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# Reconstruction of paleotemperature for a Palaeolithic site – evaluation of uncertainties in calculation based on phosphates' stable oxygen isotope composition

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The presence of Neanderthals in Central Europe during the Weichselian glaciations (~115–35ka) was sporadic and likely resulted from migration during warm phases only. However, placing Neanderthals' migrations within a precise climatic context has been challenging, owing to significant uncertainty in dating of Palaeolithic sites older than 50ka. The radiocarbon dating of the bone or tooth samples older than 50ka is usually very difficult or impossible, due to the low collagen concentration and low resolution of the radiocarbon method for such old samples. Consequently, most of the >50ka archaeological sites are dated using Optically Stimulated Luminescence or Thermoluminescence methods only, which introduce a high level of uncertainty (±5–10ka). As a result of this uncertainty, chronologically linking a climate model to a particular archaeological site is not usually very accurate.

To overcome this problem, we propose a new approach by providing a direct estimation of mean air temperature at the precise time of a site occupation by Palaeolithic hunters, regardless of the uncertainty in dating. We have used the stable oxygen isotope composition of phosphates ($\delta^{18}O_P$) of teeth from "dining scraps" (including mammoths and bison) of Palaeolithic hunters from the Hallera site (Wroclaw/Poland) to estimate temperatures during two past periods: OIS 5a–d (~115–74ka) and OIS 3 (~59ka). We show that during these two phases of Neanderthals' presence at the studied site, temperatures were 6.8°C and 6.3°C, respectively [1]. To provide some modern context, these temperatures are ~1°C warmer than the current climate of Stockholm.

The applied analytical method required the following steps: first, verification of the preservation of $\delta^{18}O_P$ in bioapatite; then, calculation of the $\delta^{18}O_W$ value of environmental water consumed by mammals; and finally, calculation of mean air temperature ($T_{air}$) based on the relationship between $\delta^{18}O_W$ of participation and $T_{air}$. However, besides $T_{air}$, several other factors may have complex influences on $\delta^{18}O$ of meteoric water. For instance, a variation in atmospheric circulation, due to expansion or shrinkage of the Scandinavian ice cap, may have resulted in different amounts of precipitations from air masses coming from different directions, and therefore in different annual mean $\delta^{18}O_W$. We designed a cross-verification procedure to assess the accuracy of our estimates, accounting for possible changes in atmospheric circulations. We randomly selected a set of nine GNIP stations with long $\delta^{18}O_W$ and $T_{air}$ records, located ~500–1000km to the east, west and south of our study site at similar altitudes. If, during the Pleistocene, the climate was more continental, conditions at our site could have been more similar to those observed currently, e.g., in Russia. If influences of the Atlantic were higher, conditions would be expected to more closely resemble those now observed, e.g., in Western Germany.

The mean $T_{air}$ calculated for the sampling site varied around 6.8±1.5°C for the older period studied and 6.3±1.3°C for the more recent, based on the $\delta^{18}O_P$ of all analysed teeth samples and the $\delta^{18}O$–$T_{air}$ relationship for the closest GNIP station in Krakow. These uncertainties (±1.5–1.3°C) can be attributed to variation among individuals and species and uncertainty of the analysis. When data for nine other stations in the range of 1000km were used (6.9±1.6°C for the older period and 6.4±1.6°C for the more recent), the calculated values and uncertainties were not significantly different from those calculated based on the data set for the nearest GNIP station [1]. This consistency in estimated temperatures confirms that the fraction of precipitation coming from different directions likely had minor influence on the stable isotope composition of precipitation, and $T_{air}$ was the major factor governing $\delta^{18}O_W$.

[1] Skrzypek G., WiśniewskiA., GriersonP.F., 2011. *Quaternary Science Reviews* (in press).