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Integrated stratigraphy of the Oxfordian global stratotype section and point (GSSP) candidate in the Subalpine Basin (SE France)

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Abstract. An integrated biostratigraphic approach, based on ammonites, calcareous nannofossils, dinoflagellates, combined with sedimentology, carbon-isotope and physical stratigraphy, is proposed for the Subalpine Basin (Thuoux and Saint-Pierre d'Argençon sections). Within the expanded marl deposits of the Terres Noires Fm., the Callovian-Oxfordian boundary is particularly well defined by ammonite taxa from different families (*i.e.* Cardioceratidae, Oppeliidae, Aspidoceratidae and Perisphinctidae), calcareous nannoplankton (first occurrence of large-sized *Stephanolithion bigotii*) and dinoflagellate cysts (first occurrence of *Wanaea fimbriata*). This precise biostratigraphy and diversity of ammonites permit long-range correlations with Boreal and Pacific domains. The exceptional outcrop conditions and continuous sedimentation allow high-resolution chemostratigraphy and cyclostratigraphy to be used. Variations of the $\delta^{13}C$ record (1.5‰ increase during the Lamberti Zone), consistent with data from other sections of the Subalpine Basin and with the Paris Basin, provide additional markers to characterise the Callovian-Oxfordian boundary. Promising results from cyclostratigraphy should serve to constrain the duration of biostratigraphic units and thus improve the Late Jurassic Geologic Time Scale. Comparisons are made with the two other candidates for an Oxfordian GSSP, Redcliff Point (UK) and Dubki (Russian Platform). Finally, the advantages of the Subalpine Basin sections support the proposal of Thuoux as a suitable GSSP candidate for the base of the Oxfordian Stage.

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INTRODUCTION

In Western European basins, the Callovian-Oxfordian transition is frequently marked by hiatuses or condensed levels. The scarcity of available ammonite-rich continuous sedimentary successions, which would allow precise ammonite biostratigraphy and integration of ammonite taxa from various palaeobiogeographic provinces, renders difficult the choice of a reliable section to define a Global boundary Stratotype Section and Point (GSSP) for the Middle-Late Jurassic transition. Among the possibilities are 1) the Subalpine Basin (SE France), where the Callovian-Oxfordian boundary is well identified and characterised in the expanded Terres Noires Formation (Fortwengler *et al*., 1997), and 2) the Oxford Clay Formation in Dorset (England), where more condensed sections show all the biohorizons bracketing the boundary (Page, 2004). In this context, the Savournon and Thuoux sections in the Subalpine Basin were proposed some years ago as potential candidates for the Callovian–Oxfordian GSSP, as the result of several meetings organised from 1993 in the Subalpine Basin, by the Groupe Français d'Étude du Jurassique (GFEJ), the Oxfordian Working Group (OWG) and the International Subcommission on Jurassic Stratigraphy (ISJS; Enay, Meléndez, 1984; Atrops *et al*., 1993; Atrops, Meléndez, 1994). Nevertheless, since then, no official decision about the Oxfordian GSSP has been taken (Meléndez, 2003; 2004). The Redcliff Point/Ham Cliff section in Dorset (UK) was first proposed as an alternative (Page *et al*., 2009a, b) and, more recently, a new section on the Russian Platform at Dubki has also been proposed as a potential candidate (Kiselev *et al*., 2013). Here, we present recent palaeontological and other stratigraphic investigations at Thuoux in the Subalpine Basin, to propose this section as a candidate for the Oxfordian GSSP, with complementary information from a nearby section at Saint-Pierre d'Argençon, in confirmation of the initial studies (Fortwengler, Marchand, 1994a–d; Fortwengler *et al*., 1997; Fortwengler *et al*., 2012; Fortwengler *et al*., 2013; Pellenard, 2013; Pellenard *et al*., 2014b).

The Subalpine Basin is part of the Submediterranean palaeobiogeographic province. The Terres Noires Fm. is biostratigraphically subdivided, using the ammonite zonal scheme established for this faunal province (Thierry *et al*., 1997; Cariou *et al*., 1997). However, the ammonite associations are also rich in cardioceratids, characteristic of the Subboreal Province (Marchand *et al*., 1990). Both zonal schemes are thus applicable, enhancing the correlations between the two faunal realms, and providing maximum precision for the relative age determination of the sedimentary units.

Although well-preserved ammonites are abundant in the Terres Noires Fm., where they greatly exceed other fossil macroinvertebrates (*e.g.* belemnites and brachiopods), several microfossil groups (calcareous nannofossils, dinoflagellates, spores and pollen, foraminifers and ostracods) provide additional biostratigraphic data.

Biostratigraphic, sedimentological and tectonic aspects of the Middle-Late Jurassic transition have been studied, over several decades, in numerous well-exposed outcrops in the Diois, Baronnies and the Buëch Valley (Artru, 1972; Tribovillard, 1989; Dardeau *et al*., 1994; Graciansky *et al*., 1999; Fortwengler, Marchand, 1994a–d; Fortwengler *et al*., 1997; Pellenard, 2003). In many sections of this domain, abundant, characteristic, well-preserved ammonites provide an accurate biostratigraphy. The Callovian-Oxfordian boundary is especially well exposed at the Thuoux and Saint-Pierre d'Argençon sections, where all ammonite biohorizons and subzones of the uppermost Callovian Lamberti and basal Oxfordian Mariae zones can be clearly identified (Fortwengler *et al*., 2012). New investigations were recently performed on these sections, across the Callovian-Oxfordian boundary, with precise facies analyses, nannofossil and dinoflagellate/palynomorph determination, clay mineralogy, geophysical measurements (*i.e.* field gamma-ray spectrometry and magnetic susceptibility) and geochemical analyses (Pellenard, Deconinck, 2006; Courtinat, 2006; Boulila *et al*., 2008, 2010; Giraud *et al*., 2009; Pellenard *et al*., 2014c).

Here we summarise and integrate the recently obtained stratigraphic information for both the Thuoux and Saint-Pierre d'Argençon sections, and support the proposal that the first of them be the GSSP for the base of the Oxfordian stage.

GEOGRAPHIC AND GEOLOGICAL SETTINGS

During the Jurassic, the Subalpine Basin (SE France) formed part of the External Alpine Realm or Dauphinois Realm (Baudrimont, Dubois, 1977; Dubois, Delfaud, 1989). Four areas, defined geographically and tectonically, can be recognised within this basin (Fig. 1): 1) the Vivaro-Cevenol Platform, to the south of the French Massif Central, is the maximum western extent of the Subalpine Basin; 2) the Provençal Platform, including the Digne and Castellane arcs, is on the south-eastern margin; 3) the Subalpine Range, including the Chartreuse and Vercors ranges, lies to the north; 4) the Diois, the Baronnies and the Buëch Valley form the central part of the Subalpine Basin.

From the Late Bajocian to the Middle Oxfordian, the Subalpine Basin was strongly subsident, opening eastwards on to the Tethys Ocean through the Ligurian Trough (Enay *et al*., 1980; Thierry, Cariou, 1980; Thierry *et al*., 2000). It was bordered by carbonate platforms throughout the Callovian and Oxfordian (Elmi *et al*., 1984; Enay *et al*.,

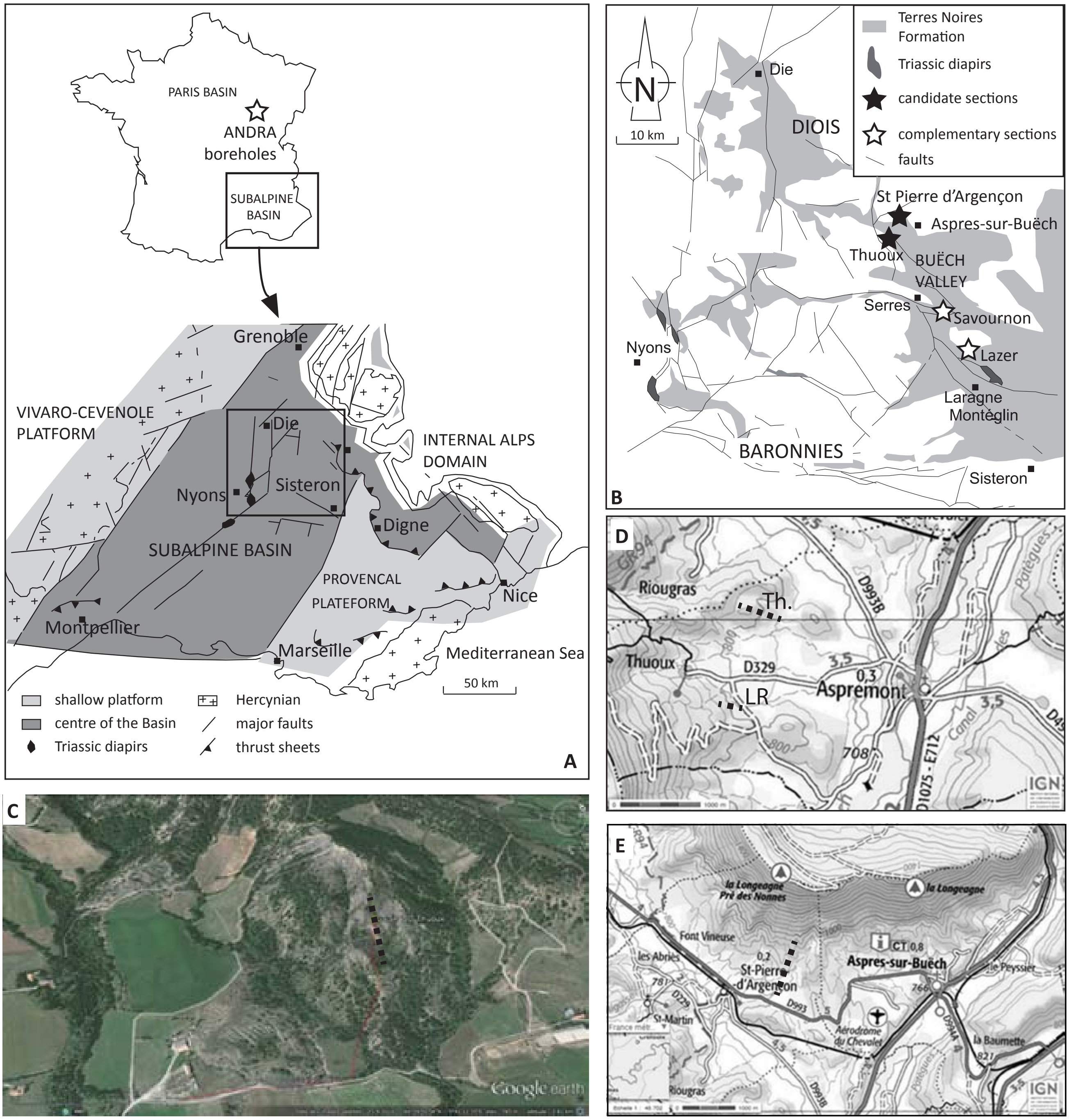

Fig. 1. A. The Subalpine Basin in SE France and the Andra boreholes in the eastern Paris Basin. **B.** Detail of the eastern part of the Subalpine Basin showing location of the Thuoux and Saint-Pierre d'Argençon sections, with two other complementary sections, Savournon and Lazer. **C.** Aerial photograph of the Thuoux outcrop. The section studied corresponds to the dashed black line, the coordinates of the Callovian-Oxfordian boundary are 44º30´0.84˝N, 5º42´13.05˝E (Image © 2014 DigitalGlobe Google Earth). **D.** The Thuoux section (Th.) and neighbouring section Les Richiers (LR; dashed black lines), a complementary section nearby, where abundant ammonites have been collected (see plate 5). **E.** The Saint-Pierre d'Argençon section (dashed black line)

1984; Atrops, 1994; Graciansky *et al.*, 1999). Fine detrital sediments were continuously deposited in this very subsident basin, implying a high sedimentation rate. These marl deposits, known as the Terres Noires Fm., are up to 2000 m thick in the central part of the Subalpine Basin (Artru, 1972; Fortwengler, 1989; Tribovillard, 1989; Graciansky *et al.*, 1999; Pellenard, 2003). On the basin margins, the Terres Noires Fm. is only a few hundreds or tens of metres thick, and may be absent from ridges and shoals.

Of the many easily accessible outcrops in the Subalpine Basin where the Terres Noires Fm. is present, only a few are suitable for high-resolution biostratigraphic investigation. In the eastern Diois and in the Baronnies, the *lamberti* and *paucicostatum* biohorizons, below and above the Callovian-Oxfordian boundary, contain either few characteristic fossils, or fossils that are not well preserved. The sections in the east (Gap/Embrun) have a poor fossil record, with some hiatuses, and the Jurassic sediments have been strongly affected by Alpine metamorphism (Artru, 1972). The sections near the margins of the basin (La Voulte-sur-Rhône on the Vivaro-Cevenol Platform, and Vauvenargues on the Provençal Platform) can be used to provide supplementary material, despite many hiatuses within the Callovian-Oxfordian succession (Elmi, 1967; Graciansky *et al.*, 1999; Charbonnier, 2007).

The section selected as a GSSP candidate is in the River Buëch Valley, between Aspres-sur-Buëch and Sisteron (Fig. 1). Here, the Terres Noires Fm. is very rich in well-preserved ammonites, and is particularly extensive, with no disconformities, major faults or hiatuses. Two sections, Thuoux and Saint-Pierre d'Argençon, have recently been investigated in detail: Thuoux is proposed as the stratotype section for the potential Callovian-Oxfordian GSSP, while Saint-Pierre d'Argençon, where the lithological and faunal successions are close and consistent with data from the Thuoux and Savournon outcrops (Fortwengler *et al.*, 1997; 2012), could be an auxiliary section. The Saint-Pierre d'Argençon section was recently used for a precise orbital calibration of the Oxfordian, on the basis of the magnetic susceptibility signal (Boulila *et al.*, 2008, 2010; Gradstein *et al.*, 2012).

MATERIAL AND METHODS

For both the Thuoux and Saint-Pierre d'Argençon sections, a detailed lithological succession has been documented, including all aligned calcareous nodules and calcareous or indurated marly beds, which act as key markers. All specimens and samples collected from the sections have been precisely recorded on the logs.

AMMONITES

Hundreds of ammonites have been collected over a period of many years (mainly by DF and DM), in the Terres Noires Fm., leading to the identification of a series of faunal levels from the Athleta Zone to the Plicatilis Zone (Levels 1 to 14). Levels define the smallest units recognisable in the field by their facies and faunal assemblages, and are well identified throughout the Subalpine Basin (Fortwengler, 1989; Fortwengler, Marchand, 1991; Fortwengler, Marchand, 1994a–d; Fortwengler *et al.*, 1997; Fortwengler *et al.*, 2012). Each level can be anchored to the relevant biostratigraphic reference framework of the Submediterranean Domain (Thierry *et al.*, 1997; Cariou *et al.*, 1997).

In the Terres Noires Fm., the presence of characteristic ammonite species, recording the majority of the zones, subzones and biohorizons defined for the Submediterranean Realm, yields a precise zonal scheme. In this paper, biohorizons are recognised as infrazonal biostratigraphic units, characterised either by a faunal assemblage or the occurrence of an index-species, following the successive definitions and improvements classically proposed by several authors (Gabilly, 1976; Callomon, 1984; Page, 1995; Thierry, Galeotti, *in* Galeotti, Rey, 2008; Rogov *et al.*, 2012). Therefore, in this paper, a biohorizon, or infrazonal biostratigaphic unit, may encompass one or more "Levels".

NANNOFOSSILS AND PALYNOMORPHS

The same set of samples, collected at moderate to very high resolution, was used for both nannofossil and palynomorph investigations, and magnetic susceptibility (MS) and geochemical analyses. Calcareous nannofossils were investigated in smear slides, with an optical microscope at a magnification of ×1250. Palynological investigation on the Thuoux section focused on a series of samples crossing the Callovian-Oxfordian boundary, from Th150 (at 21.85 m) to Th290 (at 34.15 m). These samples were subjected to standard hydrochloric and hydrofluoric acid digestion. They all provided rich assemblages of dinoflagellate cysts, spores, pollen, acritarchs, foraminifer linings and abundant dark charcoal particles. For each sample, at least 200 dinoflagellate cysts were counted (up to 400 for the most productive levels).

FIELD GAMMA-RAY SPECTROMETRY (GRS)

Field gamma-ray spectrometry (GRS) data were measured *in situ*, with a 12cm step resolution, using both Exploranium GR-320 and SatisGeo GS-512 spectrometers, equipped with a ^{137}Cs reference source. The same methodology was used for both instruments: the detector was placed against a cleaned and smoothed outcrop surface, with an acquisition time of 1 minute. Reproducibility was assessed by measuring the same spot 30 times. Replicates are normally distributed (Shapiro-Wilk test: $p = 0.235$), with a standard deviation of approximately 5%, confirming the appropriateness of a 1 minute acquisition time.

MAGNETIC SUSCEPTIBILITY (MS)

High resolution sampling (8 cm step) was carried out on the two sections. Samples collected were measured in the laboratory for magnetic susceptibility (MS) with a Kappabridge MFK-1 susceptometer. Each sample was measured three times, and the mean of these values is reported after weight normalisation. The standard deviation of the analytical error associated with the MS measurements, based on triplicate analyses, is $0.0091 \cdot 10^{-8}$ m^3/kg.

ISOTOPE GEOCHEMISTRY

Stable isotope (carbon and oxygen) analyses of bulk carbonate were performed on 100 samples from Thuoux at the Isotopic Mass Spectrometry Service (SSMIM) of the National Museum of Natural History (MNHN, Paris, France). Values for $\delta^{13}C$ and $\delta^{18}O$ values were measured in a Delta V Advantage (Thermo Fischer Scientific) isotope ratio gas mass spectrometer, directly coupled to a Kiel IV automatic carbonate preparation device (reaction at 70 °C under vacuum) and calibrated via NIST 19 to the VPDB (Vienna Pee Dee Belemnite) scale. The overall precision of the measurement was greater than 0.03‰ for carbon and 0.04‰ for oxygen, and the reproducibility of replicated standards was better than ±0.1‰ for both $\delta^{13}C$ and $\delta^{18}O$.

Additional isotope analyses ($\delta^{13}C$, $\delta^{18}O$) were performed on: *i*) bulk carbonate from Propriac-Beauvoisin and Thuoux, and *ii*) belemnite rostra ($n = 10$) from seven sections in the Subalpine Basin (Propriac-Beauvoisin, Savournon, Saint-Geniez, Ribiers, Sahune, Rottier and La Voulte-sur-Rhône) at the Biogéosciences Laboratory (University of Burgundy, Dijon, France). Polished rostra were investigated using cathodoluminescence microscopy (8200MKII Technosyn cathodoluminescence coupled to an Olympus microscope, Biogéosciences, University of Burgundy) and Scanning Electron Microscope (JEOL JSM 7600F equipped with EDS Oxford link EXL II and WDS Oxford link, platform ARCEN, ICB, University of Burgundy). Luminescent and non-luminescent areas of belemnite rostra were accurately mapped, so as to sample only the non-luminescent parts of the shells for stable isotope analysis. The calcite powders were reacted with 100% phosphoric acid at 90°C, using a Multiprep carbonate preparation line connected to an Isoprime mass spectrometer. Oxygen isotope compositions are reported in the delta notation relative to V-PDB in per mil, by assigning a $\delta^{13}C$ value of +1.95‰ and a $\delta^{18}O$ value of –2.20‰ to NBS19. Reproducibility was checked by replicate analyses of laboratory standards and is better than ±0.08‰ (1σ) for oxygen isotopes and ±0.04‰ (1σ) for carbon isotopes.

CYCLOSTRATIGRAPHY

The cyclical fluctuations observed at Thuoux were investigated using spectral analyses to better constrain their origin. Prior to spectral analyses, the linear trend of the series was removed and the residuals were normalised (average = 0; standard deviation = 1). The multitaper method was used on the series to calculate the sedimentary periods, applying three 2π-tapers (2π-MTM; Thomson, 1982, 1990). Time-Frequency Weighted Fast Fourier Transforms (T-F WFFTs) were applied to detect changes in the expression of the sedimentary period throughout the series (*e.g.* Martinez *et al.*, 2013; Matys Grygar *et al.*, 2014). The procedure consists in dividing the GRS series into 247 intervals of 15 m, separated from each other by 0.12 m. Each interval is then weighted by one Slepian sequence and treated by applying a Fast Fourier Transform. The interpretation of the GRS cycles in terms of orbital forcing was performed by comparing the ratios between the observed frequencies and frequencies of the Earth's orbital parameters calculated in the last astronomical solutions (Laskar *et al.*, 2004, 2011).

