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Supplementary material: The Oxfordian–Kimmeridgian transition in the Boulonnais (France) and the onset of organic-rich marine deposits in NW Europe: a climatic control?

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Lithostratigraphy and biostratigraphy

The **Argiles du Mont des Boucards** Formation comprises a 15–30 m thickness [Pellat, 1867] of homogeneous claystone to marlstones with some mollusc shell layers (*Ostrea*). Patch reef facies (**Calcaire de Brucquedal** Member) are locally observed in the middle of the formation, yielding a low diversity coral fauna (dominant *Thamnasteria*, *Stylosmilia*, *Comoseris*, *Fungiastraea* and *Enellhelia* genera) with microbial crusts (thrombolites) and associated with a reefal/peri-reefal fauna composed of echinoderms, brachiopods and shell fragments [Schnyder et al., 2000]. Depositional environments correspond to mid- to outer ramp, open shallow marine facies and inner ramp, reefal facies (Figure 3). Ammonites (*Orthosphinctes* and *Dichotomoceras*) found in the lower part of the formation suggest a middle Oxfordian to basal late Oxfordian age, whereas *Amoeboceras ovale* and *Dichotomopshinctes wartae* found in the Calcaire de Brucquedal Member suggest a middle Oxfordian/late Oxfordian age [Mansy et al., 2000]. Dinoflagellate cysts indicate a late *Plicatilis* to base *Cautisnigrae* zone for the lower part of the formation, and a *Pseudocordata* zone for the upper part [middle Oxfordian to late Oxfordian, Schnyder et al., 2000] (Figure 3).

The **Grès de Brunembert** Formation is 1–10 m thick [Pellat, 1878]. It consists of bivalves and locally gastropod-rich sandstone beds alternating with silty to sandy marls. These deposits are interpreted to be deltaic/coastal sandstones (Figure 3).

The **Oolithe d'Hesdin-l'Abbé** Formation consists of 6–10 m of whitish bioturbated poorly-sorted, oolitic and oncolitic limestones passing to marls with oolites [Pellat, 1867, Debrand-Passard, 1980, Schnyder et al., 2000]. This formation is very rich in littoral and subreefal fauna [bivalves, brachiopods, echinoderms, bryozoans, benthic foraminifera; Schnyder et al., 2000] and contain rare ammonites (*Ringsteadia*

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anglica, *R. frequens*, *R. branderi* and *Pictonia baylei*), indicating the late Oxfordian *Pseudocordata* zone and the earliest Kimmeridgian *Baylei* zone (Figure 3). The Oolithe d'Hesdin l'Abbé corresponds to inner ramp, distal oolitic shoals.

