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Mammoths inside the Alps during the last glacial period: Radiocarbon constraints from Austria and palaeoenvironmental implications

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ABSTRACT

This study examines remains of the woolly mammoth (*Mammuthus primigenius*) found inside the Austrian Alps, an area occupied by an extensive ice-stream network during the Last Glacial Maximum. The data demonstrate that these cold steppe-adapted animals locally migrated several tens of kilometers into alpine valleys. Radiocarbon analyses constrain the age of these fossils to the first half of Marine Isotope Stage 3, documenting ice-free conditions in major valleys at that time.

We also provide a list of all traceable Austrian sites of *Mammuthus primigenius*, totaling about 230 localities, compiled through 15 museums and collections in Austria. The vast majority of these findings are from the corridors of the Danube and Mur rivers and their tributaries and the adjacent loess-covered foreland of the Alps, areas that were never ice-covered during Pleistocene glaciations.

1. Introduction

The woolly mammoth (*Mammuthus primigenius*) was the most prominent member of the Upper Pleistocene megafauna in the middle and northern latitudes of the Northern Hemisphere (Markova et al., 2010; Lister and Bahn, 2015). This large herbivorous mammal was well adapted to the cold mammoth-steppe ecosystem that existed in northern Eurasia and between the Scandinavian and the Alpine ice sheets during the last glacial period. The distribution of the woolly mammoth (Kahlke, 2015; Puzachenko et al., 2017), its evolution and genetics (Lister and Sher, 2001, 2015; Barnes et al., 2007; Miller et al., 2008; Palkopoulou et al., 2013), ecology and diet (Tütken et al., 2007; Willerslev et al., 2014; Schwartz-Narbonne et al., 2015; Boeskorov et al., 2016), as well as the dynamics of its extinction (Stuart et al., 2004; Stuart, 2005; Kuzmin, 2010; Cooper et al., 2015) have been extensively studied.

Mammoth teeth and bones are among the most commonly found macrofossil remains of the last glacial period. They constitute an important palaeoenvironmental archive and can be dated back to about 50 ka BP using radiocarbon. For example, mammoth fossils allow to trace the migration of the southern margin of the Scandinavian ice sheet during the second half of the last glacial cycle, with rare findings almost up to the Arctic Circle during some intervals of Marine Isotope Stage (MIS) 3—which lasted from about 60 to 30 ka — and a progressive restriction towards lower latitudes subsequent to about 30 ka (Ukkonen et al., 2011), reflecting the expansion of the ice sheet.

Numerous mammoth discoveries were made in the northern, eastern and western — and to a lesser extent in the southern — forelands of the European Alps. During glacial periods, this 1200 km-long mountain range was occupied by an ice-stream network whose temporal evolution mimicked that of the Scandinavian counterpart, e.g. reduced and probably highly variable glacier sizes during MIS 3, followed by a maximum ice extent around 25 ka, when large piedmont glaciers advanced onto the Alpine foreland (e.g., Ivy-Ochs et al., 2008; Heiri et al., 2014; Monegato et al., 2017). In the northern foreland of the Western Alps mammoth remains were found in proglacial gravel beyond the outermost ice margin of the MIS 2 (Last Glacial Maximum, LGM) and also up to a few tens of kilometres inside of this margin (Furrer, 2005, 2014). This suggests that mammoths followed the waxing and waning of the LGM ice margin. Data from the Eastern Alps (they comprise the central and western part of Austria and the southernmost part of Bavaria, Germany) reveal an interesting difference

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in the distribution of mammoth remains compared to the Western Alps of Switzerland: Although fossils are known up to some 40 km inside the LGM ice margin in northern Switzerland, there is no evidence that this mammal migrated into the west alpine valleys during the last glacial period, e.g. the Rhone or the Aare valleys. In contrast, there is clear evidence that mammoths entered the valleys of the Eastern Alps during that time (e.g., Tichy, 1989; Patzelt, 2014). The aim of this study is to address this apparent discrepancy by examining and dating all available mammoth specimens from the western (mountainous) part of Austria. We show that mammoths were indeed present in major inneralpine valleys during MIS 3 and discuss palaeoenvironmental and palaeoclimatic implications.

2. Inneralpine mammoth sites

Fig. 1 provides an overview of all mammoth remains found so far in Austria including findings close to the German-Austrian border (e.g., Ebers, 1960; Dehm, 1982; Ziegler, 1994). A complete table of all currently known Austrian sites (about 230) is provided in the electronic supplement. The map reveals the highest density of mammoth remains outside the formerly glaciated part of the Alps, i.e. along the corridor of the river Danube between the foothills of the Alps and the Bohemian Massif in the north, in the northern part of Lower Austria, in the Vienna Basin and along the Mur Valley in Styria (Fig. 1). The density of findings rapidly decreases towards the west of the meridian of Linz. Even when taking perialpine findings in southern Bavaria into account the abundance of findings is conspicuously smaller than along the northern margin of the Western Alps (Döppes and Rabeder, 1997; Furrer, 2005, 2014; Göhlich, 2015). Only few reports of mammoth fossils exist from the southern alpine foreland (Gleirscher and Pacher, 2005; Mussi and Villa, 2008; Braun and Palombo, 2012).

