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Resolution-enhanced stable isotope profiles within the complete tooth rows of Late Pleistocene bisons (Middle Urals, Russia) as a record of their individual development and environmental changes

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A B S T R A C T

Well-preserved left hemi-mandibles with complete tooth row from two late-Pleistocene individuals of bison *Bison priscus* were discovered in the Bobylek cave deposits in the Middle Urals, Russia. One of the mandibles belonged to a young bison, approximate age of two, and another belonged to a mature bison, approximate age of eight. We investigated the oxygen ($\delta^{18}O_{carb}$) and carbon ($\delta^{13}C$) isotope variations in structural carbonate of hydroxyapatite and carbonate content in sequential enamel samples from all teeth from both individuals to address inter- and intra-individual variability in the timing of tooth formation of studied fossil bison as well as their environments. The isotopic and chemical data presented the intra-tooth profiles which were compiled into individual intra-row profiles for both specimens. A comparison between the chemical and isotopic ($\delta^{18}O_{carb}$ and $\delta^{13}C$) intra-row profiles inferred no inter-dependent relationship, indicating that the fossil enamel did not undergo significant diagenetic modifications and primary isotopic signals were preserved. Carbonate content decreased as enamel maturated. The $\delta^{18}O_{carb}$ intra-row profile demonstrated sinusoidal shape variations (with an amplitude of 3.6‰ for one bison and 3.0‰ for another bison) related to seasonal isotopic variability in precipitation during the course of enamel formation of all permanent teeth with except mandibular first molar (M1). The $\delta^{18}O_{carb}$ values in M1 enamel could be controlled by intrauterine metabolic processes as M1 started its formation at early embryonic life. The timing of formation of second and third molars of fossil specimens was estimated to be several months later compared to modern bison (*B. bison*). The $\delta^{18}O_{carb}$ variations within tooth row of both specimens reflected environmental conditions in which bison lived that were estimated to be significantly colder than today. Basing on the average $\delta^{18}O_{carb}$ value of the sinusoidal signals of intra-row profiles (~18.2‰ for both bison), the annual mean $\delta^{18}O$ value in precipitation was estimated to be approximately 16.9‰. It was lower by 2.7‰ than today in the Middle Urals. Using the local relationship between $\delta^{18}O$ values in modern precipitations and air temperatures we estimated the mean annual air temperature to be approximately 6.6 °C, ~9 C° lower than today. The carbon isotope data from serially sampled bison teeth revealed that isotope diet of both bison was seasonally independent and determined by C3-type plants.

1. Introduction

Oxygen and carbon isotope ratios in hydroxylapatite, a structural element of vertebrate bone and tooth enamel, have been shown to be a reliable instrument in palaeoreconstructions of continental environments (Longinelli, 1984; Luz et al., 1984; Luz and Kolodny, 1985; Bryant et al., 1994; Fricke and O'Neil, 1996; Kohn et al., 1998). *Over the past decade*, the isotopic records preserved in skeletal remains of large mammals have been successfully used to reconstruct the palaeoecological and palaeoclimatic conditions of the past in Europe (Arppe and Karhu, 2006, 2010; Tütken et al., 2007; Ukkonen et al., 2007; Bernard et al., 2009; Fabre et al.,

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2011; Julien et al., 2012). Despite the fact that the fossil remains of the large mammals are widespread in Pleistocene deposits throughout central and northeast Eurasia, isotope studies of bones and teeth found in these regions are rare in the literature. Most studies based on stable oxygen isotopes in bone and bulk enamel samples have been undertook across the arctic coasts of Siberia and western Beringia (Genoni et al., 1998; Tütken et al., 2002; Fox et al., 2007; Iacumin et al., 2010), and central Eurasia, Western Siberia and the Urals (Genoni et al., 1998; Velivetskaya et al., 2011) to reconstruct regional paleoclimate.

The study based on stable isotope analyses from incremental sampling of teeth can provide information on animal diet, animal mobility and environmental conditions at the relatively high level of the temporal and spatial resolution (Gadbury et al., 2000; Balasse, 2002; Zazzo et al., 2006; Britton et al., 2009; Feranec et al., 2009; Widga et al., 2010; Julien et al., 2012). Ideally, this is a possibility to capture any annual and inter-annual variability within the lifespan of a single prehistoric animal if the isotopic records preserved in tooth enamel are obtained through incremental sampling of multiple teeth belonging to the same individual. However, the findings of the skeletal remains such as mandible with full dentition are rare (Fricke and O'Neil, 1996; Bryant et al., 1996a); and usually odd teeth belonging to different animal individuals were analysed for stable isotopes (Bernard et al., 2009; Brookman and Ambrose, 2012).

In this study, we present reconstructions of stable isotope variations recorded within the tooth rows from individual animals. The isotopic data consist of the incremental $\delta^{18}O$ and $\delta^{13}C$ records obtained from incrementally sampled teeth of two Pleistocene bison individuals (*Bison priscus*) from the Middle Urals. The aim of this study is to investigate whether the high-resolution intra-individual isotopic record can be useful to provide additional information concerning the features of timing of formation of teeth from Pleistocene bison and also to apply the intra-row records to reconstructions of the environmental conditions in which the bison lived.

