

## Author's Response to the Review Comments

**Journal:** Climate of the Past

**Manuscript #:** EGUSPHERE-2025-3832

**Title of Paper:** Decoding the North Atlantic Ocean Circulation Breakthrough in the Aptian–Albian Transition

**Authors:** João M. F. Ramos, Jairo F. Savian, Daniel R. Franco, Milene F. Figueiredo, Rodolfo Coccioni, and Fabrizio Frontalini.

**Date Sent:** Dec 16, 2025

Dear Editor Shiling Yang,

We appreciate the time and efforts by the Editor and Reviewers in reviewing this manuscript. We have addressed all issues indicated in the review report and believe that the revised version can meet the journal publication requirements. We have also complemented the paper with additional information as suggested by the Reviewers.

Yours sincerely,

João M. F. Ramos

## Response to Comments from Editor

### Comment 1:

*Dear João Ramos,*

*Thank you for submitting your manuscript, “Decoding the North Atlantic Ocean Circulation Breakthrough in the Aptian–Albian Transition”, to *Climate of the Past*. The reviewers and I have now completed our assessment.*

*We find the topic of your work highly valuable and of potential interest to our readership. However, to meet the journal’s standards for publication, major revisions are required to address the substantive points raised by the reviewers.*

*We appreciate your contribution to *Climate of the Past* and encourage you to undertake a thorough revision. We look forward to receiving your revised manuscript.*

*Kind regards*

*Shiling Yang*

.

### Response:

We greatly appreciate the Editor efforts to carefully review the paper and the valuable suggestions offered. Thank you for the opportunity to make major revisions and necessary changes. We agree with Editor and Reviewer’s comments and recommendations, as you will see in the following replies point-by-point.

## Response to Comments from Anonymous Referee #2

### Overall Comment:

*The study's contribution lies in establishing a highly precise chronostratigraphic framework for the Aptian–Albian section at ODP Site 1049. This precise age control rigorously constrains the timing of CORBs, thereby providing a solid foundation for subsequent regional correlation and mechanistic studies. However, the discussion regarding the CORB formation mechanism could be significantly enhanced by providing greater depth and incorporating more independent evidence, which currently represents the main area for improvement in this manuscript.*

### Response:

Thank you very much for reviewing the manuscript and for suggesting such important points to improve the overall quality of the text. ODP Site 1049 has been extensively studied using multiple methodologies (e.g. Klauss et al., 2000; Erbacher et al., 2001; Ogg & Bardot, 2001; Leckie et al., 2002; Huber & Leckie, 2011; Huber et al., 2011; Kochhann et al., 2023), and the mechanism of CORB formation at this site — from a geochemical perspective — has been thoroughly detailed by Li et al. (2011) and Hu et al. (2012) in the North Atlantic realm, and by Giorgioni et al. (2017) in the Tethyan realm. Both studies discuss the origin of the Aptian and Albian CORBs. The differential contribution incorporated in our manuscript lies in the tie points derived from the new datings of bioevents (Leandro et al., 2022; Ramos et al., 2024a), as well as the ages of the carbon-isotope curve markers (Ramos et al., 2024a), which together enabled a high-resolution cyclostratigraphic study. We hope that the responses provided below are sufficient for the manuscript to meet the standards of *Climate of the Past*.

**Comment 1:***Main Concerns:*

*The authors propose that "long-term Aptian CORBs were driven by sustained thermohaline circulation and global cooling (Cold Snap)." To enhance the persuasiveness of this mechanistic conclusion, the authors are encouraged to consider the following points:*

*To fully verify the proposed "enhanced thermohaline circulation" and "global cooling" mechanisms, it would be highly beneficial to incorporate or discuss critical geochemical and paleoclimatic evidence.*

**Response:**

Thank you for the suggestion to improve the manuscript. In the revised version, we have incorporated additional geochemical and paleoclimatic evidence to clarify the possible mechanisms underlying the differences observed between Aptian and Albian CORBs.

Regarding the theoretical framework linking thermohaline circulation and global cooling mechanisms, we now address these aspects throughout the revised manuscript by progressively introducing relevant information. For example, in the Introduction we state:

*"Among the proposed mechanisms for CORB formation, the presence of oxygenated bottom waters is considered the primary prerequisite for organic matter oxidation and the associated early diagenetic processes that characterize CORBs (Wang et al., 2009; Jansa and Hu, 2009). In this context, thermohaline circulation is widely recognized as the dominant mechanism responsible for deep-ocean oxygenation (Yamamoto et al., 2015). A fundamental requirement for the establishment of such circulation is the existence of strong latitudinal temperature gradients between cold polar regions and warm equatorial zones (Hay, 2008)—a condition generally considered atypical for the Cretaceous."*

(Lines 61–66 of the revised manuscript)

In the Results section, we further develop this framework by introducing geochemical evidence, such as the behavior of the CaCO<sub>3</sub> curve:

*"The cyclic patterns are consistent with enhanced variability in bottom-water ventilation and primary productivity, in agreement with previous observations of orbitally paced changes in Early Cretaceous deep-ocean oxygenation (Herbet et al., 1986; Leandro et al., 2022; Gambacorta et al., 2016). In contrast, Aptian proxies display more uniform behavior, with low-amplitude CaCO<sub>3</sub> variations and the absence of clear productivity cycles (Fig. 3). This suggests a more stable paleoceanographic regime during the Aptian, likely maintained by restricted oceanic connectivity prior to the full opening of the Equatorial Atlantic Gateway (EAG; Duarte et al., 2025; Ramos et al., 2025) and by the persistence of the Cold Snap climatic state. Orbital pacing, however, is still recorded in Aptian MS fluctuations, indicating sensitivity to insolation forcing even under comparatively steady circulation."*

(Lines 307–314)

To enhance the visualization of these geochemical patterns, Figure 3 has been modified in the revised manuscript to include additional datasets from Li et al. (2011) and Hu et al. (2012). Correspondingly, we added the following discussion:

*"During the Albian, renewed greenhouse conditions suppressed deep-water formation by reducing latitudinal thermal gradients, with ocean heat transport dominated*

by mesoscale eddies and low-latitude sinking of warm, saline waters (Hay, 2008, 2009; Gambacorta et al., 2016). This shift is reflected in clay-mineral assemblages and geochemical proxies: Aptian Ca-rich CORBs formed under drier conditions with limited terrigenous input, whereas Albian Al-rich CORBs indicate more humid climates, greater paleoceanographic variability, and orbitally paced alternations in ventilation (Li et al., 2011; Hu et al., 2012).

