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**Disentangling the control of tectonics, eustasy, trophic conditions and climate on
shallow-marine carbonate production during the Aalenian-Oxfordian interval: from the
western France platform to the western Tethyan domain**

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Abstract

The objective of this work is to improve our understanding of the processes controlling changes in the architecture and facies of intracontinental carbonate platforms. We examined the facies and sequence stratigraphy of Aalenian to Oxfordian limestones of western France. Seventy-seven outcrop sections were studied and thirty-one sedimentary facies identified in five depositional environments ranging from lower offshore to backshore. Platform evolution was reconstructed along a 500 km cross-section. Twenty-two depositional sequences were identified on the entire western France platform and correlated with European third-order sequences at the biozone level, demonstrating that eustasy was the major factor controlling the cyclic trend of accommodation. The tectonic subsidence rate was computed from accommodation measurements from the Aalenian to the Oxfordian in key localities. Tectonism controlled the sedimentation rate and platform architecture at a longer time scale. Tectonic subsidence triggered the demise of carbonate production at the Bathonian/Callovia boundary while the uplift made possible the recovery of carbonate platform from Caen to Le Mans during the mid Oxfordian. Topography of the Paleozoic basement mainly controlled lateral variations of paleodepth within the western France platform until the mid Bathonian. A synthesis of carbonate production in the western Tethyan domain at that time was conducted. Stages of high carbonate production during the Bajocian/Bathonian and the middle to late Oxfordian are synchronous with low $\delta^{13}\text{C}$, high eccentricity intervals, and rather dry climate promoting (1) evaporation and carbonate supersaturation, and (2) oligotrophic conditions. Periods of low carbonate production during the Aalenian and from the middle Callovian to early Oxfordian correlate with high $\delta^{13}\text{C}$ and low eccentricity intervals, characterized by wet climate and less oligotrophic conditions. Such conditions tend to diminish growth potential of carbonate platforms. This work highlights the importance of climate control on carbonate growth and demise at large scale in western Tethyan epicontinental seas.

42 **Keywords:** Carbonate platform, Facies, Sequence stratigraphy, Tectonics, Jurassic

1. Introduction

In recent decades, numerous studies have been conducted on Jurassic carbonate platforms of the Western Tethys to characterize their architectures, facies, and discontinuities. They highlighted the importance of interactions among the multiple processes that control the evolution of carbonate depositional systems, that is: (1) eustasy, (2) tectonism in that it modifies accommodation, and (3) environmental conditions including seawater temperature, depth, salinity, chemistry, trophic conditions and productivity, with this last aspect determining the nature of carbonate producers and production rates (Pomar et al., 2001; Brigaud et al., 2009, Carpentier et al., 2010). Deciphering the precise influence of each factor on depositional sequences, on carbonate platform architecture, growth, and demise, and on facies distribution and composition is still a challenge (Mutti and Hallock, 2003; Léonide et al., 2007; Merino-Tomé et al., 2012), especially because accommodation and carbonate production are interdependent factors (Pomar et al., 2001). For instance, intracratonic basins were considered stable until recent studies showed that tectonics influenced sedimentation (Guillocheau et al., 2000; Carcel et al., 2010; Brigaud et al., 2014; Wright et al., 2014). Nevertheless, determining the specific control of tectonics on carbonate platform development is complex, especially because vertical movements are of low amplitude and detected over long wavelengths. Moreover, the control of the inherited basement structure over the architecture of carbonate platform is rarely discussed (Allenbach et al., 2002).

Western Tethyan carbonate platforms underwent several stages of growth and demise during the Jurassic, which are particularly well-marked in the Paris Basin (Brigaud et al., 2014). However, no large-scale synthesis of such changes in sedimentation patterns and facies has been conducted, while it could provide new insights on the main factors controlling the type of carbonate producers and production rate.

67 From the Aalenian to the Oxfordian (about 17 My, Gradstein et al., 2012), a vast carbonate
68 platform developed in western France. Several stratigraphic studies based on the distribution
69 of ammonite and brachiopod species provide a precise and reliable biostratigraphic
70 framework within which to study the evolution of this platform at the biozone level. However,
71 such studies remain limited to specific geographic areas or stages (Caen to Alençon: Dugué,
72 1989; Rioult et al., 1991; Pr  at et al., 2000; Dugu  , 2007; Poitiers region: Mourier, 1983;
73 Lorenz, 1992; Gonnin et al., 1992, 1993, 1994; Lenoir, 2012; Saint-Maixent l'  cole to
74 Montbron: Foucher, 1986; Faugeras, 1988; Branger, 1989). The western France platform has
75 tremendous potential for improving our understanding of Jurassic intracratonic carbonate
76 systems because (1) it offers a continuous record of 17 My that can be studied through
77 numerous outcrops and boreholes with a good time control based on biostratigraphy, (2) it
78 rests upon a highly structured Hercynian basement, and (3) it has never been studied as a
79 whole.

80 The first objective of this work is to reconstruct changes in facies and architecture of the
81 western France platform and to determine the respective influences of eustasy, tectonics,
82 environmental conditions, and the topography of the Paleozoic basement on platform
83 evolution. The second objective is to compare our results at broad scale with other platforms
84 in western Tethyan epicontinental sea. Facies were described and classified so as to define
85 depositional environments. A 500 km-long north–south cross-section from Deauville to
86 Montbron is examined within a sequence stratigraphy framework to model the evolution of
87 the platform from the Aalenian to the Oxfordian. Four accommodation curves are established
88 to quantify the amplitude of vertical movements and precisely identify tectonic control over
89 the evolution of this intracontinental carbonate platform. A synthesis of sedimentation
90 patterns in western Tethyan domain during the Middle Jurassic and the Oxfordian is

conducted and a large-scale model for western Tethyan carbonate platforms evolution is provided.

2. Geological setting

The Paris and Aquitaine Basins are two intracontinental sedimentary basins filled with Triassic to Quaternary deposits. They developed respectively over a Cadomian and Variscan basement (Paris Basin, Guillocheau et al., 2000) and a Variscan basement (Aquitaine Basin, Biteau et al., 2006). The study area stretches from Deauville, in the northwestern Paris Basin, to Angoulême, in the northern Aquitaine Basin, along an approximately 500-km transect (Fig. 1). From Aalenian to Oxfordian times, western France was positioned at subtropical latitudes (20–30°N) and was covered by a shallow epicontinental sea. Sediments are predominantly composed of shallow marine carbonates deposited over a vast platform open to the Atlantic, Tethys, and Arctic oceans (Fig. 2A-B; Enay and Mangold, 1980; Thierry and Barrier, 2000).

Several studies of ammonite and brachiopod fauna have been conducted for Middle and Late Jurassic outcrops in areas around Caen (Rioullet et al., 1991), Argentan (Kuntz et al., 1989; Ménillet et al., 1997; Moguedet et al., 1998), Poitiers (Gabilly et al., 1978; Mourier, 1983; Cariou and Joubert, 1989a; Lorenz, 1992), and between Saint-Maixent l'École and Montbron (Cariou et al., 1973; Foucher, 1986; Faugeras, 1988; Branger, 1989; Cariou et al., 2006). They have made it possible to define a precise and reliable biostratigraphical framework at the ammonite biozone level (Fig. 3). The stratigraphic framework is briefly described for the five areas of our study, displaying numerous outcrops and various facies: Caen, Argentan/Alençon, Poitiers Saint-Maixent-l'École, and Montbron. Readers should refer to Mégnien and Mégnien (1980) for a detailed description of lithostratigraphic units of the study area.

The Caen area was more or less isolated from the Paris Basin during the Trias and at the onset of the Jurassic, and remained separated from Argentan by emergent basement reliefs until the

116 end of the Bathonian (Enay and Mangold, 1980; Dugué, 2007). Around Caen, the Bajocian to
117 Oxfordian succession includes two major episodes of carbonate platform growth, (1) from the
118 late Bajocian (*parkinsoni* Zone) to the late Bathonian (*discus* Zone) and (2) from the mid
119 (*densiplicatum* Zone) to late Oxfordian (*glosense* Zone; Fig. 3, Rioult et al., 1991). From the
120 late Bajocian to the late Bathonian, bioclastic facies rich in echinoderms (*Calcaires de Caen*,
121 *Calcaires de Creully*, *Calcaires de Ranville* Formations), bryozoans (*Calcaires de Lagrune*
122 Formation), and sponge bioconstructions (*Caillasses de Basse-Ecarde* Formation) dominated.
123 The middle to upper Oxfordian deposits display ooid- and coral-dominated facies (*Calcaires*
124 *d'Auberville*, *Calcaires oolithiques de Trouville*, *Coral Rag* Formations; Fig. 3; Rioult et al.,
125 1991). The Aalenian to late Bajocian (*garantiana* Zone) was, like the Toarcian, a period of
126 low carbonate production, with highly condensed ferruginous levels (*Oolithe ferrugineuse*
127 *aalénienne*, *Couche verte*, *Conglomérat de Bayeux*, *Oolithe de Bayeux* Formations, Rioult et
128 al., 1991). A carbonate platform demise occurred from the very late Bathonian (*discus* Zone)
129 to late early Oxfordian (*cordatum* Zone), a period characterized by clayey deposits (*Argiles de*
130 *Lion*, *Marnes d'Escoville*, *Marnes d'Argences*, *Marnes à Belemnopsis latesulcata*, *Marnes et*
131 *calcaires sableux de Crevecoeur*, *Marnes de Dives*, *Marnes de Villers*, *Oolithe ferrugineuse*
132 *de Villers* and *Argiles à Lophogregarea* Formations; Fig. 3).

133 The area from Argentan to Alençon formed a small basin, separated from Caen by emersive
134 basement reliefs (Dugué, 2007). Detrital deposits formed during the Aalenian (*Sables et*
135 *graviers de Tessé* Formation), displaying brachiopods and ammonites (*Graphoceras* sp.,
136 *Graphoceras cornu*) from the *murchisonae* and *concaum* Zones (Fig. 3; Juignet et al., 1984).
137 During the Bajocian to late Bathonian (*discus* Zone), a bioclastic to oolitic carbonate platform
138 grew (*Oolithe à pentacrines*, *Oolithe de Vilaines-la-Carelle*, *Calcaires d'Ecouché*, *Calcaires*
139 *de Sarceaux* and *Calcaires d'Argentan* Formations; Fig. 3; Juignet et al., 1984; Kuntz et al.,
140 1989). The very late Bathonian (*discus* Zone), Callovian, and early Oxfordian deposits are

141 characterized by clays to sands (*Marnes de Montcel*, *Marnes du Chevain*, *Oolithe de Suré*,
142 *Marnes et calcaires sableux*, *Oolithe ferrugineuse de Chemilli*, *Marnes de Montarlo*, *Sables*
143 *de Saint-Fulgent*, *Marnes à Pernes*, *Sables de Mortagne* Formations; Fig. 3 ; Ménillet et al.,
144 1997). The mid to late Oxfordian limestone displays ooid and coral rich facies (*Calcaires*
145 *coralliens de Mortagne*, *Calcaires à Astrates*; Fig. 3; Moguedet et al., 1998).

146 Around Poitiers, the marl/limestone alternations (*Calcaires argileux d’Airvault* Formation) of
147 the early Aalenian pass upwards into bioclastic to oolitic limestones (*Calcaires finement*
148 *dolomitiques à silex*, *Calcaires roux bioclastiques à oncolithes*, *Calcaires dolomitiques à*
149 *bioclastiques de Poitiers*, *Calcaires graveleux de Poitiers*, and *Pierre des Lourdines*
150 Formations; Fig. 3 ; Mourier et al., 1986 ; Cariou and Joubert, 1989a). There is a sedimentary
151 gap between the late Callovian and the late early Oxfordian (*athleta*, *lamberta* and *mariae*
152 Zones; Cariou and Joubert, 1989a). Middle and upper Oxfordian deposits are composed of
153 crinoid limestones (*Pierre grise de Bonnillet*, *Calcaires crinoïdiques* Formations) and clayey
154 sedimentary sets (*Banc de Pierre sublithographique*, *Calcaires argileux et glauconieux de*
155 *Mirebeau* Formations; Fig. 3 ; Cariou and Joubert, 1989a).

156 The Saint-Maixent-l’École area was located on a relatively low-energy platform at the margin
157 of the *Golfe Charentais* basin during the Mid Jurassic (Enay and Mangold, 1980). The Saint-
158 Maixent-l’École area is dominated by marl/limestone alternations overlying the Aalenian
159 (*Marnes bleues* Formation) and from the early Callovian to the late Oxfordian
160 (*macrocephalus* to *bimmamatum* zones; *Calcaires argileux de Pamproux*, *Marnes de Velluire*,
161 *Pierre chauffante*, *Marnes gris-bleues à ammonites pyriteuses*, *Marnes grises à spongiares*,
162 *Marnes Schisteuses* and *Calcaires blancs de Fors* Formations; Cariou et al., 2006). The
163 Bajocian and Bathonian limestones are characterized by bioclast-rich facies (*Calcaires*
164 *ponctués de Saint-Maixent*, *Calcaires à silex* Formations; Cariou et al., 2006).

In the Montbron area, in the western part of the high-energy Central Platform (Figs 2A and 3), dolomite (*Dolomies de Montbron* Formation) and shallow carbonate facies (*Calcaires de Combe Brune*, *Calcaires de Saint-Sauveur*, *Calcaires de Vilhonneur*, *Calcaires crayeux à stromatolithes de Montbron*, *Calcaires oolithiques et coralliens de Garat* Formations; Foucher, 1986; Le Pochat et al., 1986) were deposited from the Bajocian to Oxfordian. The biostratigraphy of brachiopod faunas (Foucher, 1986) reveals a sedimentary gap during the early Callovian. The Aalenian deposits are characterized by clay and marl facies (*Argiles et marnes grises* Formation).

3. Material and methods

3.1. Sedimentology

This study is based on the detailed examination of 77 outcrop sections lying between the cities of Deauville and Montbron. Observations were completed with data from previous works carried out on 13 outcrop sections (Foucher, 1986; Dugué, 1989; Louail et al., 1989; Maire, 1983; Rioult et al., 1991) and 37 boreholes (Guyader et al., 1970; Bourgueil et al., 1971; Roger et al., 1979; Rioult and Doré, 1989; Ménillet et al., 1999 and from borehole data of the French Geological Survey available online <http://infoterre.brgm.fr/>, Fig. 1). Outcrop sections were logged in detail: lithology, texture (Dunham, 1962; Embry and Klovan, 1971; Insalaco, 1998), allochem content, and sedimentary structures were reported. A total of 268 thin sections were examined to determine the microfacies using a polarizing microscope. The proportion of facies components (bioclasts and non-bioclastic elements), texture, granulometry, grain sorting, and early cement types were characterized in each thin section. We followed the definition (1997) of James for photozoan and heterozoan grain associations. Photozoan grain association is rich in hermatypic corals, chlorophytes, benthic foraminifera and non-bioclastic components as ooids, peloids and aggregates. Heterozoan facies association displays abundant rhodophytes, molluscs, echinoderms and bryozoans.

Transitional facies designates grain associations in which neither heterozoan or photozoan producers are prevailing.

3.2. Sequence stratigraphy

Following Embry's definition (2009), outcrop sections and boreholes were interpreted in terms of sequence stratigraphy to establish a stratigraphic cross-section. In this sequence stratigraphy model, units are bounded either by a subaerial unconformity (SU) when the surface was exposed, or by a maximum regressive surface (MRS) when the surface was not exposed. Maximum regressive surfaces, also called transgressive surfaces (Van Wagoner et al., 1988) or flooding surfaces (Homewood et al., 1992), coincide with shifts in stacking patterns between shallowing-upward and deepening-upward trends, and correspond to the shallowest depositional environment recorded within a sequence (Embry, 2009). Maximum flooding surfaces (MFSs) mark a shift between deepening-upward and shallowing-upward trends, and correspond to the deepest facies encountered within a sequence. Subaerial unconformities or maximum regressive surfaces form sequence boundaries (SBs). Depositional sequences are composed of transgressive and regressive systems tracts (TSTs and RSTs). The transgressive systems tract is characterized by retrograding architectures, with more distal facies upward and the regressive systems tract is characterized by prograding architectures, with more proximal facies upward.

3.3. Decompacted depth, accommodation, subsidence, and tectonic subsidence calculation

Decompacted depth, also called total subsidence, corresponds to the thickness of sediments after decompaction (Steckler and Watts, 1978; Allen and Allen, 2005). Goldhammer (1997) demonstrates that, in mud-supported carbonates at least, compaction mainly occurs during shallow burial with 100 to 400 m overburden. Considering that all the formations of the Middle and Upper Jurassic were buried beneath more than 500 m of sedimentary deposits, the following compaction factors were used for the entire sedimentary series: 1.2 for grainstones,

1.5 for packstones, 2 for wackestones, 2.5 for mudstones, and 3 for marls (Hillgärtner and Strasser, 2003).

Accommodation space can be defined as the sum of the decompacted thickness of sediments and of paleodepth variations (Robin et al., 2000). For each facies, paleodepths were estimated based on the examination of sedimentary structures and fossil fauna (especially corals, Lathuilière et al., 2005). The classic wave zonation is used, considering depths of 10–15 m for the fair-weather wave base and more than 40 m for the storm wave base (Walker and James, 1992; Sahagian et al., 1996).

Subsidence corresponds to the increase in accommodation that is not due to eustasy, and so created by basement movements. It was calculated by subtracting eustasy variations from accommodation using the eustasy curve of Haq et al. (1987). The curve was placed in the European context of third-order sequences as defined by Hardenbol et al. (1998b). Although there is debate about this curve (Miller et al., 2005), it is the only eustasy curve precise enough to estimate eustatic variations at the time resolution used in this study, and so the only curve that can be used to reconstruct subsidence variations at the third-order sequence scale. Current criticisms of Haq's charts claim that it overestimates the amplitude of eustatic variations. In Cretaceous and Cenozoic times, Rowley et al., (2013), based on worldwide continental flooding, have identified large overestimations of the magnitude of variations and restored elevations of eustatic level. No reassessment of the kind has yet been published for the Jurassic, but this could be a major bias in estimates of subsidence amplitudes. However, as the eustasy values subtracted from the measured accommodation are all from the same chart (Haq, 1987), this misestimate may affect the amplitude but not the trend. We therefore focus mainly on the trend and variations between sites.

Tectonic subsidence is independent of the isostatic adjustment due to sediment deposition or paleodepth variations. It was calculated using the equation of Steckler and Watts (1978):

$$Y = S \left(\frac{\rho_m - \rho_b}{\rho_m - \rho_w} \right) - \Delta SL \left(\frac{\rho_m}{\rho_m - \rho_w} \right) + Wd$$

Y is tectonic subsidence, S is decompacted sediment thickness, ρ_m is mantle density, ρ_b is mean sediment density, ρ_w is water density, ΔSL is eustasy variation, and Wd is paleodepth variation. Mean densities of 3.3 g.cm⁻³, 2.6 g.cm⁻³, and 2.4 g.cm⁻³ were used for mantle rocks, carbonates, and marls respectively.

Decompacted sediment thickness, accommodation, subsidence, and tectonic subsidence values were calculated for each third-order sequence top, corresponding to maximum regressive surfaces, and with an average time step of 0.8 My (Gradstein et al., 2012), to reconstruct sequence evolution over the Aalenian to Oxfordian time interval.

Uncertainties in accommodation, subsidence, and tectonic subsidence calculation may be due to uncertainties in the estimates of (1) the decompacted sediment thickness, (2) paleodepth, and (3) eustasy (for subsidence and tectonic subsidence only). Uncertainties in the decompacted sediment thickness depend on the chosen compaction law (Hillgärtner and Strasser, 2003). Uncertainties in paleodepth estimates are 60 m +/-15 m for the lower offshore, 30 m +/-10 m for the upper offshore, 10 m +/-5 m for the shoreface and the lagoon, and 0 m to 10 m above sea level for continental environments. A +/-5 m uncertainty was used to take into account reading precision of the curve by Hardenbol et al. (1998b). However, as explained above, the eustasy variations used (Haq, 1987) are probably overestimated and the subsidence and tectonic subsidence curve should not be regarded as absolute values but as trends.

4. Results

4.1. Sedimentary Facies

Thirty-one different facies were identified in the limestones under study. The facies were grouped into five positions within the downdip profile (Fig. 4): (1) the lower offshore for facies deposited below the storm wave base, (2) upper offshore for facies deposited between

the storm wave base and the fair-weather wave base, (3) shoal/barrier environments for wave- and tide-dominated facies deposited above the fair-weather wave base, (4) lagoon to intertidal environments for most mud-supported carbonate rocks deposited in calm and shallow environments, and (5) backshore for facies deposited in sebkha, brackish, or continental environments, above high tides. Observations and descriptions are summarized in Table 1. Five synthetic sedimentological logs synthesize the succession of Aalenian to Oxfordian deposits in the Caen, Alençon, Poitiers, Saint-Maixent-l'École, and Montbron areas (Fig. 5).

4.1.1. Lower offshore: facies F1a to F1f

Claystones and marls with micritic limestone alternations (F1a-b-c, Fig. 6A-B), ferruginous ooid wackestones to packstones (F1d, Fig. 6C-D), ferruginous oncoid floatstones (F1e, Fig. 6C-E-F), and glauconitic to phosphatic bioclastic wackestones to floatstones (F1f, Fig. 6G) are present in the lower offshore. Fauna are composed of ammonites, belemnites, bivalves, brachiopods, benthic and planktonic foraminifers, sponge spicules, ostracods, echinoderms, dinoflagellates, serpulites, and gastropods. Bioturbation is frequent and trace fossils abundant (*Chondrites*, *Thalassinoïdes*, *Walthonensis*; Dugué, 1989). Ferruginous oncoids of facies F1e are composed of microstromatolitic iron mats dominated by filamentous bacteriae and fungi living below the photic zone in dysaerobic waters (Préat et al., 2000). The very fine grain size, the absence of sedimentary structures, the absence of scleractinian corals that are typical of the euphotic zone, the abundant bioturbation, and the presence of ammonites and belemnites indicate a very calm depositional environment, probably below the storm wave base (Pomar, 2001; Lathuilière et al., 2005).

4.1.2. Upper offshore: facies F2a to F2f

Mostly bioclastic limestones, intercalated with thin marl interbeds are present in the upper offshore environments (Fig. 7A). Six facies were identified: (1) alternations of marl and echinoderm/peloid packstones to grainstones (F2a, Fig. 7A-B), (2) alternating marls and

bivalve/brachiopod wackestones to packstones (F2b, Fig. 7C), (3) marl/ooid grainstone alternations (F2c), (4) sponge wackestones to floastones (F2d, Fig. 7D-E), (5) sheetstone to platestone facies with lamellar corals, and (6) sponge bioconstructions in marls (F2e-f, Fig. 7F). The dominant fauna is composed of echinoderms, bivalves, sponges, lamellar microsolenid corals, brachiopods, bryozoans, and foraminifers. It indicates normal oxygenation and salinity conditions. The dominance of lamellar microsolenid corals argues for an environment located within the photic zone. In the eastern Paris Basin, similar coral associations developed in paleodepths ranging between 20 m and 40 m during the Oxfordian (Lathuilière et al., 2005). The upper surface of the limestone beds is often bioturbated by vertical burrows filled in with the overlying clays. The accumulation of fragmented bivalve shells forming shell-graded layers (F2a-b), gutter casts (F2a-b-c, Fig. 7A), hummocky cross-stratification (HCS, F2b), and upturned sponges (F2c) suggests that sedimentation was under storm influence in the upper offshore between the storm wave base and the fair-weather wave base.

4.1.3. Shoreface: facies F3a to F3l

Twelve facies are distinguished in shoreface environments: (1) very fine peloidal grainstones (F3a, Fig. 8A), (2) superficial ooid grainstones (F3b), (3) bivalve grainstones to rudstones (F3c, Fig. 8B), (4) bioclastic peloidal grainstones (F3d, Figs 8C and 9A), (5) quartz bioclastic sands to sandstones (F3e, Fig. 9B), (6) sponge bioconstructions in bioclastic grainstones (F3f, Fig. 9C), (7) mixstone to domestone coral bioconstructions (*Isastrea*, *Thecosmilia*, Rioult et al., 1989) in oolitic grainstones (F3g), (8) echinoderm grainstones (F3h, Figs 8D and 9D), (9) bryozoan grainstones to rudstones (F3i, Fig. 8E), (10) ooid grainstones to sands (F3j, Figs 8F and 9E-F-G), (11) lithoclast-ooid grainstones to rudstones (F3k, Figs 8G and 9F), (12) lithoclast-oyster calcareous conglomerates (F3l, Figs 8H and 9H). The presence of grainstone to rudstone textures, common low-angle large-scale clinobeds (Fig. 9A), tabular to trough

cross bedding in dunes (Figs. 9B and G), erosive channels (Fig. 9A), wedges in clinobedded oolitic grainstones (Fig. 9F), and herringbone cross bedding suggests a high-energy wave- or tide-influenced environment located above the fair-weather wave base. This is congruent with the mixstone to domestone texture of coral bioconstructions and with the occurrence of the coral genera *Isastrea* and *Thecosmilia*, which characterize paleodepths between 20 m and 0 m in the eastern Paris Basin during the Oxfordian (Lathuilière, 2005).

