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Polar climates during the early Cretaceous greenhouse world: Evidence from clumped isotope thermometry of belemnites

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Here we determine sub-Arctic marine temperatures obtained from fossil mollusks (belemnites) using carbonate clumped-isotope thermometry, an approach based on the 'clumping' of 13C and 18O in the carbonate mineral lattice into bonds with each other. From these analyses we infer sub-Arctic early Cretaceous marine temperatures ranging from of 10–20°C. These warm sub-Arctic temperatures are warmer than present mean summer water temperatures at 60-65°N and are consistent with a warmer 'greenhouse' world featuring a shallow (equable) latitudinal temperature gradient. Our combined temperature and δ18O-carbonate data imply seawater δ18O values that have a remarkably modern character in that they are similar to modern high latitude seawater but more positive that modelled Cretaceous seawater. We identify a cooler Late Valanginian interval with temperatures consistent with polar regions a few degrees above freezing and are also coincident with increased δ18O seawater values. Thus we find evidence of intervals when polar ice was unlikely, and also when polar ice was plausible. Both scenarios support the view of generally warm but dynamic polar climates during greenhouse intervals that were punctuated by minor periods of ice growth.