



High frequency floral changes at the Paleocene–Eocene boundary revealed by comparative biomarker and palynological studies



Sylvain Garel^{a,b,c,d,e,f,*}, Florence Quesnel^{c,d,e,f}, Jérémy Jacob^{c,d,e}, Emile Roche^g, Claude Le Milbeau^{c,d,e}, Christian Dupuis^h, Mohammed Boussafir^{c,d,e}, François Baudin^{a,b}, Johann Schnyder^{a,b}

^a Sorbonne Universités, UPMC Univ Paris 06, UMR 7193, IStEP, F-75005 Paris, France

^b CNRS, UMR 7193, IStEP, F-75005 Paris, France

^c Université d'Orléans, ISTO, UMR 7327, 45071 Orléans, France

^d CNRS/INSU, ISTO, UMR 7327, 45071 Orléans, France

^e BRGM, ISTO, UMR 7327, BP 36009, 45060 Orléans, France

^f BRGM GéoRessources/GAT, 45060 Orléans Cedex 2, France

^g Paléontologie végétale, ULg, Sart Tilman, 4000 Liège, Belgium

^h Laboratoire de Géologie Fondamentale et Appliquée, Faculté Polytechnique de Mons, Université de Mons, rue de Houdain 9, B-7000 Mons, Belgium

ARTICLE INFO

Article history:

Received 18 November 2013

Received in revised form 6 June 2014

Accepted 8 September 2014

Available online 16 September 2014

Keywords:

PETM

Molecular geochemistry

Pollen and spores study

Floral changes

Paleohydrology

Dieppe–Hampshire Basin

ABSTRACT

The Cap d'Ailly area (Upper Normandy, France) shows several terrestrial–lagoonal sections recording the negative carbon isotope excursion (CIE) associated with the Paleocene–Eocene Thermal Maximum (PETM; 55.8 Ma). A study of the biomarkers and spore/pollen content of the Vasterival section gave complementary information on paleofloral changes that occurred around the Paleocene–Eocene (P–E) boundary. Aliphatic hydrocarbon fractions revealed a high abundance of vascular plant biomarkers, including tricyclic diterpanes derived from conifers, fernenes derived from ferns and des-A-triterpenes derived from angiosperms. Whereas the vegetation of the depositional environment surroundings seemed alternately dominated by ferns and angiosperms (revealed from biomarkers), the regional flora seemed dominated strictly by angiosperms such as Juglandaceae (revealed by pollen). Spore/pollen assemblages revealed no major turnover in the paleovegetation, but slight variation in vegetation composition. However, both biomarkers and spores/pollen exhibited two intervals of rapid floral change: the first occurred around the P–E boundary and the second at the top of the strictly terrestrial unit that coincides with a marine transgression. Comparison of the data with published paleoclimatic results, obtained from the same samples, indicated that the first interval of floral change correlates with strong paleohydrological perturbations, whereas the second is linked to an increasing marine influence.

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1. Introduction

The Paleocene–Eocene (P–E) boundary, 55.8 Ma (Charles et al., 2011), is characterized by an event of extreme (4–8 °C) and short lived (160–210 ka) warming (Kennett and Stott, 1991; Zachos et al., 2003; Sluijs et al., 2006; Aubry et al., 2007; Westerhold et al., 2008; Murphy et al., 2010; Storme et al., 2012a). The P–E Thermal Maximum (PETM) is defined by a global negative carbon isotope excursion (CIE) of 2.5–6‰ (Kennett and Stott, 1991; Koch et al., 1992; Magioncalda et al., 2004; Zachos et al., 2005), which may have been triggered by the rapid and massive injection of isotopically light carbon, such as

methane clathrates, into the ocean–atmosphere system (Dickens et al., 1995; Higgins and Schrag, 2006).

The PETM had major consequences for the marine realm, where it is associated with a rise in surface and bottom ocean temperature (Kennett and Stott, 1991; Zachos et al., 2001), acidification of the deep ocean (Zachos et al., 2005), a large benthic foraminifera extinction (Kennett and Stott, 1991; Kaiho et al., 1996) and an increase in abundance and geographical range of dinoflagellates (*Apectodinium* spp.; Bujak and Brinkhuis, 1998; Crouch et al., 2003; Aubry et al., 2007). On land, the PETM is associated with the appearance and rapid dispersal of modern mammalian orders (Gingerich, 1989, 2006; Smith et al., 2006) and changes in the hydrological cycle (Pagani et al., 2006; Schmitz and Pujalte, 2007; Handley et al., 2011, 2012; Tipple et al., 2011; Garel et al., 2013).