4.1.4. Lagoon and intertidal environments: facies F4a to F4d

Four facies are distinguished in : (1) coral bioconstructions (mixstones to domestones) in micritic limestones (F4a), (2) bioclastic/peloid/quartz mudstones (F4b, Fig. 10A), (3) pellet/peloid grainstone/packstones (F4c, Fig. 10B), and (4) oncoid-oid rudstones to packstones associated with grapstones and lithoclasts (F4d, Fig. 10C-D-E). In these mud-dominated facies, the fauna is mainly composed of bivalves, corals, gastropods, and miliolids. Brachiopods, bryozoans, and echinoderms occur in low numbers. From Argentan to the Alençon area, these facies may be directly transgressive on the basement highs and alternate with oolitic shoal deposits (Fig. 10F). The dominance of peloid to oncoid facies and the presence of miliolids and well-preserved gastropods (especially nerineids) argue for protected lagoonal environments. However, washover deposits in facies F4b are characteristic of events of high-hydrodynamism (storms probably). Tangential cross bedding in dunes, and grain-supported to mud-supported textures in facies F4c and F4d indicate variable hydrodynamic conditions. Microbialites and microbial peloids are common in facies F4c and F4d (Fig. 10C). Microstalactitic and meniscus cements also occur in both facies (Fig. 10D); they are characteristic of cementation occurring in a vadose diagenetic environment. The local occurrence of birdseyes (Fig. 10E) and of planar-bedding in facies F4c and F4d indicate that they can form in intertidal environments.

4.1.5 Supratidal to continental environments: facies F5a to F5c

Three facies can be present in supratidal to continental environments: (1) dolomitic facies (F5a, Fig. 10G), (2) lignite-rich facies (F5b), and (3) paleosoil layers (F5c). The dolomitic facies (F5a, Fig. 10G), exclusively present at Montbron, includes stromatolites (Le Pochat et al., 1986). It is characteristic of supratidal environments of high salinity or evaporation rates present in sabkha environments. The lignite facies (F5b) consists of organic matter rich deposits, of very fine grain size (silt), and displays characeae gyrogonites and ostracods (Foucher, 1986) suggesting a very calm and protected brackish depositional environment. Paleosoils (F5c) are described by Dugué (1989) and Ménillet et al. (1999) around Caen and Argentan. They are composed of silts, clays, and quartz grains of about 0.1 mm diameter. The occurrence of characeae gyrogonites and roots suggests environments of coastal plain deposits (Dugué, 1989).

4.2. *Facies architecture and depositional sequences*

The spatial distribution and temporal evolution of the facies defined above is described below. Twenty-two transgressive–regressive cycles were identified between the early Aalenian and the late Oxfordian, whose maximum flooding surfaces are underlined by clays (Figs 5 and 11). Considering a time range of about 17 My for the entire interval (Gradstein et al., 2012), a rough estimate of the average duration of each cycle comes to 0.8 My, which is close to the duration range of third-order cycles as reported by several authors (Haq et al., 1987; Hardenbol et al., 1998a; Schlager, 2004). Moreover, it corresponds to a multiple of 0.4 My, which is the duration of Earth's eccentricity cycle, often considered as the controlling factor for third-order sequences (e.g. Strasser et al., 2000).

These cycles are arranged into lower-order cycles from an Aalenian regressive hemicycle topped by the maximum regressive surface Bj1 (Caen) or Bj3 (Montbron); a Bajocian–Bathonian cycle topped by the maximum regressive surface Bt2 (Caen) of Bt4 (Montbron;

maximum flooding surface *zigzag*); and a Callovian–mid Oxfordian cycle until the maximum regressive surfaces Ox6 (maximum flooding surface *mariae* or *tenuiserratum*).

A constant characteristic of the western France platform throughout the Aalenian to Oxfordian interval is the presence of clayey lower offshore environments from La Flèche to Mirebeau, where sedimentation only occurred during sequences MJIV, MJVII, LJV I and LJVII (Figs 11 and 12).

4.2.1. Aalenian to early Bathonian: detrital to bioclastic ramp (sequences MJI to MJVIII)

This interval contains eight third-order sequences from Deauville to Montbron (Figs 5 and 11): MJI (Middle Jurassic I, *opalinum* Zone), MJII (*opalinum* to *murchisonae* Zones), MJIII (*bradforensis* to *concovum* zones), MJIV (*discites* and *laeviuscula* Zones), MJV (*propiquans* and early *humphriesianum* Zones), MJVI (late *humphriesianum* and *niortense* Zones), MJVII (*parkinsoni* Zone), and MJVIII (*zigzag/progracilis* Zones). The Aalenian to early Bathonian is characterized by ramp geometries that are either detritic (Aalenian) or bioclastic (echinoderms, bivalves, and sponge bioherms; Bajocian/early Bathonian; Figs 11 and 12A to D). The *zigzag* Zone maximum flooding surface is marked by an increase in paleodepth leading to large-scale retrogradations and maximum expansion of clayey facies in the study area (Figs 5, 11, and 12D).

Offshore environments dominate from Argentan to Deauville, where a ramp deepens northward. Sequence MJI consists in 1 meter of ferruginous oncoid facies (F1d, *Oolithe ferrugineuse aalénienne* Formation, *opalinum* Zone) and is capped with marly to silty limestones of sequences MJII to MJIV (facies F1c, *Malière* Formation, *murchisonae* to *concovum* Zones, Figs 5, 11, and 12A). Sequences MJV and MJVI are located in a condensed succession composed of glauconitic limestones (F1f, *Couche verte* Formation, *propiquans* Zone), oncoid ferruginous facies (F1e, *Conglomérat de Bayeux* Formation, *humphriesianum* zone), and ooid ferruginous facies (F1d, *Oolithe ferrugineuse de Bayeux* Formation,

389 *garantiana* to *niortense* Zones, Figs 5, 11, and 12B). Sequence MJVIII is marked by a mid
390 ramp rich in sponges that progrades northward (F2d, *Calcaires à spongiaires* Formation, Figs
391 5A, 11, and 12C). Around Caen, the maximum regressive surface between sequences MJVII
392 and MJVIII (Bj5) is characterized by upper offshore sponge facies sharply overlain by lower
393 offshore marl/limestone alternations of sequence MJVII (F1a-b, *Marnes de Port-en-Bessin*
394 Formation, Figs 5D, 11, and 12D).

395 Over the Aalenian to early Bathonian, the shallowest environments were located on
396 Ordovician basement highs, between Argentan and Le Mans. For the Aalenian, facies are
397 clastic sands with rare ammonites (*Graphoceras* sp. and *Graphoceras cornu*) characterizing
398 the *concaum* Zone (facies F3e-l, *Sables et graviers de Tessé* Formation, Figs 5B, 11, and
399 12A). Sequence MJIII is bounded at the top by a maximum regressive surface marked by a
400 perforated hardground with encrusting bivalves, also characterizing a sedimentary gap that
401 occurs during sequences IV to VI (Bj1, Figs 5, 11, and 12B). Over sequence MJVII, basement
402 highs are covered with oolitic sands to grainstones (F3j, *Oolithe de Vilaines-la-Carelle*
403 Formation, Figs 5B, 11, and 12C) that prograde toward Saumur. These shallow oolitic facies
404 were dated to the *niortense* and *parkinsoni* Zones based on ammonites *Pseudogarantiana* sp.
405 and *Parkinsonia cf parkinsoni* respectively. At the top of sequence MJVII, the maximum
406 regressive surface Bt5 is underlined by (1) a lignite layer attesting to emersion at Argentan
407 (French Geological Survey, <http://infoterre.brgm.fr/>) and (2) a perforated hardground
408 encrusted with oysters around Le Mans, which also marks a sedimentary gap of sequence
409 MJVIII (Juignet et al., 1989).

410 From Saumur to Poitiers, a ramp gently shallowed southward from lower offshore to
411 shoreface environments, dominated by echinoderms and bivalve mud-supported facies (F2a-b,
412 *Calcaires dolomitiques à bioclastiques de Poitiers*, *Calcaires graveleux de Poitiers*, and
413 *Calcaires à silex* Formations; Figs 5C, 11, and 12a to D). Maximum regressive surfaces are

marked by bioclastic to superficial ooid grainstones at Poitiers changing to micritic limestones toward Saumur (Aa1 to Bt1; F3b-h, F2a-b, *Calcaires roux bioclastiques à oncolithes* and *Calcaires graveleux de Poitiers* Formations; Figs 5 and 11). Sequence MJVI is condensed from Mirebeau to Saint-Maixent-l'École.

Depositional environments deepen again towards Saint-Maixent-l'École and Ruffec, where upper offshore bioclastic mud-supported facies to lower offshore marls and glauconitic limestones were deposited (F2b, F1f, and F1b, *Calcaires ponctués de Saint-Maixent*, *Banc pourri* and *Marnes bleues* Formations, Figs 5D, 11, and 12A to D).

Towards Ruffec then Montbron, the ramp became shallower during the Aalenian to early Bajocian with the deposition of upper offshore detrital to bioclastic facies (sequences MJII to MJV, Figs 11, 12A, and B). Paleodepth decreased abruptly from offshore to shoreface, marking the platform edge around Montbron over sequences MJV to MJVIII. An oolitic shoal protected lagoonal/supratidal environments where dolomite precipitated over the regressive systems tracts of sequences MJV and MJVI (Fig. 11). During sequences MJVII and MJVIII, the lagoon was filled by mud-supported facies. The maximum regressive surfaces Bj3 to Bj5 correspond to periods of maximum expansion of lagoon environments prograding to the northwest during the deposition of regressive systems tracts. The maximum regressive surface at the top of sequence MJVIII (sequence boundary Bt1) is marked by lignite, characterizing subaerial exposure (F5b; Fig. 11; Foucher, 1986).

4.2.2. Mid and late Bathonian: echinoderm/bryozoan ramp from Deauville to Le Mans, oolitic platform at Montbron (sequences MJIX-X-XI).

The middle to late Bathonian is composed of three third-order sequences: MJIX (*subcontractus* to early *morrissi* Zones), MJX (late *morrissi* to *orbis* Zones), and MJXI (early *discus* Zone). Maximum regressive surfaces (Bt2-3-4) are marked either by marine perforated surfaces encrusted with bivalves in upper offshore and shoreface environments, or by exposure surfaces with vadose cements, stromatolites, or lignite levels in shoal and lagoonal

440 environments (Figs 5A-B-E and 11). During sequences MJIX and MJX, an echinoderm-rich
441 shallow ramp, prograding northwards, stretched from Argentan to Deauville (F3h, *Calcaires*
442 *de Saint-Pierre-du-Mont* and *Calcaires de Ranville* Formations, Figs 5A, 11 and 12E). A
443 protected lagoon composed of peloidal mudstones to packstones (F4b-c-d, *Calcaires de*
444 *Valframbert* Formation, Figs 11 and 12E) developed between the basement highs from
445 Argentan to Alençon. Basement highs were overlain by shallow shoreface and lagoonal facies
446 during the Bathonian (Figs 11 and 12A; *Calcaires de Villedieu*, *Calcaires de Valframbert*,
447 *Calcaire et oolithe ferrugineuse à Montlivalentia* Formations; Dassidat et al., 1982; Juignet et
448 al., 1989, Ménillet et al., 1994 and 1997). The brachiopod fauna in the *Calcaires de*
449 *Valframbert* Formation is composed of *Burmihynchia turgida*, *Rhynchonelloidella*
450 *elegantula*, and *Epithyris oxonica* that indicate a mid Bathonian age (*Subcontractus* to *Morrisi*
451 *Zones*; sequence MJIX; Rioult and Fily, 1975; Rioult et al., 1991). The *Calcaire et oolithe*
452 *ferrugineuse à Montlivalentia* Formation displays cephalopods (*Paroecotraustes waageni*,
453 *Grossouvria bathonica*, *Homoepanulites* sp., *Cosmoceras contrarium*, *Opis lorierei*, and *O.*
454 *similis*) and brachiopods (*Rioultina triangularis* and *Avonothyris* sp.) indicating the early late
455 Bathonian, *hodsoni* Zone (sequence MJX; Juignet et al., 1989; Le Gall et al., 1998). The fauna
456 can be used to date the flooding of the basement highs to the mid and late Bathonian,
457 *subcontractus* to *hodsoni* Zones (sequence MJIX and MJX). During sequence XI (*Discus*
458 *Zone*), a flat and shallow bryozoan to bivalve-rich ramp stretched from Deauville to Le Mans
459 (F3i-c; Figs 11 and 12F). Oolitic limestones prograde from Le Mans to La Flèche (Fig. 11).
460 For sequences MJIX and MJXI, a ramp shallowing southward developed between Poitiers and
461 Saumur. Facies alternate between echinoderm to sponge wacke/packstones (sequences MJIX
462 and MJXI; F2a-d; *Calcaires à silex* and *Calcaires graveleux de Poitiers* Formation) and
463 prograding superficial ooid grainstones (sequence MJX and regressive systems tract of
464 sequence MJXI; F3b; *Calcaires graveleux de Poitiers* Formation; Figs 5C-D, 11, and 12E).

465 Another ramp profile deepened southwards from Poitiers (shoreface to upper offshore) to
466 Saint-Maixent-l'École (upper to lower offshore; Figs 11, 12E, and F). Around Montbron,
467 shallow lagoon environments rich in peloids and oncoids (F3b-c-d, *Calcaires de Saint-*
468 *Sauveur* and *Calcaires de Vilhonneur* Formations, Figs 5E, 11, and 12E-F) were edged by
469 ooid/lithoclast wedges prograding to the northwest over the mid to late Bathonian (F3j-k,
470 *Calcaires de Combe Brune* Formation).

471 4.2.2. *Callovian and early Oxfordian: clayey ramp (sequences MJXII-XIII-XIV-V and LJI-II)*

472 The Callovian to early Oxfordian contains six third-order sequences: MJXII (*herveyi* and
473 early *koegini* Zones), MJXIII (late *koegini* and *calloviense* Zones), MJXIV (*jason* and
474 *coronatum* Zones), MJXV (*athleta* and *lamberti* Zones), LJI (*mariae* and early *cordatum*
475 Zones), and LJII (Late *cordatum* Zone). Transgressive systems tracts are characterized by
476 increasingly clayey sedimentation upward, with a gradual disappearance of carbonate beds.
477 The upper reaches of regressive systems tracts are commonly marked by prograding sandy to
478 carbonate deposits until maximum regressive surfaces, corresponding to marine surfaces
479 (Cal1 to Cal4, Ox1), which can display encrusting bivalves and phosphate coatings (Cal4,
480 Foucher 1986), or exposure surfaces, with early meniscus cements (Ox 1; *Sables ferrugineux*
481 *de Varais* Formation; Figs 5 and 11). From Deauville to Le Mans, the study area is dominated
482 by a flat clayey ramp (F1a-b-c; Figs 5A-B-C-D; 11 and 12G). From Mirebeau to Poitiers, a
483 ramp progressively shallowed to upper offshore environments dominated by echinoderm to
484 bivalve wackestones/packstones during Callovian sequences MJXII to MJXIV (F2a-b, *Pierre*
485 *des Lourdines* and *Calcaires argileux de Pamproux* Formations, Figs 5C, 11, and 12G).
486 Sequences MJXV and LJI are missing (gap of the *athleta* to *mariae* Zones) and sequence LJII
487 is condensed in a less than 1 m-thick carbonate level in Poitiers. A ramp gradually deepened
488 from Poitiers to Ruffec, and the paleodepth then abruptly shallowed at Montbron, with the
489 development of a shallow platform lagoon protected by an oolitic shoal over sequence MJXIV

(F3j and F4b; *Calcaires Crayeux à Stromatolithes* de Montbron Formation; Figs 5E, 11, 12G). Brachiopod-based biostratigraphy indicates a gap for sequences MJII and MJXIII (Foucher, 1986), and sequences MJXV to LJI might be missing as well (Figs 5C-D-E and 11).

4.2.3. Middle to late Oxfordian: Coral/ooid platforms development (sequences LJIII-IV-V-VI-VII)

The mid to late Oxfordian interval is composed of five third-order sequences: LJIII (Early *plicatilis* Zone), LJIV (Late *plicatilis* Zone), LJV (*tenuiserratum* Zone), LJVI (*glosense* to early *serratum* Zones), and LJVII (late *serratum* to *rosenkranzi* Zones). Ooid/coral shallow platform geometries predominate, with very steep slopes (Figs 11 and 12H-I).

Transgressive systems tracts are characterized by major retrogradations from Deauville to Argentan, from La Flèche to Le Mans, and from Saint-Maixent l'École to Montbron. The maximum flooding surfaces are marked by the deposition of marl to mud-supported upper offshore facies over the entire study area. Regressive systems tracts are marked by major progradations of lagoonal to shoreface environments from Argentan to Deauville, from Le Mans to Saumur, and from Montbron to Saint-Maixent-l'École (e.g. *Calcaire oolithique de Lisieux* Formation, Fig. 11). Maximum regressive surfaces correspond to periods of maximum expansion of lagoonal and shoreface facies, and may be either marine (Ox4, Ox5 and Ox6) or emersive, with the occurrence of meniscus cements (Ox4, Argentan to Alençon) or soils (Ox6, Caen to Le Mans, Fig. 11 and 12I).

Sequence LJIII occurs only in the northern part of the study area, where it is composed of clayey offshore facies. Over sequence LJIV and LJV, a shallow platform stretches from Caen to Le Mans, where a 100 km-long lagoon developed (F4d and F4a; *Calcaires coralliens de Mortagne* and *Calcaires coralliens de la Ferté-Bernard* Formations; Figs 5A-B, 11, and 12H). An oolitic to coral barrier delimited the northern and southern lagoon (F3a-j, Figs 11 and 12H). During the regressive systems tract of sequence LJVI, cross-bedded sands prograded from Caen towards Deauville (F3e, *Sables de Glos* Formation, Fig. 11). They

change abruptly to lower offshore clays around Deauville (*Argiles de Villers* Formation, Fig. 11). These are overlain by the lagoon, mud-supported facies of sequence LJVII (F5c; *Calcaires à Astrates* Formation; Figs. 5B, 11, 12I; Dugué, 1989; Ménillet, 1999). During sequence LJV, facies changed suddenly from marls (*Marnes à spongiaires* Formation) to fine peloid/echinoderm grainstones between Mirebeau and Poitiers (F3a-h; *Pierre grise de Bonnillet* and *Calcaires crinoïdiques* Formations), and a ramp deepened from Poitiers to Ruffec, where lower offshore facies dominated. Over sequences LJVI and LJVII, lower offshore clayey environments predominate from Saumur to Ruffec (F1c; *Banc de pierre sublithographique*, *Calcaires argileux et glauconieux de Mirebeau*, *Marnes grises à spongiaires* Formations; Figs. 5C, 11, and 12H-I). During the mid/late Oxfordian, the Montbron area saw the emplacement of an ooid/peloidal barrier with coral bioconstructions ahead of a calm lagoon where coral/peloidal mudstones accumulated (F3a-d-j, F4b, *Calcaires oolithiques et coralliens de Garat* Formation, Figs. 5E, 11, and 12H-I).

4.3. *Decompacted sedimentation, accommodation, subsidence, and tectonic subsidence*

- *Early to early mid Aalenian (sequences MJI and MJII)*. This interval is characterized by stable accommodation and near-zero decompacted sediment thickness rates (Figs. 13 and 14). Notable decompacted accumulation (13 m/My) and subsidence rates (5 m/My) are only present in the Poitiers area.

- *Late mid Aalenian to early Bajocian (sequences MJIII to MJV)*. Accommodation and decompacted sediment thickness rates for the entire interval range from 0 m/My in Argentan to 15 m/My in Montbron (Fig. 13). A substantial accommodation rate is only recorded in Poitiers for sequence MJIV (70 m/My, Fig. 14). This interval is marked by a tectonic uplift, synchronous over the entire western France platform (Fig. 13).

- *Late Bajocian to late Bathonian (sequences MJVI to MJXI)*. In this time interval, decompacted sedimentation rates vary from 27 m/My in Poitiers to 46 m/My in Caen, and

accommodation rates vary from 27 m/My in Poitiers to 34 m/My in Argentan (Fig. 13). The highest accommodation rates are recorded for sequence MJXI, with values of 83 m/My in Montbron, 130 m/My in Caen and Poitiers, and 240 m/My in Argentan. Continuous subsidence and tectonic subsidence are recorded in the Argentan, Poitiers, and Montbron areas.

- *Early Callovian (sequence MJXII)*. The Caen and Argentan areas show high rates of decompacted sedimentation (respectively 76 m/My and 65 m/My) and accommodation (104 m/My, Figs 13 and 14), whereas Poitiers and Montbron are characterized by decompacted sedimentation and accommodation rates of about zero. High positive subsidence and tectonic subsidence rates are recorded for Caen and Argentan, whereas negative tectonic subsidence rates characterized the Poitiers and Montbron areas (Fig. 13).

- *Late early Callovian to mid Oxfordian (sequences MJXIII to LJIV)*. Over this interval, high decompacted sedimentation rates (respectively 51 m/My and 58 m/My) and accommodation rates (41 m/My and 46 m/My) are recorded in Caen and Argentan. A negative accommodation rate (-17 m/My) coupled with a high negative tectonic subsidence rate mark an uplift in Caen during sequence LJIV, following a period of relative stability (Figs 13 and 14). Stage 5 is characterized by near-zero rates of decompacted sedimentation, accommodation, and subsidence (Figs 13 and 14). Subsidence and tectonic subsidence curves display negative rates in Poitiers and Montbron over the entire interval. Only sequence MJXIV displays a different pattern in Montbron, with high decompacted sedimentation (154 m/My) and accommodation rates (163 m/My).

- *Late mid to late Oxfordian (sequences LJV to LJVII)*. This last phase is characterized in Caen by high rates of decompacted sedimentation (109 m/My) and accommodation (124 m/My), which correlate with major tectonic subsidence (Figs 13 and 14). In Argentan, stage 6 exhibits low decompacted sedimentation and accommodation rates of 27 m/My and 34 m/My,

and steady tectonic subsidence. The Poitiers area recorded a very high accommodation rate over sequence LJV (192 m/My), contemporaneous with significant tectonic subsidence (Figs 13 and 14). During deposition of sequences LJVI and LJVII, a stable tectonic phase is recorded in Poitiers, where the decompacted sedimentation and accommodation rates are 34 m/My (Figs 13 and 14). Around Montbron, the decompacted sedimentation rate (67 m/My) and accommodation rate (67 m/My) might have been constant over the last stage, and the area was subsiding (Figs 13 and 14).

5. Discussion

5.1. Accommodation changes on the western France carbonate platform – Global and regional trends

Platform architecture and sedimentary dynamics change with time from Deauville to Montbron over the Mid Jurassic and the Oxfordian, raising questions about the factors controlling this evolution. Sedimentary sequences, systems tracts, and platform architectures depend directly on the ratio between accommodation space (A) and sedimentation rate (S); (Jervey, 1988; Schlager, 1993, 2005; Catuneanu et al., 2009). The A/S ratio controls the progradational, aggradational, or retrogradational geometries of sediments. Retrograding structures and facies that are more distal upward mark the transgressive systems tract, when the A/S ratio is higher than 1. Prograding structures and upwardly more proximal facies characterize the regressive system tract, when the A/S is lower than 1. Accommodation space is generated by changes in (1) global eustasy and/or (2) subsidence, the latter being associated with (3) isostatic adjustment due to sediment deposition or paleodepth variation, and with (4) tectonics. At local scale, tectonic subsidence can be explained by syn-sedimentary active faults. Sedimentation rate relates to (1) terrigenous input or to (2) in-situ carbonate production and its redistribution, which is largely influenced by environmental conditions (e.g. trophic conditions and seawater temperature).

Overall eustasy variations in European basins have been modeled by Hardenbol et al. (1998b) and are presented in Figures 13 and 15. Changes in depth, decompacted sediment thickness (observed total subsidence, Steckler and Watts, 1978; Alen and Alen, 2005), accommodation (total subsidence +/- depth variation), subsidence, and tectonic subsidence (Steckler and Watts, 1978; Fig. 13) were reconstructed in four key localities to discuss the factors controlling sediment architectures (Caen, Argentan, Poitiers, and Montbron, Fig. 13). By reconstructing long-distance depositional sequences and dating basement flooding it was possible to reconstruct the ante-Aalenian topography and discuss its influence on platform architecture.

5.1.1. Eustasy as the major control on 3rd-order transgressive–regressive systems tracts

The overall correlation between European third-order sequences and the 22 depositional sequences along with their continuity over the entire western France platform suggests that eustasy is the main factor affecting accommodation variations at the scale of third-order sequences (Hardenbol et al., 1998a, Fig. 15). The maximum flooding surfaces identified were also found in other European basins of similar ages at the biozone scale (Hardenbol et al., 1998a). However, five third-order sequences described in other European basins were not identified in the study area: two within the Bathonian deposits (*zigzag/progracilis* Zones transition and *discus* subzone maximum flooding surfaces), two within the Callovian succession (*koegini* and *lamberti* Zones maximum flooding surfaces), and one within the late Oxfordian (*bimmamatum* Zone; Fig. 15; Hardenbol et al., 1998a). The absence of several European basin sequences from western France can be explained by (1) non deposition/preservation in proximal areas (hardgrounds and exposure surfaces), especially at the Bathonian/Callovian boundary (Figs 5 and 11), and by (2) condensation in deep clay-dominated environments, which is the case for Callovian and early Oxfordian sequences (*koegini*, *lamberti* and *bimmamatum* Zones; Fig. 11).