TERRES NOIRES FORMATION LITHOLOGY AND FACIES

Terres Noires Fm. deposits are dominated by clayey and silty calcareous marls, often with aligned calcareous nodules, some limestone beds and calcareous bundles. In the Upper Callovian and at the base of the Lower Oxfordian, small, dark grey to chocolate-brown nodules are aligned in beds. Above, the marls contain beds of aligned cream-coloured nodules and larger, flatter, rust-coloured nodules, containing fine laminations interpreted as distal tempestites (Pellenard, 2003). The top of the Terres Noires Fm. contains beds of aligned red nodules, and the marl deposits are more and more calcareous, gradually becoming true marl/limestone alternations (Argovian facies). Marl deposits are composed of carbonate (30%) and a mixture of silt (mainly detrital quartz) and clay. Clay assemblages are relatively homogeneous, with iron-rich chlorite (15–20%), illite (35–50%), R1 illite-smectite mixed-layer minerals (25–50%), and kaolinite (10%; Pellenard, 2003; Pellenard, Deconinck, 2006). Several thin bentonites (weathered volcanic ash layers) have been identified, interbedded with the marl, thus allowing correlations between the Subalpine Basin and the Paris Basin (Pellenard *et al.*, 2003; Pellenard, Deconinck, 2006). Clay mineralogy reveals the overprint of weak burial diagenesis on the sediment, consistent with: *i*) the nature of the detrital and authigenic illite-smectite mixed-layers, *ii*) the Tmax of the organic matter, around 450°C, and *iii*) the fluid inclusion study, suggesting that temperatures never exceeded 120–150°C during maximal burial (Barlier *et al.*, 1974; Guilhaumou *et al*., 1996; Pellenard, Deconinck, 2006).

The precise definition of each ammonite biohorizon within these biostratigraphic frameworks is proposed in the ammonite biostratigraphy section, which follows the detailed descriptions of each section, Thuoux and Saint-Pierre d'Argençon.

THUOUX SECTION (Figs 2 and 3)

In the Thuoux section, the boundary between the Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, and the Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, is clearly and precisely located at the boundary

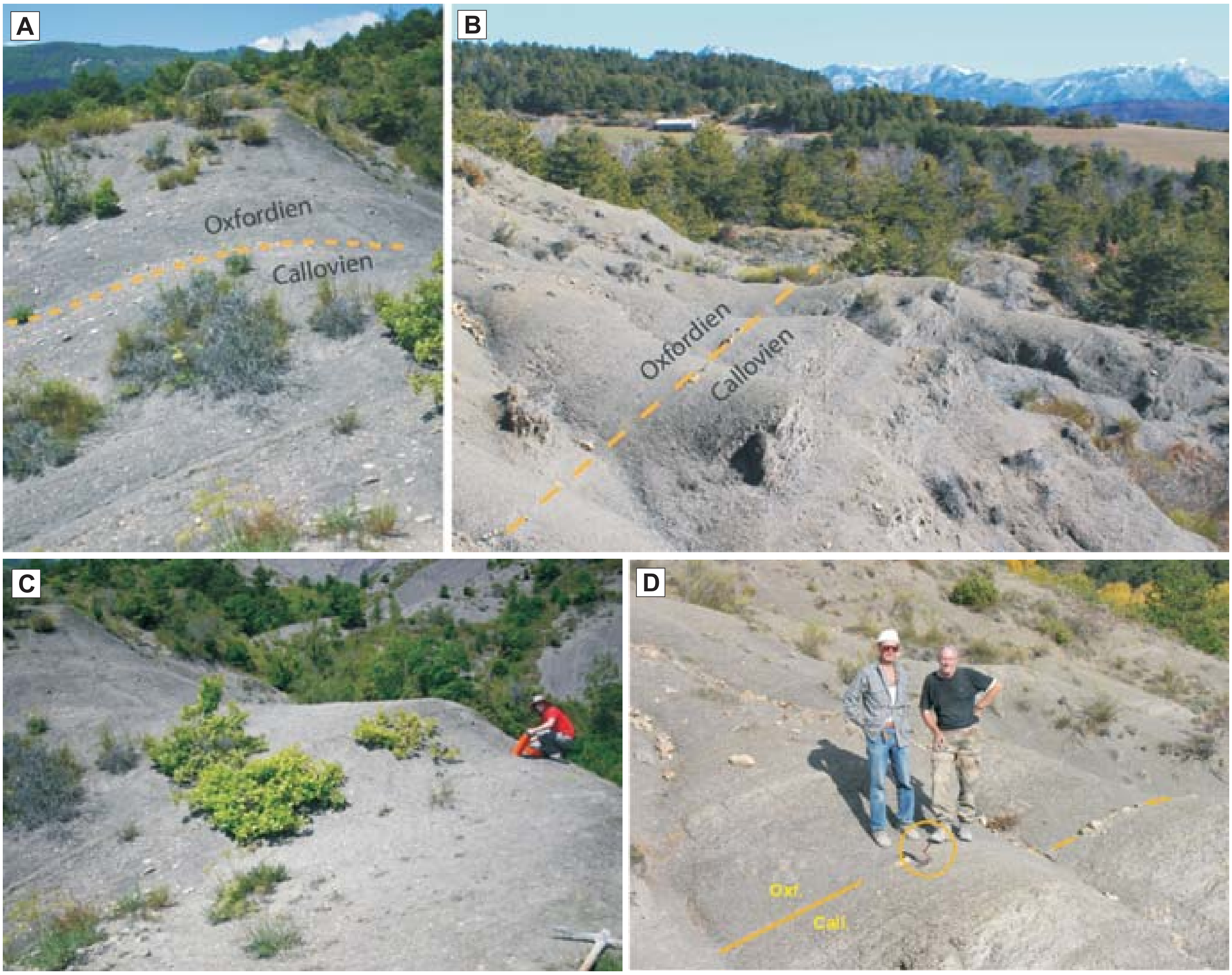

Fig. 2. Photographs of the Callovian-Oxfordian boundary in the Subalpine Basin

A. The position of the Callovian-Oxfordian boundary at Thuoux. **B.** The position of the Callovian-Oxfordian boundary at Saint-Pierre d'Argençon. **C.** Typical outcrop conditions for high-resolution gamma-ray spectrometry measurements at Thuoux. **D.** Detail of the Callovian-Oxfordian boundary at Saint-Pierre d'Argençon.

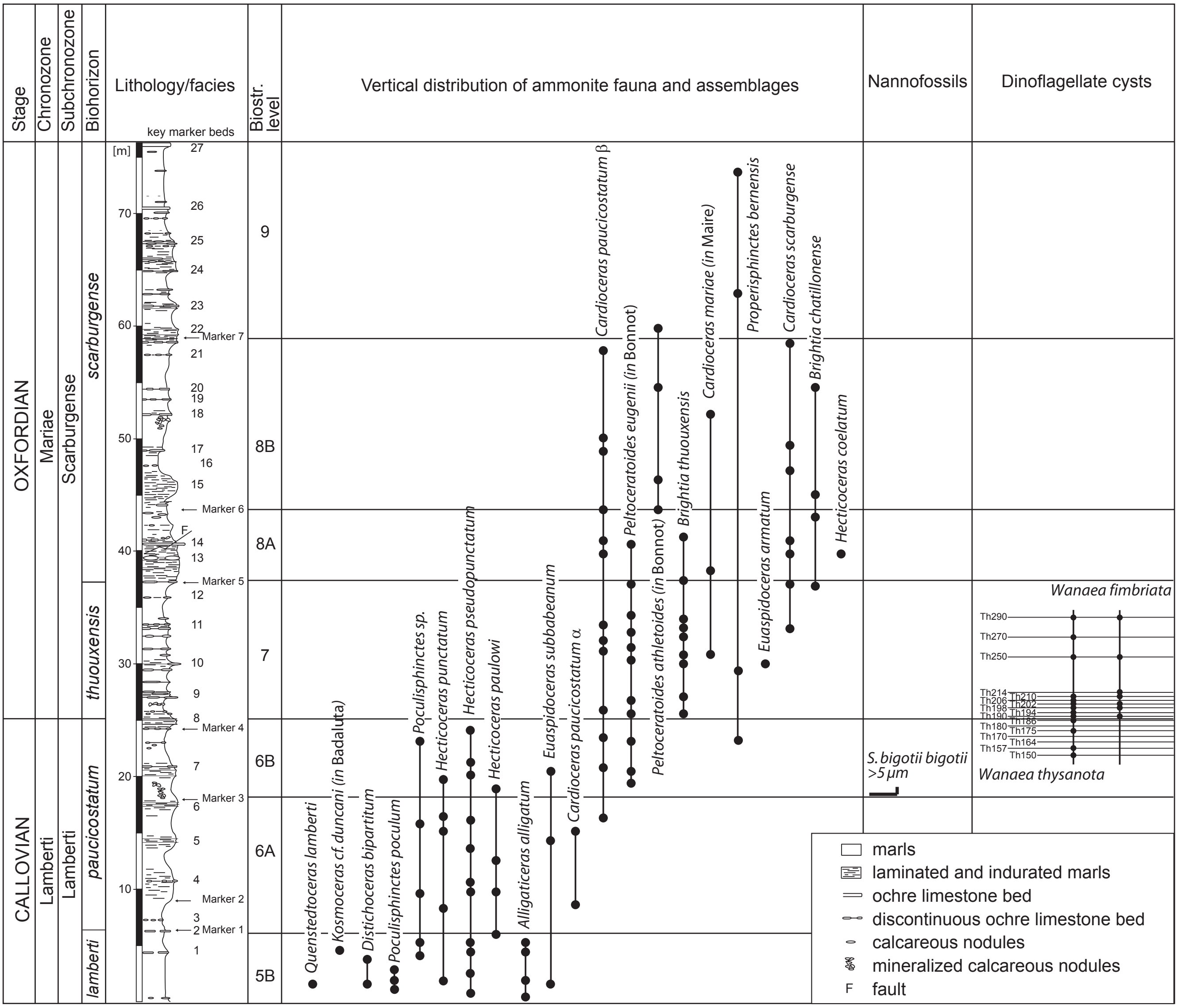

Fig. 3. Detailed lithology, biostratigraphy and distribution of ammonite fauna, calcareous nannofossils and dinoflagellate cysts, for the Thuoux section

between Level 6B and Level 7 (Fortwengler, 1989; Fortwengler, Marchand, 1994d; Fortwengler *et al*., 1997, 2012). Only the interval encompassing the Callovian-Oxfordian boundary (from Level 5B to Level 10A), is described here, with around 80 m of marly sediments, from the late Upper Callovian (Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon) to the base of the Lower Oxfordian (Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon, Figs 2 and 3):

Level 5B: around 9 m of dark grey marl, with some grey calcareous nodules, occasionally large and platy; Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon.

Level 6: around 17 m of softish, grey marl, with small grey nodules and thin, harder clayey limestone intercalations. The progressive transition between the upper part of Level 5B and Level 6 is marked by more frequent thin calcareous levels. Calcareous mineralised concretions are abundant in the upper part of Level 6, which can be divided into Level 6A (11 m) and Level 6B (6 m); Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon.

Level 7: around 13 m of yellowish grey marl with numerous intercalations of aligned rust-to-ochre large platy nodules at the base, particularly rich in ammonites; Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon.

Level 8A: around 6 m of marl, starting with 3 m of more calcareous marl. This level also contains aligned large rust-to-ochre coloured lenticular platy nodules, with laminae interpreted as distal tempestite storm deposits, and erosional surfaces; Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon.

Level 8B: after another 3 m of more calcareous marl, around 13 m of fairly homogeneous marl, with calcareous mineralised concretions; pyritous nodules are interbedded in soft marl at the top; Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon.

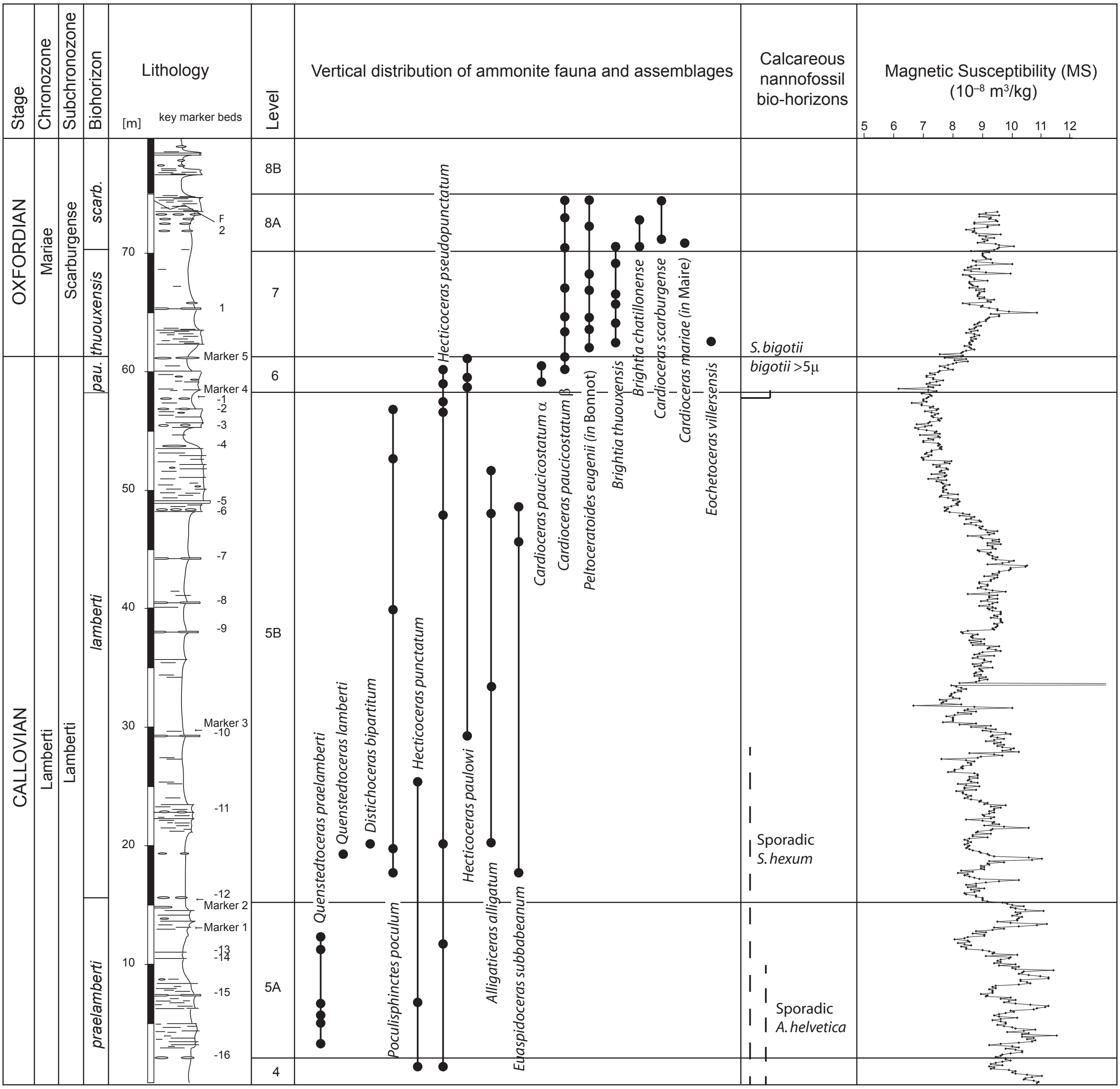

Fig. 4. Detailed lithology, biostratigraphy and distribution of ammonite fauna, calcareous nannofossils and magnetic susceptibility, for the Saint-Pierre d'Argençon section

For explanations see Figure 3

Level 9: around 17 m of homogeneous pale grey marl, interbedded with rust-to-ochre coloured calcareous bundles with large platy nodules and rare pyritous nodules; Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon.

Level 10A: about 15 m of soft darker marl with grey nodules and, locally, small greenish grey phosphatic nodules; Mariae Zone, Scarburgense Subzone, *woodhamense* Biohorizon.

SAINT-PIERRE D'ARGENÇON SECTION
(Figs 2 and 4)

The Terres Noires Fm. at Saint-Pierre d'Argençon/ Aspres-sur-Buëch covers a stratigraphic interval encompassing the Upper Callovian (Lamberti Zone, Lamberti Subzone, *praelamberti* Biohorizon) to Middle Oxfordian (Transversarium Zone) interval (Gaspard *et al.*, 2005; Huret, 2006; Boulila *et al.*, 2008; Fortwengler *et al.*, 2012). Only Levels 4 to 10A are presented here (Figs 2 and 4):

Levels 4 to 5B: composed of about 60 m of grey marl. Several thin calcareous intercalations are found, each about 1 m thick, and which stand out due to weathering (base of Level 5A and top of Level 5B). Whatever the level, orange-ochre nodules are quite frequent; some of them show laminae interpreted as tempestite storm deposits. Abundant, diversified ammonites allow precise attribution to Levels 4 to 5B (Lamberti Zone, Lamberti Subzone, *praelamberti* biohorizon and *lamberti* biohorizon).

Levels 6 to 8B: about 40 m thick, with soft marl, especially in the lower part, and alignments of orange-to-ochre or rust-coloured nodules, with frequent laminae. The Callovian-Oxfordian boundary is situated within a homogeneous marly layer, between Levels 6 and 7, where both the *paucicostatum* Biohorizon and the *thuouxensis* Biohorizon can be clearly and precisely recognised by their characteristic ammonite assemblages (Fig. 4).

Levels 9 and 10A: a thick series (109 m) of marl, harder than the lower levels, containing many large platy nodules. There are also two metre-thick intercalations of calcareous nodules and, finally, a greenish phosphatic layer, near the top of Level 10A. (Level 9: Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon; Level 10A: Mariae Zone, Scarburgense Subzone, *woodhamense* Biohorizon).

AMMONITE BIOSTRATIGRAPHY

The biostratigraphic framework shown in Figure 5 represents the synthetic succession and association of ammonite species and genera for the Subalpine Basin, based on a similar figure in Fortwengler *et al.* (2012). Plates 1–5 present ammonites from the Thuoux and Saint-Pierre d'Argençon sections.

UPPER CALLOVIAN

In the Terres Noires Fm., the presence of characteristic ammonite species records the majority of the zones, subzones and biohorizons defined for the Submediterranean Realm.

Athleta Zone (d'Orbigny, 1852; Oppel, 1857, *sensu* Callomon, 1964). This zone can be identified throughout the basin; it has a moderate thickness of about 50 m. The index species, *Peltoceras athleta* (Philips), can often be found in association with numerous Phylloceratinae.

Trezeense Subzone (Cariou, 1969; Level 1 *in* Fortwengler, 1989). The presence of *Pseudopeltoceras* marks the base of the Upper Callovian. The associated fauna, characteristic of the upper part of the subzone, includes Peltoceratinae (*Peltoceras baylei* Prieser macroconch, *Rursiceras pseudotorosum* Prieser microconch), Oppeliidae, Perisphinctidae and Phylloceratinae.

Collotiformis Subzone? (Bourquin, Contini, 1968; Level 2 *in* Fortwengler, 1989). The Collotiformis Subzone is not always easily identified. Peltoceratinae disappear and Kosmoceratidae appear. *Collotia* cf. *odyssea* (Mayer) is regarded as a good indicator for the subzone. Grossouvrinae (gr. *Grossouvria evexa-sulcifera* (Quenstedt-Oppel)) and Hecticoceratinae are still well represented, as are Phylloceratidae (mostly *Sowerbyceras tortisulcatum* (d'Orbigny).

Lamberti Zone (Hébert, 1857, 1860, *emend*. Marchand, 1986; Levels 3, 4 and 5 *in* Fortwengler, 1989).

Henrici Subzone (Sayn, 1830; Callomon, Sykes *in* Cope *et al*., 1980). The index species *Quenstedtoceras henrici* (Douvillé) and *Distichoceras nodulosum* (Quenstedt) are present but rare, as is *Quenstedtoceras* aff. *messiaeni* Marchand, Raynaud (Level 3 *in* Fortwengler, 1989). The ammonite fauna is dominated by Hecticoceratinae (*Hecticoceras* (*Orbignyceras*) *pseudopunctatum* (Lahusen); *H.* (*Brightia*) *brighti* Pratt), Pseudoperisphinctinae (*Grossouvria evexa-sulcifera* (Quenstedt-Oppel), Euaspidoceratinae and Phylloceratidae. In several sections (Buëch Valley and around Sahune), a fossil-rich layer with *Peltoceras schroederi* Prieser can be used to define the top of the subzone.

