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New mineralogical and organic carbon-isotope data from the Tithonian of Boulonnais (France) – relationship with the VOICE

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Key words: Tithonian, Jurassic/Cretaceous boundary, VOICE (VOlgian Isotope Carbon Excursion), global correlation, northern France.

Abstract. As part of the research initiated by the Berriasian Working Group, we have conducted a detailed study of the Tithonian sedimentary successions of Boulonnais (northern France), given their interest as being deposits which are contemporaneous with the Kimmeridge Clay Formation (KCF) of Dorset (southern England), but situated in more proximal environments on the edge of the London-Brabant massif. The determination of $\delta^{13}C_{org}$ highlights a negative excursion of approximately –2‰ which probably corresponds to the VOICE (VOlgian Isotope Carbon Excursion). The chemostratigraphic data were correlated with the Geologic Time Scale using a compilation of orbital and magnetic stratigraphy. As in the KCF, the onset of this negative excursion occurs in the Pallasioides Zone (M21r to lower M21n). Further, a detailed study of the clay mineralogy shows an increase in the proportion of smectite at the expense of illite and kaolinite in the Albani Zone (M20r to lower M20n), which correlates with the lower part of the middle Volgian. This widespread mineralogical change marks the onset of the period of significant aridification which characterizes the Jurassic/Cretaceous boundary interval regionally. The onset of the aridification phase was nearly synchronous with, or slightly preceded the paleoceanographic changes in some Tethyan basins including the Nannofossil Calcification Event, stratification of water masses, and trace metal enrichments. All these environmental changes in the Alpine Tethys took place around the early/late Tithonian boundary, in the early M20n magnetochron.

INTRODUCTION

As part of the research carried out within the Berriasian Working Group, the objective of which is to determine markers within the Jurassic–Cretaceous boundary interval (see Gale *et al.*, 2020; Wimbledon *et al.*, 2020; Grabowski *et al.*, 2022), and to specify the environmental changes in the vicinity of this boundary, we have resumed detailed study of the Tithonian of Boulonnais (northern France), whose formations are well exposed on the coastal cliffs between Wimereux and Pointe aux Oies, on either side of Pointe de la Rochette (Fig. 1).

This study mainly has a chemostratigraphic approach, the objective being to search for the negative excursion of $\delta^{13}C_{org}$ called the VOICE (VOlgian Isotope Carbon Excursion) (Hammer *et al.*, 2012; Koevoets *et al.*, 2016; Galloway *et al.*, 2019, 2024; Turner *et al.*, 2019; Jelby *et al.*, 2020). This negative excursion is known in several sections of the boreal domain and in the Neuquén Basin in Argentina (Weger *et al.*, 2023), but it is not recorded in the Tethyan realm. The excursion could constitute a stratigraphic marker within the Tithonian, which is otherwise difficult to correlate from one sedimentary basin to another due to the significant provincialism of the ammonite faunas. After a precise lithological survey of the section (see supplementary material), $\delta^{13}C_{org}$ isotopic analyses were carried out, as well as a detailed study of the clay mineralogy in order to specify the precise stratigraphic position of the

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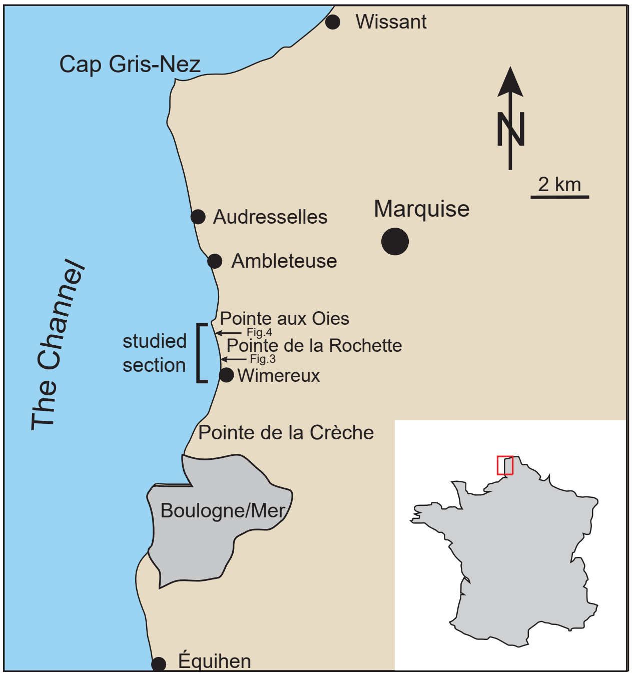

Fig. 1. Location map. The studied section is located along the coastal cliffs from the North of Wimereux to the Pointe aux Oies on either side of Pointe de la Rochette

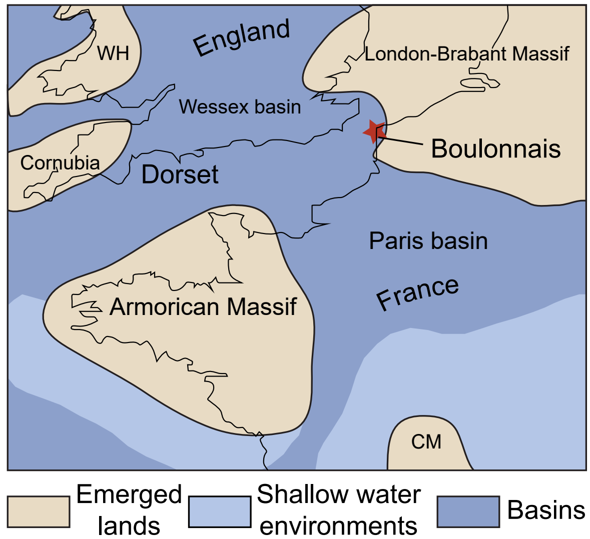

Fig. 2. Late Jurassic palaeogeographic map from NW France and Southern England (after Dercourt *et al.*, 2000)

CM – Central Massif, WH – Welsh High

major mineralogical change previously identified by Deconinck *et al.* (1983).