However, there are significant differences in second-order transgressive–regressive cycles between European basins and the western France platform, but also within the western France platform (Figs 11 and 15). Lateral dissimilarities in sedimentation rate and carbonate production, and the sharp local depth variations recorded over the western France platform cannot have been under global or eustatic control and must be related to local tectonics (Fig. 11).

5.1.2. Tectonics contribution on sedimentation rate, carbonate platform architecture, growth, and demise

Several episodes of facies and platform architecture change are interpreted to be connected with tectonic activity over all or part of western France. The major tectonic uplift, associated with an accommodation rate of about zero, that occurred over the entire study area from the mid Aalenian to the early Bajocian (sequences MJIII to MJV, Fig. 13) corresponds to the Mid-Cimmerian Unconformity, a subtle deformation event identified all around the Paris Basin (Guillocheau et al., 2000; De Graciansky and Jacquin, 2003) and in Western Europe related to North Sea doming (Underhill and Partington, 1993). Eustatic rise between sequences MJIII and MJV was not sufficient to offset the loss of accommodation due to the uplift (Haq et al., 1987). The consequences were the very low sedimentation rates (0 to 15 m/My) and overall shallowing (Figs 11 and 13). Around Montbron, lagoon environments expanded northwards during the *humphriesianum* Zone, marking the regressive maxima of a second-order cycle, and oolitic wedges formed in Poitiers over sequences MJIV and MJV, (Figs 11 and 15). In Caen, uplift was active until the end of sequence MJVII (negative accommodation rate of -17 m/My, Fig. 14) and may have induced the shallowing trend marked by upper offshore sponge facies prograding northwards.

During the late Bajocian and the Bathonian, about 150 m of accommodation space was created, despite a global sea-level fall (Figs 13 and 14; Hardenbol et al., 1998b). This

641 indicates that the western France platform underwent a major phase of tectonic subsidence
642 (estimated at about 100 m considering a sea-level fall of 45 m; Fig. 13; Hardenbol et al.,
643 1998b). The accommodation generated by tectonics, coupled with the subsidence related to
644 sediment loading, made it possible for 100 to 150 m of decompacted carbonates to accumulate
645 (Fig. 13). Over sequences MJIX to MJXI, the Caen and Montbron shallow platforms
646 prograded northwards, indicating that carbonate production was sufficient to fill the
647 accommodation space generated by tectonic subsidence (Fig. 11). Significant variations in
648 decompacted sedimentation/accommodation rate were observed within sequence MJXI
649 between Falaise (decompacted sedimentation/accommodation rate about 36 m/My) and
650 Argentan (about 240 m/My; Gradstein et al., 2012; Figs 11 and 14). This implies a local
651 tectonic subsidence of about 40 m/My in the Argentan area, the remaining subsidence being
652 controlled by sediment loading. Argentan is bordered by three faults affecting the Mesozoic
653 series, which may have controlled this tectonic subsidence for the latest Bathonian: the
654 Montabard-Gouffern fault to the north (Ménillet et al., 1997; Gigot et al., 1999), the
655 Pommereux-Sentilly fault to the west, and the Sées fault to the southwest (Kuntz et al., 1989;
656 Fig.1). The Montabard-Gouffern fault displays a high subvertical dip and a vertical offset of
657 between 30 and 40 m. At its northwestern extremity, Bajocian to Bathonian limestones were
658 brought into contact with Triassic to Ordovician deposits, indicating Bathonian to post-
659 Bathonian activity (Gigot et al., 1999).

660 The early Callovian is marked by a sudden carbonate demise that is commonly explained by a
661 eustatic rise and a consequent extensive drowning event within the Paris Basin (Jacquin et al.,
662 1992, 1998; Jacquin and de Graciansky, 1998; Brigaud et al., 2014). The sudden
663 disappearance of carbonates in favor of clay sedimentation occurred from Deauville to Le
664 Mans during deposition of the early transgressive systems tract of sequence MJXII (Figs 11,
665 12G and 13). The progressive rise in the overall eustatic level, estimated at about 15 m, was

not sufficient to explain sudden shallowing of at least 40 m (Hardenbol et al., 1998b; Figs 11 and 13). From Deauville to Le Mans, the steep deepening resulting in carbonate demise for the earliest Callovian was triggered by prominent tectonic subsidence of an amplitude between at least 35 m in Argentan and 55 m in Caen (Fig. 13). The increased accommodation was then maintained through the Callovian and into the early Oxfordian due to a eustatic rise (Hardenbol et al., 1998b). Several reactivated basement faults affecting the Mesozoic series from Falaise to Alençon may have caused this tectonic subsidence: the Cordey-Ronai, Montabard-Gouffern, Merlerault, Courtomer, and Fresnay-sur-Sarthe faults (Fig. 1). The Merlerault and Courtomer faults display a vertical offset varying between 50 m and 130 m in the Mesozoic succession (Ménillet et al., 1997 and 1998). Northwards, the Cordey-Ronai and Montabard-Gouffern faults affect the Middle Jurassic series with a vertical offset of about 40 m (Ménillet et al., 1998).

In Montbron, the accommodation rate was zero for sequences MJXII and MJXIII over a period of eustatic rise (about +20 m, Figs 13 and 14, Hardenbol et al., 1998b). This implies an uplift, the amplitude of which is estimated at about 40 m, preceding emersion, which occurred during a second-order transgression in European basins, and accounting for the absence of sequences MJXII and MJXIII at Montbron (Fig. 11; Hardenbol et al., 1998a). This local tectonics implies that the sequence boundary between the two complete second-order cycles in western France corresponds to Bt4 in Montbron whereas it corresponds to Bt2 in Caen and Argentan (Figs 11 and 15). In Poitiers and Montbron, the uplift phase remained constant until the end of sequence LJIV (Middle Oxfordian, Fig. 13). The postulated lack of deposition of sequences MJXV to LJIV in Montbron was certainly due to emersion due to uplift. Over sequences LJII to LJIV, uplift in the Poitiers area controlled sedimentation despite global eustatic rise, leading to the non-deposition of sequences LJII and LJIII and to the shallowing-upward trend marked by the deposition of cross-bedded bioclastic grainstones during

691 sequence MJXIV (Figs 11 and 13). From Poitiers to Montbron, the maximum flooding
692 surface of the Callovian–Oxfordian cycle cannot be positioned in the *mariae* Zone as for the
693 Caen and Argentan areas or for European second-order cycles, but is located in the
694 *tenuiserratum* Zone (Figs 11 and 15).

695 In Argentan, the accommodation rate was zero for sequences LJII and LJIII over a period of
696 eustatic rise (about +15 m, Figs 13 and 14, Hardenbol et al., 1998b). This implies an uplift of
697 about 30 m, leading to the progradation of shoreface sands topped by an exposure surface
698 (*Roussier de Gacé* and *Sables ferrugineux de Vairais* Formations, Ox1, Figs 11 and 13). In
699 Caen, drastic shallowing from lower offshore to shoreface between sequences LJII and LJIV
700 during a period of eustatic rise (about +10 m, Hardenbol et al., 1998b) implies a major uplift,
701 of about 40 m (Fig. 13). This early/mid Oxfordian uplift made possible the growth of a
702 shallow carbonate platform prograding northwards during sequence LJIV. This carbonate
703 platform persisted until the end of the Oxfordian from Caen to Le Mans. However, the sharp
704 carbonate demise resulting in the deposition of lower offshore clays and in retrograding
705 environments southwards cannot have been the consequence of the eustatic rise alone (about
706 12 m, Hardenbol et al., 1998b) and must also have been due to intense tectonic subsidence
707 occurring in Deauville over sequences LJIV and LVI (Figs 11 and 13). Deauville is separated
708 from Caen by the Viller-Reux fault which displays a vertical offset of about 55 m and brought
709 Jurassic and Cretaceous series into contact (Fig. 1, Pareyn, 1970). This fault may have been
710 reactivated during the Late Jurassic, causing the major tectonic subsidence recorded in
711 Deauville. The deepening from shoreface to lower offshore around Poitiers during sequence
712 LJIV, in a context of relative eustatic stability (+3 m Hardenbol et al., 1998b), and leading to
713 carbonate demise, was the consequence of sudden and intense tectonic subsidence. This event
714 may have been due to the late Oxfordian reactivation of the Lusignan fault: a 100 km-long
715 basement structure oriented NW–SE and affecting Jurassic series to the north of Poitiers

(Cariou and Joubert, 1989b). In Montbron, the increased accommodation due to gradual and slow tectonic subsidence coupled with a global eustatic rise over sequences LJV to LJVII (Hardenbol et al., 1998b, Fig. 13) accelerated sedimentation and led to the deposition of about 180 m of decompacted carbonates (Figs 11 and 13).

5.2. Basement topography as a major control of paleodepth on the western France carbonate platform

The Jurassic platform of western France developed over a pre-structured bottom surface. This includes basement rocks that are mostly Cambrian and Ordovician quartz sandstones, displaying major paleotopographic changes that can be directly observed in the field (Juignet et al., 1989; M  nillet et al., 1994; Cariou et al., 2006). Post-Variscan relief of the basement has been partly lowered by the deposition of Liassic series, for example in the Montbron area that is filled by about 250 m of Triassic to Liassic deposits (Roger et al., 1979). The topography of the basement was reconstructed for the time interval under study from borehole data with paleobathymetric interpretations (Fig. 12).

Between Argentan and Alen  on, sequences MJI to MJVIII are not found overlying the basement, indicating an emerged area from the early Aalenian to the mid Bathonian (Figs 11 and 12A to D). These areas were flooded over sequences MJI to MJIX, during which shallow environments were essentially located on basement highs: from Argentan to Alen  on and in Poitiers (Fig. 12A to D). From sequence MJI to MJIX, deep platform environments (lower offshore) were located in basement depressions in Caen and from Le Mans to Saumur (Fig. 12A to D).

Over the Aalenian to early Bathonian, the basement topography was the major factor determining lateral variations of paleodepth, as shallow environments were located on basement highs and deeper environments in basement depressions (Fig. 12A to E). From the late Bathonian to late Oxfordian, the basement depressions were filled by sediments and

flattened, and the influence of the basement topography on bathymetries became negligible, except from Le Mans to Saumur, where lower offshore environments persisted (Fig. 12F to I). Local tectonic subsidence and uplifts changed basement topography through time as described in part 4.1.2. However, tectonic movements were rather homogenous across western France through the Aalenian to early Bathonian and the basement topography remained approximately the same (Figs 12A to E and 13). From the late Bathonian to late Oxfordian, local tectonic movements greatly modified the basement topography (Figs 12F to I and 13).

5.3. Growth and demise of carbonate platforms in western Tethyan domain

A bibliographic synthesis of sedimentation in western Tethyan domain was conducted and coupled with our results to propose a model of sedimentary evolution and carbonate production in Western Tethys from Aalenian to Oxfordien (see Table 2 for references and Figure 16 for maps).

Two periods of global carbonate platform growth were identified in Western Tethys in France, England, Spain and Italy platforms during this period: one during Bajocian/Bathonian and the subsequent during middle/late Oxfordian in France, England, Spain, and Italy platforms. In shoreface environments, marked by facies with grainstone texture and cross-bedding, photozoan facies are dominant and include abundant ooids, peloids, and hermatypic corals (Fig. 17A). Heterozoan facies, characterized by the predominance of mollusk, echinoderms and bryozoans (Fig. 17A), are rather found in micritic limestones and limestone/marl alternations forming in offshore environments. However, shallow facies in northern Germany and Scottish Cleveland basin are dominated by sandstones.

Two general period of low carbonate production occurred during the Aalenian and middle Callovian to early Oxfordian intervals. The middle Callovian to early Oxfordian period is marked by thick clayey accumulations in offshore environments. On the contrary, condensed levels, often ferruginous, prevailed during the Aalenian, while thick marly deposits locally

766 formed in Switzerland, Germany and southern Poland. Shallow environments are marked by
767 crossbedded siliciclastic sands (Scotland, northern Germany, and northwestern France) or
768 heterozan to transitional carbonate grain associations (southern France), except in England
769 (London platform) where oolitic grainstones were deposited during the Aalenian. In low
770 latitude areas (Apennines and Apulia platforms in Italy, Morocco) no neat carbonate
771 production demises are recorded during the Aalenian and Callovian to early Oxfordian
772 intervals, which could be the consequence of more favorable environmental conditions for
773 carbonate growth induced by a drier climate, as suggested by Dera et al. (2009) for the early
774 Jurassic.

775 5.4. *A comprehensive model for western Tethyan carbonate platform growth and demise*

776 5.4.1. *High an low eccentricity cycles*

777 Martinez and Dera (2015) synthetized the evolution of $\delta^{13}\text{C}$ measured in well-preserved
778 belemnite rostra over the Jurassic in western European basins (Fig. 15). Changes in carbonate
779 production on western Tethyan platforms during the Middle Jurassic and Oxfordian correlates
780 with stable $\delta^{13}\text{C}$ values as long-term $\delta^{13}\text{C}$ maxima are synchronous with low carbonate
781 production rates (Aalenian and from middle Callovian to early Oxfordian) and long-term $\delta^{13}\text{C}$
782 minima correspond to periods of high carbonate production (Bajocian/Bathonian and from
783 middle to late Oxfordian). Martinez and Dera (2015) interpreted these long-term $\delta^{13}\text{C}$
784 variations as resulting from a 9.1 My eccentricity orbital cycle.

785 5.4.2. *Carbonate production during high-eccentricity intervals*

786 The late Bajocian-Bathonian and middle-late Oxfordian intervals are characterized by clay
787 fraction with small kaolinite amounts in the eastern Paris Basin (0-10%, Pellenard and
788 Deconinck, 2006; Brigaud et al., 2009). Due to relative low burial depth and temperatures that
789 never exceeded 50 °C in this area (Clauer et al., 2007), mineralogical clay associations can be

790 considered as detrital, which can be used as an environmental proxy (Debrabant et al., 1992;
791 Dera et al., 2009). High kaolinite content may indicate either intense chemical weathering of
792 kaolinite soils or reworking of ancient kaolinite-bearing rocks (Chamlet, 1989, Dera et al.,
793 2009), and low kaolinite amount in the Bajocian-Bathonian and middle-late Oxfordian
794 limestones may then characterize an arid climate. This is consistent with results of Ma et al.
795 (2011) who suggested that high eccentricity intervals induced a dry climate disturbed by short
796 episodes of intensive rainfalls and storms. Although these moosonal episodes intensified the
797 net transfer of nutrient, organic carbon and carbonates ions to the ocean, organic carbon burial
798 was prevented because of the prevailing dry climate and the efficient oxidizing conditions in
799 seawater (Fig. 17B; Martinez and Dera, 2015). This lead to (1) an enrichment of seawater in
800 ^{12}C and a consequent decrease of $\delta^{13}\text{C}$ values in the oceanic reservoir, and to (2) carbonate
801 sursaturation in epicontinental seas due to high evaporation (Martinez and Dera, 2015). This
802 model is consistent with the high carbonate production rate recorded in western Tethyan
803 epicontinental seas during the Bajocian/Bathonian and middle/ late Oxfordian intervals. The
804 ratio between photozoan and heterozoan associations is mainly controlled by seawater
805 temperature, trophic conditions, and bathymetry (Fig. 17A; James, 1997, Mutti and Hallock,
806 2003). Photozoan association development is favored by high seawater temperatures
807 (subtropical to tropical, $>18^{\circ}\text{C}$) and low trophic resources (oligotrophic to mesotrophic), but
808 can also be found in temperate waters under oligotrophic conditions (Fig. 17A; Mutti and
809 Hallock, 2003). Heterozoan grain association dominates in warm waters ($>18^{\circ}\text{C}$) under
810 eutrophic conditions or in cool waters ($<18^{\circ}\text{C}$) whatever the trophic conditions. In western
811 Tethyan platforms, during the Bajocian/Bathonian and middle/late Oxfordian, photozoan
812 producers were distributed in shoreface environments, indicating prevailing olitrophic
813 conditions, whereas heterozoan producers are mainly present in offshore environments (Figs.
814 16 and 17B). Nevertheless, heterozoan producers can also be found locally in shallow wave to

815 tide-dominated environments, as in northwestern France during the Bathonian (Fig. 16). This
816 could be induced by local changes in environmental conditions as an increase of trophic
817 inputs or a decrease of seawater temperatures (e.g. Lécuyer et al., 2003).

818 *5.4.3. Carbonate production during low-eccentricity intervals*

819 During the Jurassic, low eccentricity intervals induced wet conditions, which promoted high
820 weathering rates, nutrient inputs, productivity levels, and organic burial in the ocean, and led
821 to an increase of $\delta^{13}\text{C}$ values (Martinez and Dera, 2015). This happened during the Aalenian
822 and from the middle Callovian to early Oxfordian (Fig. 17B; Martinez and Dera, 2015). The
823 high kaolinite ratio in the Paris Basin (> 20% of the clay mineralogical association; Pellenard
824 and Deconinck, 2006; Brigaud et al., 2009), and vascular plant biomarkers used as a proxy for
825 palaeoflora (Hauteville et al., 2006) support enhanced weathering conditions under a humid
826 climate during the middle Callovian to early Oxfordian. Moreover, organic-rich layers are
827 found in Central Atlantic (Dromart et al., 2003) and in the western Tethyan domain (England,
828 Kenig et al., 1994; Saudi Arabia, Carrigan et al., 1995) during the middle Callovian. The
829 Aalenian clay mineralogical association is also dominated by kaolinite in the southern Paris
830 Basin (Delavenna et al., 1989) and in England (Sellwood and Sladen, 1981). The presence of
831 anoxic conditions at the sea bottom is evidenced in southern Poland by the presence of
832 agglutinated foraminifera, but the association with organic-rich deposits is not obvious
833 (Tyszka, 1994; Tyszka and Kaminski, 1995). It is likely that organic carbon was either (1)
834 locked up but disseminated in shelf mudstones and therefore, is not readily identified, (2)
835 stored in deep marine areas or (3) stored in terrestrial settings (Price, 2010). Clay contents and
836 palaeoflora data, as well as evidences of prevailing anoxic conditions at the sea-floor during
837 the Aalenian and from the middle Callovian to early Oxfordian are consistent with the
838 hypothesis of a wet climate during low-eccentricity intervals leading to high nutrient inputs.
839 Such an eutrophication of sea waters is noxious for photozoan carbonate producers and tends

to diminish the growth potential of carbonate platforms (Weissert and Mohr, 1996; Bartolini et al., 1996; Bartolini et al., 1999; Bartolini and Cecca, 1999; Mutti and Hallock, 2003), promoting siliciclastic sedimentation (Figs. 15, 16 and 17B). On the western France platform, decompacted carbonate accumulation rate was over 60 m/My during the Bathonian and middle/late Oxfordian but fell down under 20 m/My at the Aalenian and during the middle Callovian/early Oxfordian interval. The mean biological carbonate content in marls varies from 35% to 20% in the Callovian to early Oxfordian, the lowest values being recorded in the *mariae* Zone (Dugué, 1989), which correlates with the $\delta^{13}\text{C}$ maxima (Martinez and Dera, 2015). Proximal deposits are sandstone or heterozoan to transitional grain associations, whose development is favored by eutrophic conditions (Figs. 16 and 17B). Photozoan facies can develop locally, probably due to local changes in trophic conditions or seawater temperatures (e.g. London platform during the Aalenian). Low sedimentation rates (mainly between 0 and 10 m/My), the abundance of condensed ferruginous deposits and gaps during the Aalenian are the consequence of a decrease of accommodation space related to a global uplift in Western Europe. This event corresponds to the Mid-Cimmerian unconformity (Figs. 16 and 17B; Underhill and Partington, 1993; Guillocheau et al., 2000; De Graciansky and Jacquin, 2003). High clayey sedimentation rates during the middle Callovian to early Oxfordian, generally between 20 and 50 m/My, was allowed by an increase in accommodation space both due to (1) the global eustatic sea-level rise (Hardenbol et al., 1998b) and (2) increase of subsidence rate (Fig. 17B). In western France, the demise of the carbonate platform initiated at the Bathonian/Callovian boundary because of a sharp, local tectonic subsidence, but it persisted in deeper and shallower environments until the middle Oxfordian due to (1) the eutrophic conditions of neritic environments and to (2) the global eustatic sea level rise.

6. Conclusions

Thirty-one facies were characterized in Aalenian to Oxfordian formations of western France, deposited in lower offshore to backshore settings. Changes in platform geometry and facies were identified over a time interval of ~17 Ma (Aalenian to Oxfordian) and across a long distance (500 km). A high-resolution correlation scheme was realized at the ammonite biozone scale in a sequence stratigraphy framework. Twenty-two third-order depositional sequences have been defined. They are bounded by maximum regressive surfaces that are either marine (e.g. perforated hardgrounds encrusted with bivalves) or emersive (microstalactitic, meniscus, and dogtooth cements, lignite, paleosoils). Depositional sequences of the western France platform correlate at the ammonite biozone scale with the third-order sequences of European basins, indicating that eustasy is the major factor controlling third-order transgressive–regressive systems tracts (Hardenbol et al., 1998a). Topography of the Paleozoic basement controlled lateral depth variations until the mid Bathonian, resulting in the development of (1) shoreface environments from Argentan to Le Mans and in Poitiers and to (2) lower offshore environments in Caen and from La Flèche to Mirebeau. Evolution of tectonic subsidence was reconstructed in four key areas of western France: Caen, Argentan, Poitiers, and Montbron. A major uplift was identified to have occurred over the middle/late Aalenian and the early Bajocian. It corresponds to the Mid-Cimmerian Unconformity. Throughout the Middle Jurassic and Oxfordian, tectonics controlled sedimentation rate and platform architecture; it also triggered two major phases of carbonate growth and demise. Uplifts favoured low sedimentation rates (i.e. late Aalenian to early Bajocian), the occurrence of exposure surfaces and prograding systems, as observed around Montbron during the early to mid Callovian. Tectonic subsidence promoted high sedimentation rates, for example during the Bathonian over the entire western France platform (decompacted sedimentation rate about 70m/my) or during the mid/late Oxfordian around Montbron (decompacted sedimentation rate about 70m/my). The major carbonate production demise at the Bathonian/Callovian boundary

889 was triggered by sharp tectonic subsidence of about 35 m to 55 m, causing an increase in
890 paleodepths. In contrast, the development of the prograding mid-Oxfordian carbonate
891 platform in north-western France was made possible by the tectonic uplift that generated
892 shallow-water and favourable conditions for carbonate growth. A synthesis of sedimentation
893 on western Tethyan platforms was conducted. Two periods of high carbonate production
894 during the Bajocian/Bathonian and middle/late Oxfordian, with prevailing photozoan
895 producers in shallow-marine environments, are synchronous with high eccentricity intervals
896 marked by low $\delta^{13}\text{C}$ values (Martinez and Dera, 2015). Carbonate production was promoted
897 by dry climates disturbed by short episodes of intensive rainfalls and storms leading to (1)
898 high evaporation and carbonate sursaturation and (2) low trophic conditions. Both periods of
899 low carbonate production during the Aalenian and from the middle Callovian to early
900 Oxfordian are synchronous with low eccentricity intervals and high $\delta^{13}\text{C}$ values. This was
901 marked by a wet climate and the eutrophication of epicontinental seas that tend to diminish
902 growth potential of western Tethyan carbonate platforms. The uplift of the Aalenian
903 (corresponding to the Mid-Cimmerian unconformity) lead to the formation of sedimentation
904 hiatus and condensed levels, whereas the global eustatic sea-level rise of the Callovian-early
905 Oxfordian generated an important accommodation space and favored high sedimentation
906 rates.

907 The present work shows that the development of carbonate platforms in intracontinental
908 settings was influenced by multiple factors, each one exerting a precise control on
909 sedimentation. In particular, we highlighted the control of basement topography on lateral
910 depth variations and the influence of local and regional tectonics on carbonate platform
911 architecture, even in intracontinental basins. Finally, climate evolution in western Tethys was
912 controlled by long-term eccentricity variations and can be related to the major stages of

913 carbonate platform growth and demise and largely influenced the producer types (photozoan
914 *versus* heterozoan).

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Figure captions

Fig. 1. Location of the study outcrops, boreholes, and faults with presumed Mid to Late Jurassic activity on a simplified geological map of western France.

Fig. 2. A. Global palaeogeographical map of the Callovian simplified from R. Blakey's maps (<http://cpgeosystems.com>) **B.** Location of the study area on a palaeogeographical map of the Western Tethys during the Callovian. **C.** Location of the study area during the Bathonian in a paleogeographic reconstruction (modified from Brigaud et al., 2009; based on Enay and Mangold, 1980; Ziegler, 1988; Thierry and Barrier, 2000; Hendry, 2002) **D.** Location of the study area during the Oxfordian in a paleogeographic reconstruction (modified from Strasser et al., 2015; based on Enay and Mangold, 1980; Ziegler, 1988; Thierry and Barrier, 2000).