The slightly higher illite concentrations in the Aptian CORBs—reflecting moderate to weak weathering under relatively dry conditions—suggest that the atypical conditions of the Aptian Cold Snap interlude were characterized by lower terrigenous input than during the Albian (Fig. 3). Although the  $\text{CaCO}_3$  content of the white layers interbedded with the red beds is similar in both intervals, the markedly low  $\text{CaCO}_3$  values in the Albian CORBs are noteworthy (Li et al., 2011). This observation indicates substantially greater paleoceanographic variability during the Albian. Low  $\text{CaCO}_3$  contents may be related to (a) reduced primary productivity, (b) higher dissolved  $\text{CO}_2$  concentrations, (c) increased terrigenous input, and/or (d) water-column stagnation associated with older bottom waters. Because terrigenous input at ODP Site 1049 remained relatively stable throughout the Albian (Cheng, 2008), we propose that alternation between intervals of active bottom-water oxygenation and intervals of ocean stagnation provides a more plausible explanation. Variations in the Ba/Al ratio and in  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  concentrations between Albian red and white beds further support the presence of cyclic productivity changes (Hu et al., 2012). In contrast, the absence of abrupt  $\text{CaCO}_3$  variability during the Aptian suggests more stable paleoceanographic conditions, with limited fluctuations in productivity and ocean circulation.”

(Lines 350–367)

We also substantially restructured the Discussion section to establish a clearer narrative, beginning with paleoclimatic evidence and subsequently addressing the plausibility of enhanced thermohaline circulation (Lines 329–354):

“A major paleoclimatic transition across the Aptian–Albian boundary is recorded by long-term fluctuations in the carbon isotope record, reflecting changes in the global carbon cycle linked to ocean circulation and productivity (Weissert, 1989). At ODP Site 1049,  $\delta^{13}\text{C}$  values shift abruptly from  $\sim 4\text{‰}$  to  $\sim 2\text{‰}$  VPDB, providing clear evidence for a fundamental climatic reorganization (Huber et al., 2011). Independent proxies—including floral and faunal turnover, plant fossils indicative of cooler conditions, glendonites, ice-rafted debris, and intensified hydrological cycling associated with the late Aptian Equatorial Humid Belt—corroborate this transition (Hochuli, 1981; Krassilov, 1973; Leckie, 1989; Kemper, 1987; Herrle et al., 2015; Santos et al., 2022; Ramos et al., 2025). Tethyan records further indicate reduced siliciclastic input, faunal turnover within the *G. algerianus* Zone, and a pronounced global sea-level fall (Weissert and Lini, 1991).

This cooling, commonly referred to as the Aptian ‘Cold Snap’ (McAnena et al., 2013), is widely attributed to declining atmospheric  $\text{CO}_2$  levels driven by enhanced burial of organic carbon and pyrite, which slowed carbon cycling and promoted polar ice growth (Weissert and Lini, 1991; Leandro et al., 2022). Large Igneous Province emplacement, particularly of the Kerguelen Plateau, may have further perturbed the carbon cycle and contributed to episodic cooling (Coffin and Eldholm, 1994; Percival et al., 2024). Geochemical proxies,

*including benthic and planktonic  $\delta^{18}\text{O}$ , indicate that Aptian bottom waters were up to  $\sim 10^\circ\text{C}$  cooler than Albian bottom waters, highlighting rapid warming across the boundary (Huber et al., 2011; Kochhann et al., 2023). Under typical Cretaceous greenhouse conditions, high-latitude regions were unlikely to generate dense, oxygenated deep waters, resulting in sluggish deep-ocean ventilation (Schlanger and Jenkyns, 1976; Hay, 2008, 2009). The Aptian Cold Snap temporarily disrupted this mode, enhancing thermohaline circulation through increased oxygen solubility in colder waters and possibly the presence of polar ice. This circulation regime promoted deep-water renewal and organic matter oxidation, facilitating CORB formation, as evidenced by widespread hardgrounds, intensified bottom currents, and basin-wide shifts from grey-green to red-brown sediments (Premoli Silva et al., 1989; Weissert and Lini, 1991).”*

Complementary interpretations are presented in Lines 369–385:

*“CORBs serve as key archives of mid-Cretaceous climate and circulation dynamics (Premoli Silva et al., 1989; Hu et al., 2005; Li et al., 2011; Giorgioni et al., 2016; Gambacorta et al., 2016). Their formation is linked to episodes of cold, oxygenated deep-water formation rather than enhanced productivity, as LIP-derived nutrients would have promoted organic carbon burial incompatible with oxidized conditions (Leckie et al., 2002; Browning and Watkins, 2008; Wang et al., 2011). Enhanced burial of organic carbon during OAEs, combined with LIP-induced perturbations, reduced atmospheric  $\text{CO}_2$  and promoted global cooling, increasing the oxidizing capacity of deep waters during the Aptian Cold Snap (Arthur et al., 1988; Weissert, 1989; Hu et al., 2012).*

*Aptian CORBs are long-lived, regionally correlatable, and reflect sustained thermohaline circulation over  $\sim 2$  Myr, supported by isotopic evidence for well-oxygenated, cooler, and low-productivity deep waters (Erbacher et al., 2001; Premoli Silva et al., 1989; Leandro et al., 2022). Enhanced vertical mixing driven by current–topography interactions may have further facilitated oxygenation (Ahmerkamp et al., 2017).*

*In contrast, Albian CORBs are shorter-lived, orbitally paced, and reflect transient ventilation interspersed with stratification and episodic black shale deposition (e.g., the Paquier/Urbino Level; Erbacher et al., 2011). Variations in color, facies, and geochemical signatures among Albian CORBs indicate localized differences in paleogeography and oceanography, with obliquity and short-eccentricity cycles exerting a strong control on sedimentation (Li et al., 2011; Trabucho Alexandre et al., 2010). Aptian CORBs, by contrast, display greater uniformity, consistent with sustained circulation and restricted oceanic connectivity prior to the full opening of the Equatorial Atlantic Gateway (Dummann et al., 2023; Ramos et al., 2025).”*

We hope that this expanded discussion of the geochemical and paleoclimatic evidence adequately addresses any concerns raised during the previous review. Although the revised manuscript is somewhat longer due to the inclusion of these new observations, we believe it is now considerably more robust and conceptually clearer. We thank the reviewer for encouraging these improvements.