Lamberti Subzone (Callomon, Sykes *in* Cope *et al*., 1980). Cardioceratinae species are used to define three successive biohorizons in the Lamberti Subzone.

praelamberti **Biohorizon** (Marchand, 1986). At the base (Level 4 *in* Fortwengler, 1989), Hecticoceratinae (*H.* (*Putealiceras*) *punctatum* (Stahl)) are frequent; they are accompanied by *Horioceras baugieri* (d'Orbigny) and *Alligaticeras* sp. Rare Cardioceratinae are present; some with morphotypes close to *Quenstedtoceras henrici* (Douvillé), while the majority can already be identified as *Quenstedtoceras praelamberti* (Douvillé). Level 4 is easily recognised in

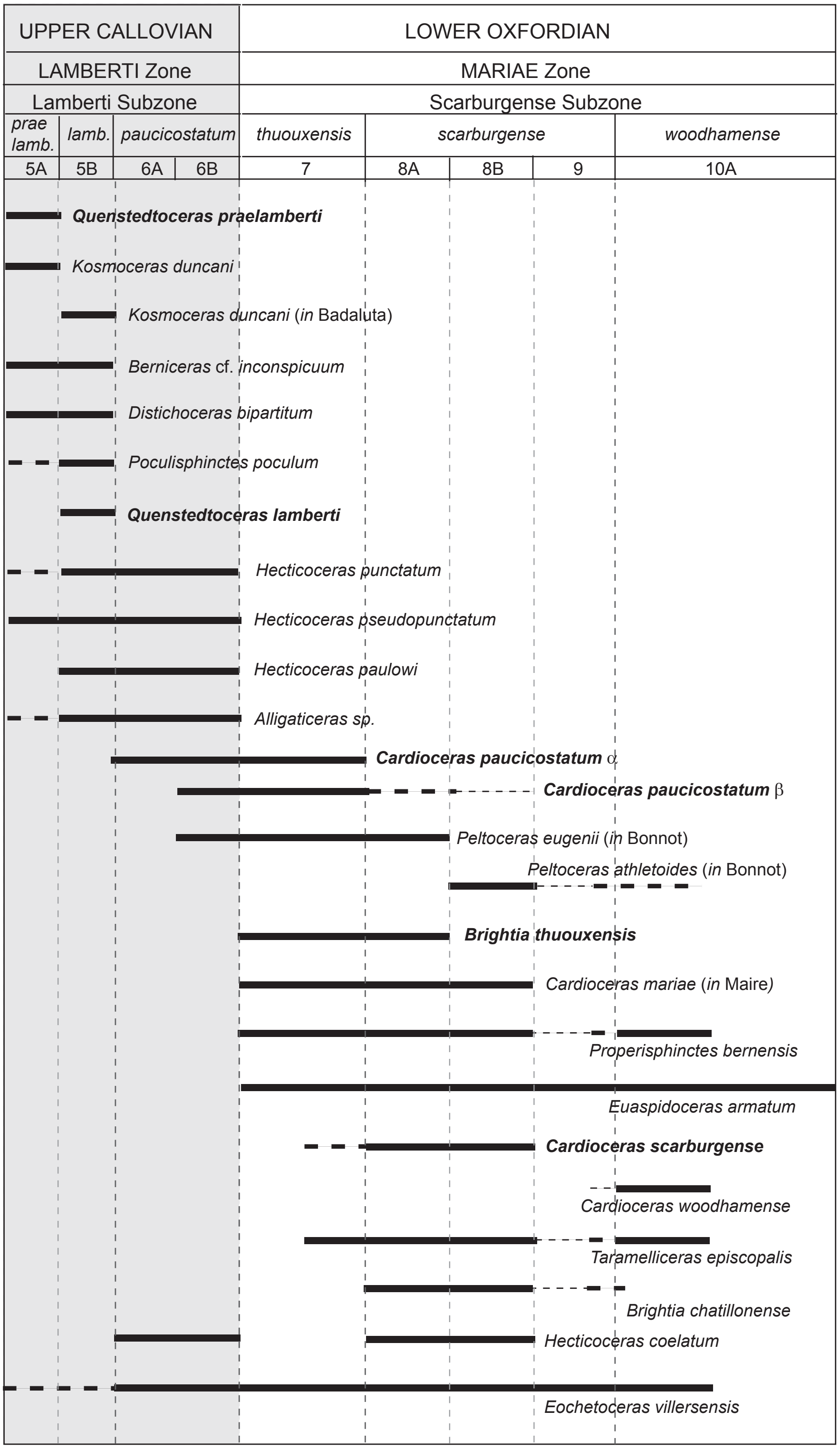

Fig. 5. Stratigraphic range of the major ammonite species found in Levels 5A to 10A of the Terres Noires Fm. at the Callovian-Oxfordian boundary

Chronostratigraphic levels and biostratigraphic zonal scheme are based on first and last appearance of ammonite taxa and ammonite associations. Dashed black lines indicate fluctuating levels of abundance the centre of the basin, but is more difficult to observe elsewhere, especially on the margins. Near the top, (Level 5A *in* Fortwengler, 1989) *Quenstedtoceras praelamberti* (Douvillé) is abundant, with characteristically fine, not very prominent ribbing, with only one or two intercalaries. Diverse accompanying fauna include *Hecticoceras* (*Orbignyceras*) *paulowi* (de Tsytovich) and *Kosmoceras duncani* (Sowerby). Level 5A is easily recognised throughout the basin and sometimes on the margins.

***lamberti* Biohorizon** (Callomon, 1964; Level 5B *in* Fortwengler, 1989). Cardioceratinae are very rare, and their ribbing morphology is different from their older relatives: the primaries are thickened, with more intercalaries. Perisphinctinae and Pseudoperisphinctinae (*Alligaticeras* and *Poculisphinctes* genera) are frequent. Hecticoceratinae are represented mainly by *Hecticoceras pseudopunctatum* (Lahusen). No *Kosmoceras*, *Distichoceras* or *Berniceras* are found after the *lamberti* Biohorizon. This biohorizon corresponds to a stratigraphic gap everywhere in the basin, except for the Buëch Valley and the Propiac section (western part of the basin). The following species have been collected: *Quenstedtoceras lamberti* (Sowerby), *Poculisphinctes poculum* (Leckenby), *Alligaticeras* cf. *alligatum* (Leckenby), *Rollieria* sp., *Distichoceras bipartitum* (Zieten), *Kosmoceras duncani* (Sowerby) *in* Badaluta, 1976, *Euaspidoceras hirsutum* (Sayle), *Euaspidoceras subbabeanum* (Sintzow), *Hecticoceras (Brightia) svevum* (Bonarelli), *Hecticoceras (Lunuloceras) pseudopunctatum* (Lahusen).

***paucicostatum* Biohorizon** (Marchand, 1979, *emend*. Fortwengler, Marchand, 1991; Level 6 *in* Fortwengler, 1989; Fortwengler *et al.*, 1997). The *paucicostatum* Biohorizon is the uppermost biostratigraphic unit of the Callovian. It can sometimes be divided into two parts if the unit is thick enough, with an abundant fossil record. The lower part (Level 6A, *in* Fortwengler *et al.*, 1997) still contains some Cardioceratinae, with a morphology very close to *Quenstedtoceras lamberti* (Sowerby).They can thus be considered as the α morph of *Cardioceras paucicostatum* Lange, because their primaries and intercalaries (rarely very numerous) are equally strong (Debrand-Passart *et al.*, 1978, fig. 9, 10). The morphologically more advanced individuals, with fine, dense, straight ribs, and almost always a single intercalary, on an ogival venter without a keel, but with a smooth, slightly raised siphonal band, are considered to be the β morph of the same species, *Cardioceras paucicostatum* Lange (Lange, 1973; Debrand-Passard *et al.*, 1978; Fortwengler, Marchand, 1994a; Fortwengler *et al.*, 1997). It should be noted that these Cardioceratinae are morphologically close to *Quenstedtoceras pseudolamberti* Sintzow-Lahusen, especially to individuals recently published from Russia (Kiselev *et al*., 2013). *Hecticoceras* (*Orbignyceras) paulowi* (de Tsytovich) is the most frequent of the Hecticoceratinae. The upper part (Level 6B, *in* Fortwengler *et al.*, 1997) is characterised by relatively numerous *Peltoceratoides eugenii* (Raspail), which present duplicated latero-ventral tubercles for the first time (Bonnot, 1995; Bonnot *et al.*, 1997; Chapman, 1999; Bonnot *et al.*, 2002). In Level 6B, all the Cardioceratinae are morphologically advanced and therefore correspond to the β morph of the *Cardioceras paucicostatum* Lange. *Hecticoceras* (*Orbignyceras) paulowi* (de Tsytovich) is less frequent than in Level 6A. No Pseudoperisphinctinae are found above Level 6B. Level 6 (*paucicostatum* Biohorizon) can be identified wherever Level 5B (*lamberti* Biohorizon) is present. The *paucicostatum* Biohorizon has been identified in the Buëch Valley, near Sisteron and in several parts of the Baronnies. Elsewhere in the Subalpine Basin, its absence is associated to the *lamberti* Biohorizon gap.

LOWER OXFORDIAN

There is a slight change in facies (from the end of the *paucicostatum* Biohorizon) to blue-grey marls, with frequent thin intercalations of calcareous beds and beds with aligned calcareous nodules. The total thickness of the Lower Oxfordian Substage varies from 300 to 400 m.

Mariae Zone (Douvillé 1881; Levels 7–10 *in* Fortwengler, 1989; Fortwengler, Marchand, 1994a). The Mariae Zone is much thicker than the Cordatum Zone, which is frequently reduced and in some sections more difficult to recognise.

Scarburgense Subzone (Buckman, 1913). New ammonite species of Cardioceratinae and Hecticoceratinae are used as index fossils to define three successive biohorizons in the Scarburgense Subzone.

***thuouxensis* Biohorizon** (Fortwengler *et al.*, 1997; Level 7 *in* Fortwengler, 1989; *elisabethae* Biohorizon, Fortwengler, Marchand, 1991, 1994a). A brief, marked faunal turnover took place in the *thuouxensis* Biohorizon. The last Callovian ammonite genera and subgenera (Fig. 5) disappeared (*Poculisphinctes*, *Lunuloceras*, *Orbignyceras*, *Putealiceras*, *Alligaticeras*, *Orionoides*), while new species appeared, in particular *Hecticoceras* (*Brightia) thuouxensis* Fortwengler et Marchand, which is easy to distinguish morphologically from the Callovian Hecticoceratinae (Fortwengler et Marchand, 1994a–b; Fortwengler *et al.*, 1997; Chapman, 1999). The Cardioceratinae are still morphologically close to *Cardioceras paucicostatum* Lange, β morph (Levels 6A and 6B), although some show clear affinities to *Cardioceras scarburgense* (Young et Bird): the ribs on the body-chamber are decidedly prorsiradiate and the primary ribs are divided once, but intercalaries are extremely rare. The Peltoceratinae are very similar to those in Level 6B, but the latero-ventral tubercles are more clearly duplicated (Bonnot, 1995; Bonnot *et al.*, 1997, 2002). The Euaspidoceratinae reappear at the top of the biohorizon (Bonnot, 1995) with a new species, *Euaspidoceras armatum* (de Loriol), accompanied by the first *Properisphinctes bernensis* (de Loriol). The *thuouxensis* Biohorizon has been identified throughout the Subalpine Basin and its margins. It is an outstanding biostratigrapically-defined marker-bed, observed in more than 60 sections. It has also been formally identified in the Callovian-Oxfordian Argiles de la Woëvre Fm. in the eastern Paris Basin (Thierry *et al.*, 2006), in the French Jura Mountains (Jardat, 2010) and in the south of England (Chapman, 1999). *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand, has been collected in the Bugey and Swiss Jura. Apparently, it also exists in Russia (Kiselev *et al.*, 2013).

***scarburgense* Biohorizon** (Buckman, 1913, *emend.* Fortwengler, Marchand, 1994a; Levels 8 and 9 *in* Fortwengler, 1989; Fortwengler *et al.*, 1997). Based on various ammonite associations, this biohorizon can be divided into three parts: 8A, 8B and 9 (Fortwengler, Marchand, 1994a–b; Fortwengler *et al.*, 1997, 2012).

Level 8A: *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand is still present but gradually replaced by *Hecticoceras (Brightia) chatillonense* de Loriol (de Loriol, 1898; Fortwengler *et al.*, 1997). Macroconchs have weak ornamentation, while microconchs still have strong, but denser ribbing, as there are fewer intercalaries. Another species of Hecticoceratinae, *Hecticoceras coelatum* (Coquand), was collected for the first time in this level (Thierry *et al.*, 2006), associated with *Taramelliceras episcopale* (de Loriol). Some of the Cardioceratinae have a narrower umbilicus, more sinuous ribbing and a more oval section. With a more marked prorsiradiate design, the ribs tend to form a chevron pattern on the venter; at the same time, the smooth siphonal band tends to disappear. All these morphological features are typical of *Cardioceras scarburgense* (Young et Bird). *Peltoceratoides eugenii* (Raspail) persists without morphological changes (Bonnot, 1995; Bonnot *et al.*, 1997).

Level 8B: The level begins with the first appearance datum of *Peltoceratoides athletoides* (Lahusen); this species shows a very clear duplication of the ventro-lateral tubercles (Bonnot, 1995; Bonnot *et al.*, 1997, 2002), with ribs-branching lower on the flanks than in *Peltoceratoides eugenii* (Raspail). Among the Oppeliidae, *Hecticoceras* (*Brightia) thuouxensis* Fortwengler et Marchand is absent but *Hecticoceras* (*Brightia) chatillonense* de Loriol is still present. *Eochetoceras villersense* (d'Orbigny) is more frequent but still rare (Douvillé, 1912; Chapman, 1997, 1999; Thierry *et al.*, 2006). The Cardioceratinae are the same as in Level 8A, but less frequent (only 4.6% of the total ammonite fauna), with an increasing number of variants, a thicker whorl section, and pronounced, wide-spaced ribs, similar to *Cardioceras mariae* (d'Orbigny), forerunners of *Cardioceras* morphologies in the *woodhamense* Biohorizon. Phylloceratidae are very abundant here, with a high proportion of *Sowerbyceras tortisulcatum* (d'Orbigny).

Level 9: The upper part of the *scarburgense* Biohorizon (lower and middle part of Level 9) shows a drastic decrease in ammonite faunal diversity, coeval with a noticeable increase in Phylloceratidae, which become dominant (80 % of the total fauna). In the most fossiliferous outcrops, we observe the association of species generally linked to open sea or deeper environments (Thierry *et al.*, 2006), such as *Eochetoceras villersense* (d'Orbigny), *Lytoceras fimbriatum* (Sowerby) and *Lissoceras erato* (d'Orbigny). At the top of Level 9, the genus *Properisphinctes* is more frequent, and Phylloceratidae are still numerous. In rare outcrops in the Subalpine Basin, some Cardioceratinae, with prorsiradiate ribs on the venter, are morphologically close to *Cardioceras woodhamense* Arkell, which possibly indicates the lowermost part of the *woodhamense* Biohorizon (Arkell, 1939; Fortwengler, Marchand, 1994a–b; Fortwengler *et al.*, 1997; Jardat, 2010). Like the *thuouxensis* Biohorizon, the *scarburgense* Biohorizon is recognised throughout the basin, but it is sometimes difficult to subdivide Level 8 into two parts, particularly on the margins.

***woodhamense* Biohorizon** (Fortwengler, Marchand, 1994a–b; uppermost part of Level 9 *in* Fortwengler, 1989; lowermost part of Level 10 *in* Fortwengler, Marchand, 1994a–b). The Ammonitina are again frequent and more diversified. The Perisphinctinae form about one third of the total population, chiefly *Properisphinctes bernensis* (de Loriol). The Cardioceratinae are very rare, with characteristic morphologies found at the base of the *woodhamense* Biohorizon. Among the Oppeliidae, the subgenus *Brightia* is still present, with *Hecticoceras* (*Brightia*) *matheyi* de Loriol, and the first *Campylites* are found.

Praecordatum Subzone (Morley-Davies, 1916; Level 10 *in* Fortwengler, Marchand, 1994a–b). At the base of the subzone, a level consistently occurring throughout the Subalpine Basin contains an abundant ammonite fauna, dominated by Perisphinctinae. The Oppeliidae are still frequent, with *Taramelliceras episcopale* (de Loriol). We can note the last appearance datum of *Perisphinctes picteti* de Loriol. Specimens of *Cardioceras praemartini* Spath indicate the base of the Praecordatum Subzone. At the top, in the western and south-western parts of the basin, *Peltoceratoides williamsoni* (Phillips) and *Cardioceras praecordatum* occur.

Cordatum Zone (d'Orbigny, 1852; Levels 11 and 12 *in* Fortwengler, 1989; Fortwengler, Marchand, 1994a–b). Near Sahune, the Cordatum Zone is about 120 m thick (Pellenard, 2003). In the majority of the sections studied, the upper part of the Terres Noires Fm. contains fauna characteristic of the

Cordatum Zone, in some sections rich in Cardioceratinae. At the base, the Cardioceratinae are morphologically very close to *Cardioceras bukowskii* Maire (Level 11; Bukowskii Subzone). In the Baronnies, the western Diois and around Sisteron, as well as on the Ardèche margin, they are abundant and accompanied by *Cardioceras korys* (Buckman) (Fortwengler, 1989; Marchand *et al*., 1990; Marchand, Fortwengler, 2010). The uppermost part still contains fauna of the Cordatum Subzone (Level 12), with *Cardioceras persecans* Buckman. However, Level 12 is poorly individualised and contains rare *Cardioceras cordatum* (Sowerby), and abundant *Sowerbyceras* genus.

NANNOFOSSIL BIOSTRATIGRAPHY

The transition from the Lamberti Zone to the Mariae Zone is marked by a succession of first and last occurrences (FO and LO) of nannoplankton species, whose calibration and correlation potential has remained somewhat limited, due to low resolution studies, provincialism, dominance of siliceous sedimentation, and the presence of hiatuses in the southern Tethys sections. In recent biostratigraphic syntheses, the main nannoplankton biohorizons established for the Callovian-Oxfordian transition are: the LO of *Ansulasphaera helvetica* (lower part of the Lamberti Zone; Bown *et al*., 1988; Kaenel *et al*., 1996) and the total range (FO and LO) of *Stephanolithion bigotii* maximum, reported from the uppermost part of the Lamberti Zone to the Cordatum Zone in NW Europe (Bown *et al*., 1988) and across the Lamberti/Mariae zones in England (Medd, 1979; 1982) and SE France (Fauconnier *et al*., 1996; Kaenel *et al*., 1996; Giraud *et al*., 2009; Fig. 6 herein). Competing correlations for this nannofossil biohorizon, if not related to proven diachroneity, or low resolution sampling, could also be caused by differing taxonomic concepts among specialists.

The potential of this nannofossil biohorizon as a useful proxy for the Callovian-Oxfordian boundary has been tested in the Thuoux and Saint-Pierre d'Argençon sections (see Figs 3–4) and also in the Savournon section. All the samples studied yielded scarce to abundant nannofossil assemblages, of moderate to poor preservation, with a species richness of about 25–30 species. The assemblages are dominated by *Watznaueria britannica* morphotypes (Giraud *et al*., 2009)

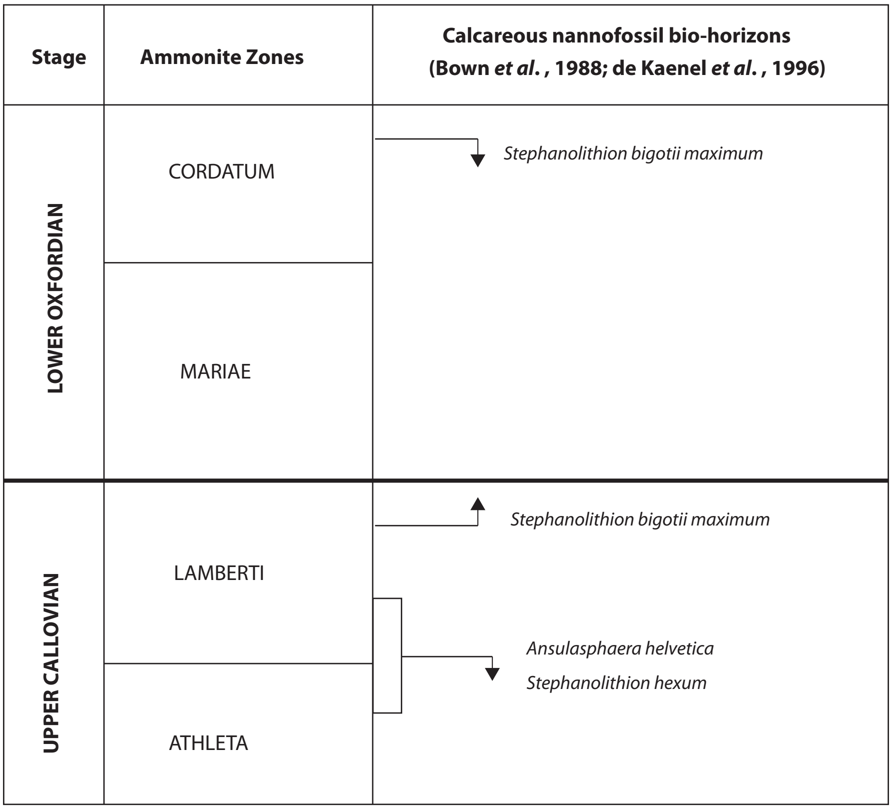

Fig. 6. Late Callovian–Early Oxfordian calcareous nannofossil biohorizons

at 75%, followed by quite abundant *Watznaueria fossacincta*, *Zeugrhabdotus erectus*, *Discohabdus podorhabdids* and *Stephanolithion bigotii*. Very rare and sporadic *Ansulasphaera helvetica* and *Stephanolithion hexum* are observed in the lowermost part of the Saint-Pierre d'Argençon section (*praelamberti* Biohorizon). The sub-species *Stephanolithion bigotii maximum*, the marker of the NJ7 biozone (Bown *et al*., 1988) was originally described as having "overall measurements exceeding 6 × 3 µm" (Medd, 1979); this size criterion was strictly followed here and all the *Stephanolithion bigotii* encountered were accurately measured. Biometric measurements revealed that large-sized *Stephanolithion bigotii*, *i.e*. reaching a maximum rim length of 5.80 µm (Plate 6), are recorded from the *paucicostatum* Biohorizon in all three sections, roughly at the beginning of a positive carbon isotope shift at Thuoux and Savournon (see the Isotope Geochemistry section). This size increase is clearly visible, yet no specimen reaching 6 µm, to be conveniently classified as *Stephanolithion bigotii maximum*, was encountered in any of the three sections. Giraud *et al*. (2009) reported the occurrence of *S. bigotii maximum* from the uppermost Lamberti Zone of the Savournon section. The diagnostic criteria used for this subspecies are not reported and it is difficult to conclude whether we failed to recognise *S. bigotii maximum*, or rather if the subspecies documented by the authors (Giraud *et al*., 2009; fig 4, no 10) corresponds to our large-sized *S. bigotii bigotii* >5µm. If we follow the size criterion of the diagnosis in Medd (1979), then no specimen of *Stephanolithion bigotii maximum* was found in any of the three sections.