GEOLOGICAL SETTING

The sedimentary succession of the Tithonian of Boulonnais has been the subject of numerous biostratigraphic and sedimentological studies (Geyssant *et al.*, 1993; Herbin, Geyssant, 1993; Proust *et al.*, 1995; Herbin *et al.*, 1995; Hesselbo *et al.*, 2009). The Tithonian deposits comprise several well characterized lithological units. The Kimmeridgian –Tithonian Boundary defined around Autissiodorensi*s* and Elegans ammonite Zones is located within the Argiles de Châtillon Formation. This lithological unit is overlain by the Grès de la Crèche, the Argiles de la Crèche, the Argiles de Wimereux, the Assise de Croï, the Grès des Oies, and finally by the Purbeckian facies (Ager, Wallace, 1966; Bonte, 1969; Bonte *et al.*, 1985). The sediments were deposited on a homoclinal ramp on the edge of the London–Brabant massif (Fig. 2) (Proust *et al.*, 1995). They are contemporary with the Kimmeridge Clay Formation outcropping in Dorset (Southern England), but in the Boulonnais the more proximal environments allowed for a better record of variations in the water depth. Thus the clayey facies were mainly deposited in an offshore environment, while the sandstones correspond to shallow upper shoreface environments (Proust *et al.*, 1995; Wignall *et al.*, 1996; Williams *et al.*, 2001; Angus *et al.*, 2020).

LA ROCHETTE SECTION

The studied section called "la Rochette" begins immediately north of Wimereux where the top of the Argiles de la Crèche and the Argiles de Wimereux outcrop (Fig. 3). The Argiles de la Crèche, a formation about 8 metres thick, is essentially clayey. The lithology comprises more or less plastic black clays, occasionally laminated, and can contain up to 4% organic matter of mainly planktonic marine origin (El Albani *et al.*, 1993). The upper part of the formation, is characterised by a progressive enrichment in millimetre-thick bioclastic beds followed upwards by discontinuous undulating sandstone lenses corresponding to storm deposits (Hummocky Cross Stratification, HCS) that represent a shallowing-upward trend. The Argiles de la Crèche contains *Pectinatites* sp. in its lower part, which does not allow a precise stratigraphic attribution to be provided, although Geyssant *et al.* (1993) suggest that the Argiles de la Crèche could belong *pro parte* to the Scitulus and to the Wheatleyensi*s* Zones. The Argiles de Wimereux formation begins with a pluri-centimetric phosphate horizon comprising centimetric phosphate nodules most often corresponding to rolled and epigenized bioclasts (mainly bivalves). This bed, called

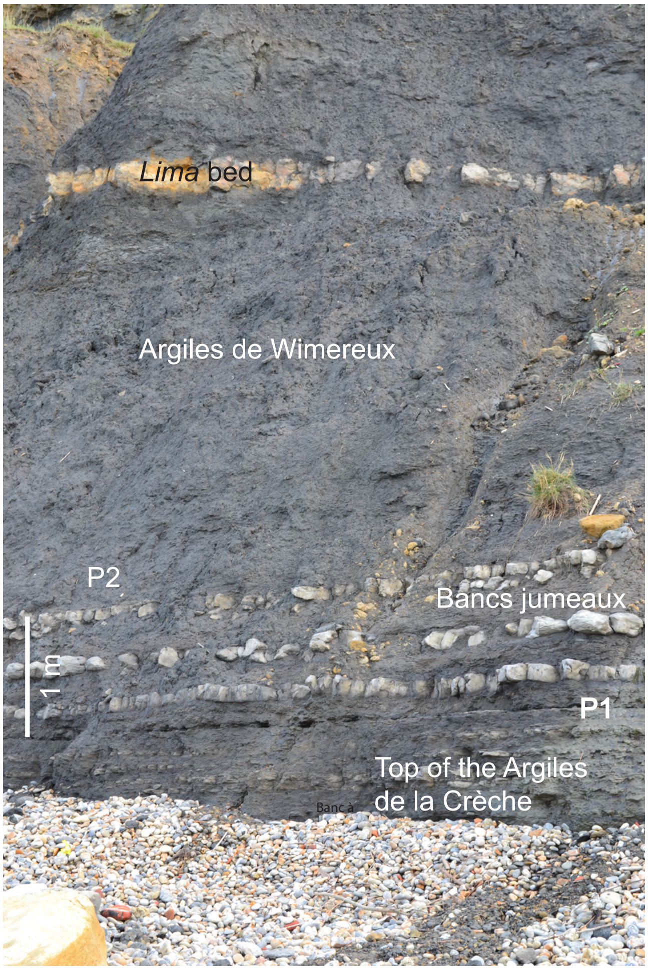

Fig. 3. Field view of the cliff to the North of Wimereux, of the base of the section from the top of the Argiles de la Crèche to the *Lima* Bed

P1 (or La Rochette phosphate level) also contains centimetric quartz pebbles. Additionally, the P1 phosphate level yields ammonites that can be attributed to the Wheatleyensis Zone (Pruvost, 1925; Geyssant *et al.*, 1993; Herbin *et al.*, 1995).