Fig. 3. Schematic lithostratigraphic illustration of the north–south transect of the study area. Biostratigraphic ammonite zonation from Gradstein et al. (2012). Standard European sequences from Hardenbol et al. (1998a).

Fig. 4. Location of the Middle Jurassic to Oxfordian facies with allochem distribution on a downdip profile from the lower offshore to backshore in the western Paris to northern Aquitaine basins. The range of variation of the fair-weather wave base and storm-wave base depths are estimated from Walker and James (1992), Lathuilière et al. (2005), and Sahagian (1996).

Fig. 5. Synthetic sedimentological log with geological stages, ammonite biozones, and biostratigraphic data (ammonites, brachiopods, and foraminifers), lithostratigraphic formations,

946 carbonate textures, depositional environments, third-order sequence stratigraphy and
 947 stratigraphic locations of outcrops and samples. The parts of the logs not observed in the field
 948 have been completed using boreholes and descriptions from the literature. **A.** Synthetic
 949 sedimentological log of the Caen region, completed from Rioult et al. (1989, 1991) and
 950 Maurizot et al., 2000). **B.** Synthetic sedimentological log of the Argentan to Alençon region,
 951 completed from Kuntz et al. (1989) and Moguedet et al. (1998). **C.** Synthetic log of the Poitiers
 952 region completed from Mourier et al. (1986) and Cariou and Joubert, (1989a). **D.** Synthetic log
 953 of the Saint-Maixent-l'École region, completed from Cariou et al. (2006). **E.** Synthetic log of
 954 the Montbron region, completed from Le Pochat et al. (1986).

955

956 **Fig. 6. A.** Clay/marl to marl/micritic limestone alternations – F1a-b-c – Port-en-Bessin (6) –
 957 *Marnes Port-en-Bessin* Formation, sequence MJVIII. **B.** Mudstone – F1c – Pierre Levée
 958 quarry (54) – *Banc de Pierre sublithographique* Formation, sequence LJVI. **C.** Historic
 959 Bajocian stratotype with ferruginous oncoids (On.), bivalves (Bi.), belemnites
 960 (Be.), stromatolites (Str.) and sponges (Sp.) – Sainte-Honorine-des-Pertes (5) – *Malière*
 961 Formation (F1c), *Couche verte* Formation (F1f), *Conglomérat de Bayeux* Formation (F1e),
 962 *Oolithe ferrugineuse de Bayeux* Formation (F1d), *Calcaire à spongiaires* Formation (F2d),
 963 sequences MJIV to MJVI. **D.** Ferruginous oolite (Oo.) wackestone with bivalves (Bi.) – F1d –
 964 Sainte-Honorine-des-Pertes (5) – *Oolithe ferrugineuse de Bayeux* Formation, sequence MJVI.
 965 **E.** Microbialites – F1e – Feuguerolles quarry (18) – *Conglomérat de Bayeux* Formation,
 966 sequence MJV. **F.** Ferruginous oncoid (On.) floatstone with belemnites (Be.) and bivalves
 967 (Bi.) – F1e – Feuguerolles quarry (18) – *Oolithe ferrugineuse aalénienne* Formation,
 968 sequence MJII. **G.** Glauconite (Gl.) wackestone with quartz (Qz), ferruginous ooids (Oo.),
 969 echinoderms (Ech.) and bivalves (Bi.) – F1f – Sainte-Honorine-des-Pertes (5) – *Couche verte*
 970 Formation, sequence MJIV.

971

972 **Fig. 7. A.** Marl/echinoderm limestone alternation with gutter clasts – F2a – Tracy-sur-Mer (7)
973 – *Calcaire de Saint-Pierre-du-Mont* Formation, sequence MJVIII. **B.** Echinoderm (Ech.)
974 packstone with peloids (Pe.) – F2a – Cintheaux quarry (20) – *Calcaire de Caen* Formation,
975 sequence MJVIII. **C.** Bivalve (Bi.) packstone – F2b – Moulin à Vent quarry (65) – *Calcaires*
976 *argileux de Pamproux* Formation, sequence MJXIII. **D.** Wackestone with sponge spicules
977 (Spi.) – F2d – Limalonges quarry (71) – *Calcaires à spongiaires et silex* Formation, sequence
978 MJX. **E.** Sponge (Sp.) limestone – F2d – Sainte-Honorine-des-Pertes (5) – *Calcaire à*
979 *spongiaires* Formation, sequence MJVI. **F.** Coral (boundstone) in marls – F2e – Belle-Eau
980 quarry (32) – *Caillasse de Belle-Eau* Formation, sequence MJXI.

981

982 **Fig. 8. A.** Very fine-grained peloidal (Pe.) grainstone with superficial ooids (Su. oo.),
983 foraminifers (Fo.), echinoderms (Ech.), and bivalves (Bi.) – F3a – Bonnillet quarry (55) –
984 *Pierre des Lourdines* Formation, sequence LJIV. **B.** Bivalve (Bi.) and brachiopod (Br.)
985 grainstone – F3c – Villedieu-lès-Bailleul quarry (25) – *Calcaires de Villedieu* Formation,
986 sequence MJIX. **C.** Bioclastic peloidal (Pe.) grainstone with crinoids (Cr.), undifferentiated
987 echinoderms (Ech.), gastropods (Ga.), bivalves (Bi.), serpulites (Se.) and a well-developed
988 isopachous early cement (Iso. Ce.) – F3d – Belle-Eau quarry (32) – *Calcaires de Belle-Eau*
989 Formation, sequence MJX. **D.** Echinoderm (Ech.) grainstone with crinoids (Cr.) and bivalves
990 (Bi.) – F3h – Vierville-sur-Mer (3) – *Calcaires de Saint-Pierre-du-Mont* Formation, sequence
991 MJVIII. **E.** Bryozoan (Br.) rudstone – F3i – Luc-sur-Mer (10) – *Calcaires de Langrune*
992 Formation, sequence MJXI. **F.** Ooid (Oo.) sand with crinoids (Cr.) – F3j – Fay quarry (41) –
993 *Oolithe de Vilaines-la-Carelle* Formation, sequence MJVI. **G.** Lithoclast (Li.) rudstone with
994 bryozoans (Br.), echinoderms (Ech.), ooids (Oo.), peloids (Pe.), and microbial peloids (Mi.
995 Pe.) – F3k – Les Aucrais quarry (21) – *Calcaires de Bon-Mesnil* Formation, sequence MJIX.

996 **H.** Detritic conglomerate with quartz (Qz), lithoclasts (Li.), feldspaths (Fe.), and echinoderms
997 (Ech.) – F3l – Fay quarry (41) – *Sables et graviers de Tessé* Formation, sequence MJIII.

998

999 **Fig. 9. A.** Channel and large-scale low-angle clinobeds – F3d – Belle-Eau quarry (32) –
1000 *Calcaires de Belle-Eau* Formation, sequences MJIX and MJX. **B.** Cross-bedding
1001 stratifications – F3e – Fay quarry (41) – *Sables et graviers de Tessé* Formation, sequence
1002 MJIII. **C.** Sponge bioherms on bryozoan rudstones – F3f and F3i – Saint-Aubin-sur-Mer (8) –
1003 *Caillasses de Basse-Ecarde* Formation, sequence MJXI. **D.** Trough cross-bedding
1004 stratifications with alternating fine and coarse levels in echinoderm grainstone – F3h –
1005 Creully quarry (12) – *Calcaires de Creully* Formation, sequence MJVIII. **E-F.** Wedge of
1006 clinobedded oolitic grainstone foresets – F3j and F3k – Combe Brune quarry (84) – *Calcaires*
1007 *de Combe Brune* Formation, sequences MJIX to MJXI. **G.** Trough cross-bedded oolitic
1008 grainstone – F3j – Cosses Noires quarry (85) – *Calcaires Vilhonneur* Formation, sequence
1009 MJX. **H.** Lithoclast-oyster rich conglomerate, probably storm deposit – F3l – Fay quarry (41)
1010 – *Sables et graviers de Tessé* Formation, sequence MJIII.

1011

1012 **Fig 10. A.** Bivalve (Bi.) mudstone – F4b – Garat Quarry (86) – *Calcaires coralliens et*
1013 *oolithiques de Garat* Formation, sequence MJXII. **B.** Peloidal (Pe.) and oolitic (Oo.)
1014 packstone to grainstone with quartz (Qz) – F4c – Boitron quarry (39) – *Calcaires de*
1015 *Valframbert* Formation, sequence MJIX. **C.** Lithoclast (Li.) and oncoid (On.) rudstone with
1016 miliolids (Mi.), ooids (Oo.), echinoderms (Ech.), and microbial peloids (Pe.) – F4d –
1017 Vilhonneur quarry (83) – *Calcaires de Vilhonneur* Formation, sequence MJIX. **D.** Lithoclast
1018 (Li.) grainstone with meniscus cements (M. Ce.) – F4d – Combre Brune quarry (84) –
1019 *Calcaires de Combe Brune* Formation, sequence MJXI. **E.** Birdseye in a lithoclast (Li.)
1020 grainstone with ooids (Oo.), peloids (Pe.), and foraminifers (Fo.) – F4d – Chez Trappe quarry

1021 (87) – *Calcaires de Saint-Martial* Formation, sequence MJIX. **F.** Unconformity of Bathonian
 1022 limestone on Brioverian flyschs – F4b, F4c and F3j – Boitron quarry (39) – *Calcaires de*
 1023 *Valframbert* Formation, sequence MJIX. **G.** Dolomite formed in a presumably supratidal
 1024 protected environment, as evidenced by the presence of stromatolites (Le Pochat et al., 1986)
 1025 – F5a – La Rochebertier (82) – *Dolomies de Montbron* Formation, sequence MJV. **H.**
 1026 Lithoclast (Li)/Ooid (Oo) grainstone with gastropods (Ga) displaying an erosive surface (Er.
 1027 S.) with microbial encrusting (Mi. En.), fibrous (Fi. Ce.), microstalactitic (Mi. Ce.) and
 1028 meniscus cements (Me. Ce.) – F3h – Les Aucrais quarry (21) – *Calcaires de Bon-Mesnil*
 1029 Formation, maximum regressive surface Bt2.

1030

1031 **Table 1.** Position on the downdip profile, lithofacies, non-bioclastic and bioclastic
 1032 components, sedimentary and biogenic structures, granulometry, sorting, and
 1033 paleoenvironmental interpretations of the Middle Jurassic and Oxfordian rocks of western
 1034 France.

1035

1036 **Fig. 11.** Correlation diagram of the Middle Jurassic and the Oxfordian in western France on a
 1037 Deauville–Montbron transect. This illustration is composed of 61 outcrop sections studied in
 1038 this work completed by previous descriptions of 13 outcrop sections (Foucher, 1986 – outcrops
 1039 72, 73, 88, and 90; Dugué, 1989 – outcrops 16, 17, and 40; Louail et al., 1989 – outcrop 47;
 1040 Rioult et al., 1991 – outcrops 1, 4, 8, 10, 13, and 15) and 37 boreholes (Guyader et al., 1970 –
 1041 borehole A; Bourgueil et al., 1971 – borehole AB; Roger et al., 1979 – borehole AK; Rioult
 1042 and Doré, 1989 – borehole B; Ménillet et al., 1999 – borehole C; and <http://infoterre.brgm.fr/> –
 1043 remaining boreholes). Correlations are based on biostratigraphy (ammonite, brachiopod and
 1044 foraminifer associations) and 22 recognized stratigraphic cycles (MJI to LJVII) delimited by
 1045 sequence boundaries (Aa1 to Ox7).

1046

1047 **Fig. 12.** Facies distribution on carbonate architecture morphology of western France in nine
1048 successive steps from Aalenian to Oxfordian in a third-order sequence stratigraphy framework.
1049 Potentially active faults, Paleozoic basement and Lias deposits are represented to illustrate the
1050 multiple influences on carbonate platform/ramp morphology. **A.** Ramp geometry marked by the
1051 dominance of silty to sandy facies – sequences MJII and MJIII, Aalenian. **B.** Ramp geometry
1052 with condensed ferruginous facies in Caen and bioclastic upper offshore facies from Poitiers to
1053 Montbron – sequence MJV, Bajocian. **C.** Predominance of a storm dominated ramp with
1054 sponges, although oolitic facies develop in shallow environments (Montbron, Le Mans) –
1055 sequence MJVII, Bajocian. **D.** Bioclastic ramp rich in echinoderms – sequence MJVIII,
1056 Bathonian. **E.** Shallow ramp with echinoderm facies from Deauville to Le Mans, oolitic
1057 platform in Poitiers and Montbron – sequence MJX, Bathonian. **F.** Shallow ramp with
1058 bryozoan facies and sponge bioherms from Deauville to Le Mans, upper offshore bioclastic
1059 ramp in Poitiers, oolitic shallow platform in Montbron– sequence MJX, Bathonian. **G.** Lower
1060 offshore clayey ramp from Deauville to Mirebeau, bioclastic upper offshore in Poitiers; lagoon
1061 protected by an oolitic shoal in Montbron – sequence MJXIV, Callovian. **H.** Shallow protected
1062 platforms in Argentan and Montbron, separated by clayey deposits in lower offshore
1063 environments – sequence LJV – Oxfordian. **I.** Emerged platform with soil horizon in Argentan
1064 separated from a shallow platform in Montbron by clayey deposits in lower offshore
1065 environments – sequence LJVI – Oxfordian.

1066

1067 **Fig. 13.** Synthetic chronostratigraphic diagram showing western France sequences, eustatism
1068 curve (Hardenbol et al., 1998b), bathymetry, decompacted sediment thickness, accommodation,
1069 subsidence, and tectonic subsidence curves in Caen/Deauville, Argentan, Poitiers, and
1070 Montbron.

1071

1072 **Fig. 14.** Accommodation rate for each western France sequence in Caen/Deauville, Argentan,
1073 Poitiers, and Montbron for the Aalenian to Oxfordian interval.

1074

1075 **Fig. 15.** Synthetic chronostratigraphic diagram from the Aalenian to Oxfordian showing
1076 western France sequences, second- and third-order European cycles/sequences (Hardenbol et
1077 al., 1998b), $\delta^{13}\text{C}$ isotopic curve (Martinez and Dera, 2015), and semi-quantitative estimation of
1078 decompacted carbonate production, carbonate producers, and depositional profile on the
1079 western France platform.

1080

1081 **Fig. 16.** Evolution of sedimentation and dominant carbonate producers during the Middle
1082 Jurassic and the Oxfordian in western Tethyan platforms represented in its regional
1083 palaeogeographical context. Data are compiled from our results (western France) and literature
1084 (France, Germany, Spain, England, Scotland, Poland, Italy, Switzerland, Morocco; see table 2
1085 for references).

1086

1087 **Fig. 17. A.** Qualitative proportions of allochems in heterozoan and photozoan grain
1088 associations (modified from James, 1997), and schematic representation of the distribution of
1089 Photozoan– Heterozoan carbonates with respect to common temperature/nutrient gradient
1090 (modified from Mutti and Hallock, 2003). The width of the bars indicates estimated
1091 abundance of each association from 0–100%. **B.** Scheme of palaeoenvironmental,
1092 sedimentation and carbonate production changes linked to $\delta^{13}\text{C}$ isotopic signal (maxima and
1093 minima of eccentricity), local and global tectonism, and eustasy.

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1442 416.

W0°30'

E1°30'

Rouen

Deauville

Caen

Argentan

Alençon

Le Mans

La Flèche

Tours

Saumur

Mirebeau

Poitiers

Saint-Maixent-
l'École

Ruffec

Montbron

20 km



Middle/Late Jurassic outcrops

Major rivers

Study outcrops

Boreholes



STUDY AREA

FAULTS

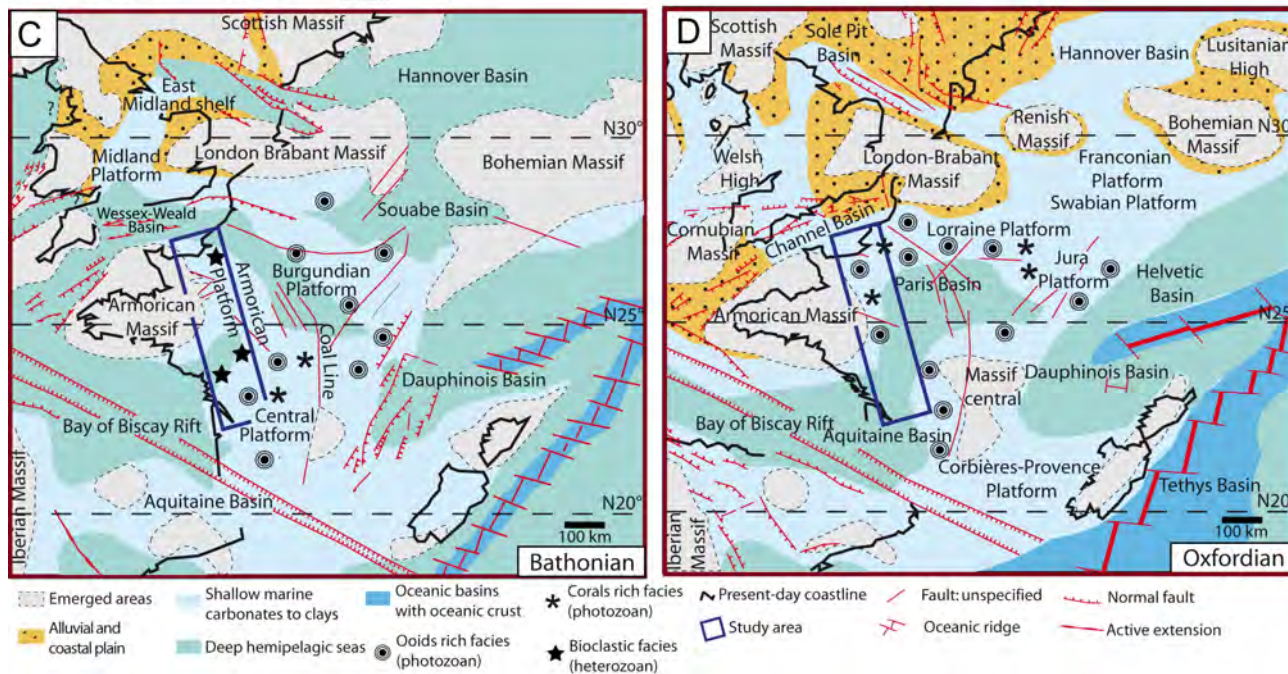
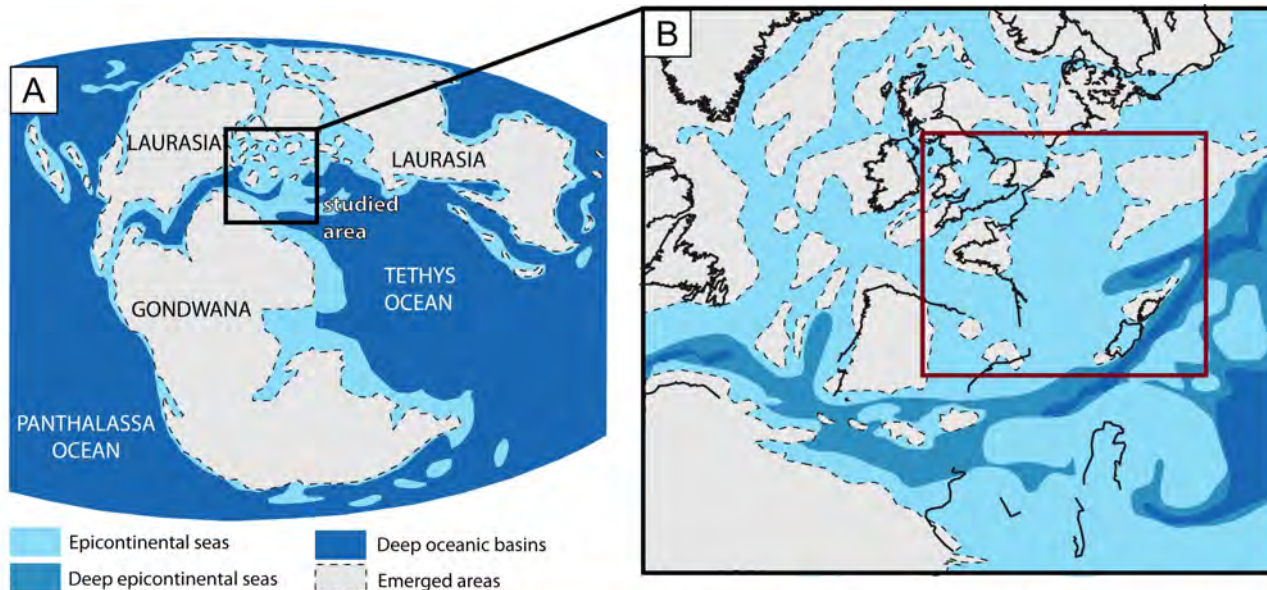
- | | |
|-----------------------------|-----------------------------|
| 1- Viller-Reux fault | 5- Merlerault fault |
| 2- Cordey-Ronai fault | 6- Sées fault |
| 3- Montabard-Gouffern fault | 7- Courtomer fault |
| 4- Pommereux-Sentilly fault | 8- Fresnay-sur-Sarthe fault |
| 9- Lusignan fault | |

BOREHOLES

A- Borehole 496	N - 02881X0507/S3	Z - 05661X0013/F
B- Touffreville n°1	O - 02885X0001	AA - 05666X0060/92-3
C- Borehole 3-13	/SA13G1	AB - BOREHOLE 1-10
D - 01468X0002/F1	P - 03222X0013_F	AC - 06125X0018/F
E - 01475X0011/SA1	Q - 03588X0053F	AD - 06371X0047/F
F - 01762X0052/F2-93	R - 03577X0002SF	AE - 06372X0052/F
G - 01771X0001/F1	S - 03922X0029F1	AF - 06612X0065/F
H - 01778X0011/S-8	T - 04244X0010/F	AG - Montignac borehole
I - 01776X0008/S1A	U - 04554X0029/F	and 04554X0030/PZ
J - 02131X0019/S8	V - 05124X0510/F	AH - 07093X0069/F
K - 02522X0001F1	W - 05137X0016/F	AI - 07094X0044/F
L - 02521X0004/F1	X - 05394X0003/F	AJ - 07102X0009/S1229
M - Valframbert borehole	Y - 05662X0010/F	AK - Tour Blanche borehole (n°758-2-7)

STUDY OUTCROPS

1- Saint-Pierre-du-Mont	30- Tourelle	60- Brifou
2- Grandcamp-Maisy	31- Ecouché	61- Moulin
3- Vierville-sur-Mer	32- Belle-Eau	62- Lombarderie
4- Hennequeville	33- Montcel	63- Smarves
5- Sainte-Honorine-des-Pertes	34- Joué-en-Plain	64- Grande Palisse
6- Port-en-Bessin	35- Croix de Libaron	65- Moulin à Vent
7- Tracy-sur-Mer	36- Merlerault	66- Bel-Air
8- Saint-Aubin-sur-Mer	37- Chailloué	67- Sainte-Eanne
9- Vaches Noires	38- Gaprée	68- Valence-en-Couhé
10- Luc-sur-Mer	39- Boitron	69- Cinq Coux
11- Lion-sur-Mer	40- Bellevue	70- Celle-sur-Belle
12- Creully	41- Fay	71- Limalonges
13- Escoville	42- Appenai-sous-Bellême	72- Puybautier
14- Grandouet	43- Bray	73- Champagne-Mouton
15- Argences	44- Ségrie	74- Nanteuil-en-Vallée
16- Saint-Aubin-sur-Algot	45- Vouvraysur-Huisne	75- Ebréon
17- Pont de Glos	46- Fourneau	76- Maine-de-Boixe
18- Feugerolles	47- Noyen-sur-Sarthe	77- Ravaud
19- Roche Blain	48- Motte-Bourbon	78- La Rochette
20- Cintheaux	49- Saint Laon	79- Taponnat
21- Les Aucrais	50- Marnes	80- Lavaud
22- Les Pierrières	51- Guichardièr	81- La Grande Fosse
23- Epaney	52- La Momie	82- Rochebertier
24- Les Sablonnières	53- Ayron	83- Vilhonneur
25- Villedieu-lès-Bailleul	54- Pierre Levée	84- Combe Brune
26- Tournai-sur-Dives	55- Bonnillet	85- Cosses Noires
27- Habloville	56- Dignes	86- Garat
28- Aubry-sur-Exmes	57- Rocher du Porteau	87- Chez Trappe
29- Grands Chemins	58- Béruges	88- Javerlhac (JE)
	59- Grotte à Calvin	89- Javerlhac (JL)
		90- Saint-Martial