BIOSTRATIGRAPHY OF DINOFLAGELLATE CYST AND OTHER GROUPS

A palynological analysis was carried out on the nearby Savournon section by Courtinat (2006). This work showed that the Callovian-Oxfordian boundary in this part of the Subalpine Basin could be defined using the usual index species, *Wanaea fimbriata* Sarjeant 1961, which is known to appear precisely at the beginning of the first ammonite zone (Mariae Zone) of the Oxfordian in western Europe (Berger, 1986; Feist-Burkhardt, Wille, 1992; Riding, Thomas, 1992; Huault, 1998). A previous study by Poulsen and Jutson, (1996) indicated that most of the stratigraphically important dinoflagellate cyst species are present in the faunal assemblages, and that *Durotrigia filapicata* Gocht disappeared at the top of the Callovian, while some rare *Wanaea fimbriata* Sarjeant appeared at the base of the Oxfordian, as also observed in the North Sea Region and in East Greenland. Poulsen and Jutson (1996) also remarked that foraminifers were poorly preserved. Only two stratigraphically significant species have been identified: *Ophthalmidium compressum* Ostenfeld and *Ophtalmidium strumosum* Gümbel. *Ophthalmidium compressum* Ostenfeld disappeared during the *thuouxensis* Biohorizon, while *Ophtalmidium strumosum* Gümbel, which appeared during the *paucicostatum* Biohorizon, persisted into the *scarburgense* Biohorizon. Preliminary research shows that ostracods are rare, but nevertheless present at Savournon (Tesakova, 2008).

Although other palynomorphs showed no significant evolution at the Middle-Late Jurassic boundary, some dinoflagellate cysts evolved and diversified rapidly, thus providing an efficient biostratigraphic tool, which is used as the focus of this palynological study. Dinoflagellate cyst assemblages at Thuoux follow the global trend described elsewhere in Europe, *i.e.* showing great diversity during the Late Callovian. These assemblages (see also references given) are overwhelmingly dominated by *Sentusidinium* spp. and *Compositosphaeridium polonicum* (Górka, 1965) Erkmen et Sarjeant, 1980. They also include common taxa such as *Gonyaulacysta jurassica* (Deflandre, 1938) Norris et Sarjeant, 1965 emend. Sarjeant, 1982; *Escharisphaeridia* spp.; *Rhynchodiniopsis cladophora* (Deflandre, 1939) Below, 1981; *Adnatosphaeridium caulleryi* (Deflandre, 1938) Williams et Downie, 1969; *Stephanelytron* spp.; *Cleistosphaeridium* spp.; *Pareodinia* spp., and *Tubotuberella* spp. Also present are *Ctenidodinium* spp.; *Sirmiodiniopsis orbis* Drugg, 1978; *Scriniodinium crystallinum* (Deflandre, 1938) Klement, 1960; *Trichodinium scarburghensis* (Sarjeant, 1964) Williams *et al*., 1993; *Liesbergia liesbergensis* Berger, 1986; *Rigaudella aemula* (Deflandre, 1939) Below 1982; *Wanaea fimbriata* Sarjeant, 1961, and *Wanaea thysanota* Woollam, 1982. Amongst cysts of biostratigraphic interest, the genus *Wanaea* (Plate 6) is present but not frequent at Thuoux (about 1% of the dinoflagellate cyst assemblages), while *Durotrigia filapicata* Gocht has not been recognized in the short time span investigated here (*paucicostatum* and *thuouxensis* biohorizons). Most of the dinoflagellate cysts show no appreciable variation in their abundance, with the notable exception of *Wanaea fimbriata* Sarjeant, 1961, which appears for the first time in sample Th190, placing the Callovian-Oxfordian boundary between samples Th 186 and Th 190 (Fig. 3). This palynological definition of the Callovian-Oxfordian boundary fits perfectly with the ammonite biohorizons defined above, proving the accuracy of the palynological data across the Callovian-Oxfordian boundary, and underlining the biostratigraphic value of the Thuoux section.

GEOPHYSICAL STRATIGRAPHY AND CYCLOSTRATIGRAPHY

Magnetic susceptibility (MS) was measured in samples collected from the Lamberti Subzone *p.p.* to the Scarburgense Subzone *p.p.* at Thuoux representing ~45 m of strata

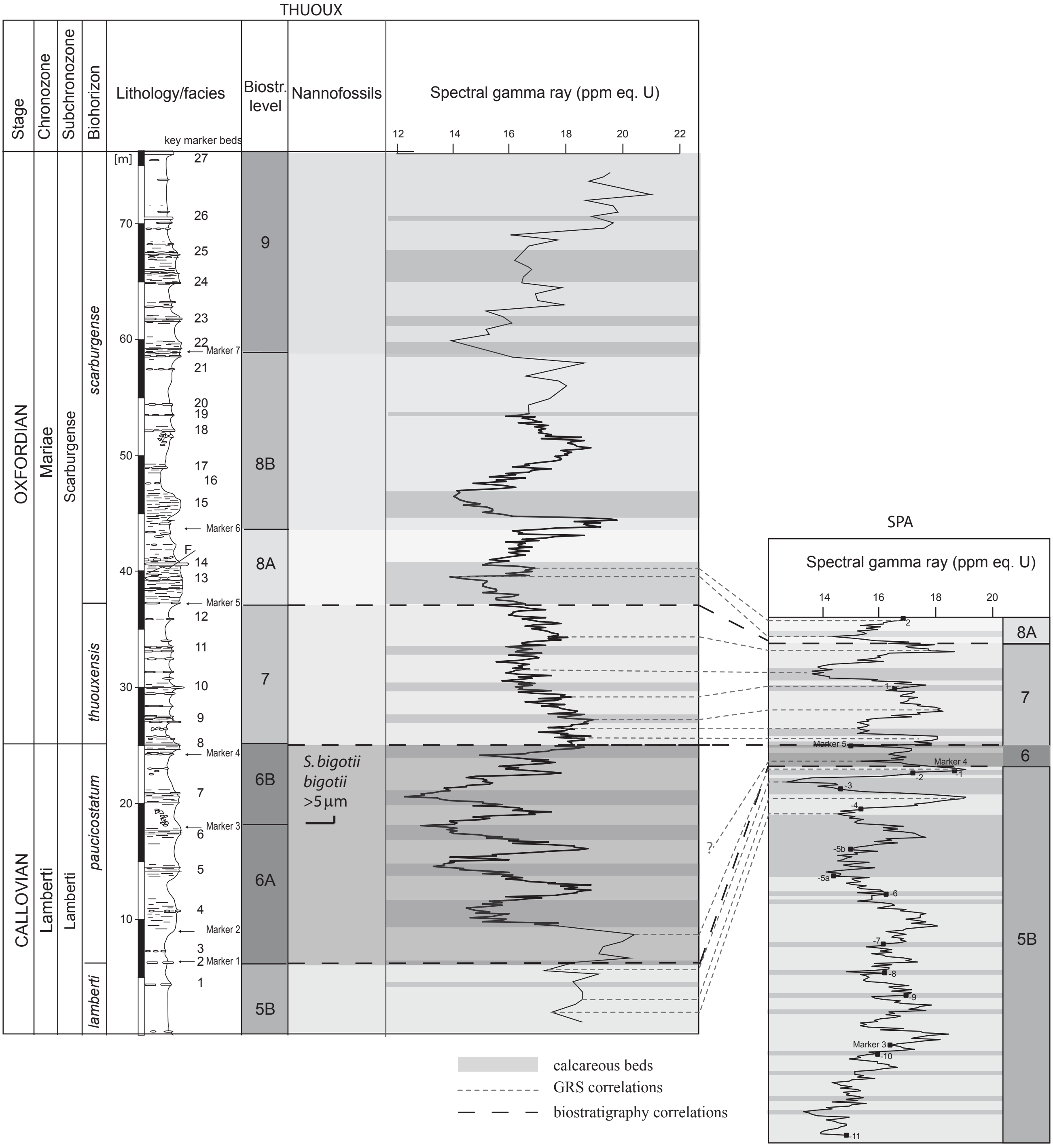

Fig. 7. Correlation between Thuoux and Saint-Pierre d’Argençon, using both ammonite biostratigraphy and field gamma-ray spectrometry

Unit 6 (*paucicostatum* Biohorizon) is condensed at Saint-Pierre d’Argençon, due to synsedimentary tilting of blocks and extensional tectonics

(Fig. 9). The sample spacing was set at ~8 cm, resulting in a total of 570 samples. The MS values are relatively low, ranging from 6 to $10 \cdot 10^{-8}$ m^3/kg, and their variation follows a strongly cyclical pattern. There are short-wavelength cycles superimposed on a long-wavelength cycle, which reaches its maximum ($10 \cdot 10^{-8}$ m^3/kg) around the Callovian-Oxfordian boundary. Visual inspection indicates a mean wavelength of ~6.5 m for the high-frequency oscillations. In the Saint-Pierre-d'Argençon section, about 73 m of strata were sampled, from the Lamberti Subzone *p.p.* to the Scarburgense Subzone *p.p.* (Fig. 4). The sample spacing was set at 10 cm, resulting in a total of 735 samples. The MS values are relatively low, ranging from 6.5 to $11.5 \cdot 10^{-8}$ m^3/kg, and their variation also follows a strongly cyclical pattern, with short-wavelength cycles superimposed on a long-wavelength cycle.

Field gamma-ray spectrometry (GRS) was used to measure a total of 1730 points across the Callovian-Oxfordian boundary, with sample spacing of ~50 cm, in the western part (Condorcet, Montréal-les-Sources sections) and in the eastern part (Savournon, Thuoux, Aspres-sur-Büech and Saint-Pierre-d'Argençon sections) of the Subalpine Basin, for accurate correlation of the signal in relation to the biostratigraphy (Gaspard *et al.*, 2005). High-resolution investigations were also performed, with a sample spacing of precisely 12 cm, from Level 6A to Level 8B (280 datapoints) at Thuoux and from Level 5B to Level 8A (415 datapoints) at Saint-Pierre d'Argençon, to analyse the cyclostratigraphic signal and also to correlate these sections (Fig. 7). Data range from 12 to 22 ppm eq.U, which are common values for marls. At Thuoux, well-expressed cyclical fluctuations are observed, especially for the Upper Callovian, which generally match the MS signal, with an inverse relationship to carbonate-rich deposits, proving that high values are linked to a high concentration in clay minerals. These sharp cyclical fluctuations are also observed from the top of Level 5B to Level 8A, at Saint-Pierre d'Argençon. In this section, Level 6 (*paucicostatum* Biohorizon) is very condensed due to synsedimentary tectonics and a tilted-block structure, so fine correlation with Thuoux using GRS is not possible for this interval. High-resolution correlation for Level 7 shows that the same number of cycles is present, but cycles are better developed at Saint-Pierre d'Argençon, probably due to the sedimentary facies which is more calcareous than at Thuoux.

The 2π-MTM spectrum of the Thuoux section displays two high-amplitude periods, at around 10.2 m and 3.3 m (Fig. 8). In the T-F WFFT, the 3.3-m cycle has its strongest amplitude from the base of the series to 22.5 m. The ~10-m cycle has its strongest amplitude from 20 m to the top of the series, and the period fluctuates from 7.3 m to 11.8 m. A Taner low-pass filter with a frequency cut of 0.4028 cycles.m^{-1} covers the bands of the ~10-m and 3.3-m cycles. From the base of the series to 20 m, the filter dominantly evolves following the 3.3-m cycle. From 20 m to 24 m, there is a transition from the 3.3-m to the 10-m dominant zone. Finally, from 24 m to the top of the series, the filter is dominated by the fluctuations of the 10-m cycle. This pattern is in agreement with the T-F WFFT analysis.

The ~10-m cycle and the 3.3-m cycle have a period ratio of 1:3. By comparing this ratio to the ratios between the astronomical periods, it is possible that the 1:3 ratio might be related to the ratio between the 100-kyr eccentricity cycle and the main period of the obliquity cycle (35.4 kyr). Based on the filter results and the T-F WFFT analysis, there is a visible change in the expression of the orbital cycles during the Callovian-Oxfordian transition. Nevertheless, further analyses on other sections, a larger time interval and other proxies are needed to confirm these preliminary results.

These first results display the potential of the Terres Noires Fm. to record an orbital forcing at the Callovian-Oxfordian transition, following the works of Boulila *et al.* (2008; 2010), thus allowing potential durations of stratigraphic units to be accurately calculated.

ISOTOPE GEOCHEMISTRY

Bulk-carbonate $\delta^{13}C$ data ($\delta^{13}C_{carb}$) obtained on marls from the Thuoux section show marked fluctuations, with minimum values from around 0‰ to maximum values close to 2 ‰. Although the values are quite scattered in some intervals, significant trends across the Middle-Late Jurassic boundary are still clearly discernible (Fig. 9). In the lower part of the section (uppermost part of the *lamberti* Biohorizon and lower part of the *paucicostatum* Biohorizon), $\delta^{13}C_{carb}$ is characterised by low values (interval a) and two pronounced negative spikes (b and d). In the upper part of the *paucicostatum* Biohorizon (interval e–f), the values gradually increase to maximum values (2‰) close to the Callovian-Oxfordian boundary and remain relatively high over a large part of the *thuouxensis* Biohorizon and the lower part of the Scarburgense Subzone, interrupted by a negative spike (g–h) in the uppermost part of the *thuouxensis* Biohorizon. In the upper part of the curve (interval m–n) the $\delta^{13}C_{carb}$ values decrease again. This general pattern of the $\delta^{13}C_{carb}$ curve does not correlate with carbonate content and oxygen-isotope values, and therefore mirrors at least in part the primary environmental signal (Fig. 9). The isolated outlier negative $\delta^{13}C_{carb}$ values correlated with low $\delta^{18}O$ values are probably due to diagenetic alteration. Some short-lived segments of negative $\delta^{13}C_{carb}$ values in the curve correspond to minor variations in $\delta^{18}O$. This peculiar pattern could indi-

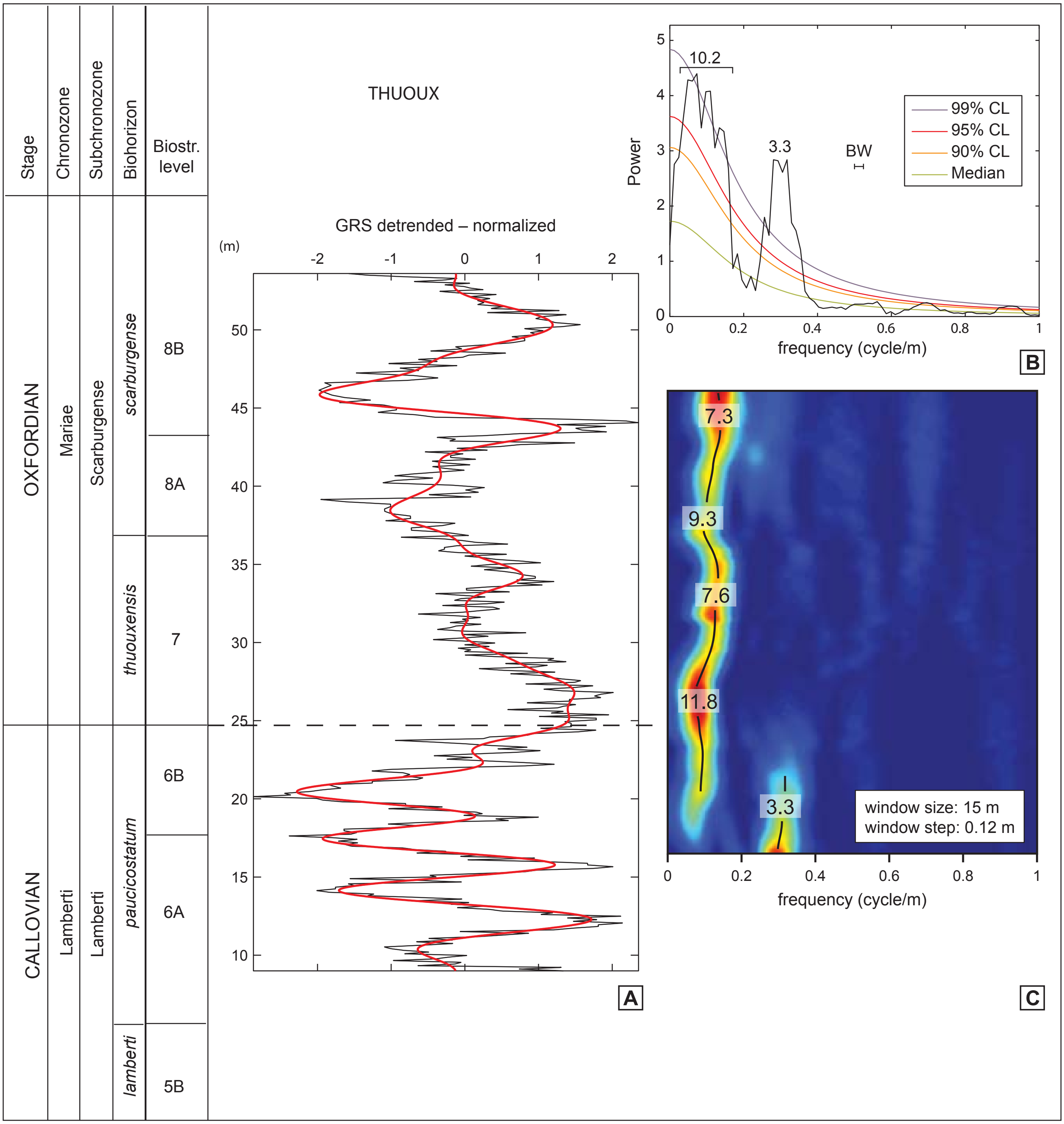

Fig. 8. Spectral analyses of the GRS signal, sampled with a 0.12 m step, from the Thuoux section

A. GRS signal detrended and normalised (in black), with the Taner low-pass filter (in red), encompassing the obliquity and eccentricity bands (frequency cut: 0.4028 cycles · m^{-1}). **B.** 2π-MTM spectrum. The median curve was calculated by fitting a red-noise model on a median-smoothed spectrum, applying a smoothing-window width of 1/5 of the Nyquist frequency. The 90%, 95% and 99% confidence levels are then χ-square distributed (Mann, Lees, 1996). Significant periods are labelled in metres. BW: Band width. **C.** Time-Frequency Weighted Fast Fourier Transforms of the GRS series, with window widths of 15 m, separated from each other by 0.12 m. Highest-power cycles are labelled in metres