**Comment 2:**

*Given the clear cyclical characteristics of the Aptian CORBs, a more detailed investigation into the coupling relationship between short-term orbital control and the proposed long-term thermohaline circulation drive would strengthen the analysis.*

**Response:**

Thank you for the reviewer's comment regarding the relationship between orbital forcing and thermohaline circulation. We would like to clarify that we do not propose a direct causal link between short-term orbital forcing and long-term thermohaline circulation. Instead, our intention is to emphasize that high-frequency cyclicity within Milankovitch bands is a pervasive characteristic of Cretaceous marine sedimentary successions and is consistently recorded by multiple independent proxies, including  $\text{CaCO}_3$  and  $\text{SiO}_2$  contents (Herbert et al., 1986), carbon-isotope ratios, and magnetic susceptibility (Leandro et al., 2022). These signals document orbitally paced variability that is superimposed on longer-term circulation regimes rather than driving them.

Based on the reviewer's suggestion, we expanded the theoretical framework in the revised manuscript to better contextualize sedimentary cyclicity and its potential forcings in both Aptian and Albian CORBs. Throughout the revised text, we explicitly discuss how orbital-scale variability interacts with background climatic and paleoceanographic boundary conditions. For example, we now state that:

*“High-frequency Milankovitch-scale cyclicity is widely recorded in Lower Cretaceous pelagic successions and is expressed in variations of  $\text{CaCO}_3$  and  $\text{SiO}_2$  contents (Herbert et al., 1986), carbon isotopes, and magnetic susceptibility (Leandro et al., 2022). These cycles are superimposed on a long-term perturbation of the global carbon cycle (Weissert, 1989), characterized by reduced carbon turnover and multi-million-year cold interludes (Leandro et al., 2022), potentially associated with polar ice-sheet growth (Trabucho Alexandre et al., 2010) and eustatic sea-level fall (Weissert & Lini, 1991). Orbital-scale variability in ocean circulation reflects the interplay between seasonal contrast, hydrological balance, and water-column stratification. Humid climates with strong seasonality favor stratification and are typically associated with non-CORB intervals, whereas reduced seasonality under more arid conditions promotes weaker stratification and CORB deposition (Giorgioni et al., 2017). Variations in runoff, evaporation, saline exchange between basins, and temperature-dependent oxygen solubility further modulate surface-water density gradients and deep-water formation (Ryan & Cita, 1977; Weissert et al., 1985; MacLeod et al., 2001; Steinig et al., 2024). Episodic saline incursions and astronomically paced bottom currents may have intermittently enhanced deep-water renewal and seafloor reoxygenation without requiring major reorganization of global circulation (Friedrich et al., 2008; Gambacorta et al., 2016). At ODP Site 1049, the Albian interval displays pronounced orbital-scale cyclicity in  $\text{CaCO}_3$ ,  $\text{Ba/Al}$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and magnetic susceptibility (Li et al., 2021; Hu et al., 2022), consistent with repeated alternations between enhanced ventilation and stratified conditions (Figs. 3 and 4). Albian CORBs are best explained by the combined effects of evaporation-driven deep-water formation—through episodic saline flooding—and orbitally regulated bottom-current activity that transiently reoxygenated the seafloor, enabling cyclic early diagenesis.*

*In contrast, the Aptian interval shows more uniform proxy behavior, limited CaCO<sub>3</sub> variability, and weaker productivity signals, pointing to a comparatively stable circulation regime. Although orbital forcing is still expressed in magnetic susceptibility, its impact was muted, consistent with sustained deep-water ventilation during the Aptian cold snap and restricted oceanic connectivity prior to the full opening of the Equatorial Atlantic Gateway.”* (Lines 419 – 439 of the revised manuscript)

We hope that this expanded discussion strengthens the interpretation of cyclicity at ODP Site 1049 and clarifies the distinction between orbitally paced high-frequency variability and longer-term thermohaline circulation regimes. We thank the reviewer for identifying this point, which has significantly improved the conceptual clarity of the revised manuscript.

### **Comment 3:**

*The assertion that the erosional event between ~114.5 and 111.9 Ma may have caused a global hiatus needs careful re-evaluation. If a global scale is proposed, the manuscript should clearly address: a) the reasons for any inconsistency in the record (unconformity presence/absence) across correlated sections; and b) supporting evidence from other global sections.*

### **Response:**

Regarding the unconformity, other reviewers also pointed out that we should better describe its causes, particularly those related to bottom currents. Accordingly, we decided to include the following text in the Discussion section:

*“The unconformity observed at ODP Site 1049 is consistent with the local geological setting of the Blake Escarpment, a continental-slope environment characterized by persistent bottom-current activity and high erosional potential (Benson et al., 1978; Li et al., 2011). Along continental margins in both the Tethyan Ocean and the North Atlantic, buried contourite drifts and stratigraphic gaps are common features and are widely attributed to variations in bottom-current strength and reorganizations of deep-water circulation, frequently linked to OAEs and major paleoceanographic transitions (Gambacorta et al., 2016; Liu et al., 2023).*

*However, hiatuses of comparable duration have been documented at multiple sites, including DSDP Sites 511, 545, 763B, and 392A (Huber and Leckie, 2011), as well as at DSDP Site 545 off Morocco and ODP Site 1276 in the Newfoundland Basin (Trabucho Alexandre et al., 2010). The recurrence of similarly timed unconformities across different ocean basins indicates that the discontinuity at Site 1049 reflects a regional to global paleoceanographic signal rather than a purely local phenomenon. Incomplete stratigraphic records near the Aptian–Albian boundary—commonly associated with OAE 1b (Ramos et al., 2024b)—are therefore not unusual; several drill sites, including DSDP Sites 390, 392A, and 511, show partial or complete removal of upper Aptian and lower Albian successions (Huber et al., 2011).*