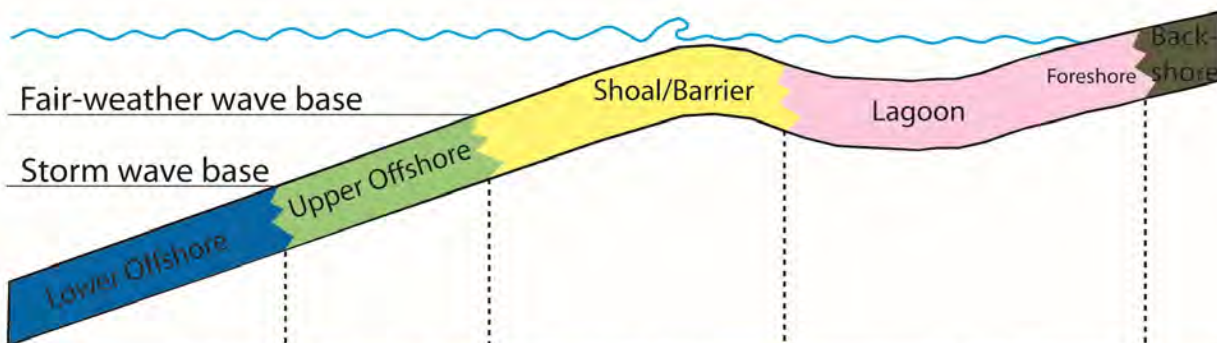
SERIES	STAGES	ZONES			WESTERN PARIS BASIN SEQUENCES (this study)	STANDARD EUROPEAN SEQUENCES (Hardenbol et al, 1998a)	SEDIMENTARY FORMATIONS					SOUTH
		TETHYAN	SUBBOREAL	BOREAL			CAEN	ARGENTAN	POITIERS	SAINT-MAIXENT l'ÉCOLE	MONTBRON	
LATE JURASSIC	OXFORDIAN	LATE	bimamm- atum	pseudo- cordata	LJVII	Ox8	Erosion	Calcaires à Astartes	Calcaire argileux et glauconieux de Mirebeau	M. Schisteuses et Calcaires blancs de Fors	Calcaires oolithi- ques et coralliens de Garat	
			bifur- catus	cautisnigrae		Ox7	Argiles de Villers		Calcaires crinoïdiques	Marnes grises à spongiaires		
			transver- sarium	pimulus		Ox6	Calcaire gréseux d'Hennequeville		Banc de Pierre sublithographique			
						Ox5	Coral Rag		Pierre grise de Bonnillet			
						Ox4	Calcaire oolithique de Trouville					
		MIDDLE		plicatilis	LJV	Ox3	Calcaire d'Auberville					
					LJIV	Ox2	Argiles à Lophogregaria					
					LJIII		Oo. ferrugineuse de Villers					
			EARLY	cordatum	LJI			Sables de Mortagne				
				mariae		Ox1	Marnes de Villers	Marnes à Pernes	Marnes gris-bleues à ammonites pyriteuses			
MIDDLE JURASSIC	CALLOVIAN	L.		lamberti	MJXV	Ox0	Marnes de Dives	Sables de Saint-Fulgent		Pierre chauffante	Calcaires de Vilhonneur	
				athleta		MJXIV	Call5	Ma. ca. et sa. de Crevecoeur	Marnes de Montarlo			Marnes de Velluire
				coronatum			Call4	Marnes, à Belemnopsis latesulcata	Oolithe ferrugineuse de Chemilli			
							Call3	Marnes d'Argences	Marnes et calcaires sableux d'Assé-le-Riboul	Pierre des Lourdines		Calcaires argileux de Pamproux
							Call2	Marnes d'Escoville				
		EARLY	gracilis	jason calloviense	MJXIII	Call1	Argiles de Lion	Oolithe de Suré				
				koegini		Call0	Calcaires de Lagrune	Marnes du Chevain				
						Bat5	Caillasse de Basse-Ecarde	Marnes de Montcel				
						Bat4	Calcaires de Ranville	Calcaires d'Argentan				
						Bat3	Calcaire de Blainville	Caillasses de Belle-Eau				
	BAJOCIAN	L.		herveyi	MJXII	Bat2	Caillasses de Fontaine-Henry	Calcaire de Sarceaux	Cal. graveleux de Poitiers	Calcaires à silex	Calcaires de Combe Brune	
						Bat1	Calcaires de Creully		Calcaires graveleux de Poitiers			
							Calcaire de Caen					
							Marnes de Port-en-Bessin					
		EARLY		zigzag	MJVIII	Bj5	Couches de Passage	Calcaire d'Ecouché	Calcaires dolomitiques à bioclastiques de Poitiers	Calcaires à silex		
						Bj4	Calcaire à spongiaires	Oolithe de Vilaines-la-Carelle				
						Bj3	Oolithe ferrugineuse de Bayeux	Oolithe à pentacrines				
						Bj2	Conglo. de Bayeux					
						Bj1	Couche verte					
	AALÉNIAN	MIDDLE		parkinsoni	MJVII	Aa2	Calcaire à spongiaires		Calcaires roux bioclasti- ques à oncolithes	Marnes bleues	Argiles et marnes grises	
				garantiana			Oolithe ferrugineuse de Bayeux		Calcaires finement dolomitiques à silex			
				niortense								
				humphriesianum								
				propinquans								
	EARLY	L.		laeviuscula	MJIII							
				discites								
				concevum								
				bradforensis								
				murchisonae								
	EARLY	EARLY		opalinum	MJII							

DEPOSITIONAL
ENVIRONMENTS

- continental
- lagoon
- shoal
- mid-ramp
- outer ramp

DEPOSITIONAL ENVIRONMENTS

continental
lagoon
shoal
mid-ramp
outer ramp

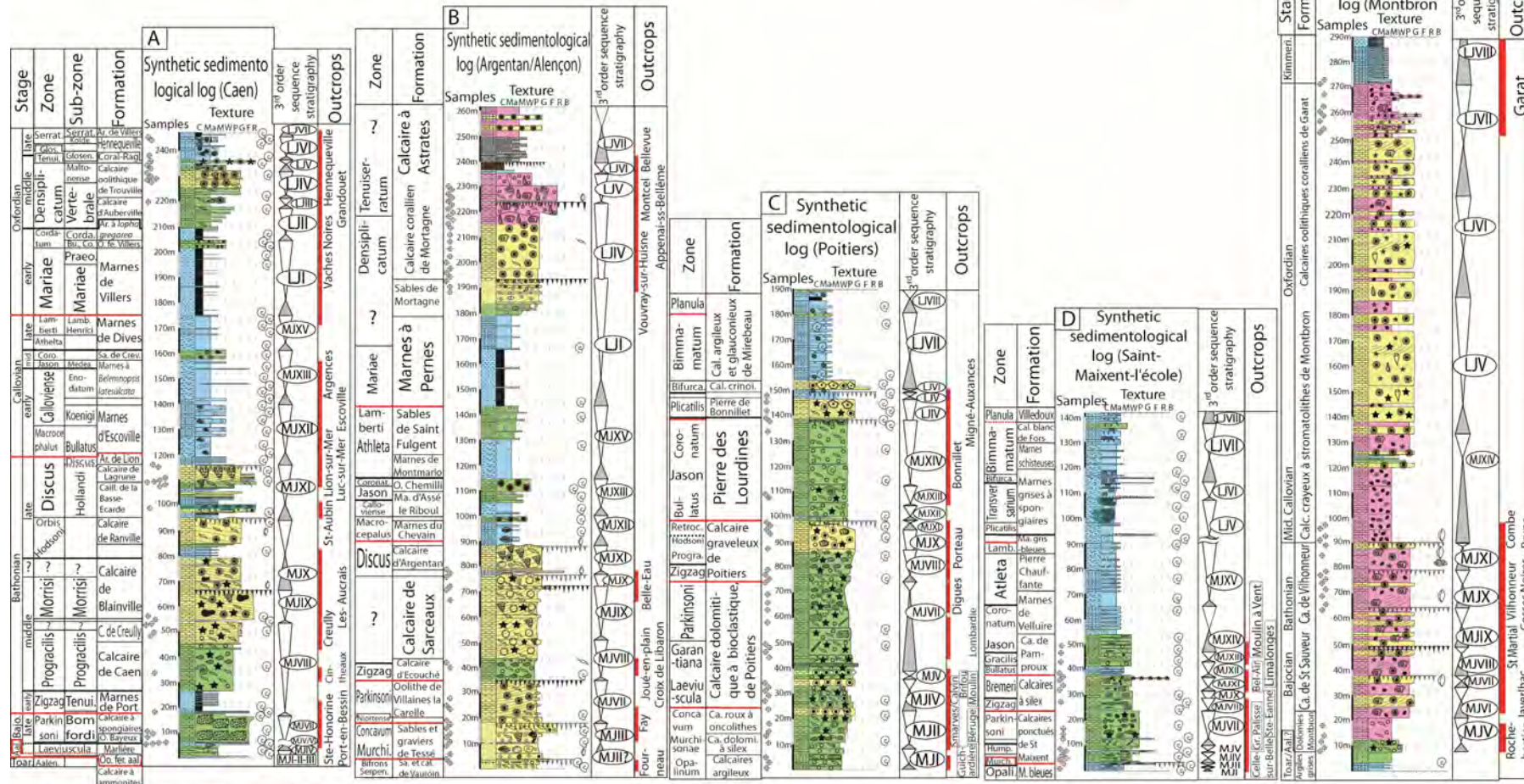


FACIES		F1a to F1f	F2a to F2f	F3a to F3l	F4a to F4d	F5a-c
COMPONENTS	BIOCLASTIC	Characeae gyrogonites				
		Ostracods				
		Gastropods				
		Echinoderms				
		Bryozoans				
		Bivalves				
		Brachiopods				
		Miliolids				
		Other foraminifers				
		Corals				
		Sponges				
		Red algae				
		Serpulites				
		Ammonites				
		Belemnites				
	NON-BIOCLASTIC	Microbialites				
		Ooids				
		Oncoids				
		Peloids				
		Lithoclasts				
		Lumps				
		Quartz				
		Glauconites				
		Phosphates				

NORTH

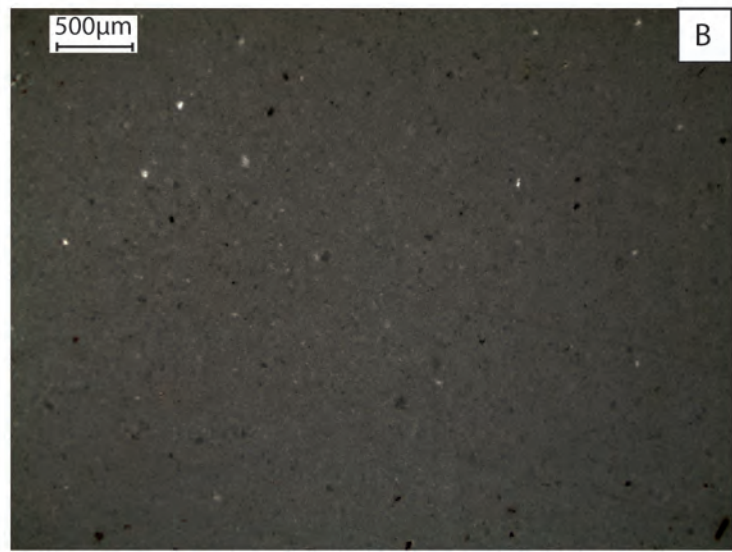
SOUTH

CAEN $\leftarrow \sim 75\text{km} \rightarrow$ ARGENTAN/ALENCON $\leftarrow \sim 230\text{km} \rightarrow$ POITIERS $\leftarrow \sim 45\text{km} \rightarrow$ SAINT-MAIXENT-L'ÉCOLE $\leftarrow \sim 100\text{km} \rightarrow$ MONTBRON





A



B

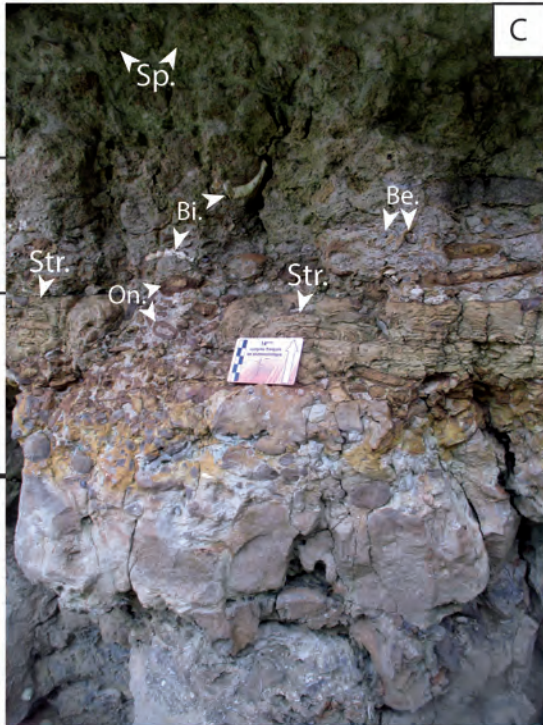
Calcaire à spongiaires

Oolithe ferrugineuse de Bayeux

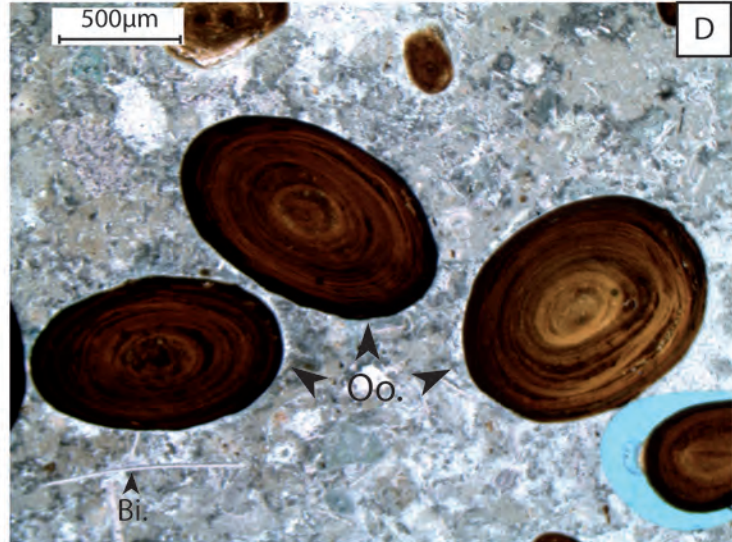
Conglomérat de Bayeux

Couche verte

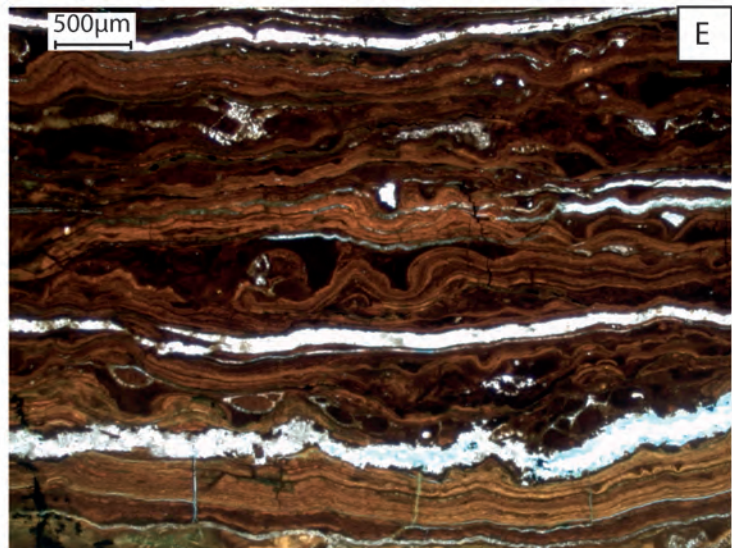
Malière



C



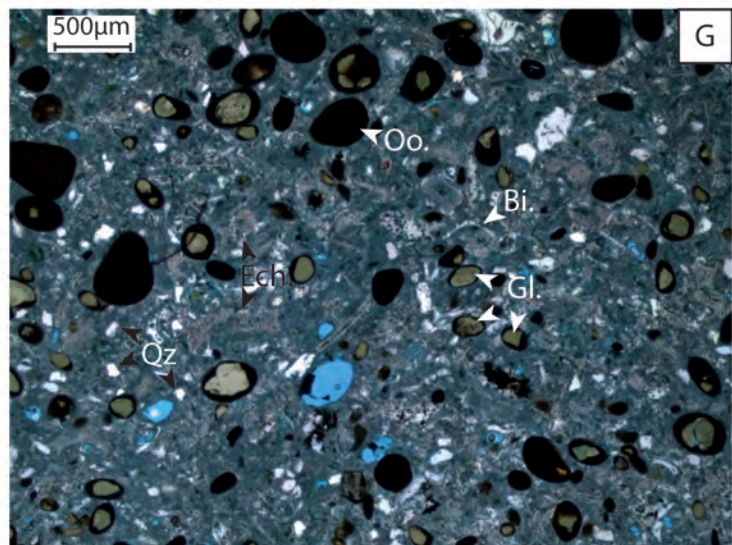
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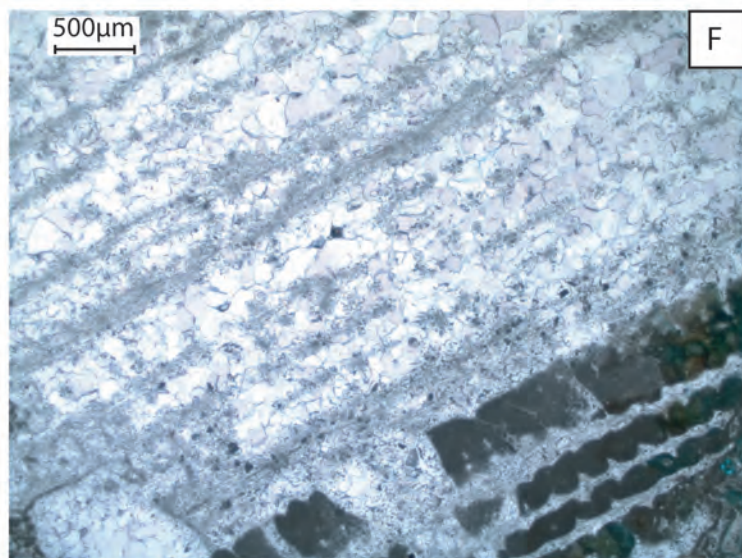
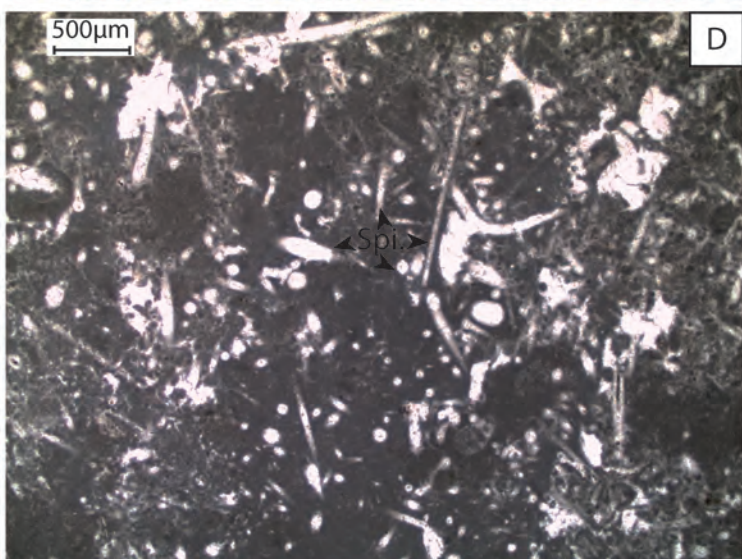
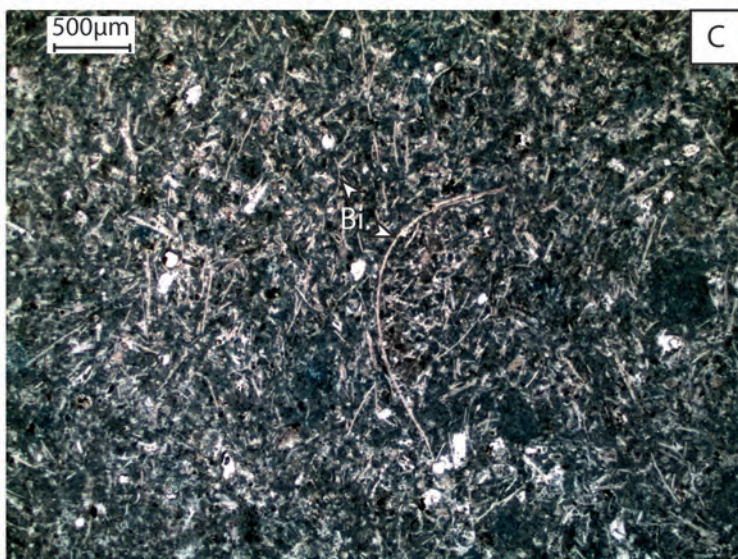
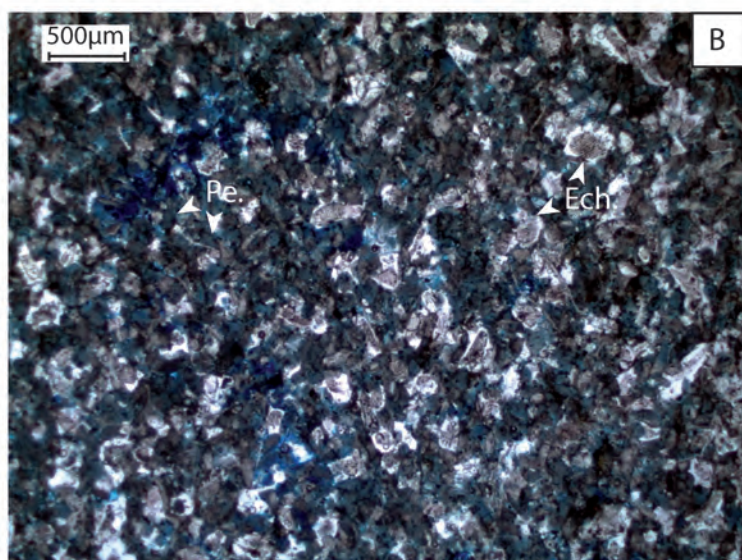
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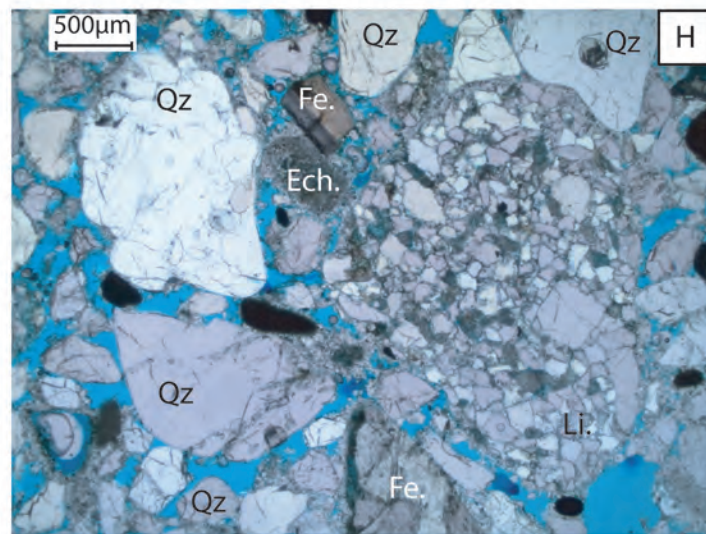
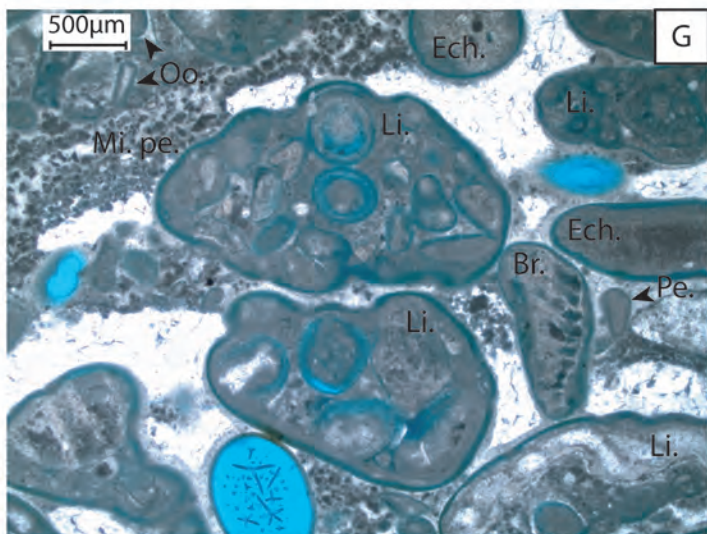
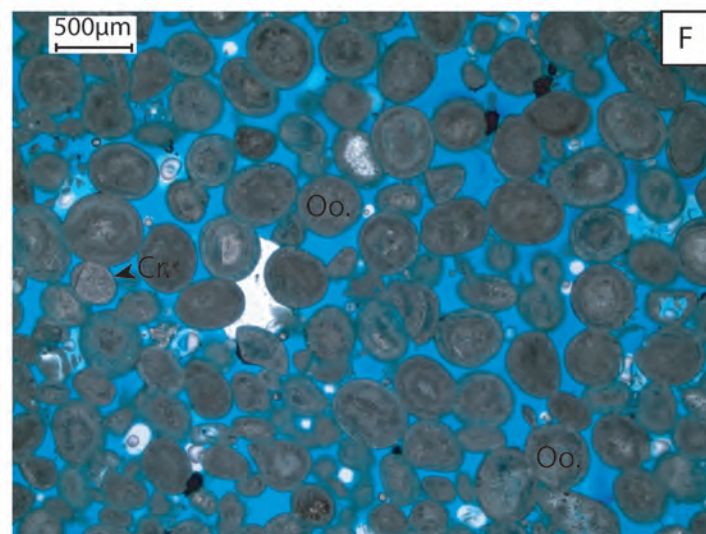
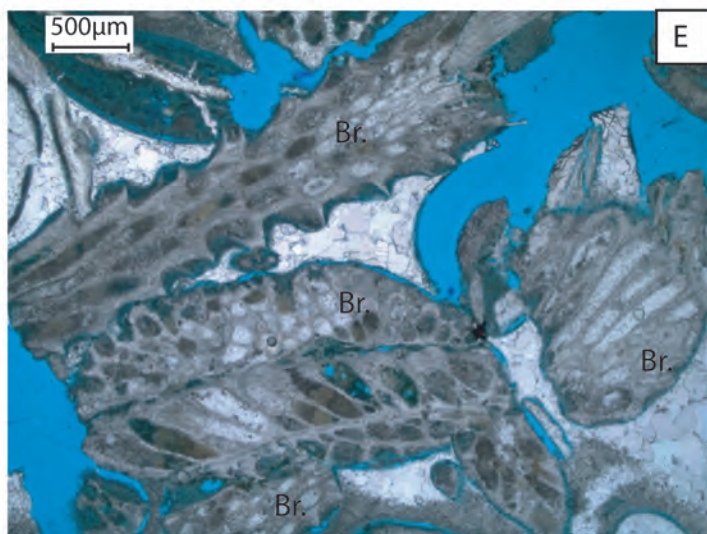
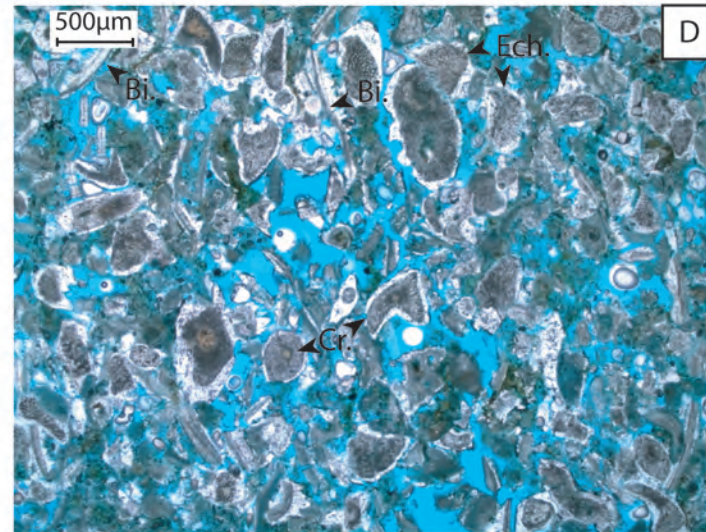
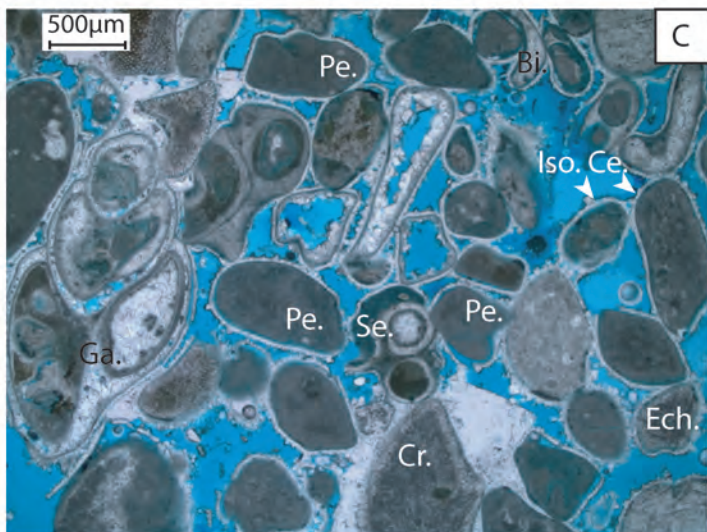
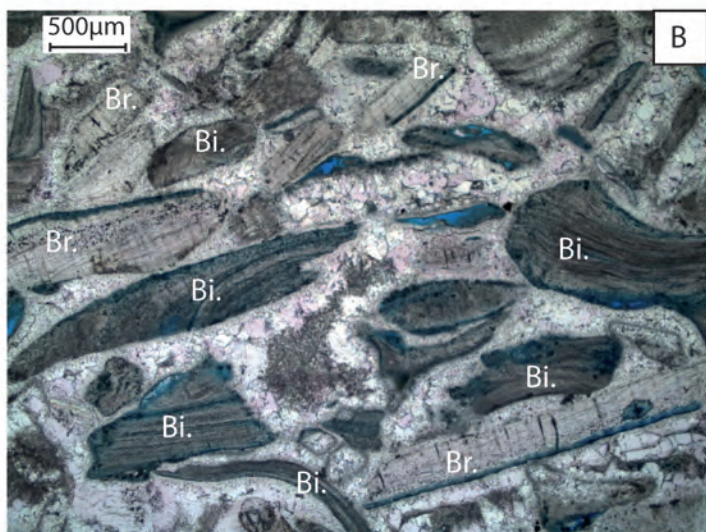
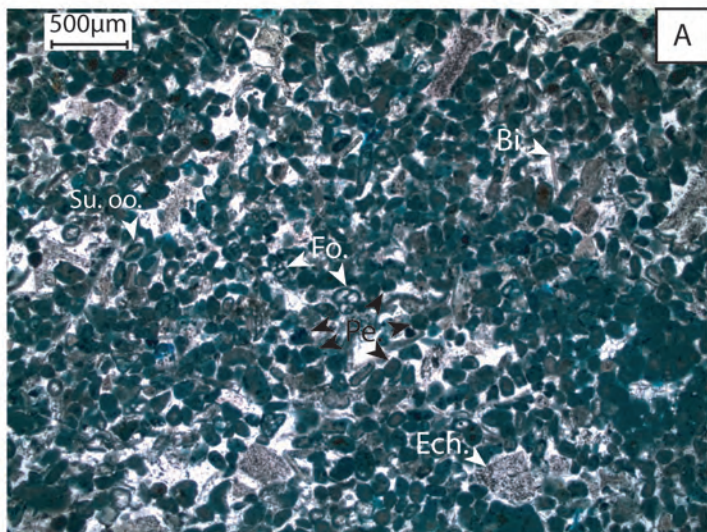