Above the P1 level, regionally, two prominent heavily bioturbated micritic carbonate beds called «bancs jumeaux» occur. However, on the studied section to the north of Wimereux, this lithological unit includes three carbonate beds due to the development of a nodular intercalary bed of diagenetic origin (Fig. 3). The bancs jumeaux are topped by a second phosphate level, indexed P2, devoid of ammonites. Ammonites are only present in the overlying Argiles de Wimereux and indicate the Pallasioides Zone (Geyssant *et al.*, 1993). The Hudlestoni and Pectinatus ammonite Zones do not seem to be represented in the Boulonnais due to the significant condensation of the succession represented by the P1 and P2 phosphate levels. Compared to the Argiles de la Crèche, the Argiles de Wimereux are siltier and glauconitic, and also rich in illite, kaolinite and woody debris (Deconinck *et al.*, 1983). Their middle part is highlighted by an easily identifiable carbonate bed corresponding to the *Lima bononiensis* bed, here labelled *Lima* bed (Fig. 3).

Immediately above the Argiles de Wimereux is the Assise de Croï, which we suggest renaming the Argiles et Calcaires de Croï (Fig. 4) in order to conform to the international nomenclature of formations (Hedberg, 1976). This formation is limited at the base by a bed of phosphate nodules called the Tour de Croï phosphate bed and denoted P3. The P3 phosphate level contains numerous ammonites including *Pavlovia pallasioides* (Townson, Wimbledon, 1979; Geyssant *et al.*, 1993). The Argiles et Calcaires de Croï are characterized by alternating nodular limestone beds and silty-glauconitic marls. Only about ten metres thick, the series presents several indices of condensation, in particular the frequency of nodulization processes, the presence of phosphate grains and glauconite whose dark green grains are mineralogically very evolved (Tribovillard *et al.*, 2023). The Argiles et Calcaires de Croï yields poorly preserved ammonites from the Albani, Glaucolithus and Okusensis Zones *pro parte* (Townson, Wimbledon, 1979), but the Rotunda and Fittoni ammonite Zones have not been recognized in the Boulonnais. It is likely that these two ammonite zones are absent or highly condensed.

The Argiles et Calcaires de Croï are overlain by the Grès des Oies lithological unit assigned *pro parte* to the Okusensis and Kerberus Zones (Fig. 4). These are fine sandstones with carbonate cement containing numerous bivalves including *Cardium* and *Trigonia* and probably deposited in a beach environment. Figure 5 brings together all the observations made on this section and a detailed description of the section is provided as supplementary materials.

Fig. 4. Field view of the cliff between Pointe de la Rochette and Pointe aux Oies, showing the succession from the Argiles de Wimereux to the Purbeckian facies