*Independent support for an erosional surface at ODP Site 1049 is provided by abrupt shifts in  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, coincident with the major planktic foraminiferal extinction*

at the Aptian–Albian boundary and expressed lithologically as a sharp contact. In addition, the  $\text{CaCO}_3$  record shows a pronounced decrease indicative of dissolution and/or sediment removal (Li et al., 2011), further supporting the presence of a depositional hiatus. While initial estimates placed the duration of this gap at  $\sim 0.8$ – $1.4$  Myr (Huber et al., 2011), astrochronological constraints indicate that the absence of the *Microhedbergella renilaevis* and *M. miniglobularis* zones corresponds to  $\sim 0.76$ – $0.84$  Myr (Ramos et al., 2024). Because the overlying *M. rischi* zone may also be incomplete at Site 1049, the total duration of the unconformity likely exceeded 2 Myr.

This extended depositional gap has contributed to discrepancies in the estimated amplitude and duration of OAE 1b (Ramos et al., 2024b) and complicates global correlations based on carbon-isotope excursions or the nomenclature of organic-rich sub-events. In the Vocontian Basin, up to four organic-rich horizons—Jacob, Kilian, Paquier, and Leenhardt (Br  h  ret, 1994)—have been attributed to OAE 1b, whereas other studies recognize fewer levels (Herrle et al., 2004; Trabucho-Alexandre et al., 2011). Consequently, the expression of OAE 1b in complete Tethyan sections (Coccioni et al., 2012, 2014) cannot be straightforwardly correlated with the incomplete records of the North and South Atlantic basins, including ODP Site 1049 and DSDP Site 511.

Multiple processes likely contributed to the development of the Aptian–Albian unconformity. Paleoclimatic reconstructions indicate cooler temperatures and reduced humidity during this transition, coincident with high-latitude cooling and a global sea-level fall, consistent with the buildup of polar ice caps (Weissert and Lini, 1991). Carbon-cycle perturbations during the Aptian closely track eustatic variations (Haq et al., 1987), and the pronounced negative  $\delta^{13}\text{C}$  excursion at the base of the Albian (C-mark v; Ramos et al., 2024) coincides with a lowstand. We therefore propose that eustatic sea-level fall was a primary control on sediment removal at ODP Site 1049, while bottom-current activity acted as an amplifying mechanism rather than the initial driver of erosion.

Although the progressive opening of the Equatorial Atlantic Gateway during the Albian may have strengthened contour currents along continental slopes (Duarte et al., 2025), the presence of a comparable unconformity at DSDP Site 511 in the southern South Atlantic suggests that intensified bottom currents were a response to global sea-level change rather than a purely gateway-driven process. Transient bottom currents, potentially modulated by orbital forcing, may have further promoted episodic seafloor erosion and reoxygenation (Gambacorta et al., 2016). The estimated duration of  $\sim 2.56$  Myr for the unconformity at ODP Site 1049 is compatible with long-period ( $\sim 2.4$  Myr) eccentricity modulation, supporting recent suggestions that grand orbital cycles exerted a first-order control on global deep-water circulation and sediment preservation prior to 70 Ma (Dutkiewicz et al., 2024).

Overall, the long duration and widespread expression of the Aptian–Albian unconformity likely reflect the superposition of eustatic, climatic, and circulation-driven processes operating under distinct mid-Cretaceous boundary conditions.” (Lines 441–485, new manuscript).

We thank the reviewer for this valuable suggestion.

**Comment 4:***Specific Text and Figure Issues*

*Lines 103-106: To strengthen the paleoclimate argument, the discussion regarding the use of clay mineral assemblages and benthic foraminifera species could benefit from including necessary detail and specific literature support on how these proxies reflect the inferred climate changes.*

**Response:**

Regarding the clay-mineral assemblages, the following text was added to the revised manuscript: *“This shift is reflected in clay-mineral assemblages and geochemical proxies: Aptian Ca-rich CORBs formed under drier conditions with limited terrigenous input, whereas Albian Al-rich CORBs indicate more humid climates, greater paleoceanographic variability, and orbitally paced alternations in ventilation (Li et al., 2011; Hu et al., 2012). The slightly higher illite concentrations in the Aptian CORBs—reflecting moderate to weak weathering under relatively dry conditions—suggest that the atypical conditions of the Aptian Cold Snap interlude were characterized by lower terrigenous input than that experienced during the Albian (Fig. 3). Although the CaCO<sub>3</sub> content of the white layers interbedded with the red beds is similar in the Aptian and Albian intervals, the markedly low CaCO<sub>3</sub> values in the Albian CORBs are noteworthy (Li et al., 2011). This observation indicates substantial paleoceanographic variability (instability) during the Albian compared to the Aptian stage. Low CaCO<sub>3</sub> content may be related to: (a) reduced primary productivity, (b) higher dissolved CO<sub>2</sub> concentrations, (c) increased terrigenous input, and (d) water-column stagnation with the absence of younger waters. Because terrigenous input at ODP Site 1049 remained stable throughout the Albian (Cheng, 2008), we propose that alternation between intervals of active water bottom oxygenation and intervals of ocean stagnation (white and green beds) provides a more plausible explanation. Variations in the Ba/Al ratio and in SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> concentrations between the Albian red and white beds (Fig. 3) further support the presence of cyclical changes in productivity (Hu et al., 2012). In contrast, the absence of such abrupt CaCO<sub>3</sub> variability during the Aptian suggests more stable paleoceanographic conditions, with limited fluctuations in paleoproductivity and ocean circulation.”* (Lines 352–367).

As can be noted, we also enhanced Figure 3 in the revised manuscript by incorporating the geochemical profiles discussed above. We hope that this additional discussion of paleoenvironmental proxies from the literature—now incorporated into the revised manuscript—adequately clarifies the proposed model and reflects the inferred climate changes between the Aptian and Albian stages.

