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Isotopic seawater temperatures in the Albian Gault Clay of the Boulonnais (Paris Basin): palaeoenvironmental implications

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ABSTRACT

Oxygen isotopes were measured on several types of fossil hardparts from the Gault Clay Formation including benthic and planktonic foraminifera, belemnite guards, and fish small-teeth. Belemnites $\delta^{18}O$ values indicate low temperatures (13.5–19.3 °C) with an increase from the Middle to Late Albian. Foraminifera provide variable $\delta^{18}O$ values, some too low to be relevant in terms of temperature (until 42 °C). These low values probably result from a diagenetic alteration of the foraminiferal tests even though SEM observations revealed well-preserved microstructures. However, higher foraminiferal $\delta^{18}O$ values recorded in some levels indicate temperatures in the range of previously published estimates for the Albian at comparable palaeolatitudes. In these levels, temperatures inferred from benthic and planktonic foraminiferal $\delta^{18}O$ range between 15–17 °C and 27–30 °C respectively, during the Middle–Late Albian interval. This slight increase in temperature is coherent with the long-term warming that characterises the Aptian–Cenomanian interval. The temperature difference between sea-surface and bottom waters fits well with a deposition at a palaeodepth of about 180 m in lower offshore environments, assuming a temperature gradient with depth comparable to the modern one in similar epicontinental tropical environments. Fish small-teeth indicate a temperature range from 22 to 28 °C consistent with previously published data from planktonic foraminifera, with a greater variability recorded during the late than during middle Albian. This correspondence suggests that small-teeth assemblages may be dominated by pelagic fishes, thus recording upper ocean temperatures. Finally, the markedly lower temperatures recorded by the belemnite guards compared to other analysed materials suggest a necto-benthic mode of life of belemnites.

1. Introduction

Seawater temperature of Mesozoic oceans and epicontinental seas are frequently estimated using oxygen isotopes of biogenic calcite produced by various groups of marine organisms. These include bivalves (oysters, *e.g.* Brigaud et al., 2008 or rudists, Steuber et al., 2005), foraminifera (Huber et al., 1999; Wilson and Norris, 2001; Bornemann et al., 2008; Erbacher et al., 2011), brachiopods and belemnites guards (*e.g.* Van de Schootbrugge et al., 2000; Rosales et al., 2004; McArthur et al., 2007; Dera et al., 2011; Price et al., 2013; Stevens et al., 2014). Although foraminifera, brachiopods and belemnites are composed of stable low Mg calcite (LMC), some works have shown that primary calcite may encounter recrystallisation during burial diagenesis (*e.g.* Pearson et al., 2001). Consequently, prior to isotopic analyses, careful examination of the preservation state of the biogenic hardparts is required (*e.g.* Niebuhr and Joachimski, 2002). Typically, molluscs and brachiopods are studied under cathodoluminescence and/or analysed for their trace element concentrations (Mn, Fe, Sr: *e.g.* Mutterlose et al., 2012), while the preservation state of foraminifera is checked using optical microscope (Wilson et al., 2002; Moriya et al., 2007) and scanning electron microscopy (SEM;

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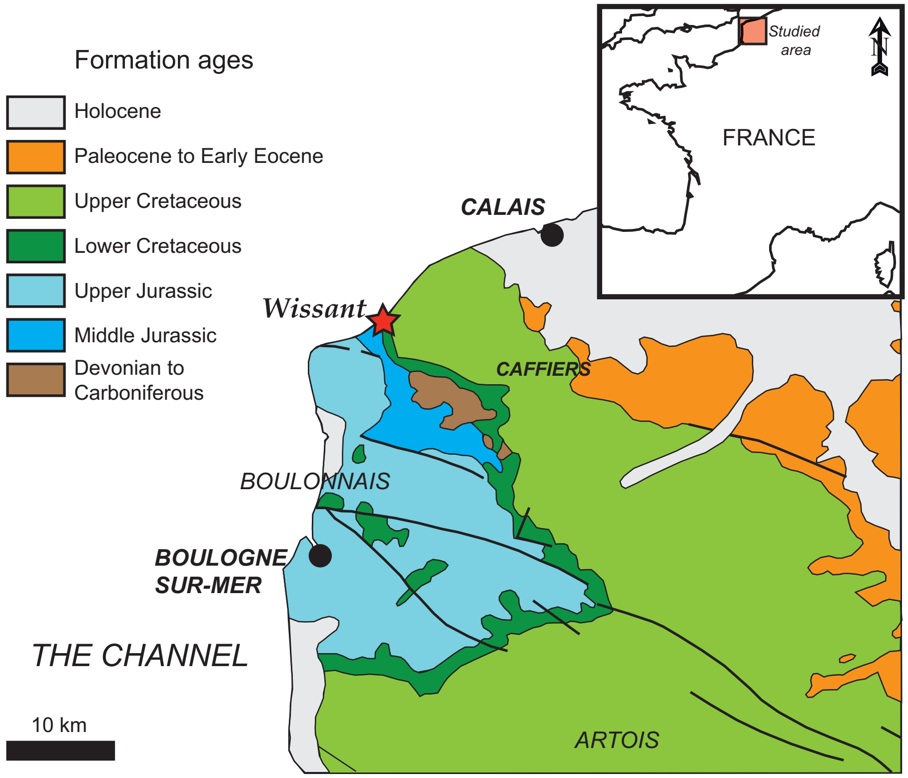