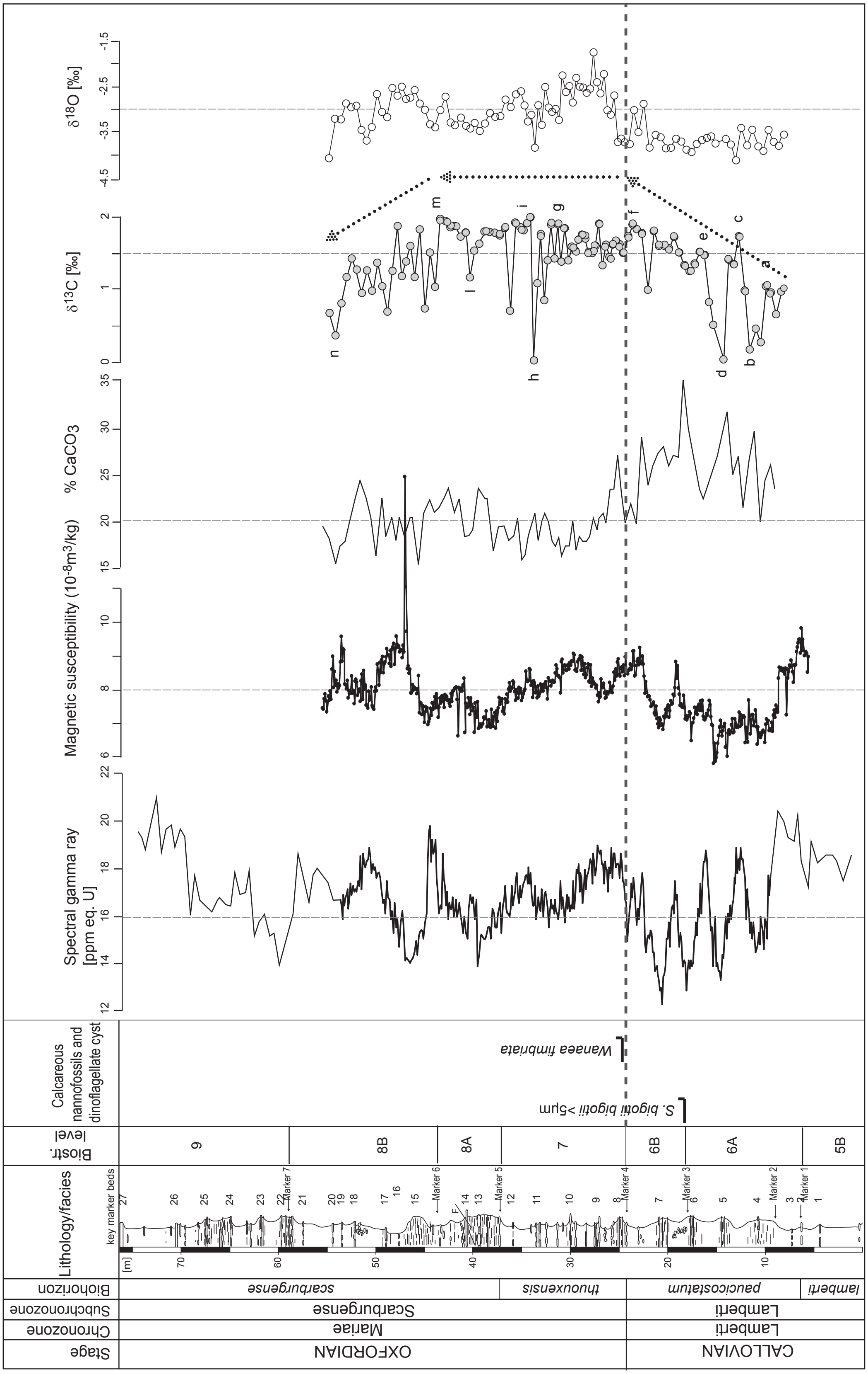

Fig. 9. Integrated stratigraphy, across the Callovian-Oxfordian boundary at Thuoux, including lithology, ammonite, dinoflagellate cyst and calcareous nannofossil biostratigraphy, high-resolution physical stratigraphy (GRS and MS), $CaCO_3$ content and isotope stratigraphy ($\delta^{13}C$, $\delta^{18}O$)

cate ^{13}C-depleted carbonate precipitation as the result of the microbial anaerobic oxidation of methane and sulphate reduction (causing relatively high δ^{18}O values), occurring within a few centimetres of the seafloor in a hydrocarbon seep environment (Louis-Schmid *et al*., 2007). These negative $\delta^{13}C_{carb}$ spikes could have a local cause. Further analyses of $\delta^{13}C_{org}$ are needed to better understand the local or global nature of these negative $\delta^{13}C_{carb}$ spikes. The ~ 1.5 ‰ increase in the $\delta^{13}C_{carb}$ trend around the Callovian-Oxfordian boundary and the lowermost Oxfordian has already been documented in other sections and boreholes in France, Switzerland and elsewhere (Tremolada *et al*., 2006; Louis-Schmid *et al*., 2007; Pellenard *et al*., 2014a). In particular, the same trend was recognised in the eastern part of the Paris Basin from the Andra boreholes, where a detailed ammonite biostratigraphy was established (Thierry *et al*., 2006). In this area, despite a lower sedimentation rate, all subzones and biohorizons are preserved in a continuous claystone series, allowing high-resolution carbon and oxygen isotope curves to be constructed (Pellenard *et al*., 2014a). This first high-resolution chemostratigraphy for the entire Middle Callovian-Lower Oxfordian series is compared with the geochemical signal obtained in the Subalpine Basin (Fig. 10). The $\delta^{13}C_{carb}$ values are in the same range and show the same significant increase in values just before the Callovian-Oxfordian boundary. This $\delta^{13}C_{carb}$ positive shift therefore provides a useful auxiliary marker for the Middle-Late Jurassic boundary.

Some well-preserved belemnites ($n = 10$), mainly *Hibolites hastatus* and rare *Belemnopsis*, collected in the Subalpine Basin from several sections (La Voulte-sur-Rhône, Saint-Geniez, Propriac-Beauvoisin, Ribiers, Savournon, Sahune, Rottier), have been used for oxygen and carbon isotope analyses, after screening by cathodoluminescence, SEM observations and trace element concentration measurements (<100 ppm Mn, <300 ppm Fe). As the belemnites were found in various sections, they are plotted on a time-scale graph with error-bars corresponding to the biostratigraphic uncertainty (Fig. 10). Taking into account these uncertainties, carbon isotope data from belemnites seem to have more positive values (1.5–4.0‰) than carbon isotopes

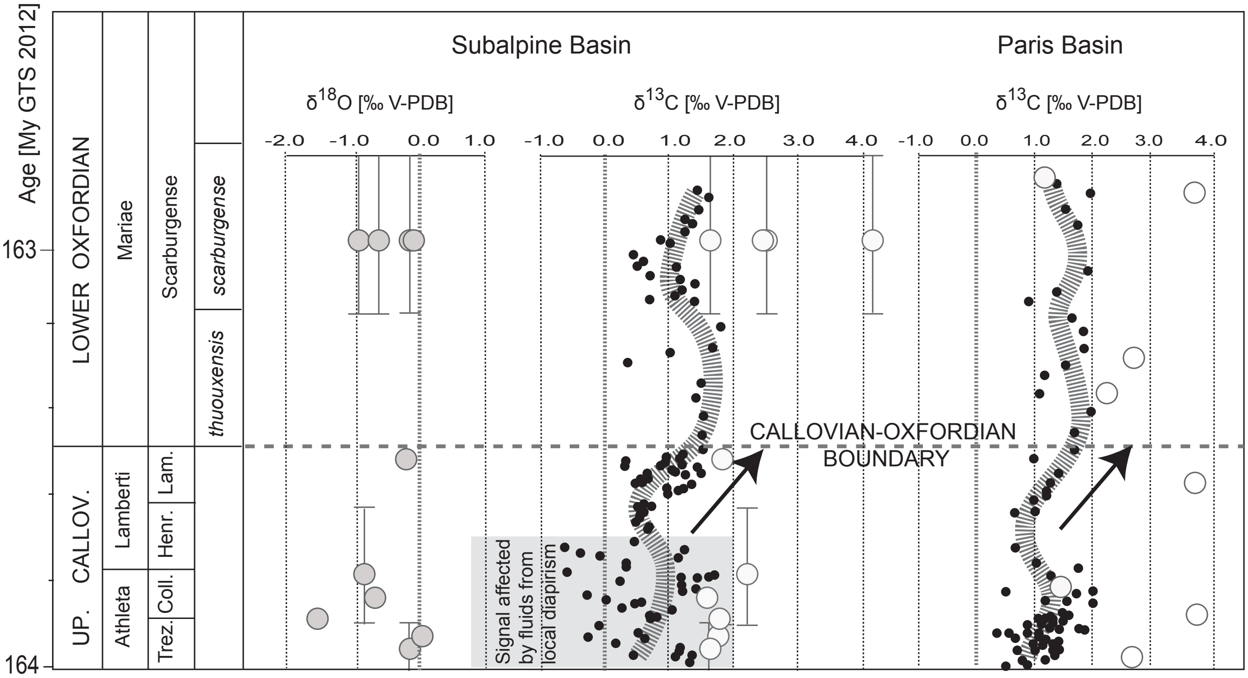

Fig. 10. Carbon-isotope stratigraphy from bulk carbonate data of the Subalpine Basin for the Upper Callovian–Lower Oxfordian interval (composite section using data from Propriac-Beauvoisin and Thuoux, Pellenard *et al.*, 2014c) and comparison with the Paris Basin (Pellenard *et al.*, 2014a)

An increasing trend in the δ^{13}C curve is observed close to the Callovian-Oxfordian boundary, from the end of the Athleta Zone, providing a key marker for the stage boundary. Carbon and oxygen isotope data from diagenetically screened *Hibolites* belemnites from the Subalpine Basin are also shown (circles). Note that some specimens are from collections (several sections), thus requiring the use of a numerical age model (GTS 2012), which generates larger error bars, of the duration of an ammonite biohorizon. N.B Grey box: only the Beauvoisin–Propriac section close to a diapir present scattered δ^{13}C values. The other sections are not affected by diapirism.

from bulk-rock, but with similar values to those for belemnites from the Paris Basin (Fig. 10). The sample resolution is not sufficient here to detect any stratigraphic pattern. Oxygen isotope analyses show values ranging from 0‰ to –1.53‰, corresponding to palaeotemperatures between 12 and 18°C, using the equation of Anderson and Arthur (1983), assuming a δ_w value of –1.0‰ (SMOW). These seawater temperatures deduced from belemnites of the Subalpine Basin are consistent with data from European domains during the Callovian-Oxfordian (Price and Page, 2008; Wierzbowski *et al.*, 2013; Pellenard *et al.*, 2014a). Again, the sample resolution is not sufficient here to detect any change in climate. The $^{87}Sr/^{86}Sr$ measurements from these belemnites and other specimens are in progress and expected to allow comparison with the $^{87}Sr/^{86}Sr$ reference curve of Jones *et al*. (1994), which shows the lowest values of the entire Phanerozoic at the Middle-Late Jurassic boundary (McArthur *et al*., 2001).

OTHER METHODS

MAGNETOSTRATIGRAPHY

Pilot magnetostratigraphic studies were conducted in the Subalpine Basin at Thuoux (10 samples analysed) and Savournon (13 samples analysed). Thermal demagnetisation of these samples produced normal-polarity orientation trends but failed the fold test of Graham (1949) indicating that the polarity orientations measured in these sections contain a component of remanent magnetisation. This result indicates that the magnetostratigraphy for Callovian-Oxfordian transition of sections from the Subalpine Basin is unreliable (Gipe, 2013, J. Ogg pers. comm. 2014).

RADIOMETRIC DATA

Bentonite layers have been extensively explored around the Callovian-Oxfordian transition in the Subalpine Basin. Volcaniclastic deposits of explosive volcanic events characterise the basin at the Lower/Middle Oxfordian transition in the Cordatum Zone and the Plicatilis Zone and can be used to provide isochron markers allowing correlations with the Paris Basin (Pellenard, 2003; Pellenard *et al.*, 2003). These layers are very thin and/or altered and are not suitable for the Ar/Ar method using sanidine crystals, as was the case for bentonites from the Transversarium Zone in Northern Italy (Pellenard *et al*., 2013). The U-Pb method investigations using zircon crystals are still in progress and, with precise cyclostratigraphy (*i.e.* Boulila *et al.*, 2010), could be of great interest to anchor the base Oxfordian in the Geologic Time Scale.

DISCUSSION

Comparisons between the Subalpine Basin and Redcliff Point/Ham Cliff and Dubki sections, alternative sections for an Oxfordian GSSP, have previously been discussed, in particular concerning the conditions of the outcrops and the ammonite faunal composition, including the opportunity to create new taxa for Cardioceratidae in order to refine the stratigraphic position of the Callovian-Oxfordian boundary (Page *et al.*, 2009a; Fortwengler *et al*., 2012). Here we summarise these observations, and add discussion about other stratigraphic methods used in this integrated study, in comparison with data recently reported in Kiselev *et al.* (2013).

OUTCROP CONDITIONS AND ACCESSIBILITY

As the Terres Noires Fm. crops out very well throughout the badlands of the Subalpine Basin, the Thuoux and Saint-Pierre d'Argençon sections are likely to preserve geological information over time. From both administrative and practical points of view, these two gently sloping sections, one on public land (Thuoux), are readily accessible on foot. All biostratigraphic units will be easily recognised using the proposed logs (Figs 3 and 4), and clearly identified in the field by permanent markers, in the form of metal spikes.

The Redcliff Point/Ham Cliff section is a coastal outcrop, where accessibility and quality of exposure depend to some extent on vegetation cover, coastal erosion, and the height of the shingle storm beach. This mudrock facies, in the Oxford Clay Fm. is not favourable for long-term preservation, given the wet Dorset climate, which favours slumping and landslide conditions. These poor, very variable outcropping conditions have been mentioned by many authors (Callomon, Cope, 1993; Page, 1994; Meléndez, 2003, 2004; Fortwengler *et al*., 2012). Consequently, access to the biostratigraphic units is often difficult, and it has proven problematic to provide homogeneous descriptions of these sections over time.

In order to propose the Dubki exposure as a reference section for the Callovian-Oxfordian boundary in European Russia, outstanding data have been published for around ten metres of silty-clayey deposits, by means of an accurate ammonite range chart and detailed descriptions (Kiselev *et al*., 2013). However, the Dubki exposure is currently a quarry for nearby road construction; it is temporarily protected as a geological heritage site of regional significance by the government of the Saratov region (Kiselev *et al*., 2013).

PRESERVATION AND BIOSTRATIGRAPHY OF FOSSIL GROUPS

In the Subalpine Basin, the macrofauna is mainly composed of ammonites, with bivalves often found inside ammonite body chambers. Belemnites and rhyncholites are infrequent, and nautilids are extremely rare. Microfauna (foraminifera, dinoflagellates, ostracoda) are moderate in abundance, but palynological investigations on the Thuoux section show the good quality of preservation and the great richness of the organic residue, with abundant dark charcoal particles, spores and pollen, acritarchs, rare foraminifer linings and numerous dinoflagellate cysts. Foraminifer and ostracod diversity and distribution have not been studied in detail in the Subalpine Basin, but new data are currently under analysis for the Thuoux and Savournon sections. Calcareous nannofossils, although only moderately well preserved, have been studied through quantitative analyses and biometric measurements. These groups have also been recognised in detailed studies of the Redcliff Point and Dubki sections (see Kiselev *et al*., 2013, p.78, table 2). In the Subalpine Basin, ammonites are often well preserved within calcareous nodules; specimens are mainly calcareous, and only occasionally altered. By contrast, at Redcliff Point, many ammonites are crushed, hindering precise observation of the section, venter shape, ribbing relief and tubercles.

Ammonite biostratigraphy

The Subalpine Basin is considered to belong to the Submediterranean Province, with fauna characterised by Oppeliidae, Aspidoceratidae, and Perisphinctidae, but also Cardioceratidae, which represent around 20% of the ammonite fauna at Thuoux, Saint-Pierre d'Argençon, Savournon and nearby sections. In contrast, Kosmoceratidae are relatively rare in the Upper Callovian (Fortwengler *et al*., 2012). In European Russia, Kosmoceratidae and Cardioceratidae are dominant, while Hecticoceratinae, Distichoceratinae, and Aspidoceratidae are present, but with few individuals (Kiselev *et al.*, 2013). This assemblage is fairly characteristic of the Subboreal Province. Such faunal diversity is also found, but to a lesser extent, in south-west England, which also belonged to the Subboreal Province. Hecticoceratinae, which are abundant in the Subalpine Basin sections, are rare in the Redcliff Point/Ham Cliff section. The same difficulties arise with the genus *Peltoceratoides*, a very efficient biostratigraphic marker, well known in the Subalpine Basin, but rare in Dorset. Ammonite biostratigraphy for the Redcliff Point section was based specifically on the vertical distribution of Cardioceratidae, choosing a single evolutionary sequence, in order to avoid the problem of diachronous immigration of taxa (Page *et al.*, 2009a). Nevertheless, biostratigraphy based on a single ammonite group is bound to impede accurate correlation with other domains, in particular in the Submediterranean or Mediterranean-Tethyan areas. In contrast, the data from the Russian Platform and the Subalpine Basin provide greater opportunities for global correlation, especially with Argentina, Chile, North America and the Pacific area, based on the Oppeliidae (Hecticoceratinae, Distichoceratinae and Taramelliceratinae) and Aspidoceratidae (Peltoceratinae, Euaspidoceratinae).

The identification of the new species index, *Cardioceras* (*Pavloviceras*) *redcliffense* Page, Meléndez et Wright, 2009, also merits discussion. Based on individuals collected at Redcliff Point, it was created in order to refine the stratigraphic position of the Callovian-Oxfordian GSSP (Page *et al*., 2009a, b). *Cardioceras (Pavloviceras) redcliffense* Page, Meléndez et Wright, 2009 was chosen as the species index of the lowest biohorizon of the Oxfordian Stage in the Subboreal Province. For Kiselev *et al*. (2013), the new species *Cardioceras (Pavloviceras) redcliffense* Page, Meléndez et Wright, 2009, is considered as synonymous with *Q. paucicostatum*, meaning that the *redcliffense* Biohorizon is included in the *paucicostatum* Biohorizon, also confirmed by the recognition of *C. redcliffense* by J. K. Wright at Dubki (pers. comm), in precisely the same interval as *Q. paucicostatum.* Comparison of the new species *C. redcliffense* with *Cardioceras paucicostatum* Lange, 1973 reveals that both belong to the same taxon (Fortwengler *et al*., 2012). It therefore becomes necessary to establish a complete inventory of the morphological variability of the species. Without a thorough palaeobiological approach, investigating intraspecific morphological variability, the validity of the "*redcliffense* Biohorizon" remains problematic.

It is also debatable whether biohorizons should be based solely on morphs: *e.g*. the creation of four new biohorizons, for the same *paucicostatum* species, in the Lamberti Zone, and perhaps even a fifth, in the Mariae Zone, if *Cardioceras redcliffense* is in fact synonymous with *Q. paucicostatum*, as suggested by Kiselev *et al*. (2013). This debate could undoubtedly be resolved by figuring the associated ammonite fauna from the Redcliff section to allow comparison with the fauna from the Subalpine Basin and the Russian Domain.

There is also an apparent discrepancy in the biostratigraphy of the lower part of the Oxfordian at Redcliff Point: the *woodhamense* Biohorizon lies below the *scarburgense* Biohorizon (Page *et al*., 2009a, b). In the succession of biohorizons, observed throughout Western Europe, including the Dorset coast (Cariou *et al.*, 1997; Chapman, 1999), the *scarburgense* Biohorizon is always located below the *woodhamense* Biohorizon. The succession of biohorizons is based on the morphological evolution of the Cardioceratidae, and the stratigraphic situation of successive populations of *Cardioceras paucicostatum* Lange, *Cardioceras (Scarburgiceras) scarburgense* (Young et Bird), *Cardioceras (Scarburgiceras) woodhamense* Arkell, and *Cardioceras (Protocardioceras) praemartini* Spath (Marchand, 1986). However, in the absence of well-identified holotypes, it is possible that these taxa may have originally been poorly defined.

Comparison of the Subalpine Basin biostratigraphy with the Russian biostratigraphy is possible, despite some variation in ammonite taxa. Several ammonite species of the *paucicostatum* Biohorizon at Dubki are of interest for comparisons with species of the Subalpine Basin. Among them, *Quenstedtoceras pseudolamberti* Sintzow, 1889 appears morphologically very close to the *Cardioceras paucicostatum* β morph, collected in level 6B (Fortwengler *et al*., 2012). The type-specimen of *Quenstedtoceras pseudolamberti* Sintzow, 1889 (= *Cardioceras lamberti* Lahusen, 1883; pl. 4, fig. 3–4) comes from the neighbourhood of the Pozhva River in the Ryazan area, where the description of several specimens has been revised (Kiselev *et al*., 2013). *Kosmoceras* is still present in the *mojarowskii* Biohorizon of Kiselev *et al*. (2013), but is also described from their *paucicostatum* Biohorizon (Kiselev *et al*., 2013, plate 2), which is not consistent with the definition of the same biohorizon in Western Europe (Thierry *et al*., 1997). In addition, at Dubki, a faunal gap exists at the base of the Oxfordian between the *scarburgense* Biohorizon and the *alphacordatum* Biohorizon (corresponding to the absence of *woodhamense* and *praemartini* biohorizons), although the *praemartini* Biohorizon appears in another area (Kiselev *et al*., 2013).

Nannofossil biostratigraphy

Our nannofossil data suggest that the total range of *Stephanolithion bigotii maximum* does not extend across the Lamberti/Mariae zones, as reported by some authors in NW Europe (Medd, 1979; 1982; Bown *et al*., 1988; Fauconnier *et al*., 1996; Kaenel *et al*., 1996; Giraud *et al*., 2009). This result is confirmed elsewhere in SE France (Jonquière and Quissac sections; Gardin, unpublished), and in Russia (Dubki section; Kiselev *et al*., 2013), where this sub-species occurs only in Lower Oxfordian samples from the Praecordatum Subzone. At Redcliff Point (SE England), Page *et al*. (2009b) reported the occurrence of *Stephanolithion bigotii maximum* throughout the uppermost Lamberti and Mariae zones. In contrast with the present study, the diagnosis of the subspecies was not based on size measurements, but only on its morphological features, including a more rounded outline and less symmetrical lateral spines (Page *et al*., 2009b). If these diagnostic criteria were applied, the specimens described in the present study as large-sized *Stephanolithion bigotii bigotii* should in fact be considered as *S. bigotii maximum*, as they clearly display asymmetric spines, and a more rounded outline (Plate 6: 4, 5). Yet the Oxfordian specimens of genuine *S. bigotii maximum* do not possess the more rounded outline and asymmetrical disposition of spines (Plate 6: 6, 7). In conclusion, the reliability of *Stephanolithion bigotii maximum* as a marker for dating and correlating the Callovian-Oxfordian boundary depends on rigorous and objective diagnosis. Differential taxonomic concepts can produce apparently diachronous biohorizons, although true diachronism between the Boreal and Tethyan realms cannot be ruled out and must be thoroughly tested. Miscalibration of samples with regard to ammonite zones, reduced carbonate sedimentation, and hiatuses in southern European sections should also be taken into account.