The **Caillasses d'Hesdigneul** Formation was described by Dutertre [1925] in the "Paradis" quarry. This 5 m thick formation starts with black marls containing oolites and some oysters, overlain by several micritic beds passing upward to oolitic sandy limestones with gastropods (*Harpagodes*) and sea-urchins. Our own observations in the Diffuseur de Boulogne Sud trench confirm a marly facies for the lower part of the Caillasses d'Hesdigneul, overlaid by grey micritic limestones. In the SCP8 core, the formation corresponds to micritic limestones, mostly devoid of fauna, apart from scarce bivalves, gastropods and ostracods. The topmost beds are usually covered by hard-grounds, with eroded surfaces and encrustations of small oysters. One of these hard-grounds is a remarkable marker-bed that has been recognized both in the SCP8 core and in the Diffuseur de Boulogne Sud outcrops. It is a highly bioturbated surface filled with a sandy layer rich in small bivalves, brachiopods, foraminifers and echinoderms [Schnyder et al., 2000, see Figure 3, 45.5 m in composite log]. The depositional environment is interpreted to be an inner ramp, lagoonal facies. Although the rare ammonites yielded by the Caillasses d'Hesdigneul Formation (*Rasenia cymodoce*, *Perisphinctes achilles*) were not revised, an early Kimmeridgian *Cymodoce* zone dating is most probable [Debrand-Passard et al., 1980, Mansy et al., 2000]. Our new dinocyst observations (samples studied: CH1, CH5, CH8 see Figure 4) show that the dinocyst associations are poorly diversified and essentially characterised by non-age-diagnostic species. *Cribroperidinium* spp., *Escharisphaeridia* spp., *Systematophor*a spp. (principally *S. areolata*), *Barbatacysta brevispinosa*, are common. *Gonyaulacysta jurassica*, *Endoscrinium luridum*, *Occisucysta balios*, *Rhynchodiniopsis cladophora*, *Tubotuberella apatela*, *Glossodinium dimorphum*, *Scriniodinium inritibile*, *Aldorfia dictyota pyrum*, etc. are present. The age diagnostic species *Endoscrinium galeritum*, *Scriniodinium crystallinum*, *Ctenidodinium ornatum*, *Chlathroctenocystis asaphes* (last appearance datum or LAD-LAD being the last appearance of a species in the geologic record-generally accepted as intra *Baylei* zone and consistently observed below the Sequence Boundary Kim 1 in the topmost *Baylei*; Personal observations Roger Jan Du Chêne) are not observed. *Cribroperidinium longicorne* (First appearance datum, or FAD-FAD being the last appearance of a species in the geologic record-generally accepted at the base Cymodoce and consistently observed above the Sequence Boundary Kim 2' in the basal *Cymodoce* zone; Personal observations Roger Jan Du Chêne) is present from the base of the Calcaires de Brecquerecque and above (sample Bq 8; see below and Figure 4) but is not recorded in the studied samples of the Caillasses d'Hesdigneul.

With a poor confidence level due to the low diversity of the associations recorded in the Caillasses d'Hesdigneul samples, all this suggests an uppermost *Baylei*/lowermost *Cymodoce* age dating for the Caillasses d'Hesdigneul, in line with historical ammonite findings [Debrand-Passard et al., 1980, Mansy et al., 2000].

According to Dutertre [1925], the **Calcaires de Brecquerecque** Formation is composed by the alternation of marls and limestones, containing thin sand to sandstone layers. The faunal content of the marls and limestones is dominated by bivalves (*Nanogyra*, *Gervillella*, *Pholadomya* and *Mactromya*), sea-urchins, brachiopods (*Zeilleria humeralis*) and crustacean remains, without ammonites. In the Diffuseur de Boulogne Sud trench, the Calcaires de Brecquerecque show a 15 m thick alternation of marls and limestones, with several cm thick platy micaceous sandstone layers, having a parallel bedding and being rich in small plant debris. The thickness of the limestone beds ranges from 0.1 to 0.2 m in the basal part of the formation and reaches 0.3–0.5 m in the middle part. A 0.5 m sandy and glauconitic limestone bed, rich in ammonites, is visible at the base of the formation and was also described in the "Paradis" quarry [Dutertre, 1925] (Figure 3, 49.5 m). This is interpreted as a transgressive event at the base of the Calcaires de Brecquerecque (Figure 3). The depositional environments are interpreted as inner to mid-ramp deposits, and a deepening-up trend is obvious with respect to the underlying Caillasses d'Hesdigneul Formation. The ammonites found in this bed [Dutertre, 1925, *Rasenia cymodoce*, *Perisphinctes achilles*] indicate the *Chatelaillonensis* subzone (*Cymodoce* zone). Two samples were studied in the Calcaires de Brecquerecque for the

dinocyst associations (Bq 8 and Bq 7; 50.6 m and 52.4 m, respectively, Figures 3 and 4). Both show poorly preserved palynological associations, largely dominated by continental microfossils. In Bq 8, the dinocyst assemblage looks similar to the ones observed in the Caillasses d'Hesdigneul with rare additional specimens of *Cribroperidinium longicorne*. It definitely indicates an age equivalent to or younger than the lowermost *Cymodoce* zone. This age dating is coherent with the ammonites found in the glauconitic limestone.