Fig. 1. Geological map of the studied area (after Chantraine et al., 2003) and location of the Wissant section.

Barrera et al., 1987; Pearson et al., 2001). Each type of organism carries specific information on temperature and environmental conditions. Oysters and rudists living in shallow coastal environments record sea-surface temperatures (SST) or upper-ocean temperatures (typically 0–100 m), depending on the depth of the depositional environment (Surge et al., 2001; Steuber et al., 2005; Brigaud et al., 2008). Seasonal variations of temperature and salinity can be inferred through microanalyses of bivalve shells (*e.g.* Steuber et al., 2005). Foraminifera record temperatures at various depths of the water column, from the upper surface to the deep ocean, depending on the depth habitat of the planktonic and benthic taxa (Barrera and Savin, 1999; Spero et al., 2003; Friedrich et al., 2012; Birch et al., 2013). Belemnites belong to an extinct group and although several studies have recently suggested that they may have recorded intermediate to deeper water temperatures (Dutton et al., 2007; Wierzbowski and Joachimski, 2007; Dera et al., 2009), their depth-related ecology is still debated (*e.g.* Price and Page, 2008; Rexfort and Mutterlose, 2009; Price et al., 2009).

Oxygen isotope ratios of biogenic apatite constitute another proxy that can be used to reconstruct temperatures of past oceans. Selachian fish tooth enamel is more resistant to a secondary diagenetic alteration than biogenic carbonates (Lécuyer et al., 2003; Pucéat et al., 2003). Selachian teeth $\delta^{18}O$ has been therefore used to determine Mesozoic upper surface temperatures in the Tethyan realm. Yet, such records are often produced at low temporal resolution because large selachian teeth are not common in the sedimentary record. In addition, selachian fish teeth are mineralised in less than a season, which generates variability in $\delta^{18}O$ of several teeth from a specific horizon (Lécuyer et al., 2003; Pucéat et al., 2003). The resolution of these records may be improved by analysing selachian or teleostean small teeth which appear far more common in sediments (Dera et al., 2009).

Sedimentary sections yielding well-preserved benthic and planktonic foraminifera, together with belemnite guards and fish teeth, are still very scarce. As a consequence, in most studies, the determination of past oceans seawater temperatures is usually based on oxygen isotope data originating from only one or two fossil groups. Some recent studies have focused on the comparison between belemnite and foraminiferal $\delta^{18}O$ data but generally do not include bivalves of fish tooth $\delta^{18}O$ data (*e.g.* Dutton et al., 2007). In the present paper, we compare stable isotope data from belemnites, fish teeth and benthic and planktonic foraminifera, which remarkably co-occur throughout the Gault Clay Formation (Middle and Upper Albian) that outcrops near the city of Wissant in the northern France (Fig. 1). The studied section was chosen mainly because it contains a large diversity of *a priori* very well-preserved shells (Knight, 1997). Our main objective is to compare and discuss Middle and Late Albian seawater temperatures deduced from co-occurring biogenic calcite and apatite from various fossils groups. In addition, the comparison of belemnite $\delta^{18}O$ data with those from benthic and planktonic foraminifera may further our knowledge of the ecology and depth habitat of belemnites.

2. Geological setting

The Wissant section is exposed along coastal cliffs in the Boulonnais area (Northern Paris Basin, Fig. 1). From the Jurassic–Cretaceous transition (Purbeckian facies) to the Aptian, the Anglo-Paris Basin was characterised by a trend to continental facies (Purbeck-Wealden facies; Allen, 1998). Transgressive Upper Aptian/Lower Albian glauconitic sands (greensands) were deposited in epicontinental marine environments (shore-face). In the Boulonnais, glauconitic dark-green sandstones, which deposited between the late Aptian and the early Albian, are occasionally exposed on the beach at low spring tides while the overlying argillaceous "Gault Clay Formation" of middle and late Albian in age (Owen, 1975; Gale et al., 1996; Hart, 2000) is exposed at the base of the coastal cliffs. These ones are formed mainly by early and mid-Cenomanian chalks. The Wissant section (Fig. 2) was first described in details by Destombes and Destombes (1938), Amédro