ISOTOPE STRATIGRAPHY AND PHYSICAL STRATIGRAPHY

We have established that the $\delta^{13}C$ record is a useful tool for intrabasinal and interbasinal correlations. By contrast, oxygen-isotope data from bulk sediment are likely to have been affected by diagenetic alteration in the Subalpine Basin, and so cannot be used for correlation.

At Redcliff Point, carbon and oxygen isotopic analyses have been performed on some belemnites (n = 13), *Gryphaea* (n = 13) and ammonites (n = 18), but the sampling interval and resolution are not sufficient to detect any stratigraphic changes (Price, Page, 2008; Page *et al.*, 2009b). The strontium isotope data (n = 10) were also obtained from belemnites and can be compared to the evolution of $^{87}Sr/^{86}Sr$ ratios in Jurassic seawater (Page *et al.*, 2009b). Their values are consistent with reference curves that correspond to an overall low-point in the Phanerozoic Sr isotope record (Jones *et al.*, 1994; Podlaha *et al.*, 1998; McArthur *et al.*, 2001). The flat pattern of the $^{87}Sr/^{86}Sr$ ratios across the Callovian-Oxfordian boundary does not, however, allow precise stratigraphic calibration. On the Russian Platform, Wierzbowski and Rogov (2011) performed isotopic analyses on well-preserved belemnite rostra (n = 53) and well-preserved ammonite shells (n = 13) for the Lamberti Zone-Mariae Zone interval. Despite numerous analyses, the belemnite $\delta^{13}C$ isotope record across the Callovian-Oxfordian boundary is characterised by scattered values, masking any significant changes useful for isotope stratigraphy.

Magnetostratigraphy is unreliable for Callovian--Oxfordian deposits from the Subalpine Basin. It was applied to an 8 m thick section of the Upper Oxford Clay Fm., east of Ham Cliff, near Redcliff Point (Page *et al.*, 2009b). The results of 24 useable samples yielded eight reversed polarity intervals from the Lamberti Subzone to the Scarburgense Subzone. The Callovian-Oxfordian boundary occurs in a normal-polarity zone, verified by the presence of a narrow normal-polarity band at the same interval in Staffin Bay (Isle of Skye), correlated to the latest part of polarity chron M37n of the M-sequence (Ogg *et al.*, 2010). On the Russian Platform, 25 samples from a 9 m thick section of the Callovian-Oxfordian sediments at Dubki, spanning the Henrici-Bukowskii subzones, belong to a single normal-polarity zone. This result is in contradiction with the magnetostratigraphy of the English sections, and with the international palaeomagnetic scale (Kiselev *et al.*, 2013), preventing precise magnetostratigraphic correlation of ammonite biostratigraphic units between the European Russian domain and the Western European domain. This method is therefore of limited use for the Callovian-Oxfordian boundary.

Cyclostratigraphy is applied neither at Redcliff Point nor at the Dubki section, due to the low sedimentation rate and the outcrop conditions. By contrast, in the Subalpine Basin, the use of high-resolution GRS and MS data allows a detailed cyclostratigraphy to be proposed for the Callovian-Oxfordian boundary.

ADVANTAGES OF THE SUBALPINE BASIN SECTIONS FOR AN OXFORDIAN GSSP

According to the recommendation of the International Commission on Stratigraphy for the satisfaction of geological requirements for a GSSP proposal (Remane *et al.*, 1996), the following major stratigraphic features can be considered as advantages for the establishment of a GSSP in the Subalpine Basin:

Geological requirements: The exposure of the Terres Noires Fm. in the Subalpine Basin provides an adequate thickness of deposits. Exposures are perennial for long-term observations and easy to access; vegetation cover is relatively sparse, and thus amenable for high-resolution measurements, while key lithological markers are easily recognisable from lithological descriptions, despite the relatively homogeneous clayey facies of the Terres Noires Fm. The stratigraphic expansion of the series is remarkable, with 75 m in thickness from the base of the *lamberti* Biohorizon to the *scarburgense* Biohorizon at Thuoux, and 210 m at Saint-Pierre d'Argençon, where the *scarburgense* Biohorizon and the *woodhamense* Biohorizon are easily recognisable. The two biohorizons bracketing the Callovian-Oxfordian boundary at Thuoux are ~20 m in thickness for the *paucicostatum* biohorizon, and ~17 m for the *thuouxensis* Biohorizon. This unusual feature, known only in the Subalpine Basin among the European and Russian sections considered, is due to a high sedimentation rate in a very subsident basin, and allows the use of several stratigraphic methods (*i.e.* biostratigraphy of ammonites and other fossil groups, cyclostratigraphy, and chemostratigraphy) in an expanded stratigraphic interval, a requirement for correlation with other areas. The sedimentation is continuous, as indicated by sedimentology studies and physical stratigraphy (*e.g.* GRS and MS data). The faunal succession, knowledge of the entire basin and good comparison with the Paris Basin all indicate that no hiatus or condensation is present at Thuoux. At Saint-Pierre d'Argençon, however, there is a slight decrease in the sedimentation rate for the *paucicostatum* Biohorizon, readily explained by the presence of tilted-block structures known to cause lateral variations in thickness in this well-explored basin. Apart from these easily recognisable local effects and minor faults, no tectonic disturbances or metamorphism affected the strata at the Callovian-Oxfordian transition. Although no magnetostratigraphic signal can be obtained due to remagnetisation, the burial diagenesis is moderate, as demonstrated by clay mineralogy and organic matter studies (Pellenard, Deconinck, 2006). Carbon-isotope geochemistry for bulk sediment is therefore reliable and additional isotopic signals are available from belemnites, including oxygen, carbon and potentially strontium.

Biostratigraphic requirements: The biostratigraphic framework is based on the succession of different ammonite species and genera from various families including Cardioceratidae, Oppeliidae, Aspidoceratidae (Peltoceratinae, Euaspidoceratinae), and Perisphinctidae from Subboreal and Submediterranean domains. The potential for precise correlations with other palaeobiogeographic provinces throughout the world (*i.e.* Boreal Realm and Pacific Realm) constitute a major advantage of the fauna from the Subalpine Basin. The precise biostratigraphic framework allows the recognition of zones and subzones, classically described in Europe and Russia as bracketing the Middle-Late Jurassic boundary (Cariou *et al.*, 1997; Morton, 2006), including the Lamberti Subzone of the Lamberti Zone and the Scarburgense Subzone of the Mariae Zone. The *paucicostatum* and *thuouxensis* biohorizons bracketing the boundary are clearly identified in all sections of the Subalpine Basin (Fortwengler *et al.*, 2012) and also in eastern Paris Basin boreholes (Thierry *et al.*, 2006). Unfortunately, no firm consensus has yet been reached on the precise correlation between these biohorizons and those described in northern Europe and Russia (Page *et al.*, 2009a; Kiselev *et al.*, 2013).

Other groups are also of interest for biostratigraphic correlation. The potential of nannofossil biohorizons as useful proxies for the Callovian-Oxfordian boundary exists, yet is complicated by the necessity of performing a rigorous quantitative analysis and biometric measurements of key taxa. Thus, large-sized specimens of the marker species *Stephanolithion bigotii bigotii* appear during the *paucicostatum* Biohorizon, whereas the species *Stephanolithion bigotii maximum* is only recognised from the Praecordatum Subzone in the Subalpine Basin. Investigations of dinoflagellate cyst assemblages at Thuoux follow the global trend described elsewhere in Europe (Feist-Burkhardt, Wille, 1992; Riding, Thomas, 1992; Huault, 1999). The Callovian-Oxfordian boundary is well defined by the occurrence of *Wanaea fimbriata* Sarjeant at the base of the Oxfordian. The richness of the dinoflagellate samples and their good correlation with ammonite biozones provide an additional useful biostratigraphic method for the sections of the Subalpine Basin. The biostratigraphy of foraminifera and ostracoda has not yet been completely explored, but may well provide additional key biological markers.

Other methods: Although no magnetic reversal stratigraphy is recorded in the Subalpine Basin, two other promising stratigraphic methods are available. The carbon-isotope curve obtained from high-resolution bulk sediment displays an interesting pattern, with a significant increasing trend during the Lamberti Zone. The ~1.5‰ increase in $\delta^{13}C_{carb}$ around the Middle-Late Jurassic boundary has already been documented in other sections in France (eastern Paris Basin; Pellenard *et al.*, 2014a), in Switzerland, and England but with a lower resolution (Bartolini *et al.*, 1996, 1999; Jenkyns *et al.*, 2002) and could constitute an auxiliary marker of the Callovian-Oxfordian boundary (Pellenard *et al.*, 2014b). This increase in $\delta^{13}C$ values up to the Mariae Zone may reflect the burial of organic carbon, following an enhanced eutrophication of seawater, as observed for organic-rich layers around the World, during the Middle Callovian (Pellenard *et al.*, 2014a). High-resolution analysis of magnetic susceptibility and field spectral gamma-ray measurements allow a precise signal to be obtained for cyclostratigraphy in the Subalpine Basin. Sub-Milankovitch to Milankovitch cycles are clearly identified, with the long-term eccentricity (405 kyr and 2 myr) being the most prominent (Boulila *et al.*, 2008; 2010). The 405-kyr cycle is used as a high-resolution geochronometer for astronomical calibration of this poorly constrained interval of Late Jurassic time. The astronomical calibration of the Mariae Zone indicates a duration of ~2.2 myr in this basin (Boulila *et al.*, 2008, 2010). The new high-resolution magnetic susceptibility analysis and spectral gamma-ray measurements spanning the Callovian-Oxfordian transition provided in this study will allow precise astronomical calibration of the associated ammonite sub-zones and biohorizons, and assessment of variations in the sedimentation rate. The U-Pb radiometric dating on bentonites from the Plicatilis Zone, if successful, could further help to anchor this interval in the Geologic Time Scale. These physical parameters, combined with biostratigraphy, allow precise intrabasinal correlations within the Subalpine Basin, with sequence stratigraphy defined in the margins and close basins as an additional tool (Graciansky *et al.*, 1999; Gaspard *et al.*, 2005; Pellenard, Deconinck, 2006). Thus, the potential of biostratigraphic correlations of the Subalpine Basin with other sedimentary basins in Europe, or elsewhere, using other stratigraphic methods, are clearly advantageous for an Oxfordian GSSP.

Other requirements: The possibility of promoting conservation of the site by a permanently fixed marker is envisaged at Thuoux. The site of Thuoux belongs to the village of Aspremont, surrounded by vast areas of badlands, providing perennial exposure, on land suitable neither for agriculture nor construction purposes. The local authorities have granted free access for researchers and, although the site of Saint-Pierre d'Argençon is on private land, there is no problem gaining access to the outcrops.

CONCLUSIONS

The Callovian-Oxfordian transition has recently been studied in detail, in two neighbouring sections of the Subalpine Basin (south-eastern France), Thuoux and Saint Pierre d'Argençon, by means of the high-resolution biostratigraphy of ammonites, calcareous nannofossils and dinoflagellate cysts, chemostratigraphy and cyclostratigraphy, based on field gamma-ray spectrometry and magnetic susceptibility. These sections are compared to the two other candidates proposed for the establishment of the base Oxfordian GSSP, Redcliff Point/Ham Cliff in Dorset (UK) and the Dubki section on the Russian Platform. Ammonite biostratigraphy is based on several groups (Cardioceratidae, Oppeliidae, Aspidoceratidae, Perisphinctidae), typical of the Submediterranean Province, allowing the recognition of a zonal and subzonal scheme, including the *paucicostatum* and the *thuouxensis* biohorizons, which bracket the Callovian--Oxfordian boundary. Long-range correlations are also possible with other domains, including the Boreal and Pacific realms. This biostratigraphy is complemented by calcareous nannoplankton and palynology (dinoflagellate cysts), using the appearence of characteristic species at the end of the Lamberti Zone, and precisely at the Callovian-Oxfordian boundary. Studies based on biostratigraphy and sedimentology indicate continuous sedimentation, with no hiatuses. The high sedimentation rate and the good outcrop conditions in the Terres Noires Fm. allow: 1) construction of a detailed lithological succession, including key marker beds, 2) high-resolution studies for cyclostratigraphy, and 3) high-resolution studies of the carbon-isotope signal from bulk sediment. These outcrops, and more specifically Thuoux which is on public land, are readily accessible all year round, and the GSSP status will ensure permanent protection of the site. All these outstanding features of the Subalpine Basin sections, satisfy the necessary requirements for an Oxfordian GSSP, particularly the Thuoux section.

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REFERENCES

ANDERSON T.F., ARTHUR M.A., 1983 — Stable isotopes of oxygen and carbon and their application to sedimentologic and environmental problems. *In*: Stable isotopes in sedimentary Geology (eds M.A Arthur *et al*.). *Society of Economic Paleontologists and Mineralogists. Short Course Notes*, **10**, 1.1–1.151.

ARKELL W.J., 1939 — The ammonite succession at the Woodham Brick Company's Pit, Akenan Street Station, Buckinghamshire, and its bearing on the classification of the Oxford Clay. *Quarterly Journal of the Geological Society*, *London*, **95**: 135–222.

ARTRU P., 1972 — Les Terres Noires du bassin rhodanien (Bajocien supérieur à Oxfordien moyen). Stratigraphie, sédimentologie, géochimie. Thèse Université Claude Bernard, Lyon 1, [unpublished].

ATROPS F., 1994 — The Upper Jurassic in the Dauphinois Basin. General introduction. *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 32–46.

ATROPS F., ENAY R., MELÉNDEZ G., 1993 — Joint meeting of the Oxfordian and Kimmeridgian wortking groups, Warsaw, Poland, September 7–12, 1992. *Acta Geologica Polonica*, **43**: 157–168.

ATROPS F., MELÉNDEZ G., 1994 — Callovian-Oxfordian and Oxfordian-Kimmeridgian Boundary Working Groups report (March, 1994). *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 21–23.

BADALUTA A., 1976 — Biostratigraphical precisions upon the Middle Jurassic Series in Anina (zone Resite, Banat). *Dari de seama Institutul de Geologie si Geofisica*, **62**: 73–84.

BARLIER J., RAGOT J.P., TOURAY J.C., 1974 — L'évolution des Terres Noires subalpines méridionales d'après l'analyse minéralogique des argiles et la réflectométrie des particles carbonées. *Bulletin du Bureau des Recherches Géologiques et Minières*, sec. II (1974): 533–548.

BARTOLINI A., BAUMGARTNER P.O., HUNZIKER, J., 1996 — Middle and Late Jurassic carbon stable-isotope stratigraphy and radiolarite sedimentation of the Umbria-Marche Basin (Central Italy). *Eclogae Geologicae Helvetiae*, **89**: 811–843.

BARTOLINI A., BAUMGARTNER P.O., GUEX J., 1999 — Middle and Late Jurassic radiolarian palaeoecology versus carbon-isotope stratigraphy. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **145**: 43–60.

BAUDRIMONT A.F., DUBOIS P., 1977 — Un bassin mésogéen du domaine périalpin: le Sud-Est de la France. *Bulletin des Centres de Recherche-Exploration-Production Elf-Aquitaine*, **1**: 261–308.

BELOW R., 1981 — Dinoflagellaten-Zysten aus dem oberen Hauterive bis unteren Cenoman Süd-West-Marokkos. *Palaeontographica*, B, **176**: 1–145.

BELOW R., 1982 — *Rigaudella*, ein neues Genus von Dinoflagellaten-Zysten. *Neues Jahrbuch fur Geologie und Paläontologie Monatshefte*, **3**: 137–150.

BERGER J.-P., 1986 — Dinoflagellates of the Callovian-Oxfordian boundary of the "Liesberg-Dorf" quarry (Berner Jura, Switzerland). *Neues Jahrbuch für Geologie und Paläontol*ogie, **172**: 331–355.

BONNOT A., 1995 — Les Aspidoceratidae d'Europe occidentale au Callovien supérieur et à l'Oxfordien inférieur. Thèse de Doctorat, Université de Bourgogne, Dijon, 487 p. [unpublished].

BONNOT A., FORTWENGLER D., MARCHAND D., 1997 — Les Peltoceratinae (Ammonitina, Aspidoceratidae) au passage Callovien-Oxfordien dans les «Terres Noires» du Sud-Est (France). *Géobios*, **30**: 651–672.

BONNOT A., COURVILLE P., MARCHAND D., 2002 — Parallel biozonation in the Upper Callovian and the Lower Oxfordian based on the Peltoceratinae subfamily (Ammonitina, Aspidoceratidae). *Abhandlungen der Geologischen Bundesanstalt*, **57**: 501–507.

BOULILA S., HINNOV L. A., HURET E., COLLIN P.Y., GALBRUN B., FORTWENGLER D., MARCHAND D., THIERRY J., 2008 — Astronomical calibration of the Early Oxfordian (Vocontian and Paris basins, France): consequences of revising the Late Jurassic time scale. *Earth and Planetary Science Letters*, **276**: 40–51.

BOULILA S., GALBRUN B., HINNOV L.A., COLLIN P.-Y., OGG J.G., FORTWENGLER D., MARCHAND D., 2010 — Milankovitch and sub-Milankovitch forcing of the Oxfordian (Late Jurassic) Terres Noires Formation (SE France) and global implications. *Basin Research*, **22**: 717–732.

BOURQUIN J., CONTINI D., 1968 — Données nouvelles sur la stratigraphie et la paléogéographie du Callovien du jura franc-comtois. *Bulletin de la Société Géologique de France*, **10**, 3: 362–369.

BOWN P.R., COOPER M.K.E., LORD A.R., 1988 — A calcareous nannofossil biozonation scheme for the early to mid Mesozoic. *Newsletters on Stratigraphy*, **20**: 91–114.

BUCKMAN S.S., 1913 — The "Kelloway rock" of Scarborough. *Quarterly Journal of the Geological Society*, **69**: 152–168.

CALLOMON J.H., 1964 — Notes on the Callovian and Oxfordian Stages. *In*: Colloque du Jurassique à Luxembourg, 1962 (Ed. P.-L. Maubeuge). Congrès Géologique International. Commission Internationale de Stratigraphie. Volume des Comptes-rendus et Mémoires. Ministère des Arts et des Sciences, Luxembourg: 269–291. Publications de l'Institut grand-ducal, Section des Sciences naturelles, physique et mathématiques.

CALLOMON J.H., 1984 — Biostratigraphy, chronostratigrahy and all that – again! *In*: International symposium on Jurassic stratigraphy (Erlangen 1984). 1984. Vol. III: 611–624.

CALLOMON J.H., COPE J.C.W., 1993 — The Jurassic geology of Dorset: guide to excursions. *In*: Arkell International Symposium. September, 1993, University College London: 42–48.

CARIOU E., 1969 — Caractères de la faune et subdivisions du Callovien supérieur en Poitou (France). *In*: Colloque sur le Jurassique à Budapest. *Annales Instituti Geologici Publici Hungarici*, **54**, 2: 451–463.

CARIOU E., ENAY R., ATROPS F., HANTZPERQUE P., MARCHAND D., RIOULT M., 1997 — Biozonations. Ammonites. Oxfordien. *In*: Biostratigraphie du Jurassique ouest européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles (eds E. Cariou, P. Hantzpergue). Groupe Français d'Étude du Jurassique. *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine*, Pau, **17**: 79–86, 144–147.

CHAPMAN N.D., 1997 — Ammonites from the Oxford Clay near Budmouth School and Tidmoor Point, Weymouth, and their bearing on the Callovian/Oxfordian boundary. *Proceedings of the Dorset Natural History and Archaeological Society*, Dorchester, **119**: 117–127.

CHAPMAN N.D., 1999 — Ammonite assemblages of the Upper Oxford Clay (Mariae Zone) near Weymouth. *Proceedings of the Dorset Natural History and Archaeological Society*, **121**: 77–100.

CHARBONNIER S., 2007 — Le Lagerstätte de La Voulte-sur-Rhône (France, Callovien): paléoenvironnement, biodiversité et taphonomie [thèse de doctorat]. Lyon 1 [unpublished].

COPE J.C.W., DUFF K.L., PARSONS C.F., TORRENS H.S., WIMBLEDON W.A., WRIGHT J.K., 1980 — A correlation of Jurassic rocks in the British Isles. *Geological Society London Special Report*, **15**, Jurassic Part two: Middle and Upper Jurassic; Callovian and Oxfordian correlation charts: 45–76.

COURTINAT B., 2006 — Palynostratigraphie du Callovien-Oxfordien (Jurassique) dans les Terres noires, sud-est France. *Géobios*, **39**, 2: 201–213.

DARDEAU G., MARCHAND D., FORTWENGLER D., 1994 — Tectonique synsédimentaire et variations du niveau marin pendant le dépôt de la formation des Terres Noires (Callovien supérieur-Oxfordien moyen; bassin du Sud-Est, France). *Comptes Rendus de l'Académie des Sciences. Sér. 2. Sciences de la Terre et des Planètes*, **319**, 5: 559–565.

