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Implications for the Late Pleistocene climate in Finland and adjacent areas from the isotopic composition of mammoth skeletal remains

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Abstract

Nine samples of subfossil bone and teeth remains from woolly mammoth (*Mammuthus primigenius*) discovered in Finland, Russian Karelia and Western Russia were analyzed for the oxygen isotope composition of the phosphate fraction and the carbon and oxygen isotope composition of the carbonate fraction in skeletal apatite. The samples have been radiocarbon dated in previous studies and are of late Middle Weichselian to Late Weichselian age. The preservation of the samples was tested analyzing the chemical composition and checking the isotopic equilibrium between the phosphate and carbonate components in skeletal apatite. According to these tests, five out of the nine samples were determined to have retained their original isotopic composition. These samples were used to estimate Late Pleistocene climatic conditions in Finland and neighboring areas. Based on the best-preserved enamel samples, the isotopic composition of oxygen in Late Pleistocene precipitation was 1–3‰ lower than that in the mean annual precipitation in southern and central Finland today. Using the relationship between the isotopic composition of precipitation and the ambient temperature, it can be estimated that the mean temperatures during the Middle Weichselian ice-free period were 2–6 °C lower compared to the present-day values.

Keywords: Oxygen isotopes; Mammoth; Teeth; Enamel; Finland; Paleoclimatology

1. Introduction

The use of stable isotopes has proven to be one of the most effective methods in reconstructing paleoenvironmental conditions. On land, isotopic reconstruction of past climatic conditions is, however, complicated by the lack of suitable study material. The oxygen isotope composition of the mineral component of vertebrate skeletons, carbonate-hydroxyapatite $Ca_9[(PO_4)_{4.5}(CO_3)_{1.5}](OH)_{1.5}$ (Driessens and Verbeeck, 1990) is a potential tool, which has been successfully used in paleoclimatological reconstructions of continental climates (e.g. Ayliffe et al., 1992; Bryant et al., 1994, 1996b; Fricke et al., 1995; Genoni et al., 1998; Iacumin et al., 2004; Iacumin and Longinelli, 2002, Longinelli et al., 2003; Reinhard et al., 1996). Land mammals precipitate their skeletal parts at a constant temperature of ~37 °C. The oxygen isotope composition of the bioapatite is thus dependent only on the isotopic composition of the animal's body water (Longinelli, 1984; Luz et al., 1984). The $\delta^{18}O$ value of body water, in turn, is related to the isotopic composition of ingested environmental waters, which usually correspond to the mean $\delta^{18}O$ value in the regional precipitation. The isotopic composition of oxygen in meteoric waters correlates with the regional mean annual temperatures (Dansgaard, 1964). It follows that

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the oxygen isotope composition of fossil skeletal material contains information of past atmospheric temperatures in terrestrial environments. Of all skeletal components, tooth enamel is generally considered to be most resistant to post-depositional alteration, and hence is the preferred material for isotopic investigations (e.g. Ayliffe et al., 1992, 1994; Bryant et al., 1994, 1996b; Koch et al., 1997; Lee-Thorp and Sponheimer, 2003; Zazzo et al., 2004).

According to a previously widely accepted glacial history of Scandinavia, it was thought that Finland was covered by the Scandinavian Ice Sheet throughout the Middle and Late Weichselian (e.g. Andersen and Mangerud, 1989). Recent interpretations based on new radiocarbon dating results revised this view (Ukkonen et al., 1999; Lunkka et al., 2001). Data from mammoth finds reported by Ukkonen et al. (1999) from different parts of Finland suggested that the southeastern parts of Fennoscandia remained ice-free for a period of at least 10 000 years between ca. 37 and 26 ka. Summarizing the findings of the extensive QUEEN program, Hubberten et al. (2004) concluded that the time from 30 ka to the Last Glacial Maximum at 20–15 ka was a period of progressive cooling in Scandinavia and elsewhere in the Eurasian Arctic. During this period, the growth rate of the Scandinavian Ice Sheet was very rapid. The ice front advanced from the Gulf of Bothnia to the Last Glacial Maximum position, some 1000 km southeast in the northwestern Russian Plain, in only 7000 years (Lunkka et al., 2001).

