

SUPPLEMENTARY INFORMATION

Oxygen and Carbon Isotopic Measurements of Cretaceous Coccolith Calcite

Coccolithophorids are restricted to the photic zone by their autotrophic photosynthetic nutritional mode and record seasonal shallow mixed-layer hydrography (Ennyu et al., 2002). The use of coccolithophorid calcite in Quaternary carbon and oxygen stable isotope studies is limited due to significant vital effects resulting in large interspecific isotopic variability (Ziveri et al., 2003). While the vital effect on $\delta^{18}\text{O}$ generally results in a systematic offset of approx. + 1.1 ‰ from calcite in equilibrium with seawater at 25-30° (Dudley et al., 1986; Ennyu et al., 2002), the $\delta^{13}\text{C}$ vital effects are strongly species-specific (Ziveri et al., 2003). However, recent comparison of near-monogeneric isolates of Paleogene coccoliths showed that species-specific $\delta^{13}\text{C}$ vital effects were minimal relative to extant taxa, probably due to the fact that uptake strategies of dissolved organic carbon are different under increased CO_2 levels (Stoll, 2005). Thus, Paleogene and Cretaceous “Greenhouse” coccolith calcite was probably precipitated close to $\delta^{13}\text{C}$ equilibrium.

Stable Isotope Measurements

Isotopic measurements were performed with a Finnigan MAT 251 mass spectrometer at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research at Kiel University. The instrument is coupled on-line to a Carbo-Kiel device for automated CO_2 preparation from carbonate samples for isotopic analysis. Samples were reacted by individual acid addition. The system has an accuracy of $\pm 0.057\text{‰}$ for carbon and $\pm 0.084\text{‰}$ for oxygen isotopes. The results were calibrated using the National Institute Bureau of Standards and Technology (Gaithersburg, Maryland) carbonate isotope standard NBS 20, NBS 19 and 18 and are reported on the Vienna PeeDee belemnite (VPDB) scale. Replicate measurements of 87 samples from La Bédoule carbonates (Sardons Section) demonstrated external reproducibility within 0.02‰ for carbon and 0.04‰ for oxygen (Kuhnt et al., 1998).

Sea-Surface Temperature Estimates

We estimated sea surface temperatures from the bulk (mainly coccolith) $\delta^{18}\text{O}$ using the equation of Epstein et al. (1953) after subtracting 1.1 ‰ for the vital effect of coccolithophorid calcite formation: $T\text{ (°C)} = 16.5 - 4.3 (\delta^{18}\text{O}_{\text{calcite}} - \delta^{18}\text{O}_{\text{water}}) + 0.14 (\delta^{18}\text{O}_{\text{calcite}} - \delta^{18}\text{O}_{\text{water}})^2$, where $\delta^{18}\text{O}_{\text{calcite}}$ is the oxygen isotopic composition on the PDB-scale and $\delta^{18}\text{O}_{\text{water}}$ the isotope composition of the water, in which the calcite was secreted. We used a $\delta^{18}\text{O}_{\text{water}}$ of -1‰ (SMOW) for an ice-free world (Shackleton and Kennett, 1975) which corresponds to -1.27 ‰ on the PDB scale used in the paleotemperature equation, and assumed no significant $\delta^{18}\text{O}_{\text{water}}$ variability due

to changes in local precipitation/evaporation since our site was located on an open marine carbonate platform with minimal influence of continental runoff. Applying the foraminiferal calcite specific $\delta^{18}\text{O}_{\text{calcite}}$ temperature relation of Bemis et al. (1998) following Wilson and Norris (2001) and Norris et al. (2002) results in slightly cooler (by $\sim 0.4^\circ\text{C}$) paleotemperatures.

SUPPLEMENTARY FIGURES

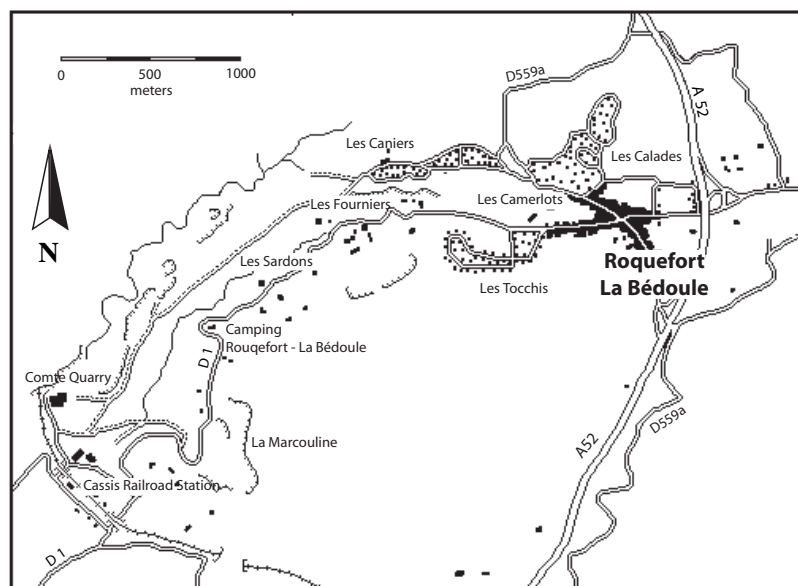
Supplementary Figure DR1. Detailed map showing location of sections investigated close to Roquefort-La Bédoule, South France.