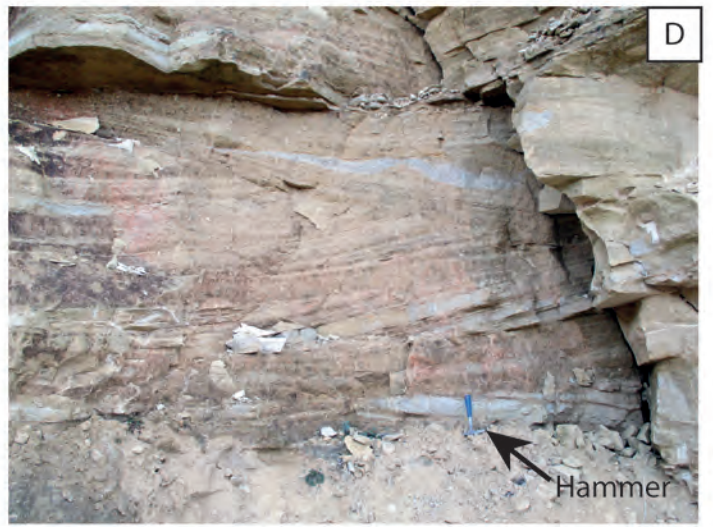
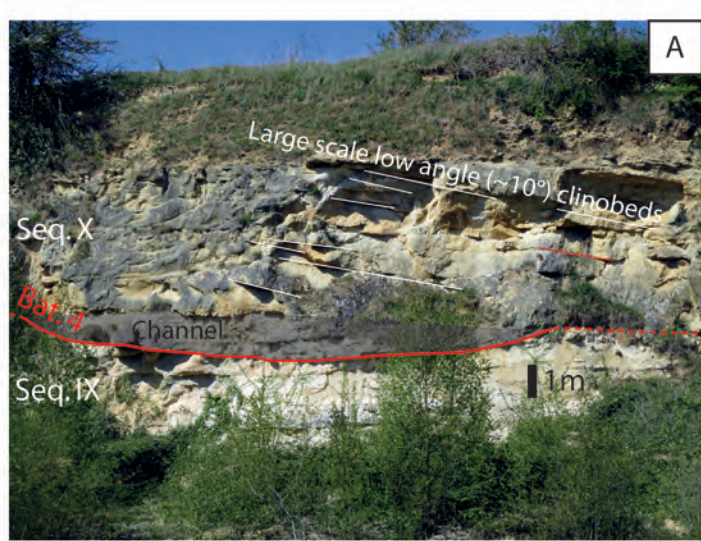
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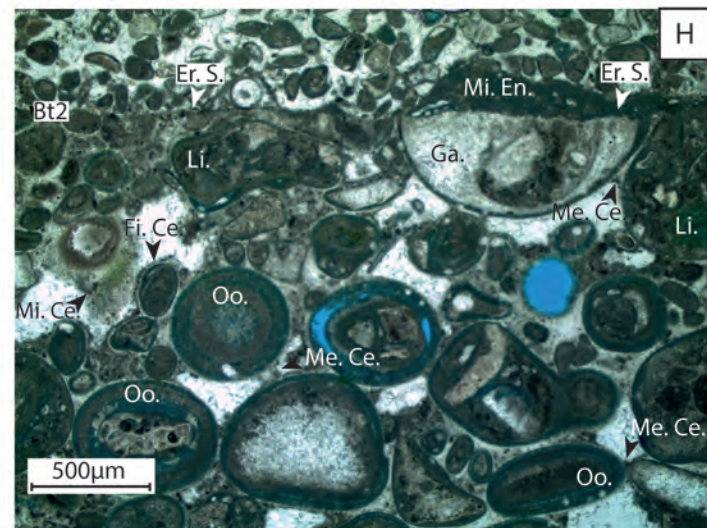
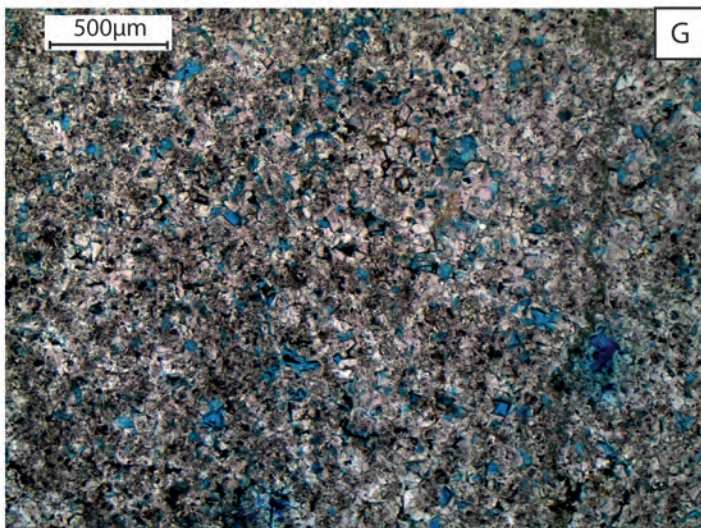
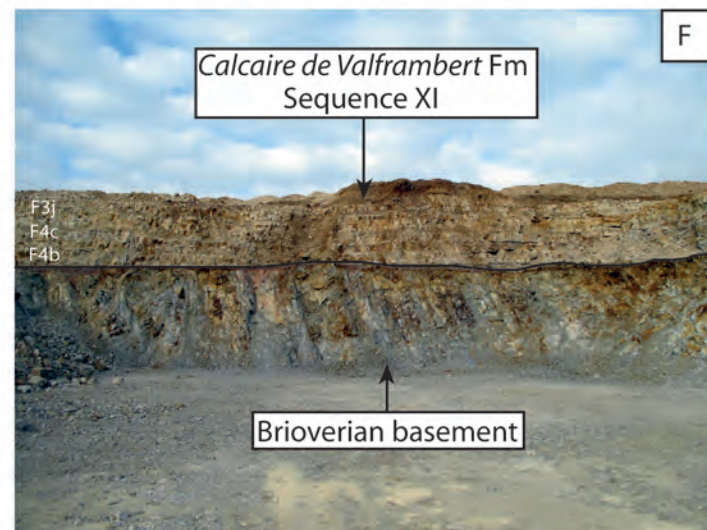
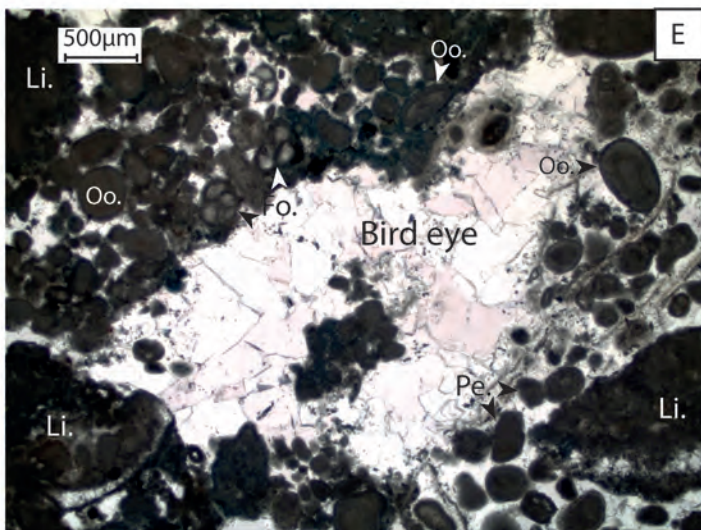
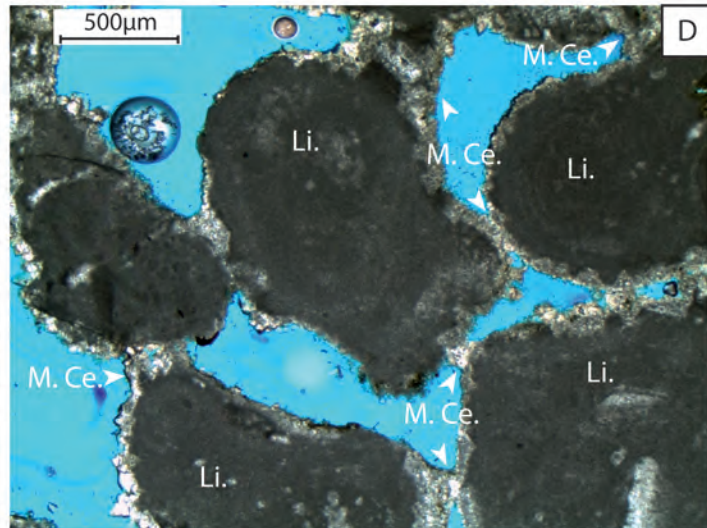
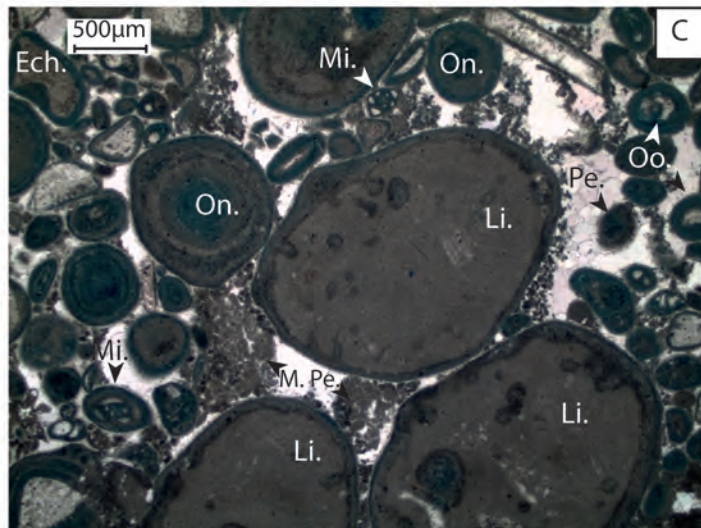
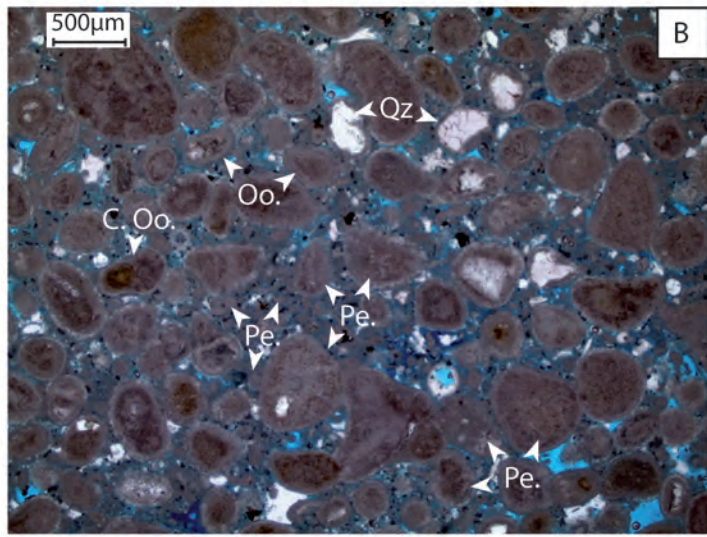
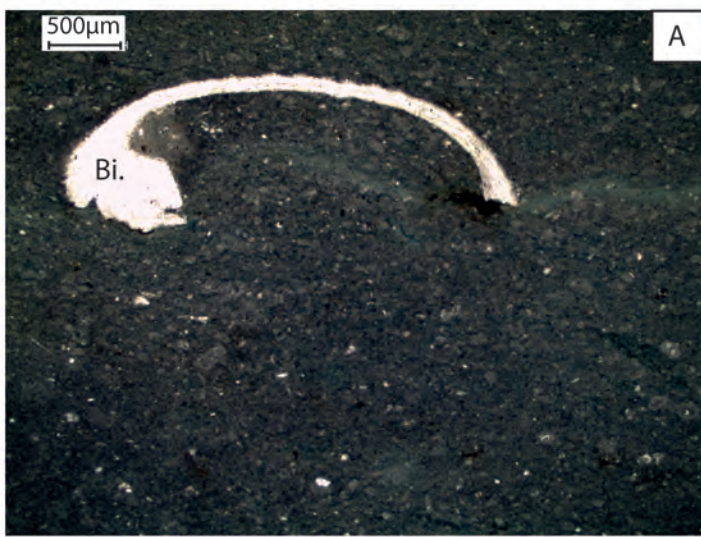


G



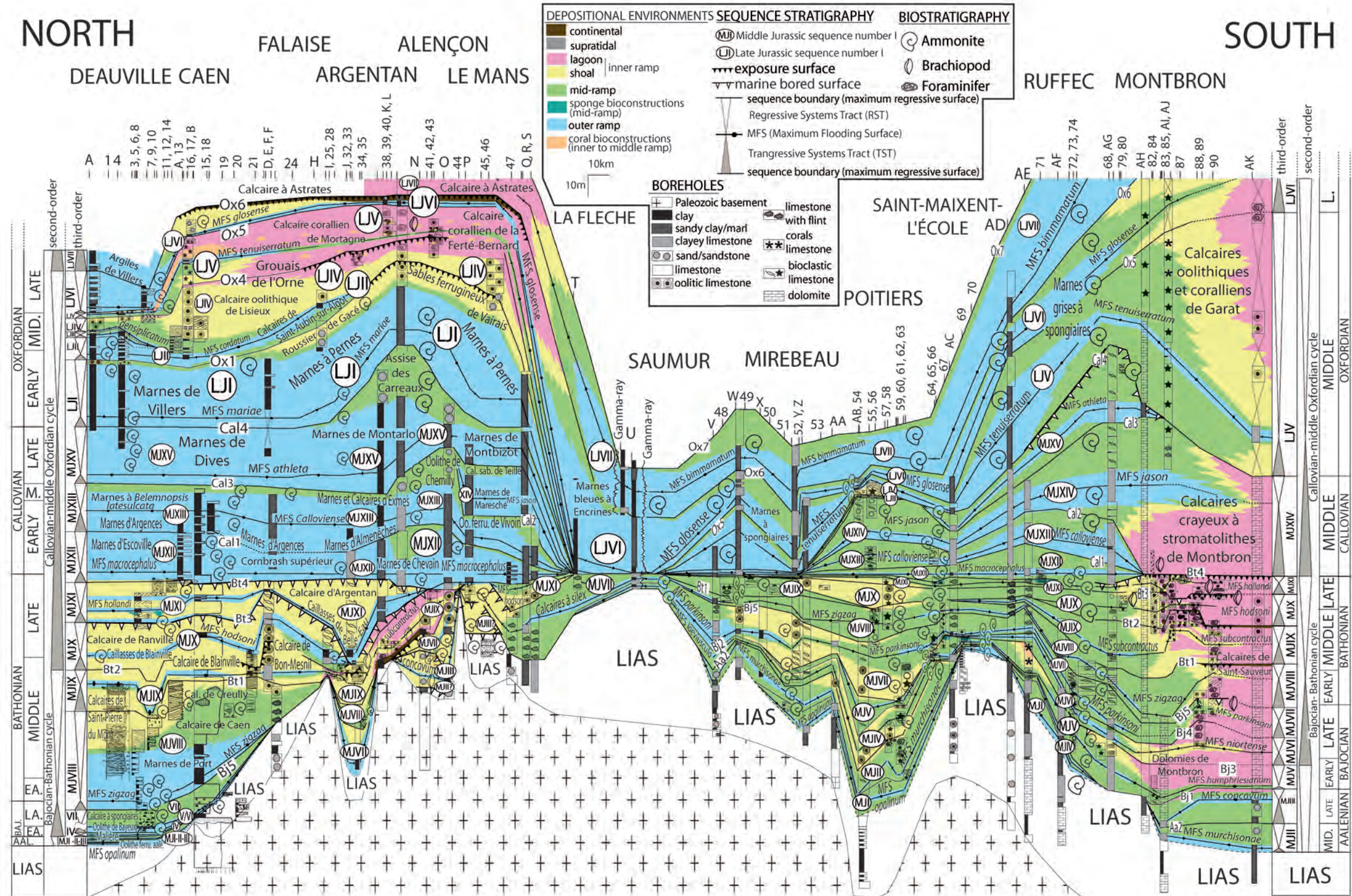


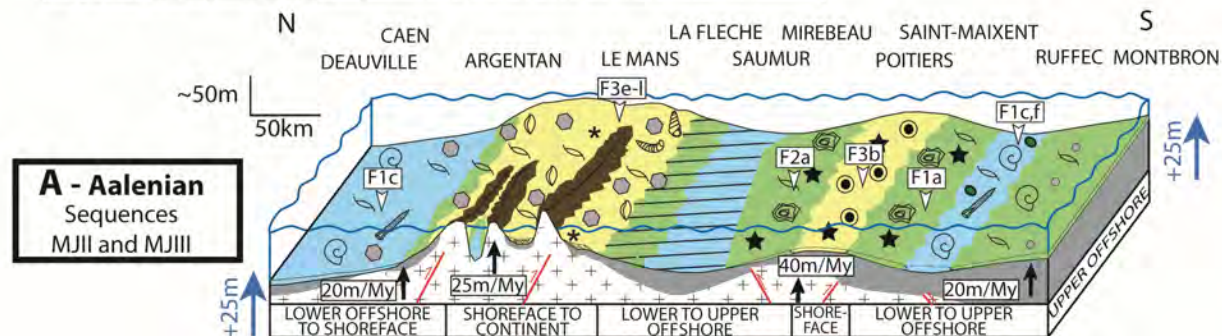
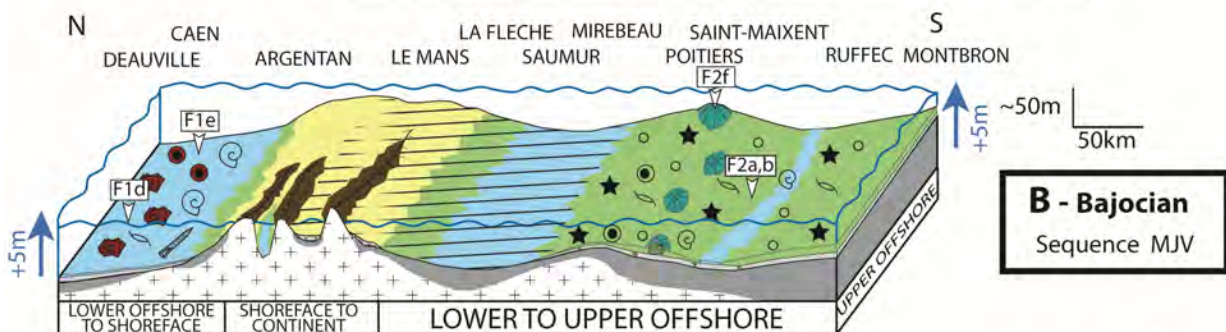
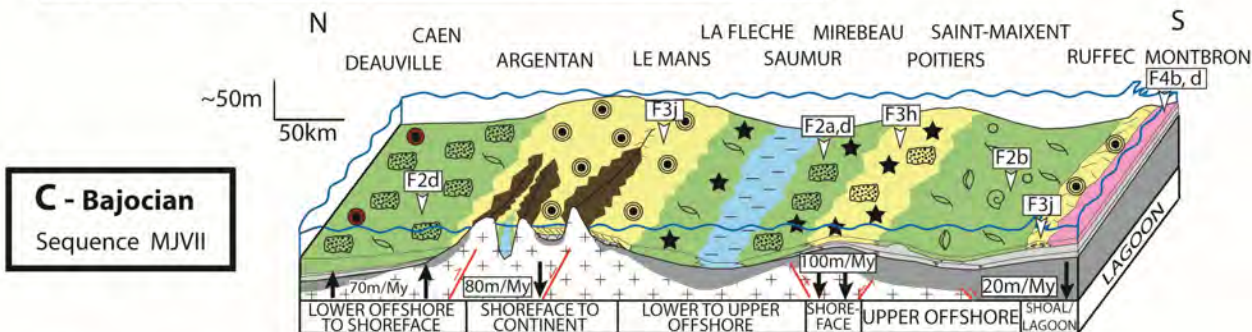
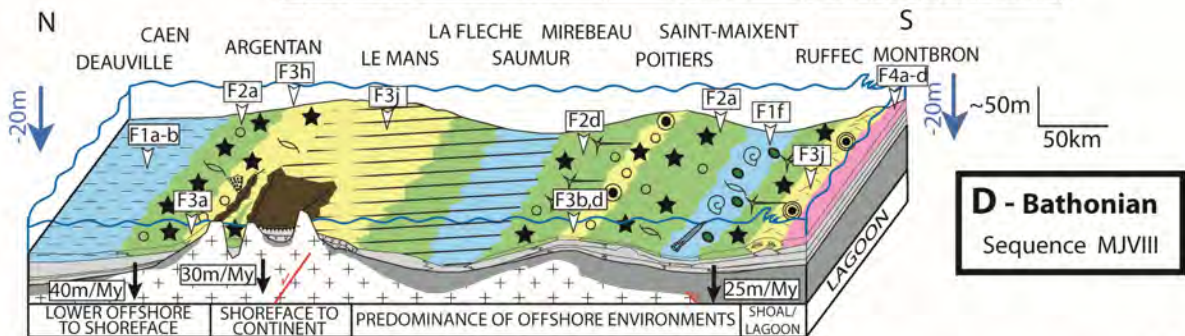
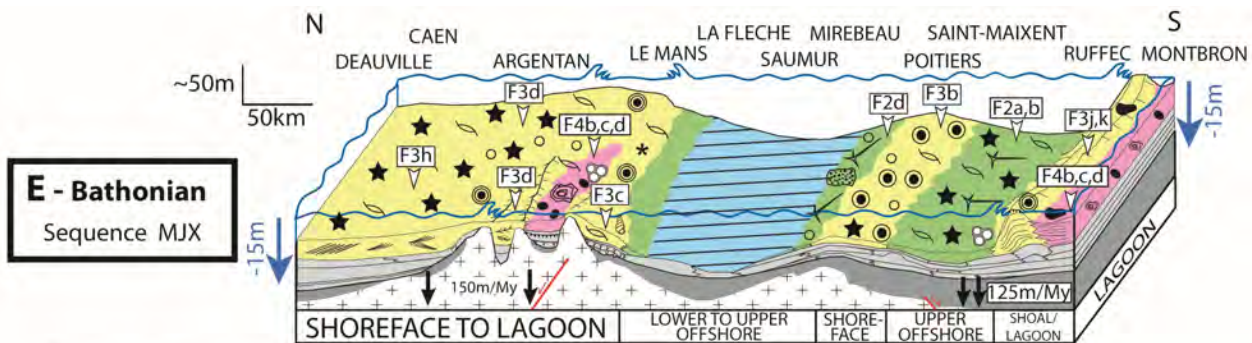