DEBRAND-PASSARD S., DELANCE H., LORENZ J., MARCHAND D., 1978 — Le Callovien supérieur et l'Oxfordien inférieur dans les départements du Cher et de la Nièvre. Précisions stratigraphiques, paléogéographiques et paléobiogéographiques. *Bulletin du Bureau de Recherches Géologiques et Minières*, sér. 2, **1**, 4: 317–331.

DEFLANDRE G., 1938 — Microplancton des mers jurassiques conservé dans les marnes de Villers-sur-Mer (Calvados). Etude liminaire et considérations générales. *Travaux de la Station Zoologique de Wimereux*, **13**: 147–200.

DEFLANDRE G., 1939 — Les stéphanolithes, représentants d'un type nouveau de coccolithes du Jurassique supérieur. *Comptes Rendus des Séances de l'Académie des Sciences*, **208**, 1331.

DOUVILLÉ H., 1881 — Note sur la partie moyenne du terrain jurassique dans le bassin de Paris. *Bulletin de la Société Géologique de France*, **9**: 439–474.

DOUVILLÉ R., 1912 — Étude sur les Cardiocératidés de Dives, Villers-sur-Mer et quelques autres gisements. *Mémoires de la Société Géologique de France*, **45**: 5–77.

DRUGG W.S., 1978 — Some Jurassic dinoflagellate cysts from England, France and Germany. *Palaeontographica* B, **168**: 61–79.

DUBOIS P., DELFAUD J., 1989 — Le Bassin du Sud-Est. *In*: Dynamique et méthodes d'étude des bassins sédimentaires: 277–297. Association des Sédimentologistes Français, Paris.

ERKMEN U., SARJEANT W.A.S., 1980 — Dinoflagellate cysts, acritarchs and tasmanitids from the uppermost Callovian of England and Scotland: with a reconsideration of the "Xanthidium pilosum" problem. *Geobios*, **13**, 1: 45–99.

ELMI S., 1967 — le Lias supérieur et le Jurassique moyen de l'Ardèche. *Documents des Laboratoires de Géologie de la Faculté des Sciences de Lyon*, **19** (fascicule 2): 257–507.

ELMI S. *et al.* (22 co-authors), 1984 — Jurassique moyen : Dogger. *In* : Synthèse géologique du Sud-Est de la France (eds S. Debrand-Passard *et al*.). *Mémoires du Bureau de Recherches Géologiques et Minières*, **125**: 177–221.

ENAY R., CARIOU E., DEBRAND-PASSARD S., MENOT J.-C., RIOULT M., 1980 — Cartes de faciès. Oxfordien inférieur et moyen (pars). *In*: Cartes de faciès du Jurassique. Groupe Français d'Etude du Jurassique. *Documents des Laboratoires de Géologie*, Lyon, h.s. 5, cartes n° 30: 72–75.

ENAY R. *et al.* (26 co-authors) (1984) — Jurassique supérieur : Malm. *In*: Synthèse géologique du Sud-Est de la France (eds S. Debrand-Passard *et al*.). *Mémoires du Bureau de Recherches Géologiques et Minières*, **125**: 223–286.

ENAY R., MELÉNDEZ G., 1984 — Report of the Oxfordian Working Group and Report of the current state of the Oxfordain Working Group. International Symposium on Jurassic Stratigraphy, Erlangen, September 1–8, 1984. International Subcommision on Jurassic Stratigraphy (ISJS-IUGS) (eds O. Michelsen, A. Zeiss), V. 1: 87–103, 105–106. Geological Survey of Denmark, Copenhagen.

FAUCONNIER D., COURTINAT B., GARDIN S., LACHKAR G., RAUSCHER R., 1996 — Biostratigraphy of Triassic and Jurassic series in the borehole "Balazuc 1" (GPF program). Stratigraphy context inferred from spores, pollens, dinoflagellates cysts and nannofossils. *Marine and Petroleum Geology*, **13**: 707–724.

FEIST-BURKHARDT S., WILLE W., 1992 — Jurassic palynology in Southwest Germany – State of the art. *Cahiers de Micropaléontologie*, **7**, 1/2: 141–164.

FORTWENGLER D., 1989 — Les “Terres Noires” d’âge Callovien supérieur à Oxfordien moyen des chaînes sub-alpines du Sud (Diois, Baronnies, Dévoluy): nouvelles données biostratigraphiques. *Comptes-Rendus de l’Académie des Sciences de Paris*, *Sciences de la Terre et des Planètes*. Sér. II, **308**: 531–536.

FORTWENGLER D., MARCHAND D., 1991 — Nouvelles unités biochronologiques de l’Oxfordien inférieur (zone à Mariae). *In*: 3rd International Symposium on Jurassic Stratigraphy; Poitiers, France, September 22–29, 1991. Résumés-Abstracts: 203–209.

FORTWENGLER D., MARCHAND D., 1994a — Nouvelles unités biochronologiques de la zone à Mariae (Oxfordien inférieur). *Géobios*, Mémoire spécial, **17**: 203–209.

FORTWENGLER D., MARCHAND D., 1994b — The Callovian-Oxfordian boundary in the Basin of South of France. *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 24–26.

FORTWENGLER D., MARCHAND D., 1994c. The Savournon section : Upper Callovian (Lamberti Zone) to Lower Oxfordian (Mariae Zone) under “Terres Noires” facies. *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 95–99.

FORTWENGLER D., MARCHAND D., 1994d. The Thuoux section: Callovian-Oxfordian boundary (Lamberti to Mariae zone) under “Terres Noires” facies. *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 103–106.

FORTWENGLER D., MARCHAND D., BONNOT A., 1997 — Ammonites et limite Callovien-Oxfordien dans les “Terres Noires” du Diois (Bassin du Sud-Est, France): exemples des coupes de Thuoux et Savournon. *Géobios*, **30**: 519–540.

FORTWENGLER D., MARCHAND D., BONNOT A., JARDAT R., RAYNAUD D., 2012 — Proposal for the Thuoux section as a candidate for the GSSP of the base of the Oxfordian stage. *Carnets de Géologie (Notebooks on Geology)*, Brest, CG2012A06: 117–136.

FORTWENGLER D., MARCHAND D., PELLENARD P., THIERRY J., CHATEAU-SMITH C. (eds), 2013 — Integrated stratigraphy of some key Callovian-Oxfordian boundary sections in South-East France. Contribution to the choice of the Global Boundary Stratotype Section and Point (GSSP) of the Oxfordian Stage. Groupe Français d’Etude du Jurassique 2013, field guide guide book: 1–78. Oxfordian GSSP Workshop 30th September–2nd October 2013.

GABILLY J., 1976 — Le Toarcien à Thouars et dans le centre-ouest de la France: biostratigraphie-evolution de la faune (Harpoceratinae, Hildoceratinae). Editions du CNRS, Paris.

GASPARD R., PELLENARD P., FORTWENGLER D., MARCHAND D., 2005 — Enregistrement HR du temps et variabilité spatiale au passage Callovien/Oxfordien : les Terres Noires du bassin subalpin. *In*: 10ème Congrès Français de sédimentologie. Livre des résumés, 2005. *Publications de l’Association des Sédimentologistes Français*, **51**: 135.

GIPE R., 2013 — Callovian (Upper Middle Jurassic) magnetostratigraphy: a composite polarity pattern from France, Britain and Germany, and its correlation to the Pacific marine magnetic anomaly model. Master’s thesis, Purdue University [unpublished].

GIRAUD F., COURTINAT B., ATROPS F., 2009 — Spatial distribution patterns of calcareous nannofossils across the Callovian–Oxfordian transition in the French Subalpine Basin. *Marine Micropaleontology*, **72**: 129–145.

GÓRKA H., 1965 — Les microfossiles du Jurassique supérieur de Magnuszew (Pologne). *Acta Palaeontologica Polonica*, **10**, 3: 291–327.

GRACIANSKY P.-C. de, DARDEAU G., BODEUR Y., ELMI S., FORTWENGLER D., JACQUIN T., MARCHAND D., THIERRY J., 1999 — Les terres-noires du Sud-Est de la France (Jurassique moyen et supérieur): interprétation en termes de stratigraphie séquentielle. *Bulletin des Centres de Recherche-Exploration-Production Elf-Aquitaine*, **22**, 1: 35–70.

GRADSTEIN F.M., OGG, J.G., SCHMITZ M., OGG G. (eds), 2000 —. The Geologic Time Scale. Elsevier.

GRAHAM, J.W. (1949) — The stability and significance of magnetism in sedimentary rocks. *Journal of Geophysical Research*, **54**: 131–167.

GUILHAUMOU N., TOURAY J. C., PERTHUISOT V., ROURE, F., 1996 — Palaeocirculation in the basin of southeastern France sub-alpine range: a synthesis from fluid inclusions studies. *Marine and Petroleum Geology*, **13**: 695–706.

HÉBERT E., 1857 — Les mers anciennes et leurs rivages dans le Bassin de Paris ou classification des terrains par les oscillations du sol. Première partie: Terrain Jurassique: 88 p. Hachette et Cie, Paris.

HÉBERT E., 1860 — Du terrain jurassique supérieur sur les côtes de la manche. *Bulletin de la Société Géologique de France*, **17**: 300–316.

HUAULT V., 1998 — Palynological characteristics of the Dogger-Malm boundary in the southeast of the Paris Basin. *Comptes Rendus de l’Academie des Sciences – Series IIA – Earth and Planetary Science*, **326**, 7: 521–526.

HUAULT V., 1999 — Zones de kystes de dinoflagellés de l’intervalle Aalénien–Oxfordien sur la bordure méridionale du bassin de Paris (Dinoflagellate cyst zonation of the Aalenian–Oxfordian interval on the southern margin of the Paris Basin). *Review of Palaeobotany and Palynology*, **107**: 145–190.

HURET E., 2006 — Analyse cyclostratigraphique des variations de la susceptibilité magnétique des argilites callovo-oxfordiennes de l’Est du Bassin de Paris: application à la recherche de hiatus sédimentaires [thèse de doctorat]. Paris 6 [unpublished].

JARDAT R., 2010 — The evolution of ammonite associations during the Early Oxfordian (Mariae and Cordatum zones) in the Jura area (Eastern France). *Carnets de Géologie (Notebooks on Geology)*, Brest, Article 2010/07 (CG2010_A07), 15.

JENKYNS H.C., JONES C.E., GROCKE J.D., HESSELBO S.P., PARKINSON D.N., 2002 — Chemostratigraphy of the Jurassic System: applications, limitations and implications for palaeoceanography. *Journal of the Geological Society*, **159**: 351–378.

JONES C.E., JENKYNS H.C., COE A.L., STEPHEN H.P., 1994 — Strontium isotopic variations in Jurassic and Cretaceous seawater. *Geochimica et Cosmochimica Acta*, **58**: 3061–3074.

KAENEL E. de, BERGEN J.-A., VON SALIS PERCH-NIELSEN K., 1996 — Jurassic calcareous nannofossil biostratigraphy of western Europe: compilation of recent studies and calibration of bioevents. *Bulletin de la Société Géologique de France*, **1**: 3–14.

KISELEV D., ROGOV M., GLINSKIKH L., GUZHIKOV A., PIMENOV M., MIKHAILOV A., DZYUBA O., MATVEEV A., TESAKOVA E., 2013 — Integrated stratigraphy of the reference sections for the Callovian-Oxfordian boundary in European Russia. *Volumina Jurassica*, **11**: 59–96.

KLEMENT K.W., 1960 — Dinoflagellaten und Hystrichosphaerideen aus dem unteren und mittleren Malm Südwestdeutschlands. *Palaeontographica,* A, **114**: 1–104.

LAHUSEN I., 1883 — Die fauna der jurassischen Bildungen des Rjasanschen Gouvernements. *Mémoires du Comité Géologique de Russie*.

LANGE W., 1973 — Ammoniten und Ostreen (Biostratigraphie, Ökologie, Zoogeographie) des Callovium/Oxfordium-Grenzbereichs im Wiehengebirge. *Münstersche Forschungen zur Geologie und Paläontologie*, **27**.

LASKAR J., ROBUTEL P., JOUTEL F., GASTINEAU M., CORREIA A.C.M., LEVRARD B., 2004 — A long-term numerical solution for the insolation quantities of the Earth. *Astronomy*, *Astrophysics*, **428**: 261–285.

LASKAR J., FIENGA A., GASTINEAU M., MANCHE H., 2011 — La2010: a new orbital solution for the long-term motion of the Earth. *Astronomy*, *Astrophysics*, **532** : A89.

LORIOL P. de, 1898 — Étude sur les Mollusques et les Brachiopodes de l'Oxfordien inférieur ou zone à *Ammonites renggerri* du Jura Bernois. *Mémoire de la Société Paléontologique Suisse*, **25**: 3–115.

LOUIS-SCHMIT B., RAIS P., BERNASCONI S., PELLENARD P., COLLIN P.-Y., WEISSERT H., 2007 — Towards a carbonate world: the Oxfordian turning point in the marine carbon cycle. *Palaeogeography*, *Palaeoclimatology*, *Paleoecology*, **248**: 459–472

MANN M.E., LEES J.M., 1996 — Robust estimation of background noise and signal detection in climatic time series. *Climatic Change*, **33**: 409–445.

MARCHAND D., 1979 — Un nouvel horizon paléontologique : l'horizon à Paucicostatum (Oxfordien inférieur, zone à Mariae, base de la sous-zone à Scarburgense). *Comptes-Rendus Sommaires de la Société Géologique de France*, **3**: 122–124.

MARCHAND D., 1986 — L'évolution des Cardioceratinae d'Europe occidentale dans leur contexte paléobiogéographique (Callovien supérieur – Oxfordien moyen) [thèse de doctorat]. Université de Bourgogne, Dijon [unpublished].

MARCHAND D., FORTWENGLER D., DARDEAU G., GRACIANSKY P.-C. DE, JACQUIN T., 1990 — Les peuplements d'ammonites du Bathonien supérieur à l'Oxfordien moyen dans les Baronnies (Bassin du Sud-Est, France): comparaisons avec la plate-forme nord-européenne. *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine*, Pau, **14**, 2: 465–479.

MARCHAND D., FORTWENGLER D., 2010 — L'Oxfordien inférieur des environs de La Voulte: Le Ravin du Chénier, La coupe de Rondette. *In*: Peuplements et environements jurassiques. En hommage à Serge Elmi. Réunion spécialisée de la Société géologique de France. Lyon 22–24 Avril, 2010. Livre des résumés.

MARTINEZ M., DECONINCK J.-F., PELLENARD P., REBOULET S., RIQUIER L., 2013 — Astrochronology of the Valanginian Stage from reference sections (Vocontian Basin, France) and palaeoenvironmental implications for the Weissert Event. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **374**: 91–102.

MATYS GRYGAR T., MACH K., SCHNABL P., PRUNER P., LAURIN J., MARTINEZ M., 2014 — A lacustrine record of the early stage of the Miocene Climatic Optimum in Central Europe from the Most Basin, Ohre (Eger] Graben, Czech Republic. *Geological Magazine* [in press]. doi: http://dx.doi.org/10.1017/S0016756813001052.

MCARTHUR J.M., HOWARTH R.J., BAILEY T.R., 2001 — Strontium isotope stratigraphy: LOWESS version 3: best fit to the marine Sr-isotope curve for 0–509 Ma and accompanying look-up table for deriving numerical age. *The Journal of Geology*, **109**: 155–170.

MEDD A.W., 1979 — The Upper Jurassic coccoliths from the Haddenham and Gamlingay boreholes (Cambridgeshire, England). *Eclogae Geologicae Helvetiae*, **72**: 19–109.

MEDD A.W., 1982 — Nannofossil zonation of the English Middle and Upper Jurassic. *Marine Micropaleontology*, **7**, 1: 73–95.

MELÉNDEZ G., 2003. — Oxfordian Working Group. *Newsletter of the International Subcommission on Jurassic Stratigraphy, International Union of Geological Sciences, International Commission of Stratigraphy*, **30**: 16–18.

MELÉNDEZ G., 2004 — Oxfordian Working Group. *Newsletter of the International Subcommission on Jurassic Stratigraphy, International Union of Geological Sciences, International Commission of Stratigraphy*, **31**: 9–11.

MITTA V.V., 2003 — On the Callovian and Oxfordian boundary beds of the Volga area. *Vernadsky Museum-Novitates*, **11**.

MORLEY-DAVIES A., 1916 — The zones of the Oxford and Amphtill Clays in Buckinghamshire and Bedfordshire. *Geological Magazine*, **3**, 9: 395–400.

MORTON N., 2006 — Chronostratigraphic units in the Jurassic and their boundaries: Definition, recognition and correlation, causal mechanisms. *Progress in Natural Science*, **16**: 1–11.

NORRIS G., SARJEANT W.A.S., 1965 — A descriptive index of genera of fossil Dinophyceae and Acritarcha. New Zealand Department of Scientific and Industrial Research.

OGG J.G., COE A.L., PRZYBYLSKI P.A., WRIGHT J.K., 2010 — Oxfordian magnetostratigraphy of Britain and its correlation to Tethyan regions and Pacific marine magnetic anomalies. *Earth and Planetary Science Letters*, **289**, 3: 433–448.

OPPEL A., 1856–1858 — Die Juraformation Englands, Frankreichs und des südwestlichen Deutschlands. *Wurttemberger Naturwissenschafften Jahresheft*, **12–14**: 857 p.

ORBIGNY A. D', 1852 — Cours élémentaire de paléontologie et de géologie stratigraphiques, Tome second, fascicule II, Paris, Masson édit., Chap. IV, Terrains jurassiques: 414–570.

PAGE K.N., 1994 — A review of the suitability of key British Callovian-Oxfordian and Oxfordian-Kimmeridgian sites as Global Stratotype Sections and Points (GSSPS) for stage boundaries. *In*: 4th Oxfordian and Kimmeridgian Working Groups meeting. International Subcommission on Jurassic Stratigraphy (Ed. F. Atrops). Lyon and South-Eastern France Basin, June 13–19, 1994. Guide book and Abstracts: 15–16.

PAGE K.N., 1995 — Biohorizons and zonules: intra-subzonal units in Jurassic ammonite stratigraphy. *Palaeontology*, **38**, 4: 801–814.

PAGE K.N., 2004 — The Callovian-Oxfordian boundary in Britain: a review of key sections and their correlation with the proposal Global Stratotype Section and Point for the Oxfordian in Haute Provence, France. *Rivista Italiana di Paleontologia e Stratigrafia*, **110**: 201–208.

PAGE K.N., MELÉNDEZ G., HART M.B., PRICE G.D., WRIGHT J.K., BOWN P., BELLO J., 2006 — Integrated stratigraphical study of the candidate Oxfordian Global Stratotype Section and Point (GSSP) at Redcliff Point, Weymouth, Dorset, UK. *Volumina Jurassica*, **6**: 1–13.

PAGE K.N., MELÉNDEZ G., WRIGHT J.K., 2009a. The ammonite faunas of the Callovian-Oxfordian boundary interval in Europe and their relevance to the establishment of an Oxfordian GSSP. *Volumina Jurassica*, **7**: 89–99.

PAGE K.N., MELÉNDEZ G., HART M.B., PRICE G.D., WRIGHT J.K., BOWN P., BELLO J., 2009b — Integrated stratigraphical study of the candidate Oxfordian Global Stratotype Section and Point (GSSP) at Redcliff Point, Weymouth, Dorset, UK. *Volumina Jurassica*, **7**: 101–111.

PELLENARD P., 2003 — Message terrigène et influences volcaniques au Callovien-Oxfordien dans les bassins de Paris et du sud-est de la France. *Société Géologique du Nord*, **31**.

PELLENARD P., 2013 — Workshop on the base of the Oxfordian Stage in the Subalpine Basin, France, 30th September to 2nd October 2013. *Volumina Jurassica*, **11**: 167–172.

PELLENARD P., DECONINCK J.F., HUFF W.D., THIERRY J., MARCHAND D., FORTWENGLER D., TROUILLER A., 2003 — Characterization and correlation of Upper Jurassic (Oxfordian) bentonite deposits of the Paris Basin, France. *Sedimentology*, **50**: 1035–1060.

PELLENARD P., DECONINCK J.F., 2006 — Mineralogical variability of Callovo-Oxfordian clays from the Paris Basin and the Subalpine Basin. *Comptes Rendus Geoscience*, **338**, 12: 854–866.

PELLENARD P., NOMADE S., MARTIRE L., DE OLIVEIRA RAMALHO F., MONNA F., GUILLOU H., 2013 — The first 40Ar–39Ar date from Oxfordian ammonite-calibrated volcanic layers (bentonites) as a tie-point for the Late Jurassic. *Geological Magazine*, **150**, 06: 1136–1142.

PELLENARD P., TRAMOY R., PUCÉAT E., HURET É., MARTINEZ M., BRUNEAU L., THIERRY J., 2014a — Carbon cycle and palaeoenvironmental changes at the Middle-Late Jurassic transition from the Paris Basin (France). *Marine and Petroleum Geology*, **53**: 30–43.