Supplementary Figure DR2. Correlation of $\delta^{13}\text{C}$ from the Camping Section at Roquefort-La Bédoule and the Cismon Apticore (Li et al., 2008). Sedimentation rates, approximately five times higher at La Bédoule, reveal stepwise increase in $\delta^{13}\text{C}$ during C4. $\delta^{13}\text{C}$ stratigraphy follows Menegatti et al. (1998).

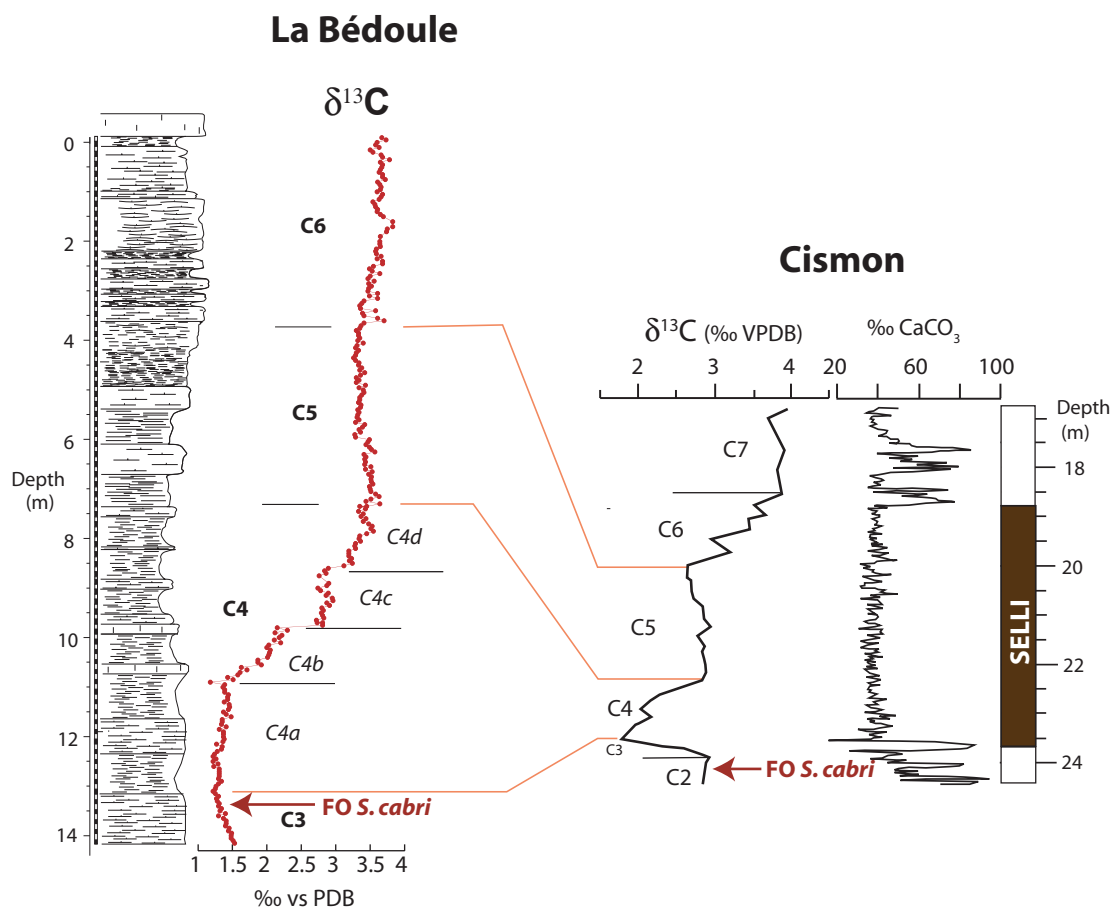
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Supplementary Figure 1



Supplementary Figure 2