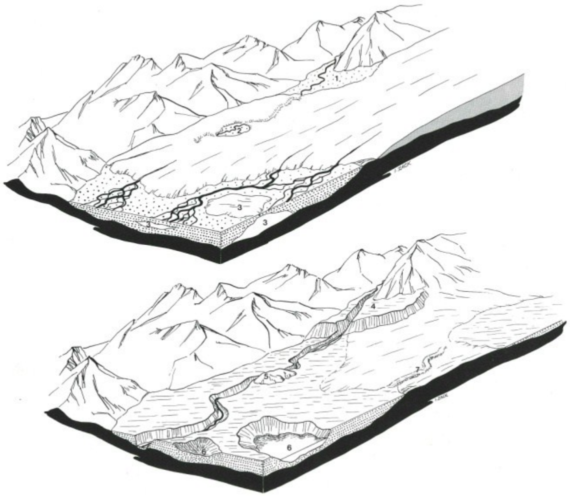

Figure 3 Schematic sketch of a decaying glacier and its deposits (van Husen 1987). The condition for the formation of a kame terrace (1 & 4) and kettle-holes (3 & 6) are indicated.

The Gschnitz glacier advance and accompanied processes - 17.000-15.000 years

Beside the onset of sparse vegetation (see ^{14}C data above) and the start of mass movements our knowledge about processes just after the phase of ice-decay is quite limited.

As a result of severe changes in the North Atlantic circulation during the so called Heinrich event 1 (H1 in Fig. 1) a major glacier advance occurred in the Alps lasting several centuries. At the type locality of the Gschnitz stadial at Trins (Northern Tyrol) a prominent terminal moraine was formed at around 16,000 years (Ivy-Ochs et al. 2006) when summer temperatures were up to 10° C below modern level (Kerschner & Ivy-Ochs 2007; Kerschner 2009). A similar situation is evident in the area of Malta near Gmünd where a fluvial terrace was formed in the forefield of the glacier terminus indicating strong aggradation under free drainage (ice-free) conditions. Preserved remains of stadial, mostly isolated lateral moraines can be found in most of the major valleys in the Hohe Tauern region. Mass movements overridden by the glacier e.g. near Fusch and in the Möll valley (Reitner, in prep.) as well as ice-marginal sediments deposited during the waxing of the glaciers, are useful indicators to constrain the starting position of this major glacial advance.

The Younger Dryas glacier advance - around 12.000 BP

Reforestation started with the onset of a prominent climatic amelioration around 14.7 ka BP linked to the Bølling - Allerød Interstadial (Fig. 1). With the stabilising effect of vegetation mass movements should have reduced. However, the biggest landslide of the province of Salzburg occurred in the Rauris valley at Kolm -Saigurn at this time (Bichler et al. 2012). As the last glacial erosion at the toe of the slope happened most probably during the previous stadial, such an event may be regarded as an aftermath of the Gschnitz stadial. In addition, higher interstadial precipitation leading to e.g. higher hydraulic pressure in tension gaps may have accelerated the slope failure as well.

Again due to changes in the North Atlantic circulation, a severe climatic deterioration called Younger Dryas occurred and Alpine glaciers once again advanced from their cirques to lower valley floors during the Egesen stadial reaching their maximum extent at summer temperatures 3.5 ° C lower than today (Kerschner & Ivy-Ochs 2007, Kerschner 2009). Multiple moraine ridges prove several phases of glacier tongue stabilisation. In the second half of the Younger Dryas cold and dry conditions promoted rock glacier formation.

This last cold phase of the Lateglacial ended around 11.7 ka BP with a tremendous warming at the onset of the Holocene.

Permafrost degradation in the Lateglacial

It is a well known fact that continuous permafrost existed during the major glaciations like the LGM in the non-glaciated areas of the Alps and at least in the Northern Alpine foreland as indicated by ice wedge features 25 to 40 m below the surface (van Husen 1997). Paleo-permafrost investigations and the re-construction of permafrost degradation in the Alps during the Lateglacial rely mostly on geomorphic-geological features as relict rock glaciers (= rock glacier deposits). In general the elevation of a rock glacier terminus is regarded to provide an indicator of the lower limit of discontinuous permafrost (e.g. Lieb 1996). This point of view has to be critically re-considered as Harris et al. (2009) showed that depending on the general conditions e.g. morphology of the slope, duration of the climatic phase the stabilisation position of rock glaciers may not represent a climatically steady-state situation.

However, based on the findings of very low reaching rock glacier deposits in Malta valley near Gmünd up to 1300 m below modern permafrost limits in these areas (Reitner 2007b) a formation of such features prior to the Younger Dryas seems to bee plausibel. Unfortunately, until now only one exposure dating age of rock glacier stabilisation, 300 m below permafrost limits of the 20th century, with an age of around 11 ka just is available (Larstig valley/ Tyrol; Ivy-Ochs et al. 2009).

Conclusions and outlook

The Lateglacial record preserved especially in protected areas provides an excellent opportunity to study the climatically controlled transformation of landscapes and to increase our understanding of possible future climate impact scenarios. It recorded, direct or indirect reaction of the different landscape elements (glaciers, permafrost, slope) to changes of the climate signal are recorded.

The early phase of ice decay after the LGM provides a large scale example and worst case scenario of what is possible in an Alpine landscape regarding e.g. mass wasting and erosion.

Situations during Gschnitz and Egesen stadial are analogues for what is going on during glacier oscillation and for mutual interactions of glaciers and mass movements. Deciphering past permafrost degradation in order to understand the reaction time of the Alpine cryosphere on climate warming is still one of the greatest challenges in Lateglacial research.

However, resilient data on Lateglacial environmental change based on modern methodology are rare in the Alps. Further progress can be achieved only by combining geological-geomorphological surveying in order to establish a relative chronology of glacial, periglacial and gravitational processes with modern absolute dating methods i.e. exposure dating using cosmogenic nuclides (e.g. ^{10}Be, ^{14}C, ^{36}Cl), luminescence and radiocarbon dating. This forms the basis for robust correlations with regional and local high-resolution climate archives such as Greenland ice cores and Alpine speleothemes. Finally, a better understanding of past climatic changes in the Alps is a pre-requisite for assessing future climate impact.

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