**Comment 5:**

*Lines 137-143: The evidence provided to overrule previous interpretations of the Aptian magnetic reversal as a diagenetic artifact appears insufficient. Relying on a single stained sample retaining initial magnetization is not fully convincing; incorporating more direct paleomagnetic evidence would be valuable for conclusively excluding diagenetic influence.*

**Response:**

We visited the Bremen Core Repository and, unfortunately, only a limited number of samples from ODP Site 1049C are available for additional paleomagnetic analyses that could potentially provide direct evidence. However, based on mineralogical and biostratigraphic studies, as well as on global correlations, we believe it is possible to validate reversal “3”, as explained below.

*“Independent mineralogical and biostratigraphic evidence argues against significant late diagenetic overprinting at ODP Hole 1049C. Clay mineral assemblages show no systematic depth-related trends; notably, illite and chlorite do not progressively replace smectite with increasing burial depth, indicating the absence of burial diagenesis (Li et al., 2011). In addition, planktonic and benthic foraminifera exhibit glassy tests with well-preserved surface ornamentation and no calcite infilling, further supporting minimal diagenetic alteration (Erbacher et al., 2001; Li et al., 2011). The occurrence of goethite precisely at the level recording the older reversed geomagnetic field provides additional support that the magnetic mineralogy remained largely unmodified and did not overprint a younger reversed polarity signal (Li et al., 2011). Therefore, this reversal is retained as valid in our study.”*

We thank the reviewer for drawing our attention to this issue and for allowing us to significantly improve the manuscript. This discussion has been added to lines 159–166 of the revised version.

**Comment 6:**

*Lines 148-149: Clarification is needed regarding the statement citing Ryan et al. (1978) concerning seven short reversals. This reference is currently vague and potentially confusing in both the text and figures. It would be helpful if the authors explicitly named these reversals and clearly indicated their positions in the section.*

**Response:**

To explicitly name these reversals and clearly indicate their positions within the section, we modified Figure 6, which illustrates the correlation between the M0r reversal and other polarity reversals within the Cretaceous Normal Superchron. In this figure, we compare the ages and stratigraphic positions of these reversals relative to the most up-to-date bioevents (Gale et al., 2020; Ramos et al., 2024; Ramos et al., 2025) with the original scheme proposed by Ryan et al. (1978). We believe that this figure clarifies the issues raised by the reviewer and also serves as a historical reference for the evolution of the nomenclature associated with these bioevents.

We also added the following text to the magnetostratigraphy section:

*“Within the broader magnetostratigraphic context, Ryan et al. (1978) documented seven*

*short-duration geomagnetic reversals during the Aptian–Albian interval, excluding M0r. The earliest of these was termed M-1r, whereas the second Aptian reversal, although listed in their Table 6 (see Ryan et al., 1978), was left unnamed. A third reversal, occurring in the Albian, was designated M-2r, followed by another unnamed event. The antepenultimate Albian reversal was termed M-3r, while the final two reversals also remained unnamed. Although commonly treated as isolated events (e.g., Gale et al., 2020), short reversals within the CNPS are frequently organized into closely spaced reversal sets (Ryan et al., 1978; Tarduno et al., 1992; Zhang et al., 2021; Ramos et al., 2025). Using biostratigraphic constraints and an estimated inter-event spacing of ~860 kyr, Ramos et al. (2024b) subdivided the reversal traditionally referred to as M-1r (sensu Gale et al., 2020) into two distinct Lower Aptian events, termed M-1r and reversal “2”. This pair of reversals has been identified both at DSDP Site 402A in the eastern North Atlantic and within the Brazilian Equatorial Margin, with comparable timespans and inter-event intervals (Ramos et al., 2024b, 2025).*

*The reverse-polarity event defined as M-2r was likewise initially recognized as a pair of closely spaced reversals (Ryan et al., 1978; Tarduno et al., 1992), occurring within the *Prediscosphaera cretacea* or *Prediscosphaera columnata* biozones. Because reversal “2” of Ramos et al. (2024b) is constrained to the Aptian and stratigraphically underlies the reversed interval identified here, we designate this newly recognized short reversal as “3” (Fig. 2). A second reversed-polarity interval at ~146.5 mbsf (171B-1049A-19X-2, 103–105 cm) is interpreted as the Albian subchron M-2r and is recorded consistently in two holes at ODP Site 1049 (Fig. 2). For both reversals, upper and lower boundaries were defined at the intersections between the inclination–depth interpolation and the 0° inclination axis. On this basis, we further subdivide the reversal previously assigned to M-2r (sensu Gale et al., 2020) into two discrete events, retaining the name M-2r for the younger reversal and assigning the older event to reversal “3”.*

We expect that this explanation, together with the new figure, resolves the lack of information concerning these events. This discussion has been incorporated into lines 168 – 187 of the revised manuscript.

**Comment 7:**

*Figure 2d: The reference to "Holes" in the Figure 2d legend appears inconsistent with the main text description.*

**Response:**

Indeed. Thank you for this observation. We have changed '12X, 1-cc' to '12X, 1-6' to resolve this inconsistency. We have also created a new Figure 2 to better represent the holes shown in the spliced core. Please see the correct figure 2 at the line 211 of the new manuscript.

**Comment 8:**

*Figure 3: The contrast between the vertical axes of the two boreholes (depth vs. age) in Figure 3 hinders direct data comparison. It is highly recommended that the authors unify the vertical axis unit (e.g., convert both to age) or provide the depth-to-age conversion clearly in the figure/caption. Additionally, the text should include a necessary background description for the PLG core.*

**Response:**

We have created a new Figure 3 that standardizes the vertical-axis units and presents all the cores in the depth domain. To include the necessary background description for the PLG core, we have inserted the text *'The Poggio Le Guaine (PLG) core, drilled in the Umbria–Marche Basin of central Italy, includes some of the most complete Aptian and Albian sedimentary successions known from the Tethyan Realm and provides the basis for an accurate and precise calibration of the Palaeogene time scale (Coccioni et al., 2012; Leandro et al., 2022). The astrochronology performed on this core, based on magnetic susceptibility, provides the most detailed zonation of OAE 1b (and its sub-events), as well as the definition of the ages of the main features of the carbon-isotope curve associated with this anoxic event (Ramos et al., 2024a), sequenced using Greek letters (Fig. 3). These c-marks, due to the global nature of the carbon-related isotopic anomalies (Weissert, 1989), incorporate chemostratigraphic tie-points that enable long-distance correlations between successions in different sedimentary basins (Ramos et al., 2024a).'* (Lines 118 to 125 of the new manuscript).