In the vicinity of the historical type-localities of the Caillasses d'Hesdigneul and Calcaires de Brecquerecque Formations, a sandy facies has been described and named Grès de Questrecque or Sables et Grès de Wirwignes Formation. According to Debrand-Passard et al. [1980], these sandstones are glauconitic with a calcareous cement. They have a limited extension, correspond probably to lenticular bodies, and their total thickness is no more than 6 m. The faunal content is dominated by large bivalves, sea-urchins, gastropods, bryozoans, crustacean and vertebrate remains. The collected ammonites, that have not been revised, range from Late Oxfordian (*Pseudocordata* zone) to early Kimmeridgian (*Cymodoce* zone), including probably species from the *Châtelaillonensis* subzone. These formations have not been observed in the Diffuseur de Boulogne Sud. Nevertheless, if the *Châtelaillonensis* subzone would be confirmed, they could be an equivalent of the glaucontic bed, described at the boundary between the Caillasses d'Hesdigneul and the Calcaires de Brecquerecque.

The following **Argiles du Moulin Wibert** Formation directly overlies the Calcaires de Brecquerecque. The formation reach up to 38 m adding the "Diffuseur de Boulogne Sud outcrop" sedimentary sequences (Figure 3). Because of the absence of clear definition of the lower boundary of the Argiles du Moulin Wibert, we have fixed it at the first thick claystone interval seen in the "Diffuseur de Boulogne Sud" outcrops (64.25 m position, Figure 3). This level is clearly the first fine-grained and dark interval since the Caillasses d'Hesdigneul. The Argiles du Moulin Wibert Formation shows an alternation of gray to black marl and limestone beds, often rich in bivalves [*Nanogyra virgula*, *Trigonia* and *Gervillia*, Mansy et al., 2000]. The dark clays are remarkably laminated between 68 and 75 m (composite section, Figure 3). The Argiles du Moulin Wibert correspond to mid- to outer ramp deposits.

The 5 samples studied in the Argiles du Moulin Wibert from the Diffuseur de Boulogne Sud reveal richer, more diversified and better preserved associations of organic microfossils than those observed in the Caillasses d'Hesdigneul and Calcaires de Brecquerecque Formations. In samples DB 1.20 and 3.2 (64.5 m and 66.8 m, respectively), broken microfossils are still abundant. The diversified dinocyst assemblages are essentially characterised by non-age-diagnostic species with *Cribroperidinium* spp., *Escharisphaeridia* spp., *Systematophor*a spp. (principally *S. areolata*), *Barbatacysta brevispinosa*, *Gonyaulacysta jurassica*, *Endoscrinium luridum*, *Occisucysta balios*, *Rhynchodiniopsis cladophora*, *Tubotuberella apatela*, *Glossodinium dimorphum*, etc. Age diagnostic species are present with *Gochteodinia mutabilis*, *Pareodinia prolongata*, *Dichadogonyaulax ? pannea*, *Cribroperidinium longicorne*. This association definitely indicates that the uppermost *Cymodoce* to lowermost *Mutabilis* zone has been reached (Figure 3). The dinocyst assemblages of samples DB 4.00, DB 5.80 and 8.80 (67.95 m; 69.75 m; 72.7 m, respectively, see Figure 4) are strongly dominated by very abundant *Subtilisphaera ? inaffecta* and *Subtilisphaera ? paeminosa*. Abundance peaks of these species are sporadically recorded throughout the Kimmeridgian from the uppermost *Cymodoce* zone and above. They are generally associated with palynofacies rich in amorphous organic matter. These samples are also characterised by the presence of *Cribroperidinium ? murochoratum*. Ammonite found at the base of the Cap de la Crèche outcrop indicate a late *Mutabilis* zone date [Geyssant et al., 1993, 74.5–76.2 m of the composite section, see Figure 3]. Above, *Orthaspidoceras orthocera*, *Aulacostephanus cf. calvescens* and *Aulacostephanus eudoxus* testify for the late Kimmeridgian *Eudoxu*s zone, *Orthoceras* subzone (Figure 3). Finally, the Argiles du Moulin Wibert are overlain by the Grès de Conningthun Formation (Figure 3).