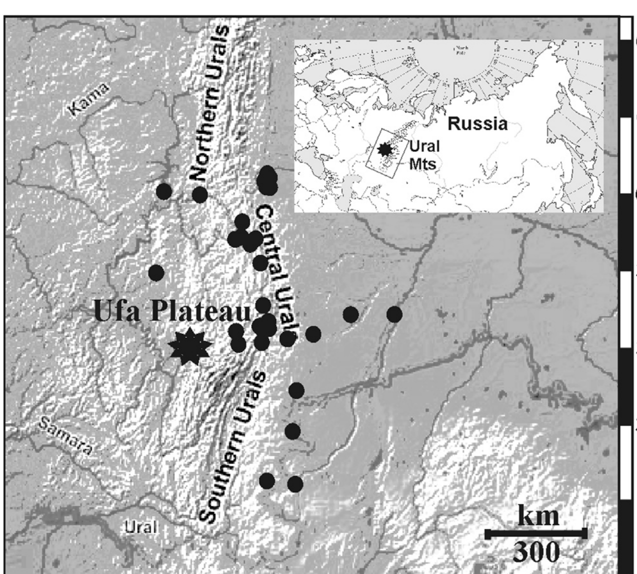

Fig. 1. A map of the Urals with the location of the bison sampling site Ufa Plateau (polygon) and the locations of the water sampling site (black circles). The upper right inset is a map of Russia with the location of the Urals.

2. Sampling site and fossils

The fossil bison teeth analysed in this study were excavated from the Bobyliok cave located in the Ufa Plateau, southwest of the Middle Ural Mountains in Russia (56°23′N, 57°37′E) (Fig. 1). The Middle Urals is the lowest part of the Urals, the average elevation of the Ufa Plateau is 150–250 m. The Ufa plateau length is approximately 270 km from north to south. In the west, Ufa plateau smoothly transforms into the East European Plain. The Ufa Plateau consists of limestone, dolomites and sandstones that form a karst landscape. The Bobyliok is a large karst cavity (250 m^2) developed in Permian limestone. Numerous fossils and archaeological artefacts have been collected from different sedimentological layers in the Bobyliok during several excavations (Smirnov, 1993; Izvarin, 2004; Razhev et al., 2005; Volkov et al., 2007; Smirnov et al., 2009).

The total area of loose sediments in the cave is formed by 6 layers. The surface layer, Layer 1 (0.5–0.7 m thick) consists of

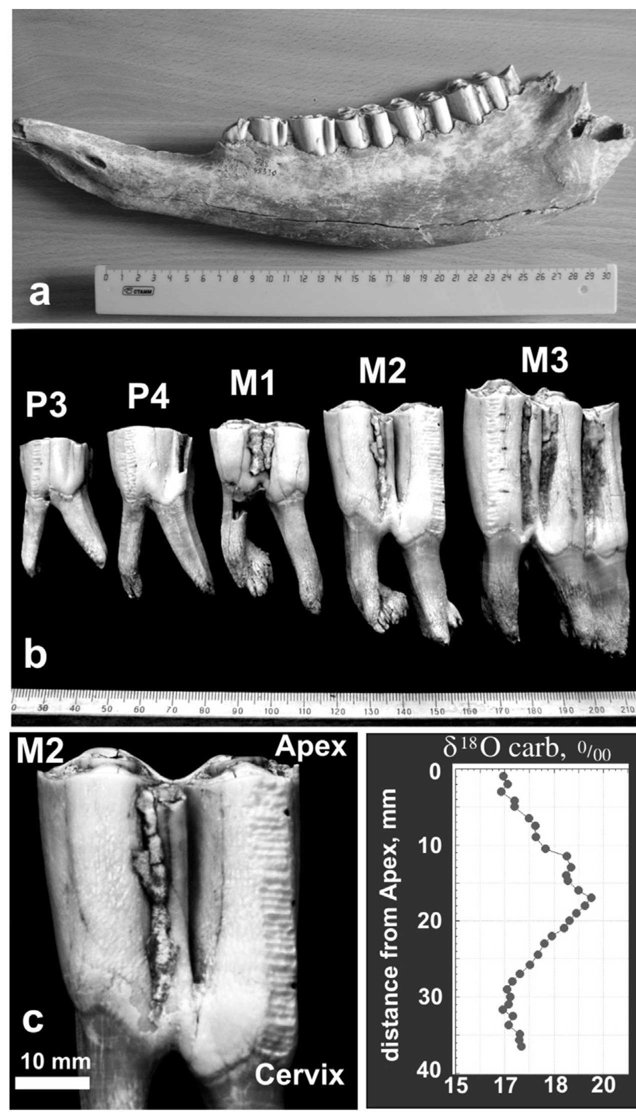

Fig. 2. Illustration of the fossil bison sample, Bison1, used in this study: (a) labial side of the left lower jaw with complete teeth sequences of an adult animal *Bison priscus*; (b) the separated teeth with roots (the M1, M2, and M3 molars and the P3 and P4 premolars) analysed for stable isotope ratios; (c) an example of sampling the tooth enamel from the cervix to the apex (left-hand side) and the $\delta^{18}O$ variations in the corresponding samples of the tooth enamel (right-hand side).