**Comment 9:**

*Line 223: Please verify the figure citation in line 223: "Figures 3c and 3d" appears to be an error and should likely be corrected to "Figures 5c and 5d."*

**Response:**

Done. Thank you for pointing out this error. Verify line 259 of the new manuscript.

**Comment 10:**

*Lines 256-257: The description of CORB B, particularly the assertion that its duration is "consistent with Milankovitch cycles," is currently too brief. To support this claim, the authors should provide a more detailed description of the eight main reddish-brown levels and relevant data.*

**Response:**

Thank you for drawing our attention to this point. In the revised manuscript, we have inserted the following text:

*'The eight main CORB levels composing CORB B (Fig. 6) have the following thicknesses and estimated durations (from oldest to youngest): ~55 cm / 125 kyr; 12 cm / 39 kyr; 7 cm / 23 kyr; 34 cm / 95 kyr; 12 cm / 39 kyr; 5 cm / 18 kyr; 6 cm / 22 kyr; and 5 cm / 18 kyr. For CORB C, from oldest to youngest, the values are: ~12 cm / 39 kyr; 5 cm / 18 kyr; 7 cm / 23 kyr; 12 cm / 39 kyr; 7 cm / 23 kyr; 34 cm / 95 kyr; and 12 cm / 39 kyr. It should be noted that these values are approximate, as some red beds appear (and disappear) abruptly, whereas others show more gradational boundaries. The cyclic patterns are consistent with enhanced variability in bottom-water ventilation and primary productivity, in agreement with previous observations of orbitally paced changes in Early Cretaceous deep-ocean oxygenation (Herbet et al., 1986; Leandro et al., 2022; Gambacorta et al., 2016). In contrast, Aptian proxies display more uniform behavior, with low-amplitude CaCO<sub>3</sub> variations and the absence of clear productivity cycles (Fig. 3). This suggests a more stable paleoceanographic regime during the Aptian, likely maintained by restricted oceanic connectivity prior to the full opening of the Equatorial Atlantic Gateway (EAG; Duarte et al., 2025; Ramos et al., 2025) and by the persistence of the Cold Snap climatic state. Orbital pacing, however, is still recorded in Aptian MS fluctuations, indicating sensitivity to insolation forcing even under comparatively steady circulation.'* (Lines 301–314 of the revised manuscript).

We also incorporated geochemically relevant data for the CORB levels (see the new Fig. 3 and the text between lines 432 and 439). Thank you for all the points of attention raised by the reviewer. We hope that our responses are sufficient for the manuscript to be accepted for publication in *Climate of the Past*.

## Response to Comments from Reviewer #2 (R. Mark Leckie)

### Overall Comment:

*A very well written and interesting paper. The authors have explored the nature of Cretaceous oceanic red beds (CORBs) in the context of oceanic anoxic events (OAEs) in Tethys and the North Atlantic. They focused on ODP Site 1049 on Blake Nose in the western North Atlantic. The study interval encompasses the late Aptian to early Albian, a time that included multiple black shale events; collectively this interval is referred to as OAE1b (Leckie et al. 2002). CORBs are associated with oxygenated conditions on the seafloor and are typically considered to represent slow sediment accumulation, although the authors present evidence that sedimentation rates are greater than other CORBs. This study presents a magneto-cyclostratigraphic analysis of a spliced record from Holes 1049A, B, and C. Planktic foraminiferal and calcareous nannofossil biostratigraphy provide the first order age control through the study interval. Orbital cycle tuning was conducted on the magnetic susceptibility data. The authors document and correlate multiple short-lived polarity reversal events.*

### Response:

Thank you for reading our manuscript and for providing these valuable comments. Below, we provide responses to each comment, along with the locations of the corresponding modifications in the revised manuscript. We hope that the responses provided below (in bold) are sufficient for the manuscript to meet the standards of *Climate of the Past*.

Regarding the comment included in the annotated text:

- Line 141 → 202–30 cm refers to the “Run name,” highlighted according to Ogg & Bardot (2001). This information has been removed from the revised manuscript to avoid potential confusion.
- Line 186 → We have added information about the PLG core (see note on the comment below).
- Lines 187, 202, 209, 250, 256 → Concerning the terms “Tie-points,” “for,” “m,” “the,” and “111.5 Ma” — done.
- Line 274 → We inserted “*Paraticinella rohri*.”
- Line 293 → “over a 250 Myr timespan of the Mesozoic.”

**Comment 1:**

*Critical outcome of this paper: Based on the age model derived from the tuning process, it was possible to evaluate the sediment accumulation rate (SAR), to date the short-lived polarity reversal events and the CORB intervals, and to correlate them with those identified in the PLG core (Coccioni et al., 2012; Ramos et al., 2025) (Figure 6). The authors compare ODP Site 1049 with the PLG core, although I couldn't find any explanation about what and where this core is located.*

**Response:**

Thank you for pointing out this missing information. To address this, we have added the following text to the revised manuscript:

*'The Poggio Le Guaine (PLG) core, drilled in the Umbria–Marche Basin of central Italy, includes some of the most complete Aptian and Albian sedimentary successions known from the Tethyan Realm and provides the basis for an accurate and precise calibration of the Palaeogene time scale (Coccioni et al., 2012; Leandro et al., 2022). The astrochronology performed on this core, based on magnetic susceptibility, provides the most detailed zonation of OAE 1b (and its sub-events), as well as the definition of the ages of the main features of the carbon-isotope curve associated with this anoxic event (Ramos et al., 2024a), sequenced using Greek letters (Fig. 3). These c-marks, due to the global nature of the carbon-related isotopic anomalies (Weissert, 1989), incorporate chemostratigraphic tie-points that enable long-distance correlations between successions in different sedimentary basins (Ramos et al., 2024a).'* (Lines 118 to 125 of the new manuscript).