Due to poor preservation of skeletal material in acid soil, only a few stray finds of terrestrial mammals have been made in Finland. A total of nine subfossil mammoth bones and teeth have been discovered, described in detail by Ukkonen et al. (2003). All finds have been radiocarbon dated in previous studies, and they range in age from >45 800 to 18 700 cal BP (>40 000 to 15 910 BP) (Table 1).

The aim of this study is to recover the climatic signal recorded in the oxygen isotope composition of skeletal remains discovered in Finland and adjacent areas. In order to evaluate the extent of diagenetic alteration, the concentrations of selected trace elements were measured. Oxygen isotope ratios were determined on carbonate and phosphate fractions in carbonate-hydroxyapatite. Comparison of the isotope records in these structural components offers an additional measure of the preservation of the isotope signal (Bryant et al., 1996a; Iacumin et al., 1996a).

2. Materials and methods

Five of the nine subfossil mammoth specimens were available for isotopic analysis. In addition, four other mammoth samples from the Russian Karelia and western Russia were investigated. The find localities are

Table 1
Sample description and isotopic results

Sample	Type	Find locality	^{14}C age (years BP[1])	Calibrated age (years BP[2])	$\delta^{18}O_P$ (‰)	$\delta^{18}O_C$ (‰)	$\delta^{13}C_C$ (‰)	$\delta^{13}C_{collagen}$ (‰)[3]	$\delta^{18}O_W$ (‰)[4]
Enamel									
M-01	Molar	Nilsiä, Syväri	22 420 ± 315[a]	26 400 ± 360	9.0	17.9	− 12.7	−21.4	− 15.3
M-02	Molar	Salmi, Ladoga	>40 000[b]	>45 800	10.0	18.9	− 11.2	− 20.5	− 14.2
M-03	Premolar	Helsinki, Töölö	23 340 ± 350[a]	27 500 ± 400	9.9	18.3	− 13.2	− 20.7	− 14.2
M-07	Molar	Kirillov	27 915 ± 575[c]	32 600 ± 640	9.6	19.7	− 11.2		− 14.6
Bone									
M-04	Humerus	Helsinki, Herttoniemi	15 910 ± 150[a]	18 700 ± 180	14.3	22.1	− 11.0	− 21.3	− 9.6
M-05	Femur	Lohtaja	24 450 ± 385[a]	28 700 ± 440	10.5	16.1	− 13.4	− 21.6	
Dentine									
M-06	Tusk	Haapajärvi	28 740 ± 670[a]	33 600 ± 750	11.9	21.0	− 10.0	− 29.1	
M-08	Tusk	Kostamuksha	25 990 ± 470[d]	30 500 ± 530	12.2	16.9	− 11.0		
M-09	Tusk	Kolodozero	>40 000[e]	>45 800	12.1	18.2	− 9.1		

Isotope values are given relative to VPDB (δ^{13} C_c, δ^{13} $C_{collagen}$) and VSMOW (δ^{18} O_P, δ^{18} O_C, δ^{18} O_w).

[1] ^{14}C ages: (a) Ukkonen et al. (1999), (b) Lõugas et al. (2002); (c) Saarnisto and Lunkka, unpublished; (d) M. Saarnisto, personal communication, 2003; (e) I. Demidov, personal communication, 2003.

[2] ^{14}C ages were calibrated according to Bard (1998).

[3] The carbon isotope composition of collagen (δ^{13} $C_{collagen}$) with permission of Eloni Sonninen, the Dating Laboratory of the Finnish Museum of Natural History, University of Helsinki.

[4] The mean annual oxygen isotope composition of environmental water (δ^{18} O_W) is only given for unaltered samples.