Palynological studies have not found any global crisis among floral communities at the P–E boundary (Harrington and Kemp, 2001;

* Corresponding author at: Université Pierre et Marie Curie – Paris 6, Institut des Sciences de la Terre de Paris, CNRS, UMR 7193, case courrier 117, Tour 56-66 5ème étage, 4 place Jussieu, 75005 Paris, France.

E-mail address: sylvain.garel@upmc.fr (S. Garel).

Wing et al., 2003, 2005; Collinson et al., 2009). However, local and regional changes have been detected, such as a decrease in the abundance of gymnosperms during the PETM, observed in the Arctic (Schouten et al., 2007) and in land masses bordering the North Sea Basin (Kender et al., 2012), as well as in Wyoming (Wing et al., 2005; Smith et al., 2007). In the London Basin, the vegetation adapted to episodic fires, which characterizes the latest Paleocene, and disappears after the P–E boundary (Collinson et al., 2003, 2007, 2009). At lower latitudes, a decrease in diversity has been observed in the paratropical flora of America (US Gulf Coast) during the earliest Eocene (Harrington and Jaramillo, 2007), whereas the equatorial flora of eastern Colombia and western Venezuela was subjected to an increase in diversity (Jaramillo et al., 2010).

Comparative studies of biomarker and spore/pollen content might provide complementary information for investigating paleofloral changes. Indeed, whereas the biomarker content of sediments most likely reflects vegetation within and immediately around the depositional environment (Ficken et al., 2002; Schwark et al., 2002; Regnery et al., 2013), the palynological assemblage generally provides a more regional signal, since pollen and spores are often transported to the depositional environment over a longer distance than biomarkers (Andrieu et al., 1997; Jansen et al., 2013).

Only a few PETM studies have used the relative abundance of biomarkers to reconstruct the evolution of terrestrial plants (Schouten et al., 2007; Handley et al., 2008, 2011, 2012; Carvajal-Ortiz et al., 2009). Among these, only Schouten et al. (2007) proposed a comparison between palynological data and biomarker data.

In northwestern Europe, the P–E boundary is represented by terrestrial and lagoonal deposits rich in organic matter (OM) from the Paris Basin “Sparnacian” and coeval stratigraphic units from adjacent basins (Thiry and Dupuis, 1998; Collinson et al., 2003; Steurbaut et al., 2003; Aubry et al., 2005). The eastern part of the Dieppe-Hampshire Basin shows several sections with Sparnacian facies known for their swamp deposits containing well preserved OM (Magioncalda et al., 2001; Smith et al., 2011; Storme et al., 2012b; Garel et al., 2013). The only molecular study performed on the Sparnacian of the Dieppe-Hampshire Basin (Garel et al., 2013) and the low resolution of the former palynological studies of the basin did not provide precise information on floral changes during the PETM (Gruas-Cavagnetto, 1966; Dupuis and Gruas-Cavagnetto, 1985; Roche et al., 2009).

Here we present a high resolution palynological and molecular record of the Vasterival section, where the CIE onset has been identified (Storme et al., 2012b; Garel et al., 2013). Comparison of palynological and biomarker data should provide insight into the evolution of the composition and diversity of the floral communities at the P–E boundary in the Vasterival area. This multi-proxy approach should also decipher how the floral communities of a mid-latitude-swamp responded to the climatic and environmental changes that occurred at the P–E boundary.