**Comment 2:**

*The paper is in need of only minor tweaks. A couple of references cited in the text are missing.*

**Response:**

We have added the missing references, as well as new references suggested by other reviewers, including, for example, Leckie et al. (2002) and Trabucho Alexandre et al. (2010), among others.

- Line 423 → Changed “not exceptionally” to “not necessarily exceptionally slow sedimentation.”
- Changed “factors played” to “factors also played.”
- We added references in the Figure 7 legend for the age of Chron M0r, using Li et al. (2023) at 121.4 Ma, and for the Aptian–Albian boundary, using Ramos et al. (2024a), *Paleoceanography and Paleoclimatology*.
- Line 376 → Added:

“This reverse chron is a proposed marker for the Barremian–Aptian boundary (Helsley & Steiner, 1968; Gale et al., 2020; Zhang et al., 2021), and its age and duration are crucial factors for constraining past oceanic, tectonic, and geodynamic behavior (Li et al., 2023). The base of this chron is dated at ~120.2 Ma by astrochronology (Leandro et al., 2022) and  $120.29 \pm 0.09$  Ma by integration of U–Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  ages (Li et al., 2023).”

- Line 362 → Added “(sensu Leckie et al., 2002).” Done.
- We also updated the reference list to include the full author lists for all citations.

**Comment 3:**

*I've included an annotated text with some minor edits (such as planktic rather than planktonic). Below are a few comments and suggestions*

*Line 313: but the late Aptian "Cold Snap" is long after OAE1a, but it is contemporary with emplacement of part of the Kerguelen Plateau, and perhaps some of this volcanism, different from Ontong Java Plateau volcanism, included more than just basaltic magmatism, and it was in part subaerial.*

**Response:**

Thank you for helping us improve the quality of our manuscript. We have revised the text in the new manuscript inserting suggestions made by reviewer (Lines 337–341) as follows:

*“This cooling, often termed the Aptian “Cold Snap” (McAnena et al., 2013), is commonly attributed to declining atmospheric CO<sub>2</sub> levels, likely driven by enhanced burial of organic carbon and pyrite, which slowed carbon cycling and promoted polar ice growth (Weissert and Lini, 1991; Leandro et al., 2022). Large Igneous Province (LIP) emplacement, particularly the Kerguelen Plateau, may have contributed to this climate shift by perturbing the carbon cycle and triggering episodic cooling (Coffin & Eldholm, 1994; Percival et al., 2024).”*

**Comment 4:**

*Line 336: such processes are features of the upper water column, with little/no affect on deep or bottom waters.*

**Response:**

Indeed, thank you for bringing this to our attention. We have removed these sentences.

**Comment 5:**

*Line 337: continental runoff and precipitation might have affected where and how deep waters formed; were deep waters originating by evaporative processes, or by seasonal sea ice formation to create waters dense enough to sink, or by seasonal cooling near Antarctica?*

**Response:**

We have added an extensive discussion of the forcing mechanisms affecting deep waters in the Discussion section. We introduced new subsections addressing the Aptian–Albian paleoclimatic reorganization of ocean circulation, circulation regimes and CORB formation, and Milankovitch-band orbital forcing of CORB deposition. We believe that these additions make the framework much clearer. We hope that the revised manuscript now adequately addresses the reviewer’s concern. We thank the reviewer for raising these issues and for encouraging us to explore additional sources of information.

**Comment 6:**

*Line 353: What depositional conditions caused Site 1049 to differ so much from other North Atlantic sites. Trabucho Alexandre et al. 2010 wrote a comprehensive paper about several Aptian-Albian North Atlantic sites, including Site 1049. Some broader considerations of how unique CORB deposition at Site 1049 is in the North Atlantic, which is dominated by green claystones and black shales would be helpful. For example, was low sedimentation rate at Site 1049 the primary reason for the deposition of CORBs there, or might it have been due to a nearby sourced intermediate water mass? A similar duration unconformity occurs in the green claystone facies of DSDP Site 545 off Morocco (Huber and Leckie 2011). Opposite side of the North Atlantic but probably at a greater paleo-water depth.*

**Response:**

Perhaps salinity contrasts between the western and eastern North Atlantic Ocean (Charboureau et al., 2012), which may, for example, drive upwelling, are responsible for the different synchronous lithologies observed within the same ocean. We will include this observation in the revised manuscript. Indeed, the paper by Trabucho Alexandre et al. (2010) is outstanding, and the points raised in that study substantially strengthened our manuscript. In the discussion addressing synchrony and the possible physiographic differences that allow facies variability and different expressions of OAEs, we inserted the following text: “*For the OAE 1b-related black shale in ODP Hole 1049C, Erbacher et al. (2001) estimated a duration of approximately 46 kyr. Our results, however, indicate a slightly longer duration of 70 kyr and a central age of 111.63 Ma. This interval correlates with the Urbino Level (111.74 to 111.65 Ma; Fig. 6). Even with marked differences in oxidation levels observed through the correlation (in geological time) between the Albian interval of ODP Site 1049 and the PLG core—differences dependent on palaeogeographic and depositional settings (Trabucho Alexandre et al., 2010)—the small age and duration offsets indicate that this event can be considered effectively synchronous between the Tethyan and North Atlantic domains. This observation suggests that the widespread anoxia associated with this particular OAE 1b sub-event transcends local physiographic barriers, supporting its interpretation as a truly global phenomenon.*” (Lines 403–410 of the revised manuscript).

In addition, we thank the reviewer for bringing to our attention the occurrence of a hiatus of similar duration in the green claystone facies of DSDP Site 545 off Morocco (Huber and Leckie, 2011). We have incorporated this information into the revised manuscript by adding the following text: “*However, hiatuses of comparable duration have been documented at multiple sites, including DSDP Sites 511, 545, 763B, and 392A (Huber and Leckie, 2011), as well as at DSDP Site 545 off Morocco and ODP Site 1276 in the Newfoundland Basin (Trabucho Alexandre et al., 2010). The recurrence of similarly timed unconformities across different ocean basins indicates that the discontinuity at Site 1049 reflects a regional to global paleoceanographic signal rather than a purely local phenomenon. Incomplete stratigraphic records near the Aptian–Albian boundary—commonly associated with OAE 1b (Ramos et al., 2024b)—are therefore not unusual; several drill sites, including DSDP Sites 390, 392A, and 511, show partial or complete removal of upper Aptian and lower Albian successions (Huber et al., 2011).*” (Lines 447–453 of the revised manuscript).

