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ISOTOPIC TEMPERATURES FROM THE EARLY AND MID-PLIOCENE OF THE US MIDDLE ATLANTIC COASTAL PLAIN, AND THEIR IMPLICATIONS FOR THE CAUSE OF REGIONAL MARINE CLIMATE CHANGE

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ABSTRACT: **Mean seasonal extreme temperatures on the seafloor calculated from the shell $\delta^{18}O$ of the scallop *Placopecten clintonius* from the basal part of the early Pliocene Sunken Meadow Member (Yorktown Formation) in Virginia are very similar to those from the same horizon at the latitude of Cape Hatteras in North Carolina (~ 210 km to the south). The lowest and highest temperatures calculated from each shell (using $\delta^{18}O_{seawater} = +0.7‰$) give mean values for winter and summer of 8.4 ± 1.1 °C (± 1σ) and 18.2 ± 0.6 °C in Virginia, and 8.6 ± 0.4 °C and 16.5 ± 1.1 °C in North Carolina (respective median temperatures: 13.3 °C and 12.6 °C). Patterns of ontogenetic variation in $\delta^{18}O$, $\delta^{13}C$ and microgrowth increment size indicate summer water-column stratification in both areas, with summer surface temperatures perhaps 6 °C higher than on the seafloor. The low winter paleotemperatures in both areas are most simply explained by the greater southward penetration of cool northern waters in the absence of a feature equivalent to Cape Hatteras. The same current configuration but a warmer general climate can account for the high benthic seasonal range (over 15.0 °C in some cases) but warmer median temperatures (15.7–21.3 °C) derived from existing $\delta^{18}O$ data from scallops of the higher Yorktown Formation (using $\delta^{18}O_{seawater} = +0.7‰$ for the upper Sunken Meadow Member and $\delta^{18}O_{seawater} = +1.1‰$ for the mid-Pliocene Rushmere, Morgarts Beach, and Moore House members). Existing $\delta^{18}O$ data from the infaunal bivalve *Mercenaria* of the Rushmere Member yields a similarly high median temperature (21.6 °C) but a low seasonal range (9.2 °C), pointing to the periodic influence of warm currents, possibly at times when the Gulf Stream was exceptionally vigorous.**

INTRODUCTION

The Pliocene (5.33–2.58 Ma) contains the most recent interval (~ 3.3–3.0 Ma) in which global mean surface temperature was significantly higher than present (by 1.9–3.6°C; Masson-Delmotte et al. 2013). This interval—the mid-Pliocene or, more strictly, mid-Piacenzian Warm Period (both abbreviated to MPWP)—has been the focus of study for nearly 30 years by the Pliocene Research, Interpretation and Synoptic Mapping (PRISM) group of the United States Geological Survey (Dowsett et al. 2016). It has been used extensively as a test-bed for numerical models of an Earth with relatively high atmospheric CO_2 because concentrations of this greenhouse gas were well above pre-industrial interglacial values according to most reconstructions (e.g., Masson-Delmotte et al. 2013; Martínez-Boti et al. 2015), yet many other large-scale aspects of paleogeography (e.g., continental positions, orography, ocean current patterns) were similar to now. Model outputs for the MPWP are consistent with proxy estimates of temperature at the global scale and for many regions. However, for certain parts of the North Atlantic, proxy estimates are substantially higher (Dowsett et al. 2012, 2013), indicating either inadequacies in the models (including the boundary conditions used) or the proxy data. At some relatively high-latitude (> 45 °N) sites in the North Atlantic, congruent evidence of substantial warming (mean annual sea surface temperature > 5 °C above present) is available from multiple proxies (foraminiferal assemblage composition, foraminiferal Mg/Ca ratios and alkenone unsaturation index; Dowsett et al. 2012), suggesting that model estimates are inaccurate. The high-latitude warmth has been ascribed (e.g., Dowsett et al. 1992; Cronin and Dowsett 1996) to stronger northward transfer of heat by ocean currents than now, but model outputs do not support this (Fedorov et al. 2013; Zhang et al. 2013).

Enhanced ocean transport of heat during the Pliocene has also been inferred from proxy temperature data for lower latitudes in the North Atlantic region, on the Middle Atlantic Coastal Plain of the USA. At present, mean winter minimum and mean summer maximum sea surface temperatures lie in the ranges 5.0–10.0 °C and 22.5–27.5 °C, respectively, at coastal to outer shelf locations off northern North Carolina (north of Cape Hatteras) and Virginia (Table 1; stations ORIN7, DUCN7, 44006, 44014, CHLV2, CBBV2, KPTV2, OCIM2, 44009). However, during deposition of the upper (Rushmere, Morgarts Beach, and Moore House) members of the Pliocene Yorktown Formation, biotic assemblage evidence (see below) points to much warmer conditions in this area: specifically, winter minimum temperatures above 10 °C. Greater warmth north of Cape Hatteras during the interval concerned, which overlaps the MPWP (Fig. 1), has been ascribed to more vigorous northward flow of warm currents, supplying more heat (Cronin and Dowsett 1996; Knowles et al. 2009;

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