Essentially all findings in the inneralpine region were made decades ago and only very few new discoveries have been reported in the last few years.

Mostly isolated teeth (tusks and less abundantly molars) and bones were found inside the Austrian Alps and the available documentation indicates that these remains were either embedded in gravel successions of MIS 3 or older or were found reworked in Late Glacial sediments or modern river beds. A notable exception is Siegsdorf in southernmost Bavaria, where a nearly complete skeleton of a large mammoth bull was excavated (Ziegler, 1994). The state of preservation of most of the other findings from inneralpine sites was poor and several specimens show signs of strong mechanical abrasion.

In the following, the different locations and their specimens are briefly described along a W-E transect across the Austrian Alps starting in the province of Vorarlberg in the west.

3. Rhine Valley and tributaries (Vorarlberg)

The Rhine paleoglacier was fed by major tributaries located in Austria (province of Vorarlberg) and to a larger extent in eastern Switzerland (e.g., Keller and Krayss, 2005a, b; Preusser et al., 2011). Here we review mammoth remains from the Austrian part of this system.

3.1. Bregenz

In 1989 a 30 cm-long and 9 cm-thick fragment of a tusk was found in the gravel pit Hochwacht, located east of Kennelbach and north of the Bregenzer Ache (city of Bregenz; Fig. 1). It occurred within delta forests about 16 m underneath their top (Krieg, 1990). The fragment showed no signs of rounding by fluvial transportation, hence it was assumed that the tusk was initially complete and the remainder was destroyed during gravel extraction

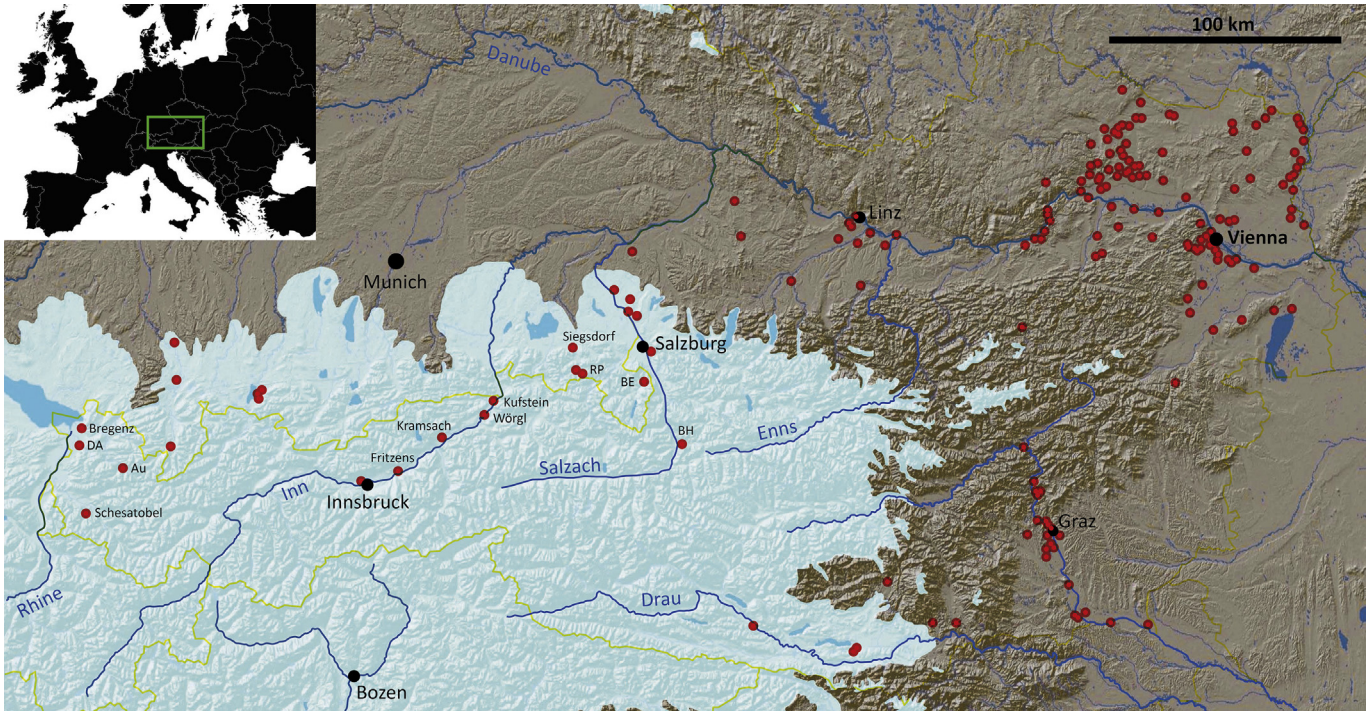

Fig. 1. Relief map of Austria showing the occurrence of mammoth remains in relation to the maximum extent of the alpine ice stream network (nunataks are omitted for clarity – source: Geologische Bundesanstalt, 2013). Locations mentioned in the text are labelled (DA. Dornbirner Ach, BH. Bischofshofen, BE. Berchtesgaden, RP. Ruhpolding). Based on the list of Austrian mammoth sites (see electronic supplement) and Scholz (1979, 2016) for some Bavarian sites close to the Alps. Yellow lines are national borders. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)