PELLENARD P., BARTOLINI A.C., BOULILA S., COLLIN P.Y., FORTWENGLER D., GALBRUN B., GARDIN S., HUAULT V., HURET E., MARCHAND D., THIERRY J., 2014b — Integrated stratigraphy of the potential candidate Oxfordian GSSP at Thuoux and Saint-Pierre d'Argençon (France). *In*: STRATI 2013 (eds R. Rocha *et al.*): 271–275. Springer International Publishing.

PELLENARD P., TRAMOY R., CORNUAULT M., PUCÉAT E., BARTOLINI A. C., HURET E., MARTINEZ M., FORTWENGLER D., MARCHAND D., THIERRY J., 2014c — Carbon and oxygen isotope signals from the Callovian–Oxfordian in French sedimentary basins. *In*: STRATI 2013 (eds R. Rocha, *et al.*): 865–867. Springer International Publishing.

PODLAHA O. G., MUTTERLOSE J., VEIZER J., 1998 — Preservation of $\delta^{18}O$ and $\delta^{13}C$ in belemnite rostra from the Jurassic/Early Cretaceous successions. *American Journal of Science*, **298**, 4: 324–347.

POULSEN N.E., JUTSON D., 1996 — Dinoflagellate cysts from two potential candidates for the Oxfordian stage basal boundary stratotype (GSSP), south-eastern France – a preliminary review. *Jurassic Microfossil Group*, *Newsletter*, Copenhagen, **5**: 4–14.

PRICE G.D., PAGE K., 2008 — A carbon and oxygen isotopic analysis of molluscan faunas from the Callovian-Oxfordian boundary at Redcliff Point, Weymouth, Dorset: implications for belemnites behaviour. *Proceedings of the Geologists' Association*, **119**: 153–160.

REMANE J., BASSETT M.G., COWIE J.W., GOHRBAND K.H., LANE H.R., MICHELSEN O., WANG NAIWEN, 1996 — Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes*, **19**: 77–81.

RIDING J.B., THOMAS J.E., 1992 — Dinoflagellate cysts of the Jurassic system. A stratigraphic index of dinoflagellate cysts. A.J. Powell. London, Chapman & Hall., 1: 7–57.

ROGOV M.A., GULYAEV D.B., KISELEV D.N., 2012 — Biohorizons as infrazonal biostratigraphic units: An attempt to refine the Jurassic stratigraphy based on ammonites. *Stratigraphy and Geological Correlation*, **20**, 2: 211–229.

SARJEANT W.A.S. 1961 — Microplankton from the Kellaways Rock and Oxford Clay of Yorkshire. *Palaeontology*, **41**: 90–118.

SARJEANT W.A.S. 1964 — New name and diagnosis for an Upper Jurassic species of *Gonyaulacysta* (Dinophyceae). *Palaeontology*, **7**: 472–473

SAYN G., 1930 — Oxfordien. *In*: Études sur le Callovien de la vallée du Rhône (eds G. Sayn, F. Roman). II. Monographies stratigraphique et paléontologique du Jurassique moyen de la vallée d Rhône. 2ème fascicule – *Travaux des Laboratoires de géologie*: 199–249.

SINTZOW M., 1889 — Carte géologique généarale de la Russie, feuille 92, Saratov-Pensa.

TESAKOVA E.M., 2008 — Late Callovian and Early Oxfordian ostracods from the Dubki section (Saratov area, Russia): implications for stratigraphy, paleoecology, eustatic cycles and palaeobiogeography. *Neues Jahrbuch für Geologie und Paläontologie*, *Abhandlungen*, **249**: 25–45.

THIERRY J., CARIOU E., 1980 — Cartes de faciès. Callovien inférieur, moyen et supérieur. *In*: Cartes de faciès du Jurassique. Groupe Français d'Etude du Jurassique. Documents des Laboratoires de Géologie, Lyon, h.s. 5, cartes n° 22, 23, 24, 29: 55–65.

THIERRY J., GALEOTTI S., 2008 — Biostratigraphy: from taxon to biozones and biozonal schemes. *In*: Stratigraphy. Terminology and practice (eds J. Rey, S. Galeotti): 65–89. Technip Édit. – B.R.G.M. – TOTAL.

THIERRY J., CARIOU E., ELMI S., MANGOLD C., MARCHAND D., RIOULT M., 1997 — Biozonations, Ammonites, Callovien. *In*: Biostratigraphie du Jurassique ouest européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles (eds. E. Cariou, P. Hantzpergue). *Bulletin des Centres de Recherche Exploration- Production ELF Aquitaine*, **17**: 63–78.

THIERRY J. *et al*. (44 co-authors), 2000 — Middle Callovian. *In*: Atlas Peri-Tethys (eds J. Dercourt *et al.*). CCGM/CGMW (edit.), Paris, Palaeogeographical map n°9 and Explanatory notes: 71–83.

THIERRY J., MARCHAND D., FORTWENGLER D., BONNOT A., JARDAT R., 2006 — Les ammonites du Callovo-Oxfordien des sondages ANDRA dans l'Est du Bassin de Paris: synthèse biochronostratigraphique, intérêts paléoécologique et paléobiogéographique. *Comptes-Rendus Géosciences*, **338**: 834–853.

THOMSON D.J., 1982 — Spectrum Estimation and Harmonic-Analysis. *Proceedings of the IEEE*, **70**, 1055–1096.

THOMSON D.J. 1990. Quadratic-Inverse Spectrum Estimates – Applications to Paleoclimatology. *Philosophical Transactions of the Royal Society of London.* Ser. A, *Mathematical Physical and Engineering Sciences*, **332**: 539–597.

TREMOLADA F., ERBA E., VAN DE SCHOOTBRUGGE B., MATTIOLI E., 2006 — Calcareous nannofossil changes during the late Callovian-early Oxfordian cooling phase. *Marine Micropaleontology*, **59**, 3: 197–209.

TRIBOVILLARD N., 1989 — Contrôle de la sédimentation marneuse en milieu pélagique semi-anoxique. Exemples dans le Mésozoïque du Sud-Est de la France et de l'Atlantique. *Documents des Laboratoires de Géologie de l'Université de Lyon,* **109**.

WIERZBOWSKI H., ROGOV M., 2011 — Reconstructing the palaeoenvironment of the Volga Basin (Russian platform) during the Middle-Late Jurassic transition using stable isotope ratios of cephalopod shells. *Palaeogeography*, *Palaeoclimatology*, *Palaeeoocology*, **299**: 250–264.

WIERZBOWSKI H., ROGOV M.A., MATYJA B.A., KISELEV D., IPPOLITOV A., 2013 — Middle–Upper Jurassic (Upper Callovian–Lower Kimmeridgian) stable isotope and elemental records of the Russian Platform: Indices of oceanographic and climatic changes. *Global and Planetary Change*, **107**: 196–212.

WILLIAMS G.L., DOWNIE C., 1969 — Generic re-allocations. *In*: Appendix to "Studies on Mesozoic and Cainozoic Dinoflagellate Cysts" (eds R.J. Davey *et al*.). B*ulletin of the British Museum (Natural History) Geology*, Append. Suppl. 3, **17**.

WILLIAMS G.L., STOVER L.E., KIDSON E.J., 1993 — Morphology and stratigraphic ranges of selected Mesozoic–Cenozoic dinoflagellate taxa in the Northern Hemisphere. *Geological Survey of Canada Paper*, **92**, 10, 137 pp.

WOOLLAM R., 1982 — Observations on the Jurassic dinocyst genera *Energlynia* and *Wanaea. Journal of Micropalaeontology*, **1**: 45–52.

PLATES

PLATE 1

Ammonites from Thuoux. Specimens are from the collection of D. Fortwengler

Fig. 1. *Alligaticeras* aff. alligatum Leckenby (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 1741

Fig. 2. *Poculisphinctes poculum* Leckenby (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 4588

Fig. 3. *Quenstedtoceras lamberti* (Sowerby) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 2584

Fig. 4. *Kosmoceras duncani* (Sowerby) *in* Badaluta, 1976 (fig. 6-2) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 18698

Fig. 5. *Hecticoceras* (*Orbignyceras*) *paulowi* (de Tsytovich) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 2467

Fig. 6. *Hecticoceras (Putealiceras) punctatum* Lahusen (m). Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 1376

Fig. 7. *Hecticoceras (Putealiceras) punctatum* Lahusen (M). Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2503

Fig. 8. *Cardioceras paucicostatum* Lange (M ?) α morph. Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2469

Fig. 9. *Hecticoceras (Lunuloceras) pseudopunctatum* (Lahusen) (M ?). Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2482

Fig. 10. *Poculisphinctes* aff. *poculum* Leckenby (m). Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 18082

Fig. 11. *Hecticoceras (Lunuloceras) pseudopunctatum* (Lahusen) (m). Level 6B, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2558

Fig. 12. *Cardioceras* aff. *paucicostatum* Lange (m ?) β morph. Level 6B, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2530

Fig. 13. *Peltoceratoides eugenii* (Raspail) (m). Level 6B, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 18098

Fig. 14. *Peltoceratoides eugenii* (Raspail) (M). Level 6B, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2573

Red dot: end of phragmocone


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14

1 cm

PLATE 2

Ammonites from Thuoux. Specimens are from the collection of D. Fortwengler

Fig. 1. *Peltoceras* aff. *schroederi* Prieser (M). Level 6A, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 2655

Fig. 2. *Cardioceras* aff. *paucicostatum* Lange (M) β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1365

Fig. 3. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 2605

Fig. 4. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 2311

Fig. 5. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Internal whorls. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 18156

Fig. 6. *Euaspidoceras armatum* (de Loriol). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1457

Fig. 7a, b. *Peltoceratoides eugenii* (Raspail) *eugenii* morph Raspail (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1666

Fig. 8a–c. *Peltoceratoides eugenii* (Raispail) *eugenii* morph Raspail (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 2655

Fig. 9a–c. *Hecticoceras coelatum* (Coquand). Level 8A, Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon, no. DF 1617

Fig. 10. *Cardioceras* aff. *scarburgense* (Young et Bird). Level 8A, base of the Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon, no. DF 18751

Fig. 11. *Cardioceras* aff. *scarburgense* (Young et Bird). Level 8A, base of the Mariae Zone, Scarburgense Subzone, *scarburgense* Biohorizon, no. DF 18752

Red dot: end of phragmocone

PLATE 2

PLATE 3

Ammonites from Thuoux and Saint-Pierre d'Argençon. Specimens are from the collection of D. Fortwengler

Fig. 1a, b. *Cardioceras* aff. *paucicostatum* Lange (M) β morph. Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 3880: Thuoux

Fig. 2. *Cardioceras* aff. *paucicostatum* Lange (m) β morph. Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 3883: Thuoux

Fig. 3a, b. *Cardioceras* aff. *paucicostatum* Lange (M) β morph. Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 3881: Thuoux

Fig. 4. *Hecticoceras (Brightia)* sp. (m). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 1608: Thuoux

Fig. 5. *Cardioceras scarburgense* (Young et Bird). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 18419: Thuoux

Fig. 6. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 18493: Thuoux

Fig. 7. *Hecticoceras (Brightia) chatillonense* de Loriol (M). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 18767: Thuoux

Fig. 8. *Peltoceratoides eugenii* (Raspail) *eugenii* morph Raspail (M). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 3717: Thuoux

Fig. 9. *Peltoceratoides athletoides* (Lahusen) *athletoides* morph Lahusen (M). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 1944: Thuoux

Fig. 10. *Peltoceratoides athletoides* (Lahusen) *athletoides* morph Lahusen (M). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 18563: Thuoux

Fig. 11. *Hecticoceras (Brightia) chatillonense* de Loriol (M). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 1875: Thuoux

Fig. 12. *Eochetoceras villersense* (d'Orbigny) (m). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 1385: Thuoux

Fig. 13. *Cardioceras scarburgense* (Young et Bird). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 1659: Thuoux

Fig. 14a, b. *Taramelliceras episcopale* (de Loriol). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 19536: Thuoux

Fig. 15. *Poculisphinctes* sp. (m). Level 4, Lamberti Zone, Henrici Subzone, no. DF 581: Saint-Pierre d'Argençon

Fig. 16. *Quenstedtoceras praelamberti* (Douville) (M). Level 5A, Lamberti Zone, Lamberti Subzone, *praelamberti* Biohorizon, no. DF 14517: Saint-Pierre d'Argençon

Fig. 17. *Hecticoceras (Lunuloceras) pseudopunctatum* (Lahusen) *in* de Loriol 1914 (pl. 2: 2). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 586: Saint- Pierre d'Argençon.

Fig. 18a, b. *Distichoceras bipartitum* (Zieten). Level 5B, Lamberti Zone, Lamberti Subzone, no. DF 2703: Saint-Pierre d'Argençon.

Fig. 19. *Poculisphinctes poculum* (Leckenby) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 2727: Saint-Pierre d'Argençon.

Red dot: end of phragmocone


1 a


1 b


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3 a


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3 b


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14a


14b


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18 b


18 a


19

PLATE 4

Ammonites from Saint-Pierre d'Argençon. Specimens are from the collection of D. Fortwengler

Fig. 1. *Hecticoceras (Orbignyceras) paulowi* (de Tsytovich) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 2719

Fig. 2. *Alligaticeras* aff. *alligatum* Leckenby (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 14518

Fig. 3a, b. *Euaspidoceras subbabeanum* (Sintzov), *subbabeanum* morph Sintzov (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 2734

Fig. 4. *Hecticoceras (Lunuloceras) pseudopunctatum* (Lahusen) (M). Level 5B, Lamberti Zone, Lamberti Subzone, *lamberti* Biohorizon, no. DF 19527

Fig. 5. *Cardioceras paucicostatum* Lange α morph. Level 6, Lamberti Zone, Lamberti Subzone, *paucicostatum* Biohorizon, no. DF 4063

Fig. 6. *Cardioceras* aff. *paucicostatum* lange β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 2814

Fig. 7. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 19532

Fig. 8. *Cardioceras scarburgense* (Young et Bird). Base of Level 8A. Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 4076

Fig. 9. *Hecticoceras* (*Brightia) chatillonense* de Loriol (M). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 19533

Fig. 10. *Peltoceratoides eugenii* (Raspail) (m). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 19537

Fig. 11. *Peltoceratoides eugenii* (Raspail) *eugenii* morph Raspail (M). Level 8A, Mariae Zone, Scarburgense Subzone, base of the *scarburgense* Biohorizon, no. DF 19528

Fig. 12. *Cardioceras* aff. *paucicostatum* Lange, specimen with thick, well-spaced ribs. Level 8A, Mariae Zone, Scarburgense Subzone, no.DF 694

Fig. 13. *Peltoceratoides athletoïdes* (Lahusen), *athletoides* morph Lahusen (M). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 19523

Fig. 14a, b. *Cardioceras scarburgense* (Young et Bird), thick specimen. Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no. DF 19534

Fig. 15. *Hecticoceras (Brightia) chatillonense* de Loriol (M). Level 8B, Mariae Zone, Scarburgense Subzone, middle of the *scarburgense* Biohorizon, no.D F 19530

Fig. 16. *Mirosphinctes* sp. Level 9, Mariae Zone, Scarburgense Subzone, top of the *scarburgense* Biohorizon, no. DF 19539

Fig. 17. *Eochetoceras villersense* (d'Orbigny) (M). Level 9, Mariae Zone, Scarburgense Subzone, top of the *scarburgense* Biohorizon, no. DF 19513

Red dot: end of phragmocone

PLATE 4


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3a


3b


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14 a


14 b


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17

1 cm

PLATE 5

Ammonites from Thuoux – Les Richers, Level 7 (*thuouxensis* Biohorizon).
Specimens are from the collection of D. Fortwengler

Fig. 1. *Cardioceras paucicostatum* Lange (M), β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 18705

Fig. 2. *Cardioceras paucicostatum* Lange (M), β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 925

Fig. 3. *Cardioceras paucicostatum* Lange (m ?), β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 932

Fig. 4. *Cardioceras paucicostatum* Lange (M ?), β morph, fine-ribbed specimen. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 918

Fig. 5. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1028

Fig. 6. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 19273

Fig. 7. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1024

Fig. 8. *Peltoceratoides eugenii* (Raspail) *eugenii* morph Raspail (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1703

Fig. 9. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1071

Fig. 10. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (m). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1030

Fig. 11. *Cardioceras paucicostatum* Lange, β morph. Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 928

Fig. 12. *Hecticoceras (Brightia) thuouxensis* Fortwengler et Marchand (M). Level 7, Mariae Zone, Scarburgense Subzone, *thuouxensis* Biohorizon, no. DF 1036

Red dot: end of phragmocone

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11

12

1 cm

Pierre PELLENARD *et al*. — Integrated stratigraphy of the Oxfordian global stratotype section and point (GSSP) candidate in the Subalpine Basin (SE France)

PLATE 6

Calcareous nannofossils and dinoflagellate cysts. Biometric measurements performed on *Stephanolithion bigotii* specimens from the studied sections

Fig. 1. *Stephanolithion bigotii bigotii*, St Pierre d'Argençon section (47.9 m), Lamberti Zone

Fig. 2. *Stephanolithion bigotii bigotii*, Thuoux section (10.3 m), Lamberti Zone

Fig. 3. *Stephanolithion bigotii bigotii*, Thuoux section (12.14 m), Lamberti Zone

Fig. 4. *Stephanolithion bigotii bigotii*, large-sized specimen, Savournon section

Fig. 5. *Stephanolithion bigotii bigotii*, large-sized specimen, Savournon section

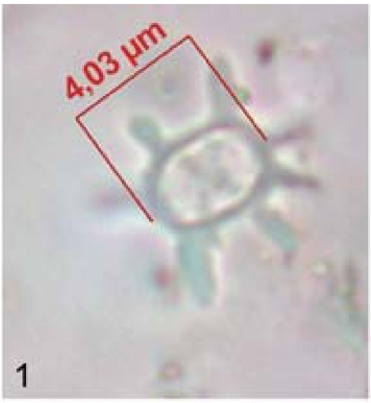
Fig. 6. *Stephanolithion bigotii maximum*, Jonquière section

Fig. 7. *Stephanolithion bigotii bigotii* and *Stephanolithion bigotii maximum*, Jonquière section

Fig. 8. *Wanaea fimbriata* Sarjeant 1961, Thuoux section (26.49 m), Mariae Zone

Fig. 9. *Wanaea thysanota* Woollam 1982, Thuoux section (34.16 m), Mariae Zone

All micrographs are taken with an optical microscope without polarizers. Scale is reported on each micrograph



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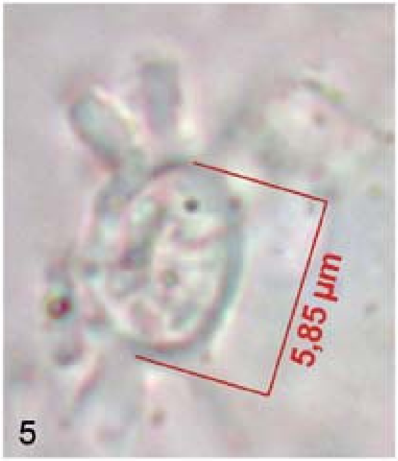

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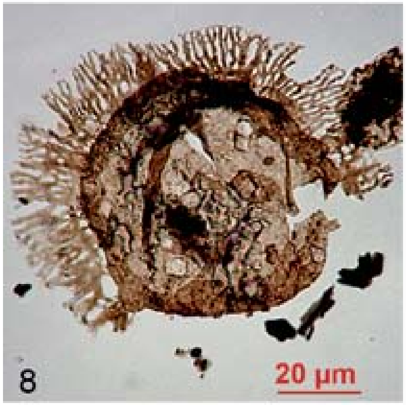

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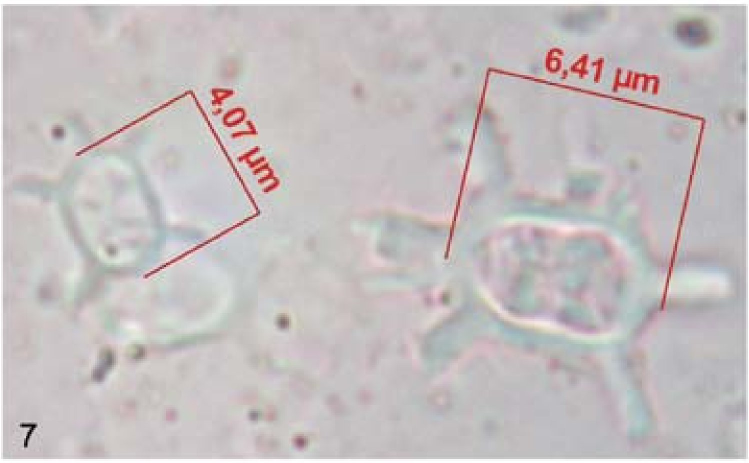

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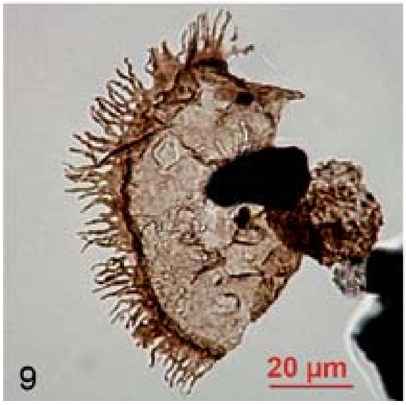

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