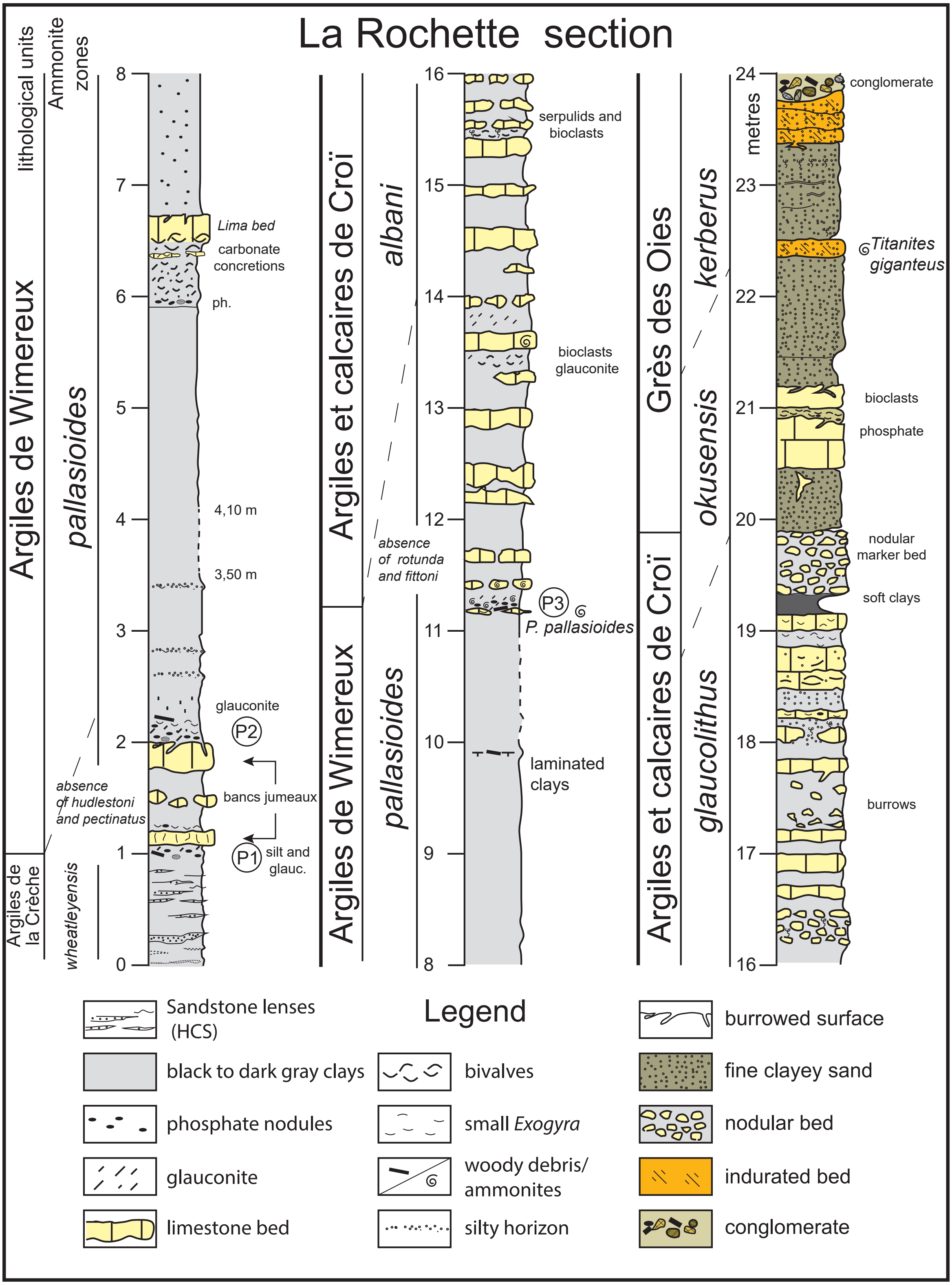

Fig. 5. Detailed lithological succession of La Rochette section

METHODS

ORGANIC CARBON ISOTOPES

Organic carbon isotope compositions ($\delta^{13}C_{org}$) were measured on carbonate-free residues of 39 samples at the Biogeosciences Laboratory, University of Burgundy in Dijon. Sample powders were reacted with HCl (2N) at room temperature for 24 h to remove the carbonate phases. Residues were rinsed with deionised distilled water until neutral, centrifuged (4500 rpm for 15 min), and then dried at 50°C overnight. Aliquots of dried decarbonated samples (~750 mg) were then weighed in tin capsules. $\delta^{13}C_{org}$ measurements were performed on a VarioMICRO cube elemental analyzer (Elementar, Hanau, Germany) coupled in continuous flow mode to an IsoPrime stable isotope ratio mass spectrometer (Isoprime, Manchester, UK). USGS40 LGlutamic acid (C ¼ 40.8 wt%; $\delta^{13}C$ V-PDB ¼ –26.39 ±0.04‰) and IAEA-600 Caffeine ($\delta^{13}C$ V-PDB ¼ –27.77 ±0.04‰) certified reference materials were used for calibration. The carbon isotopic composition is expressed in delta notation and reported in per mil (‰) relative to the Vienna Pee Dee Belemnite (V-PDB) standard; the external reproducibility based on duplicate analyses of the samples is better than ±0.2‰ (1σ).

CLAY MINERALOGY

A total of 20 samples were analysed using X-Ray Diffraction (XRD). After moderate grinding in a mortar, powdered samples were decarbonated with a 0.2 N HCl solution. The <2 μm fraction (clay-sized particles) was extracted with a syringe after deflocculation and decantation of the suspension for 95 min following Stokes' law; this fraction was then centrifuged. Clay residue was then smeared on oriented glass slides and run in a Bruker D4 diffractometer with CuK_{α} radiations, a LynxEye detector and a Ni filter with a voltage of 40 kV and an intensity of 25 mA (Biogeosciences laboratory, University of Burgundy). Goniometer scanning ranged from 2.5 to 28.0° 2Θ for each analysis. Three runs were performed for each sample to discriminate the clay phases: 1) air-drying; 2) ethylene-glycol solvation under vacuum at room temperature during 24 h; and 3) heating at 490°C during 2 h, as recommended by Moore and Reynolds (1997). Clay minerals were identified using their main diffraction (d00l) peaks and by comparing the three diffractograms obtained. The relative proportions of the clay minerals are estimated using peak intensity ratios. The error margin of the method is approximately ±5%.

RESULTS

ORGANIC CARBON ISOTOPES

In the clayey and carbonate facies, the $\delta^{13}C_{org}$ values vary between –26.7 and –24.9‰ (Table 1 of supplementary material and Figure 6). The two analyses carried out in the sandstone facies at the top of the section are not considered here since in these detrital facies, it is likely that OM is partly reworked from ancient formations including Palaeozoic rocks which outcropped on the London–Brabant Massif. There are significant variations in the $\delta^{13}C_{org}$ values in the Argiles de Wimereux (Pallasioides Zone) while in the Argiles et Calcaires de Croï, the values are more homogeneous and significantly lower, less than –25.8‰. Since the organic matter content in the Argiles de Wimereux and in the Argiles and Calcaires de Croi is very low, we did not carry out Rock-Eval pyrolysis to determine its origin since the pyrolysis parameters are insignificant in this case.

CLAY MINERALOGY

The clay mineral assemblages are dominantly composed of illite, smectite and kaolinite, with minor amounts of chlorite (Deconinck *et al.*, 1983; Hesselbo *et al.*, 2009). In the Argiles de Wimereux and the base of the Argiles et Calcaires de Croï, illite and kaolinite are the main clay minerals, while in the upper part of the Argiles et Calcaires de Croï, smectites are the most abundant minerals (Fig. 6). We performed a high resolution sampling around this mineralogical change previously identified in order to locate it precisely. The results show that the mineralogical change occurs progressively in a 2 metre-thick interval, between 13.10 m and 15.15 m which therefore corresponds to the transition (Figs. 6, 7).

DISCUSSION

SIGNIFICANCE OF THE MINERALOGICAL CHANGE

The Kimmeridgian and Tithonian deposits of Boulonnais are characterized by a very clear dependence between the composition of the clay assemblages and the depositional environment. Surprisingly, the offshore deposits (Argiles de Châtillon, Argiles de Wimereux) are rich in illite and kaolinite, while the shallow shoreface deposits (Grès de Châtillon, Grès de la Crèche) are enriched in smectite (Deconinck *et al.*, 1983; Hesselbo *et al.*, 2009). This rela-