2. Vasterival section

This section is included in the Cap d'Ailly area, known for its Sparnacian outcrops (Bignot, 1965; Dupuis and Steurbaut, 1987; Dupuis et al., 1998; Magioncalda et al., 2001; Aubry et al., 2005) on the Côte d'Albâtre of Upper Normandy (Fig. 1). The 2 m thick section reveals 1.5 m of terrestrial deposits overlain by 50 cm of lagoonal sediments of the “Sables et Argiles à Ostracodes et Mollusques” Member (SAOM Mb – Soissonnais Formation; Aubry et al., 2005; Fig. 2). The terrestrial deposits include a lignite complex (L1, Mortemer Formation) in the reference section of the Cap d'Ailly area (Dupuis et al., 1998; Storme et al., 2012b; Garel et al., 2013) and a thin bed of clay with root traces (Fig. 2). The deposits are composed of three clay beds, with evidence of fossil roots (Rb1 to Rb3; Fig. 2), five lignite beds (Lb1 to Lb5; Fig. 2),

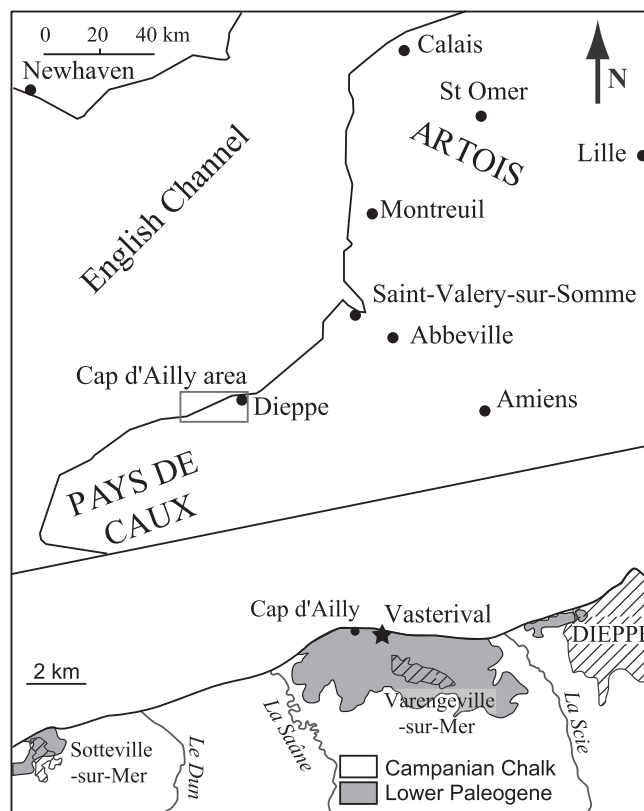


Fig. 1. Location of the Cap d'Ailly area and Vasterival section (modified from Dupuis et al., 1998).

two clay beds exhibiting carbonate nodules (Nb1 and Nb2; Fig. 2) and three clay beds presenting no root evidence or nodules (Cb1 to Cb3; Fig. 2). Fossil shells of a freshwater bivalve, *Unio* spp. can be observed between 60 cm and 1 m above the base of the section. The overlying lagoonal deposits are composed of an alternation of sands, silts and clays rich in mollusc shells. Only the lower part of the SAOM Mb can be observed in the section.

For the section, the P–E boundary has been unravelled from chemostratigraphy based on bulk OM $\delta^{13}\text{C}$ values (Storme et al., 2012b) and the PETM interval refined by way of the CIE recorded in the $\delta^{13}\text{C}$ values of vascular plant-derived *n*-alkanes (Garel et al., 2013). These results locate the P–E boundary in the Lb3 bed, 98 cm above the base of the Vasterival section (Fig. 2), and indicate that the PETM extends to the top of the section, as the CIE recovery is missing from Vasterival (Garel et al., 2013). Furthermore, two environmental changes have been identified in the section (Garel et al., 2013). The first is concomitant with the beginning of the CIE. The second occurs in the last terrestrial beds (i.e. Rb3 and Lb5) and appears related to an increasing marine influence. Lastly, studies of OM $\delta^{15}\text{N}$ values and compound-specific δD values have shown that the latest Paleocene in Vasterival was characterized by strong hydrological perturbations, switching from wet to dry conditions, and that the PETM was marked by a wetter climate with stronger seasonality (Storme et al., 2012b; Garel et al., 2013).

3. Methods

3.1. Field work and sample collection

The outcrop was cleaned by removing the superficial layers (5–10 cm) before sampling. A series of blocks (10 cm high \times 5 cm thick) were collected in order to provide continuous sampling of the section. Each sample was wrapped in Al foil and stored in

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