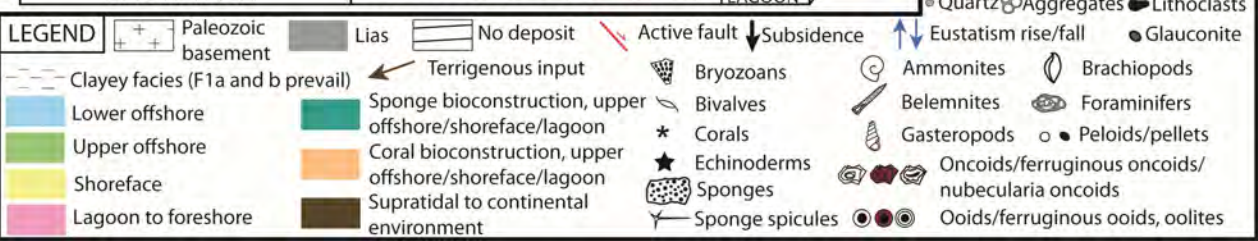
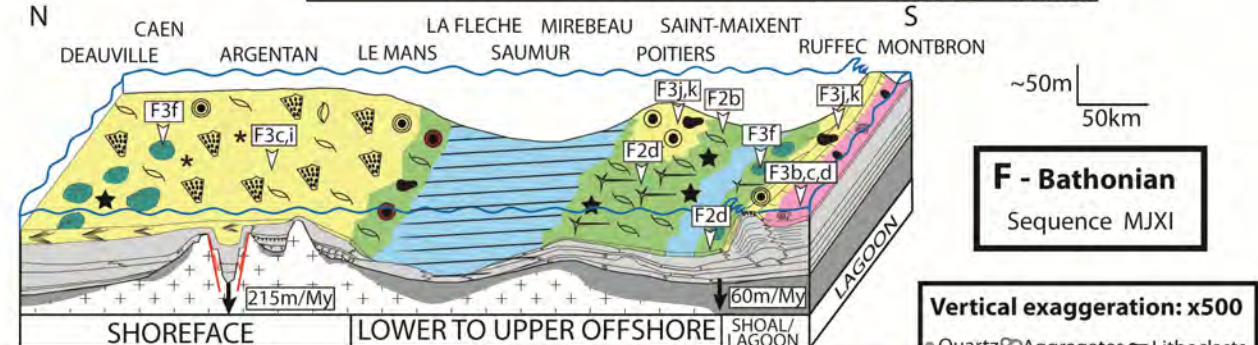
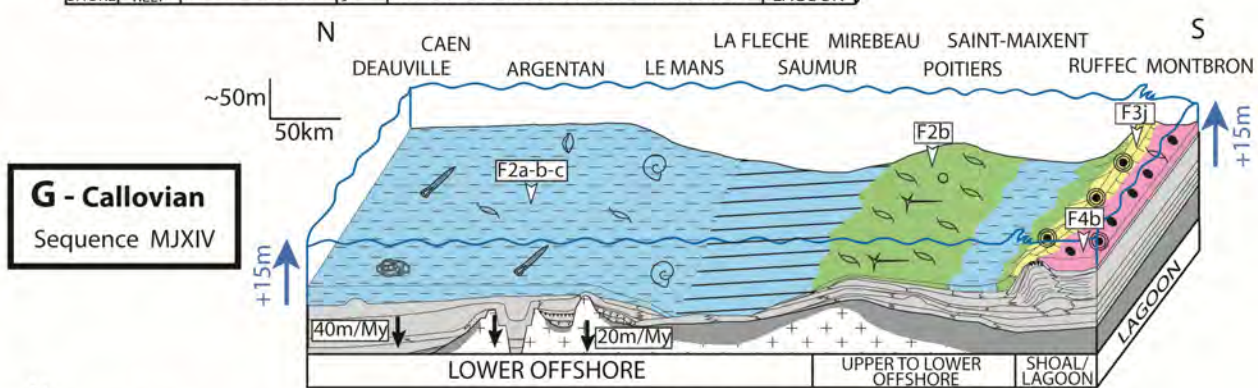
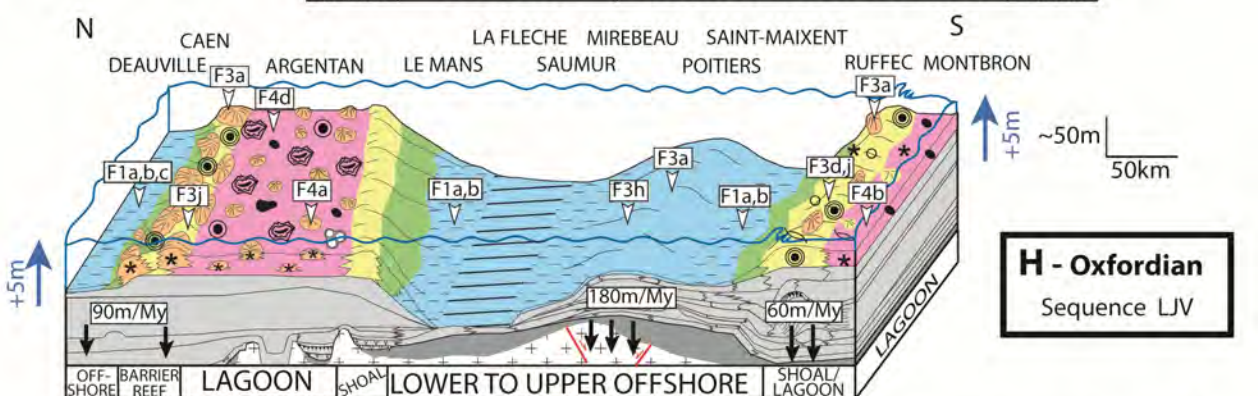
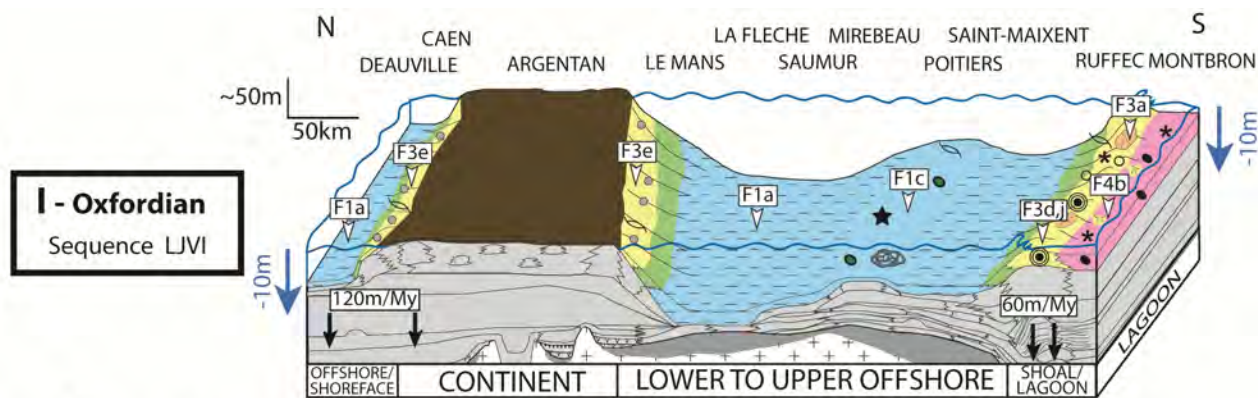