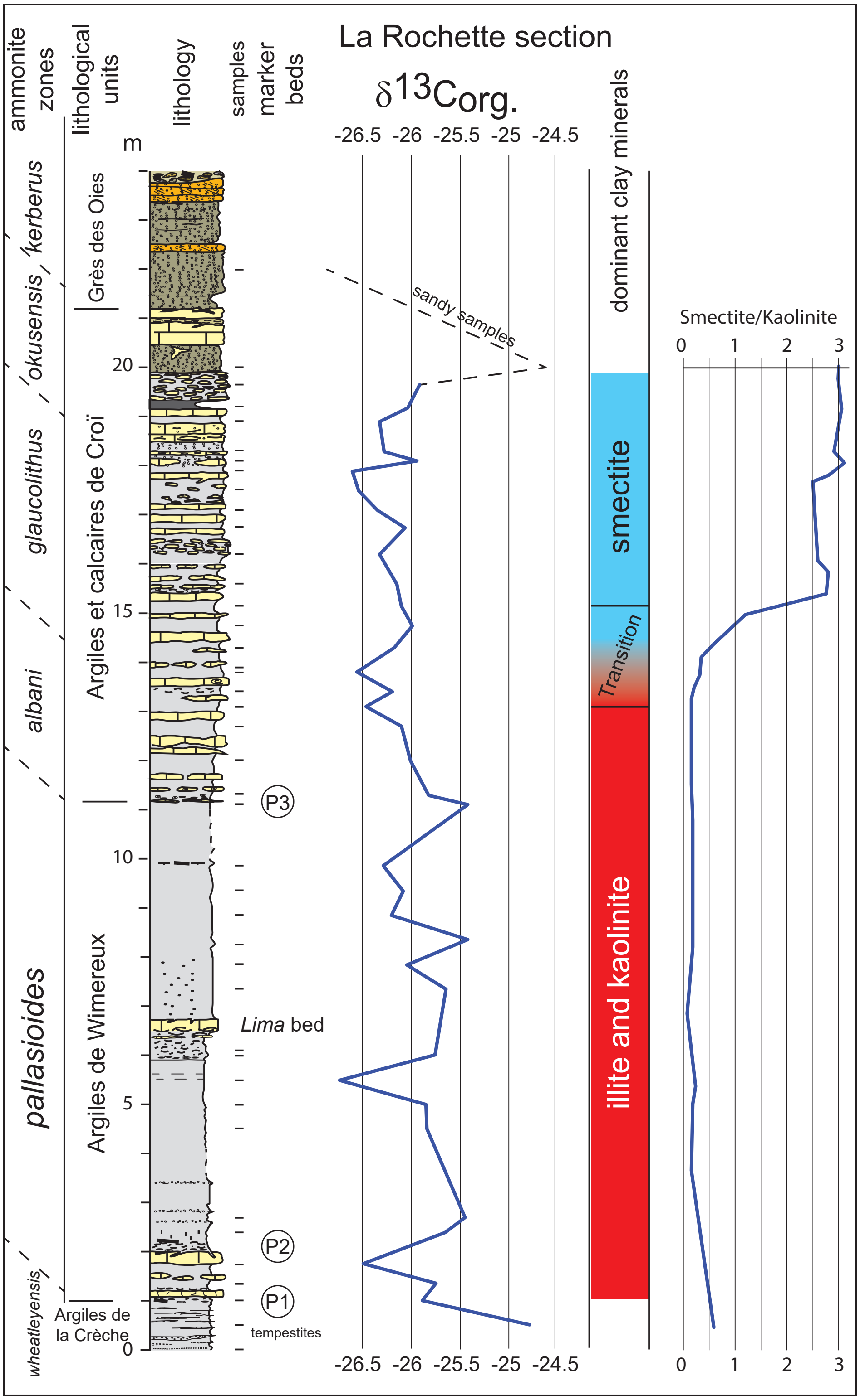

Fig. 6. La Rochette section, $\delta^{13}C_{org}$ and clay mineralogy

Same legend as in Figure 5

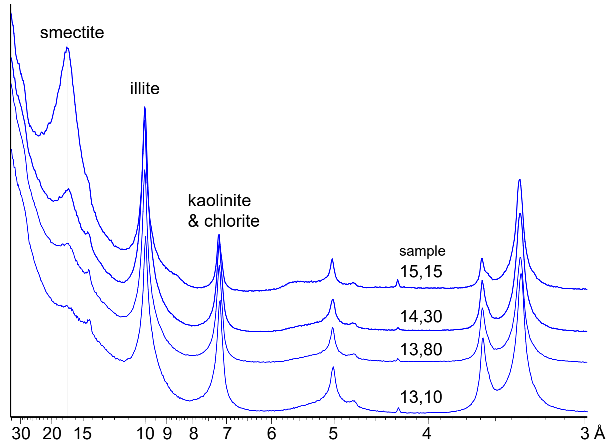

Fig. 7. X-ray diagrams (glycolated) from the transition zone occurring within the Argiles et Calcaires de Croï between illite-kaolinite-rich clay assemblages (samples 13.10 and 13.80) and smectite rich clay associations (samples 14.30 and 15.15)

tionship is quite unusual because it is contrary to the differential settling processes of clay minerals in marine environments which rather leads to the proximal deposition of illite and kaolinite, and the distal deposition of smectite. In the case of Boulonnais, the distribution is explained by the local conditions of clay sedimentation. The smectite-rich sediments of the Kimmeridgian and Tithonian are limited to the palaeogeographic zone close to the London-Brabant massif, while in other areas of NW Europe, illite and kaolinite dominate the clay assemblages of the Kimmeridgian–Tithonian (Hesselbo *et al.*, 2009). This indicates that the smectites had a local origin and came from the erosion of the superficial formations of the London-Brabant massif. During periods of high sea-level, this massif was probably submerged and could not therefore contribute to the clay sedimentation. The illite and kaolinite then came from other more distant emerged massifs. By contrast, during periods of low sea-level, the emergence of the London–Brabant massif allowed the pedogenic formation of smectites, which explains the presence of these minerals in the shallowest facies. It is interesting to note that a similar situation already existed since the Pliensbachian (Bougeault *et al.*, 2017).

Considering this particular situation, we interpret the mineralogical change occurring in the Argiles and Calcaires de Croï (Fig. 6) as a consequence of a decrease in the water depth. The emergence of the London-Brabant massif does not seem to be of tectonic origin, because in this case, it is illite and kaolinite that should significantly increase. Moreover, in the entire Kimmeridgian and Tithonian series of Boulonnais, the relay of illites and kaolinite by smectites occurs several times (Deconinck *et al.*, 1983), which would imply a yo-yo tectonics. Therefore, we suggest that the London–Brabant massif was stable and very flattened and that its emergence resulted from a drop in sea-level.

The regressive trend then continues with the increasingly shallow facies of the Grès des Oies (upper shoreface – foreshore) and then with the Purbeckian facies (Deconinck *et al.*, 2000). The mineralogical change therefore indicates the onset of the regression which will lead to the Purbeckian facies and then to the emergence of this part of the Paris Basin.

Although the biostratigraphic data are rather sparse, the mineralogical change seems to occur within the Albani Zone. A similar mineralogical change is recorded in the Polish Basin and seems contemporaneous (Błażejowski *et al.*, 2023) and interpreted as the onset of the arid phase which characterizes the Late Jurassic/Early Cretaceous interval (Ruffell *et al.*, 2002, Schnyder *et al.*, 2005a, b, 2006). Aridification is probably a consequence of a slowdown in the hydrological cycle. At the same time, temperatures decreased significantly during the end of the Jurassic (Gröcke *et al.*, 2003; Tremolada *et al.*, 2006; Nunn, Price, 2010; Dera *et al.*, 2011; Schnyder *et al.*, 2022). The end of the Tithonian is in fact the coldest period of the Jurassic (Scotese, 2021; Scotese *et al.*, 2021) and signs of glaciation have been identified in the sections located at high palaeolatitudes (Price, 1999). It is therefore appropriate to suggest the possible role of glacio-eustatism on the Late Jurassic sedimentation.

6.2. IDENTIFICATION OF THE VOICE

The isotopic data presented here are complementary to those relating to the underlying Argiles de Châtillon Formation (Late Kimmeridgian – Early Tithonian) published by Van der Hoeven *et al.*, 2022). In the Tithonian part of this formation, the measured $\delta^{13}C_{org}$ values range between –26.3 and –23.9‰, with an average of –25‰ (Fig. 8). Within the Argiles de Wimereux and more markedly in the Argiles et Calcaires de Croï, the $\delta^{13}C_{org}$ values decrease significantly down to –26,5‰ (Fig. 8). A comparable evolution is recorded in the Kimmeridge Clay Formation (Dorset, UK) where the $\delta^{13}C_{org}$ values are relatively high up to the Pectinatus Zone before decreasing in the Pallasioides Zone (Morgans-Bell *et al.*, 2001, Fig. 8). Over the entire Tithonian outcropping in Boulonnais, we therefore record a negative excursion starting in the Pallasioides Zone, which is contemporary with the negative excursion recorded in Dorset (Turner *et al.*, 2019). However, for both Boulonnais and Dorset, the amplitude of the negative excursion of about 2‰ is lower than in the paleogeographic domains located at higher palaeolatitudes where it reaches 4‰ (Galloway *et al.*, 2019). However, in the Boulonnais, it is likely that we are only recording the beginning of the isotopic excursion, the section being interrupted by the Purbeckian facies.