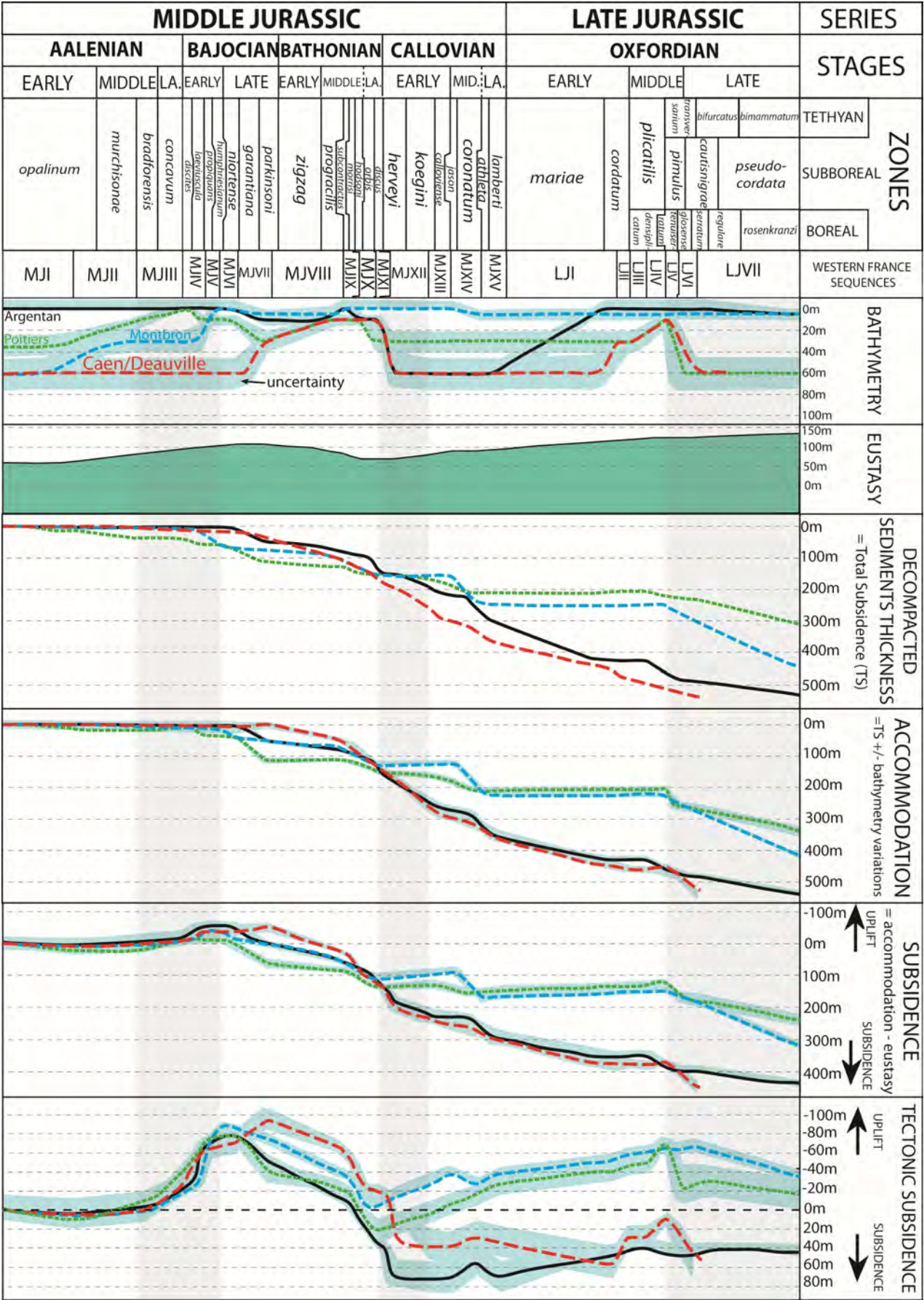
FALAISE ALENÇON
ARGENTAN LE MANS

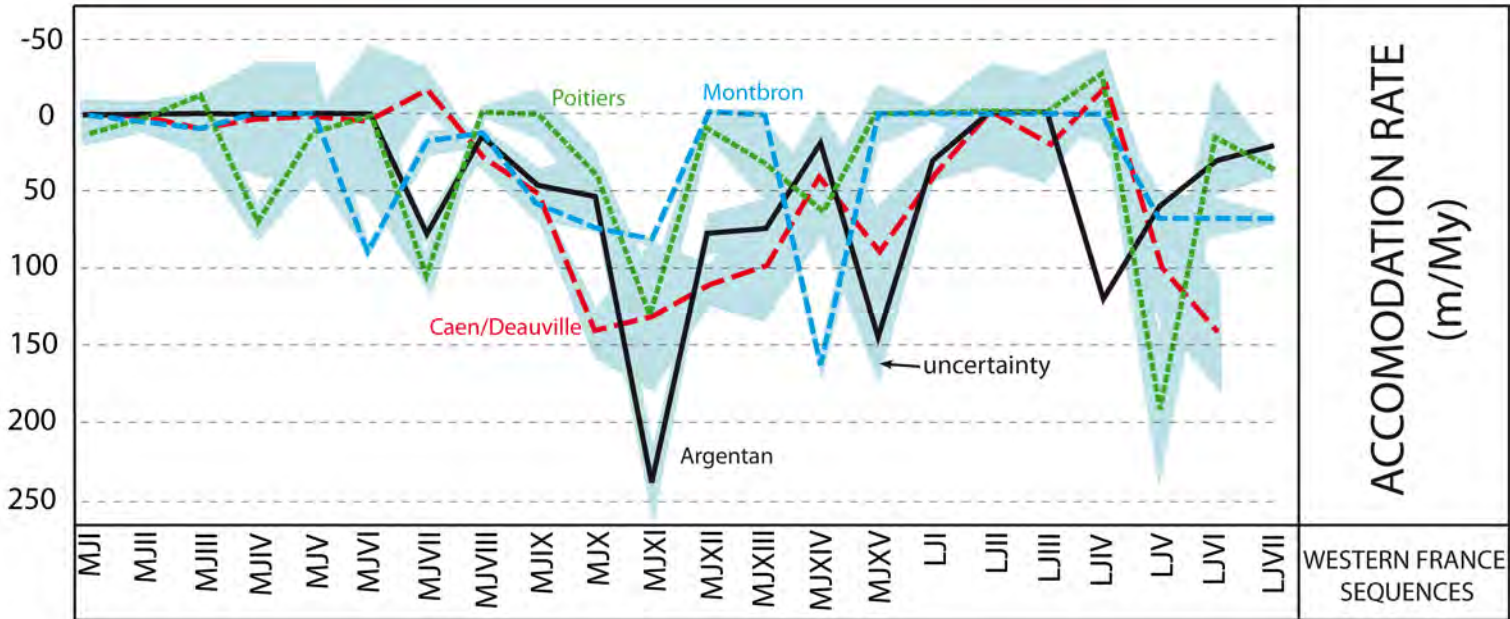
RUFFEC MONTBRON

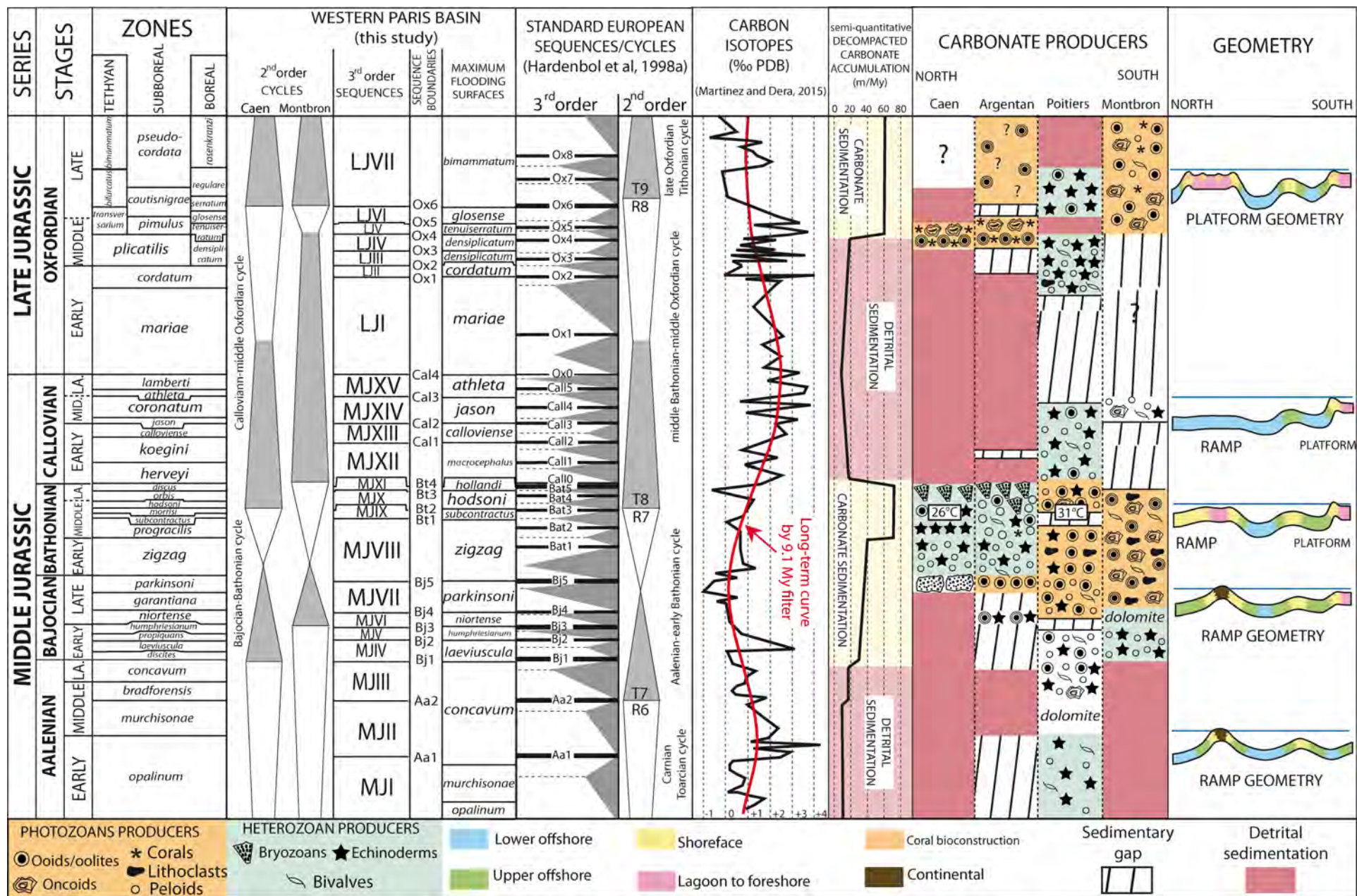


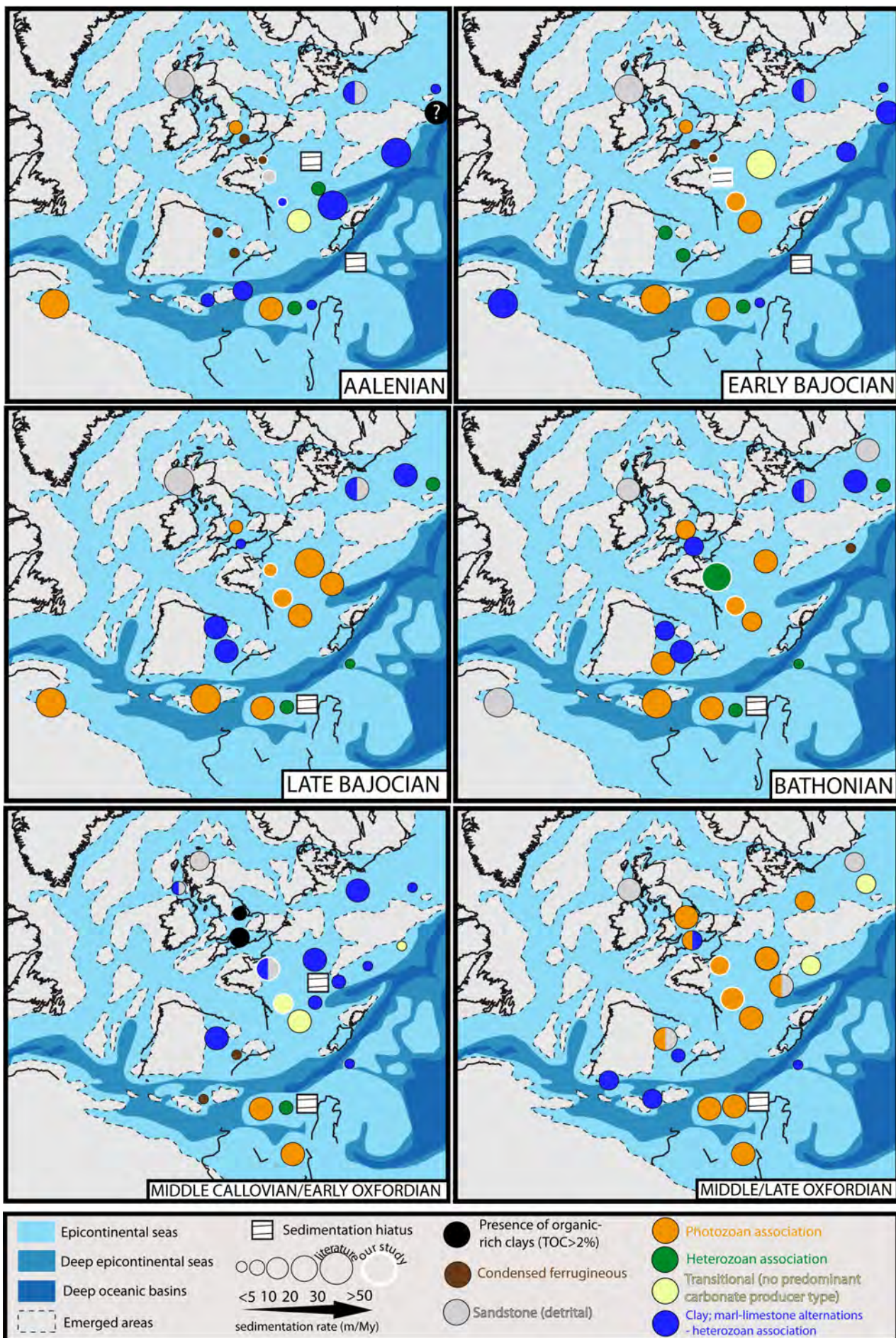


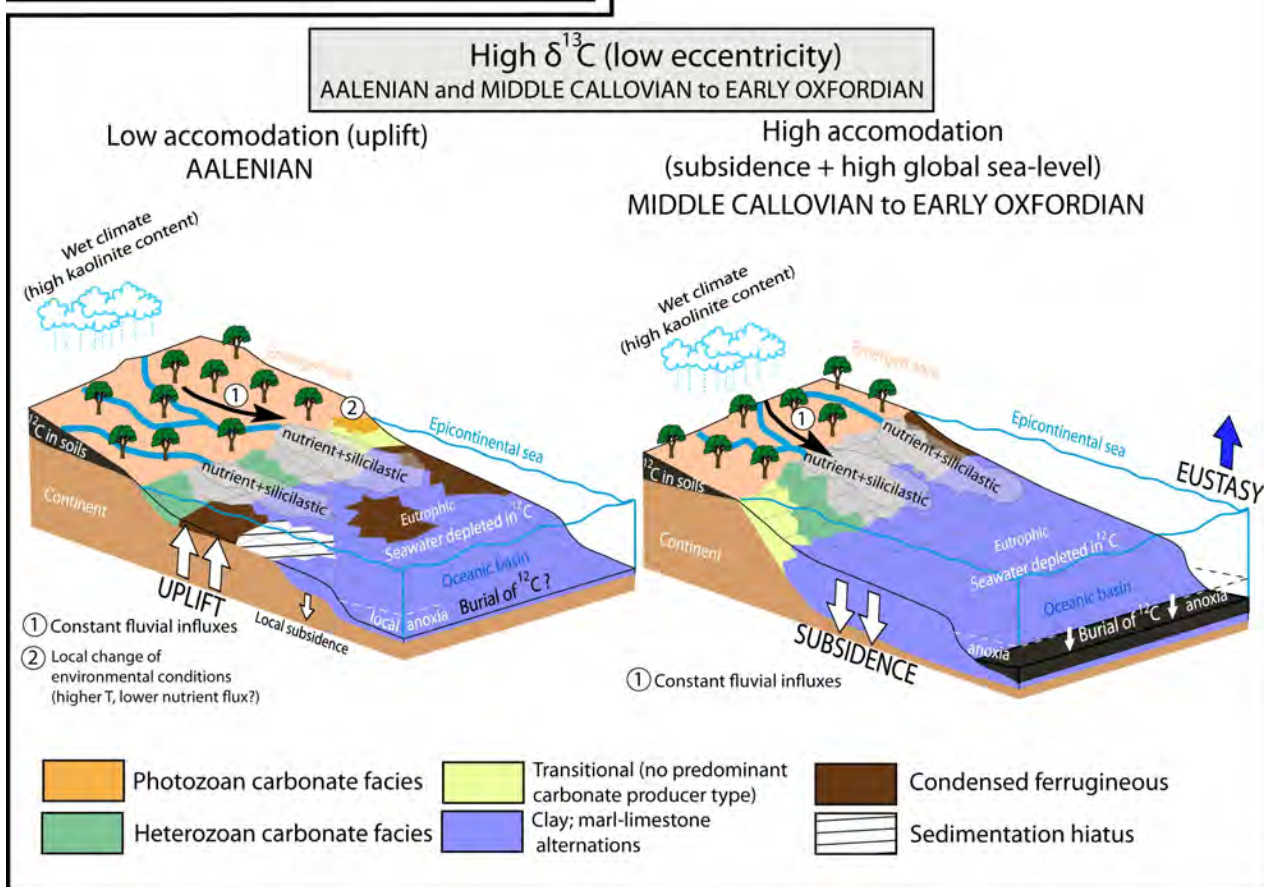
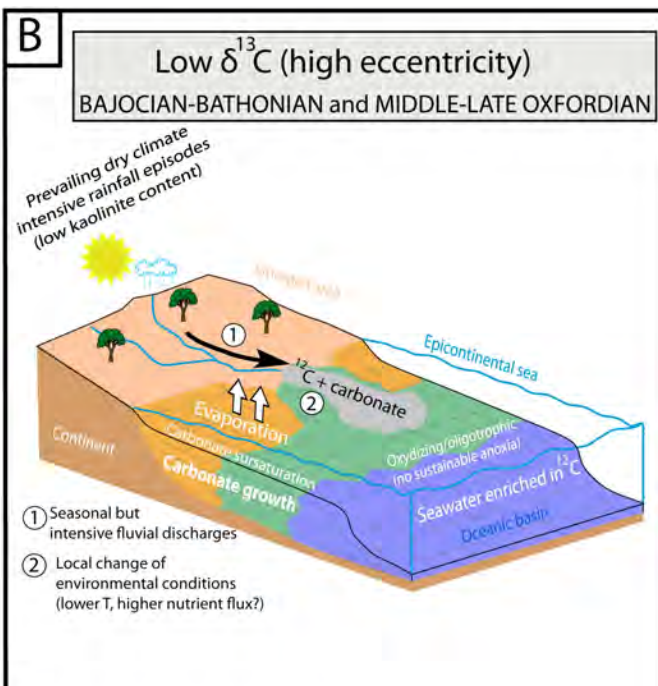
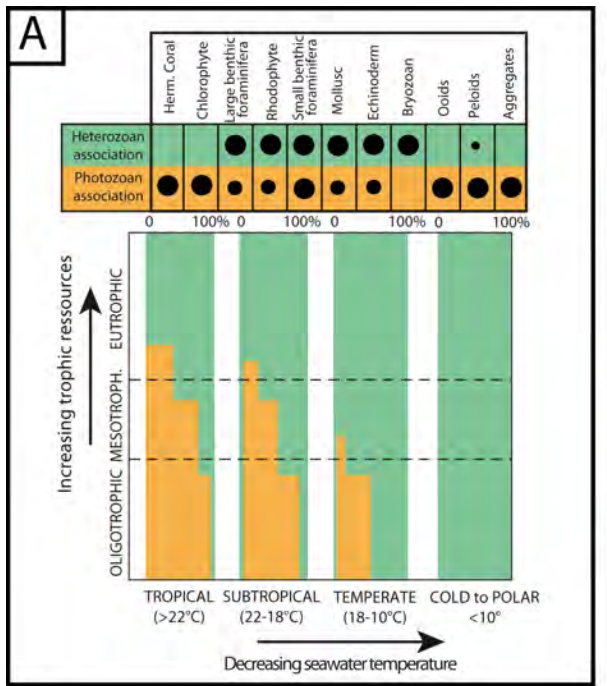












Position within the downdip profile (hydrodynamism)	Lithofacies	Non-bioclastic components	Bioclastic components	Predominant grain association	Sedimentary and biogenic structures	Sorting and grain size	Energy and depositional environment
Lower offshore	F1a: claystone	Silts (R), wood fragments (R)	Ammonites (R), belemnites (R), bivalves (R), sponge spicules (R), foraminifers (R), ostracods (R)		Abundant bioturbation: <i>Chondrites</i> , <i>Thalassinoïdes</i> , <i>Walthonensis</i>	Very well sorted; < 4 µm	Very low energy, lower offshore
	F1b: marls	Silts (C), wood fragments (R)	Ammonites (R), belemnites (R), bivalves (R), brachiopods (R), sponge spicules (R), foraminifers (R), ostracods (R), echinoderms (R), dinoflagellates (R)	Heterozoan	Abundant bioturbation: <i>Chondrites</i> , <i>Thalassinoïdes</i> , <i>Walthonensis</i>	Very well sorted	Very low energy, lower offshore
	F1c: marl/micritic limestone alternations	Peloids (A), quartz (C), glauconite (C), intraclasts (R)	Echinoderms (F), bivalves (F), foraminifers (R), serpulites (R)	Heterozoan	Abundant bioturbation	Very well sorted	Very low energy, lower offshore
	F1d: ferruginous ooids packstone to wackestone	Ferruginous ooids (A), intraclasts (R), quartz (R), glauconite (R)	Bivalves (F), echinoderms (C), sponges (R), foraminifers (R), brachiopods (R), gastropods (R), bryozoans (R)	Heterozoan	Bioturbation	Poorly sorted, 100 µm – 5 cm	Very low energy, lower offshore
	F1e: ferruginous oncoid-ooid floatstone	Ferruginous oncoids (A), ferruginous ooids (F), peloids (R), quartz (R), glauconite (R)	Bivalves (C), echinoderms (C), foraminifers (R), brachiopods (R)	Heterozoan	Ferruginous stromatolites, bioturbation	Very poorly sorted, 100 µm – 10 cm	Very low energy, lower offshore
	F1f: Glauconitic to phosphate bioclastic wackestone to floatstone	Glauconite (F), phosphate (C), quartz (C)	Echinoderms (F), bivalves (F), belemnites (C), ammonites (C), brachiopods (R), foraminifers (R)	Heterozoan	Abundant bioturbation	Poorly sorted, 100 µm – 5 cm	Very low energy, lower offshore
Upper offshore	F2a:marl/echinoderm-peloid packstone to grainstone alternations	Peloids (F), quartz (R), oncoids (R), superficial ooids (R), lithoclasts (R)	Echinoderms (A), bivalves (C), brachiopods (R), bryozoans (R), miliolids (R), corals (R), serpulites (R)	Heterozoan	Gutter casts, shell graded layers, bioturbation	Well sorted, 200 µm – 500 µm	Low to moderate energy, upper offshore

	F2b: marl/bivalve-brachiopod wackestone to packstone alternations	Peloids (C), lumps (C), oncoids (C), glauconite (R)	Bivalves (A), brachiopods (C), crinoids (C), sponges spicules (C), foraminifers (R), serpulites (R)	Heterozoan	Gutter casts, hummocky cross-stratification (HCS), shell graded layers	Well sorted, 100 μm – 1cm	Low to moderate energy, upper offshore
	F2c: marl/ooid grainstone alternations	Oolites (F), radial ooids (C), superficial ooids (R), micritic ooids (R), quartz (R), peloids (R), intraclasts (R), graptstones (R)	Crinoids (C), echinoids (R), bivalves (R), foraminifers (R), brachiopods (R), bryozoans (R)	Transitional	Gutter casts	Moderately sorted, 200 μm – 3 cm	Low to moderate energy, upper offshore
	F2d: sponge wackestone to floatstone	Peloids (C), oncoids (C), superficial ooids (R), intraclasts (R)	Sponges (A), sponge spicules (F), echinoderms (F), bivalves (C), bryozoans (R), brachiopods (R), miliolids (R), corals (R), gastropods (R), serpulites (R)	Transitional	Bioturbation, reversed sponges	Very poorly sorted, 100 μm – 10 cm	Low to moderate energy, upper offshore
	F2e: coral bioconstructions (sheetstone to platestone) in marls	Peloids (R)	Lamellar corals (A), bivalves (R), echinoderms (R), sponge spicules (R)	Photozoan	Biostroms (50 cm to 1 m thick and 2-15 m wide)		Upper offshore
	F2f: sponge bioconstruction (boundstone) in marls		Sponges (A), bivalves (C)	Heterozoan	Biostroms (50 cm thick and 2-5 m wide)		Upper offshore
Shoreface	F3a: very fine peloidal grainstone	Peloids (A), superficial ooids (R), intraclasts (R), quartz (R), intraclasts (R)	Echinoderms (C), bivalves (C), miliolids (R), foraminifers (R), brachiopods (R), gastropods (R)	Transitional	Cross stratification in megaripples, bioturbations	Well sorted, 100 μm	Moderate energy, wave dominated shoreface
	F3b: superficial ooid grainstone	Superficial ooids (A), radial ooids (C), micritic ooids (C), oolites (C), peloids (C), graptstones (R), quartz (R), oncoids (R), intraclasts (R)	Bivalves (R), echinoderms (R), miliolids (R), bryozoans (R)	Photozoan	SCS (swaley cross stratification), cross stratification, bioturbations	Well sorted, 50 μm – 1 cm	Moderate energy, wave dominated shoreface
	F3c: bivalve grainstone to rudstone	Quartz (R), peloids (R), ooids (R), oncoids (R), intraclasts (R)	Bivalves (A), echinoderms (C), brachiopods (C), corals (C), bryozoans (R), gastropods (R), red	Heterozoan	Cross stratification in megaripples	Very poorly sorted, 300 μm – 10 cm	Moderate to high energy, wave dominated shoreface

	F3d: bioclastic peloidal grainstone	Peloids (F), intraclasts (C), micritic ooids, superficial ooids, radial ooids, oolites (C), oncoids (R)	algae (R), foraminifers (R) Bivalves (C), echinoderms (C), bryozoans (C), miliolids (R), foraminifers (R), gastropods (R), brachiopods (R), corals (R)	Transitional	Tangential cross-bedding in megaripples, erosive channels (1-2 m thick and 2-5 m wide)	Moderately sorted, 300 µm – 5 cm	High energy, wave dominated shoreface
	F3e: quartz/bioclastic sand to sandstone	Quartz (A), peloids (R), feldspar (R), glauconite (R), iron oxides, intraclasts (R), ferruginous ooids (R)	Echinoderms (R), bivalves (R), gastropods (R), brachiopods (R), foraminifers (R)		Tangential cross-bedding in megaripples, herring bone stratification	Well sorted, 200 µm – 500 µm	High energy, wave to tidally dominated shoreface
	F3f: sponge bioconstruction (boundstone) in bioclastic grainstones		Sponges (<i>Platychonia magna</i>) (A), bivalves (C), bryozoans (C), serpulites (R), brachiopods (R), echinoids (R)	Heterozoan	Bioherms (2-3 m thick and 2-5 m wide)		High energy wave dominated shoreface
	F3g: coral bioconstructions (mixstone) in oolitic grainstones		Branching corals (<i>Thecosmilia</i>), lamellar corals, massive corals (<i>Isastrea</i>) (A), bivalves (F), gastropods (R), bryozoans (R), crinoids (R), echinoids	Photozoan	Bioherms and biostroms		High energy wave dominated shoreface
	F3h: echinoderm grainstone	Peloids (C), oncoids (R), ooids (R), quartz (R)	Echinoderms (A), bivalves (F), brachiopods (R), bryozoans (R), corals (R), green algae (R), miliolids (R)	Heterozoan	Tangential cross bedding in megaripples, herring bone stratification, hydraulic dunes	Well sorted, 100 µm – 2 cm	High energy, wave to tidally dominated shoreface, hydraulic dunes
	F3i: bryozoan grainstone to rudstone	Peloids (R), ooids (R), oncoids (R), intraclasts (R)	Bryozoans (A), bivalves (C), echinoderms (C), sponges (R), corals (R), serpulites (R), red algae (R), brachiopods (R), gastropods (R)	Heterozoan	Cross bedding in megaripples	Poorly sorted, 500 µm – 5 cm	High energy, wave dominated shoreface
	F3j: ooid grainstone to sand	Oolites, micritic ooids, radial ooids, superficial	Echinoderms (C), bivalves (C), foraminifers (R), bryozoans (R),	Photozoan	Tangential cross bedding in	Moderately sorted, 200 µm	High energy, wave to tidally dominated

		oids (A), peloids (C), nubecularia oncoids (R), intraclasts (R), grapstones (R), quartz (R)	brachiopods (R), gastropods (R), corals (R)		megaripples, large scale cross stratification (foresets of about 20°), herring bone stratification, decimetric channels	– 1 cm	shoreface, dunes near sea surface or carbonate platform margin
	F3k: lithoclast-oid grainstone to rudstone	Lithoclasts (F), oolites, micritic ooids, superficial ooids, radial ooids (F), peloids (C), grapstones (R)	Echinoderms (C) bryozoans (R), gastropods (R), brachiopods (R), bivalves (R), red algae (R),	Photozoan	Tangential cross-bedding in megaripples, large scale cross stratification (foresets of about 20°), microbial peloids	Poorly sorted, 200 µm – 5 cm	High energy, wave dominated shoreface, carbonate platform margin
	F3l: lithoclast-oyster calcareous conglomerate	Quartz (A), intraclasts (C), peloids (R), ferruginous ooids (R), glauconite (R), iron oxide (R), feldspar (R)	Bivalves (F), echinoderms (R)		Erosive basal surface	Very poorly sorted, 200 µm – 5 cm	High energy, probably storm deposits
Lagoon and intertidal environments	F4a : coral bioconstructions (mixstone) in micritic limestones		Branching corals (<i>Thomanesteria dendroidea</i>) massive corals (A), bivalves (C), gastropods (R), brachiopods (R)	Photozoan	Bioherms and biostroms		Low to moderate energy, protected environment
	F4b: bioclastic/ peloid/quartz mudstone	Peloids (F), quartz (F), lithoclasts (C), micritic ooids, oolites (C), oncoids (R)	Bivalves (F), corals (C), gastropods (C), miliolids (R)	Transitional	Washover deposit	Well sorted, 500 µm – 2 cm	Low energy, protected environment
	F4c: pellet/peloid grainstone/packstone	Pellets (A), peloids (F), lithoclasts (F) superficial ooids (C), oncoids (R), aggregates (R), micritic ooids, radial ooids (R), quartz (R)	Miliolids (R), bryozoans (R), bivalves (R), echinoderms (R), gastropods (R)	Photozoan	Planar-bedding, Meniscus and microstalactitic cements, birdseyes, stromatolites	Moderately sorted, 50 µm – 500 µm	Moderate to high energy, lagoon to foreshore (beach)
	F4d: oncoid-oid	Oolites, micritic ooids,	Miliolids (R), corals (R), bivalves	Photozoan	Planar-bedding,	Very poorly	Moderate to high

	rudstone to packstone with aggregates and lithoclasts	superficial ooids (F), nubecularia oncoids (F), aggregates (F), lithoclasts (F), peloids (R)	(R), gastropods (R), echinoderms (R)		sigmoid cross-bedding in megaripples, meniscus and microstalactitic cements, birdseyes, microbialites, microbial peloids	sorted, 100 µm – 3 cm	energy, lagoon to foreshore (beach)
Supratidal to continental environments	F5a: dolomite	Quartz (R)			Stromatolites		Sabkha: very low energy, backshore
	F5b: lignite	Silts (F)	Characeae gyrogonites (R), ostracods (R)			Very well sorted; < 4 µm	Brackish environment: very low energy, backshore
	F5c: paleosoil	Clays (F), silts (F), quartz (F), iron hydroxides (C)	Characeae gyrogonites (R), oysters (R)		Roots	Very well sorted; < 4 µm	Continental environment

R = rare: <10%; C = common: 10–20%; F = frequent: 20–40%; A = abundant: >40%

Country	Location	Age	Depositional environment	Lithology/carbonate producers	Reference
England	Wessex and Worcester basins, London platform	Aalenian to Oxfordian	Offshore to shallow marine	Marl-limestone alternations, condensed ferruginous, oolitic limestones (photozoan), sandstones	Hesselbo, 2008
England	Worcester Basin, London platform	Aalenian to Bajocian	Shallow marine	Oolitic limestone (photozoan)	Barron et al., 1997
England	Worcester Basin, London platform	Bathonian	Shallow marine	Oolitic limestone (photozoan)	Sellwood et al., 1985
France	Eastern Paris Basin	Aalenian to Oxfordian	Lower offshore to shoreface	Ooid/coral limestones (photozoan), crinoid/coral limestones (transitional) and marls	Brigaud et al., 2014
France	Eastern Paris Basin	Callovian		Hiatus	Collin and Courville, 2006
France	Southeastern France	Aalenian to early Bajocian	Mainly wave to tidal-dominated shoreface	Crinoid limestones (heterozoan)	Rouselle and Dromart, 1996
France	Quercy (southwestern France)	Aalenian to Oxfordian	Shallow platform	Bioclastic (mixed grain association, Aalenian and Callovian) to ooid (photozoan, Bajocian, Bathonian, Oxfordian) limestones	Cubaynes et al., 1989
Germany	Oberrhein (southwestern Germany)	Early Bajocian	Offshore	Marl-limestone alternations	Ohmert, 1994
Germany	Southwestern Germany	Aalenian	Offshore	Marl-limestone alternations	Maxwell et al., 2012
Germany	Southwestern Germany	Late Oxfordian	Upper offshore	Sponge wackestone to packstone with marl interbeds (transitional)	Pittet et al., 2000

Germany	Süntel Mountains (northwestern Germany)	Callovian-Oxfordian	Lower offshore (Callovian and early Oxfordian) to shallow marine (middle-late Oxfordian)	Marl to sandstone (Callovian and early Oxfordian) and oolitic limestone (photozoan, middle-late Oxfordian)	Helm and Schülke, 1998
Germany	North German Basin	Middle Jurassic (Aalenian-Callovian)	Offshore to shallow-marine (Wave dominated)	Claystone to sandstone	Zimmermann et al., 2015
Italy	Umbria-Marche Basin, Central Italy	Aalenian to Oxfordian	Offshore/shallow marine	Marl-limestone alternations	Bartolini et al., 1996
Italy	Umbria-Marche Basin, Central Italy	Aalenian to Oxfordian	Offshore	Marl-limestone alternations/ Heterozoan limestones	Morettini et al., 2002
Italy	Lazio-Abruzzi Platform, Central Italy	Aalenian to Oxfordian	Shallow marine	Heterozoan (Aalenian-early Oxfordian) to photozoan (middle-late Oxfordian) limestones	Bartolini et al., 1996
Italy	Apulia platform, southern Italy	Callovian to Oxfordian	Oolitic shoals and lagoon	Peloidal mudstones to packstones/oolitic grainstones (photozoan)	Bosellini et al., 1999
Italy	Apennines platform, southern Italy, Sorrento Peninsula	Aalenian to Oxfordian	Very shallow	Ooid limestone with Chlorophyte	Iannace et al., 2011
Italy	Trento Plateau, north-eastern Italy	Aalenian to Oxfordian	Offshore	Marl-limestone alternations/ Heterozoan limestones	Préat et al., 2006
Morocco	High Atlas	Aalenian	Inner to mid-ramp	Oolitic limestones (photozoan)	Pierre et al., 2010
Morocco	High Atlas	Aalenian to Bathonian	Inner ramp (Aalenian, late Bajocian, Bathonian) to lower offshore (early Bajocian)	Oolitic/bioclastic limestones (photozoan, Aalenian, late Bajocian), marls (early Bajocian) and sandstones (Bathonian)	Tomas et al., 2013; Ait Addi and Chafiki, 2013
Morocco	High Atlas	Late Bajocian	Inner ramp	Oolitic to bioclastic ramp with corals patch reef (photozoan)	Christ et al., 2012

Poland	Pieniny Kippen Basin, Carpathians (southern Poland)	Aalenian to early Bajocian	Lower offshore	Organic-rich claystones	Tyska, 1994; Tyszka and Kaminski, 1995
Poland	Polish Jura (south-central Poland)	Late Bajocian-Bathonian	Lower offshore	Clays	Zaton et al., 2009
Poland	Cracow Area, southern Poland	Callovian-Oxfordian	Lower offshore (Callovian and early Oxfordian) to shallow marine (middle-late Oxfordian)	Marl to sandstone (Callovian and early Oxfordian) and sponge-rich limestone (transitional, middle-late Oxfordian)	Matyszkiewicz and Felisiak, 1992
Poland	Tatra Mountains, southern Poland	Aalenian to Callovian	Offshore to shallow-marine	Crinoidal limestones (heterozoan), ferruginous condensed,	Luczynski, 2002
Poland	Polish Jura chain (southwestern Poland)	Late Oxfordian	Shallow marine	Sponge limestone (transitional)	Wierzbowski, 2015
Scotland	Cleveland Basin	Aalenian-Oxfordian	Shallow marine	Siliciclastic sandstone	Hesselbo, 2008
Spain	Asturias, Basque-Cantabrian, Pyrenean and Iberian basins; northern Spain	Aalenian-Oxfordian	Offshore to shallow marine	Marl-limestone alternations, condensed ferruginous, heterozoan/photozoan limestones , sandstones	Aurell et al., 2003
Spain	Betic Cordillera, southern Spain	Middle to late Oxfordian	Lower offshore	Marl-limestone alternations	Pittet et al., 200
Spain	Betic Cordillera, southern Spain	Aalenian	Lower offshore	Marl-limestone alternations	Sandoval et al., 2008
Spain	Betic Cordillera, southern Spain	Bajocian and Bathonian	Shoreface	Oolitic limestone (photozoan)	Reolid et al., 2009
Switzerland	Swiss Jura	Middle/late Oxfordian	Shoal/tidal flat/lagoon	Ooid/coral grainstoens to boundstones (photozoan)	Pittet and Strasser, 1997

Switzerland	Swiss Jura	Late Bajocian	Shallow water ramp (shoreface)	Oolitic limestone (photozoan)	Gonzalez and Wetzel, 1996
Switzerland	Swiss Jura	Late Bajocian	Shallow water ramp (shoreface)	Oolitic limestone (photozoan)	Wetzel et al., 2013

- Carbonate platform evolution was reconstructed along a 500 km cross-section
- Tectonism triggered two major phases of rise and fall in carbonate production
- Basement topography acted as a major control over lateral variations of paleodepth
- Photozoan carbonate production was promoted by dry climate and low nutrient input
- Wet climate and the eutrophication of epireic seas lead to low carbonate production