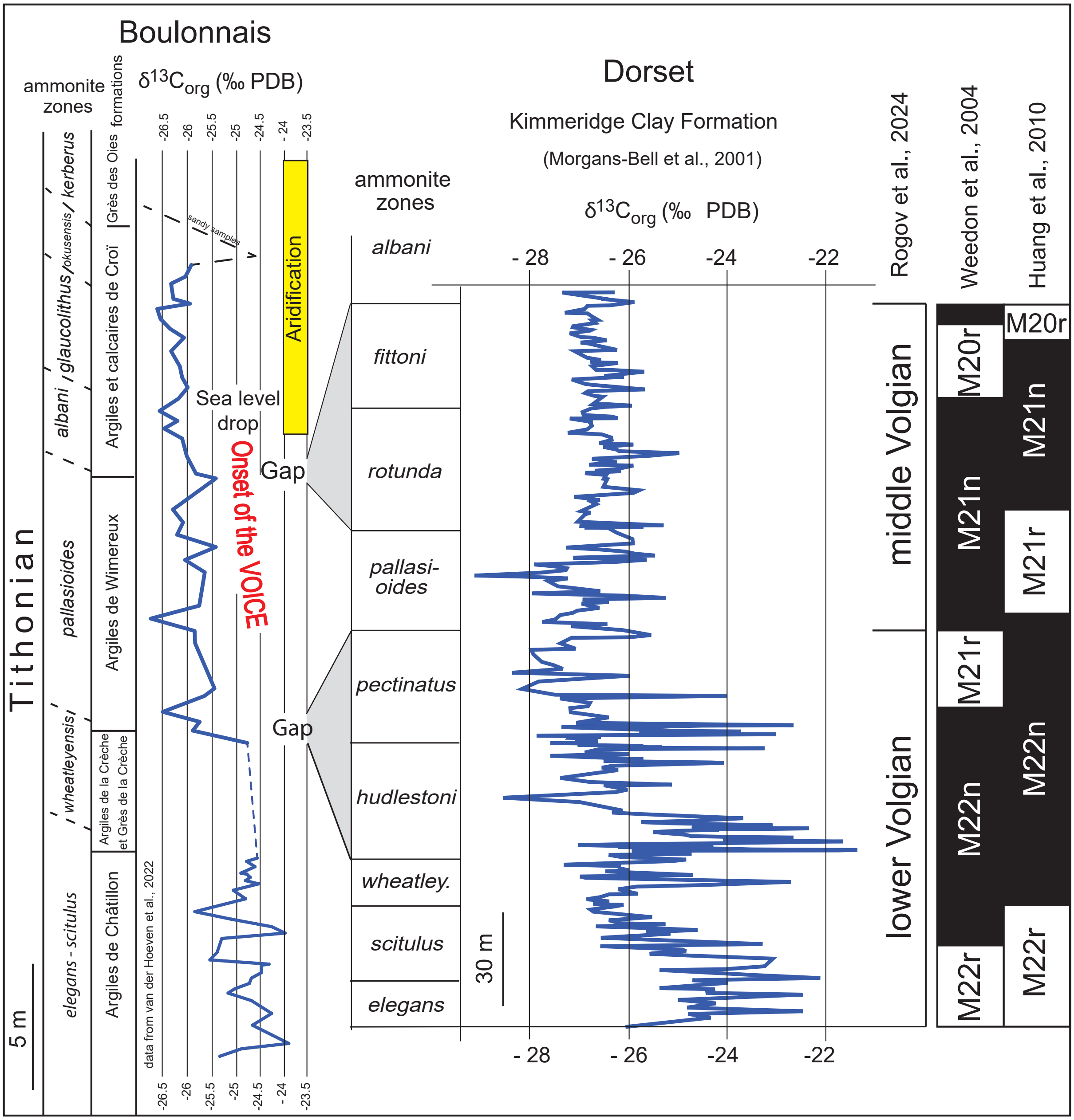

Fig. 8. Comparison between the Tithonian evolution of $\delta^{13}C_{org}$ in the Boulonnais (Northern France) and Dorset (Southern England), and possible correlation to Russian Platform and GPTS (Global Polarity Time Scale)

In the Boulonnais, as in Dorset, the amplitude of the fluctuations in $\delta^{13}C_{org}$ are relatively large in the Pallasioides Zone before stabilising around –26.5‰ from the Albani Zone onwards, an interval which coincides with a sea-level drop and the onset of the arid phase which characterizes the end of the Tithonian. The installation of a more arid climate probably caused a decrease in the input of continental organic matter. In the Argiles de Wimereux, we find much wood debris up to the P3 phosphate nodule bed, while in the Argiles and Calcaires de Croï, woody debris is much rarer. While in the Pallasioides Zone the organic matter would have a mixed marine and continental origin (El Albani *et al.*, 1993), it would be mainly marine in the Argiles and Calcaires de Croï which would explain the more constant values of $\delta^{13}C_{org}$. from the Albani zone upward. It is interesting to note that the significant decrease in $\delta^{13}C_{org}$ in the

Albani Zone coincides with the drop in sea-level and with the beginning of the arid climatic phase, which continue till the end of the Tithonian, and higher towards the mid-Berriasian (Lodowski *et al.*, 2025 and reference therein)

6.3. IMPLICATIONS FOR THE GLOBAL CORRELATION

New $\delta^{13}C_{org}$ isotopic data obtained in this study might be discussed against the present-day global polarity time scale (GPTS) for the Tithonian stage (Hesselbo *et al.*, 2020), using the astrochronological data of Weedon *et al.* (2004) and Huang *et al.* (2010; see also Huang, 2018). The task is fairly difficult since it requires adjustment of the three floating timescales (biostratigraphic, astrochronologic and magnetostratigraphic) against "absolute" numerical ages, the latter being sometimes a subject of substantial change with each new edition of the Geologic Time Scale, as compared *e.g.* between Ogg *et al.* (2012) and Hesselbo *et al.* (2020).

The approach presented here is based on general agreement that the base of the Tithonian stage is correlated with the base of M22An magnetozone and base of the Mediterranean *Hybonoticeras hybonotum* (=Hybonotum) Zone (Hesselbo *et al.*, 2020), based on a single study of Ogg *et al.* (1984) in Sub-Betic sections (Spain), and currently calibrated to 149.24 Ma. The base of Sub-Boreal Tithonian, taken as a base of *Pavlovia elegans* (=Elegans) Zone is estimated as slightly younger, falling at the base of M22r magnetozone (149.1 Ma). However, according to calculations of Huang *et al.* (2010) the base of the *P. elegans* (=Elegans) Zone falls as high as in middle part of M22r magnetozone, thus at 148.79 Ma, according to GTS 2020 (Hesselbo *et al.*, 2020). Therefore, we must be aware that uncertainty interval in numerical calibration of the Kimmeridgian/Tithonian boundary in Sub-Boreal realm might amount to at least 0.3 Ma.

Taking into account that the base of the *P. elegans* (=Elegans) Zone might be situated in the middle part of M22r magnetozone (after Huang *et al.*, 2010), the duration of the Tithonian part of the Kimmeridge Clay Formation after Weedon *et al.* (2004) and Huang *et al.* (2010) might be easily estimated (Fig. 9). The Fittoni/Albani ammonite zonal boundary (= the base of the British Portlandian) falls between the

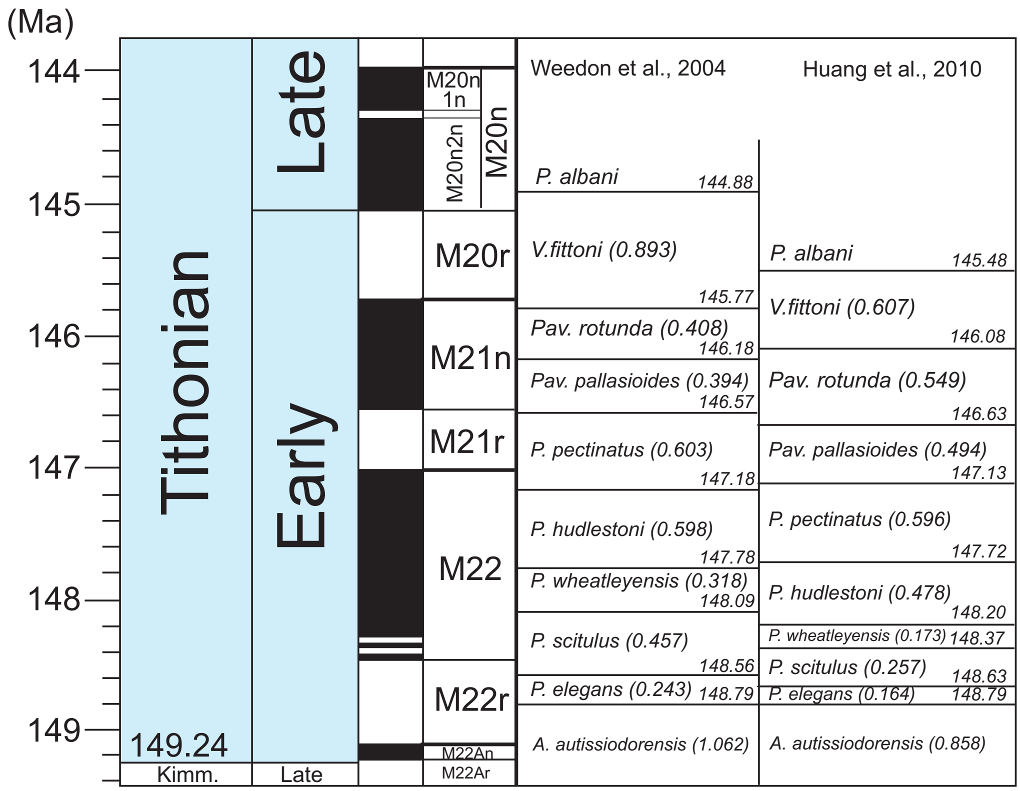

Fig. 9. Correlation of the Tithonian Sub-Boreal ammonite zones to GPTS using cyclostratigraphical approach of Weedon *et al.* (2004) and Huang *et al.* (2010)

lower part of M20r (Huang *et al.*, 2010) and the lower part of M20n magnetozone (Weedon *et al.*, 2004), with a difference of *ca.* 0.6 Ma.

The position of the Fittoni/Albani boundary as interpreted by Błażejowski *et al.* (2023), in the lower part of M20n2n magnetosubzone is more concordant with the estimates of Weedon *et al.* (2004), as shown in Figure 9. On the other hand, the scaling of Huang *et al.* (2010) should be considered as more up to date, and it was applied in the most recent GTS (Hesselbo *et al.*, 2020). The possible error might arise from multiple sources, such as uncertainty in chronostratigraphical calibration, slight inaccuracy of ammonite correlations, as well as unrecognized normal-polarity remagnetization in the Owadów–Brzezinki section of Błażejowski *et al.* (2023). The latter may not be excluded since only a short stratigraphical interval was the subject of magnetostratigraphic investigations. Nevertheless, the biostratigraphic correlation of the Fittoni/Albani boundary conforms quite well to estimations given recently by Błażejowski *et al.* (2023). They claimed that the Fittoni/Albani boundary in central Poland coincides with the Scythicus (Panderi)/Virgatus Russian ammonite zonal boundary of the middle Volgian, and is situated within the calpionellid Chitinoidella Zone. The latter is fairly well established in the Tethyan stratigraphic scheme (*e.g.*, Míchalik *et al.*, 2021; Casellato, Erba, 2021; Petrova *et al.*, 2025), falling between the middle part of M21r and lower part of M20n magnetozone. Apparently, the onset of the aridification phase documented in this study (Fig. 8) and in the Polish Basin (Grabowski *et al.*, 2021; Błażejowski *et al.*, 2023; Wierzbowski *et al.*, 2025) was nearly synchronous with, or slightly preceded the initiation of calcareous micro- and nannoplankton (Nannofossil Calcification Event, see Bornemann *et al.*, 2003) and the onset of stratification and trace metal enrichments in some Tethyan basins (Lodowski *et al.*, 2024a, b), which took place around the early/late Tithonian boundary, in the early M20n magnetochron.

If the negative excursion of $\delta^{13}C_{org}$ in the Pallasioides Zone of the Boulonnais section, and the Pectinatus – Pallasioides Zones in the Dorset section is interpreted as the manifestation of the VOICE event (Turner *et al.*, 2019), it would be situated between the upper part of M22n and lower part of M21n, close to the lower/middle Volgian boundary (Figs. 8, 9), being virtually concordant with the original estimations of Hammer *et al.* (2012). According to this definition, the acme VOICE in the Arctic areas (interval of $\delta^{13}C_{org}$ minimum values in Hammer *et al.*, 2012, and Koevoets *et al.*, 2016) would be a relatively short event, situated in the early Tithonian. Although useful as a correlation horizon in Arctic and Sub-Boreal domains, it cannot be considered as an important marker of the Jurassic/Cretaceous boundary, being stratigraphically too far from the considered Tithonian/Berriasian boundary interval (M19r–M18r).

7. CONCLUSIONS

The new $\delta^{13}C_{org}$ data obtained in the Tithonian sedimentary succession of the Boulonnais, shows that the negative excursion called VOICE (VOlgian Isotope Carbon Excursion) is recorded with an amplitude of the order of –2‰. The negative excursion begins there as in Dorset in the vicinity of the Pallasioides Zone in the early Tithonian. This negative excursion clearly constitutes an element of correlation within the Tithonian in the boreal and sub-boreal domain but cannot in any case constitute a secondary marker of the Jurassic-Cretaceous boundary. A significant drop in sea-level then occurs during the Albani Zone at the same time as a major climate change corresponding to the onset of the arid phase characterizing the transition interval between the Jurassic and the Cretaceous. The early to late Tithonian transition is therefore marked by major environmental changes probably caused by the significant cooling that characterized the end of the Jurassic.

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