**Comment 7:**

*Line 355: The drivers of Cenozoic thermohaline circulation likely differed significantly from the mid-Cretaceous. It feels like a bit of a stretch without an explanation of why you suggest such a comparison with the Dutkiewicz et al. study might apply to the Aptian-Albian.*

**Response:**

Indeed. We thank the reviewer for encouraging us to carry out an extensive review of this topic and to highlight important information in the revised manuscript. The Discussion section has been substantially improved and subdivided into the following subsections: *Aptian–Albian paleoclimatic reorganization of ocean circulation; Circulation regimes and CORB formation; Geological synchrony between the Tethyan and North Atlantic oceans; Milankovitch-band orbital forcing of CORB deposition; Long-cycle-related unconformity; Short geomagnetic reversed-polarity subchrons.*

Regarding the differences between the drivers of Cenozoic thermohaline circulation and those of the mid-Cretaceous, we highlighted several observations discussed by Hay (2008, 2009), who proposed a distinct circulation mode during the mid-Cretaceous related to the absence of polar ice caps. For the studied interval at ODP Site 1049, this interpretation applies to the Albian, during which “...renewed greenhouse conditions suppressed deep-water formation by reducing latitudinal thermal gradients, with ocean heat transport dominated by mesoscale eddies and low-latitude sinking of warm, saline waters (Hay, 2008, 2009; Gambacorta et al., 2016).” (Lines 350–352 of the revised manuscript).

However, during the Aptian Cold Snap, the circulation mode became relatively more similar to that of the Cenozoic. This discussion is developed throughout the text, and more specifically in the Discussion section, where we wrote: “*The Aptian Cold Snap temporarily disrupted this mode, enhancing thermohaline circulation through increased oxygen solubility in colder waters and possibly the presence of polar ice. This circulation regime promoted deep-water renewal and organic matter oxidation, processes that facilitated CORB formation, as evidenced by widespread hardgrounds, intensified bottom currents, and a basin-wide shift from grey-green to red-brown sediments (Premoli Silva et al., 1989; Weissert and Lini, 1991).*” (Lines 346–349 of the revised manuscript).

We believe that these new discussions strengthen the hypothesis proposed since the first version of the manuscript.

We sincerely thank you for contributing so significantly to the overall improvement of the manuscript. We hope that, with the modifications made, the revised manuscript is now suitable for publication in *Climate of the Past*.

## Response to Comments from Reviewer #3 (Helmut Weissert)

### Overall Comment:

*Ramos et al. present a cyclostratigraphic dataset based on earlier published magnetic susceptibility (MS) records from ODP Site 1049 (Blake Nose, North Atlantic). In the methods chapter, the authors reinterpret the published Aptian magnetostratigraphy of ODP Site 1049 containing several short reversals. The authors consider these reversals as initial and this provides them with a higher resolution of Aptian stratigraphy. Aim of their stratigraphic study is a more precise dating of CORB (red bed) intervals and, in consequence, a new (?) paleoceanographic interpretation regarding the formation of CORBs.*

*The manuscript is clearly structured, with data shown in several graphical displays, some of the figures are discussed below. The interpretation/paleoceanography section remains, in part, rather general and not very informative (see below). In the following paragraphs I add comments which may help improving the manuscript.*

### Response:

Thank you for reading our manuscript and for highlighting such relevant information. Below, we provide our responses to the comments and observations made by the reviewer. We hope that the responses provided below are sufficient for the manuscript to meet the standards of *Climate of the Past*.

### Comment 1:

#### Introduction

*Citation style: e.g. LIP's and climate: the authors cite two papers from 2024, this is fine, however, the authors need to show with a selection of citations that this is a topic which has been investigated over the last 40 years. I recommend including early literature, as these authors offered key hypotheses that later research expanded upon (Arthur; Larson etc). The same comment is valid for the summary on CORB research.*

### Response:

Ok, we agree. Regarding the issue of LIPs, we have included classic references such as Larson (1991) and Larson and Erba (1999). Concerning anoxic and oxic regimes, we have added the references Schlanger and Jenkyns (1976) and Bralower and Thierstein (1984), which address many of the conclusions presented in our manuscript, particularly those related to deep-water renewal rates under greenhouse conditions. To encompass the historical context of ocean circulation, we included the references Weissert (1981) and Premoli Silva et al. (1989), highlighting the importance of very weak latitudinal temperature gradients, due to the absence of large-scale continental glaciers during the mid-Cretaceous, which must have markedly reduced atmospheric and, consequently, oceanic circulation.

**Comment 2:**

*Line 57 add role of cooling or Aptian Ice Ages as forcing factors (see e.g. Weissert, 1989, Surveys in Geophysics including early relevant literature).*

**Response:**

Indeed, studies such as Weissert (1989) and Premoli Silva et al. (1989) were missing as citations in our manuscript. In general, during the Aptian–Albian stages, higher latitudes were probably not major sources of oxygenated, sinking cold waters (Schlanger and Jenkyns, 1976). Combined with reduced oxygen solubility due to high temperatures, the absence of polar ice has been interpreted as leading to slow or even “sluggish” deep-water circulation (Weissert, 1989).

We added the following text to the Discussion section: *“A major paleoclimatic transition across the Aptian–Albian boundary is recorded by long-term fluctuations in the carbon isotope record, reflecting changes in the global carbon cycle linked to ocean circulation and productivity (Weissert, 1989). At ODP Site 1049,  $\delta^{13}\text{C}$  values shift abruptly from  $\sim 4\text{‰}$  to  $\sim 2\text{‰}$  VPDB, providing clear evidence for a fundamental climatic reorganization (Huber et al., 2011). Independent proxies, including floral and faunal turnover, plant fossils indicating cooler conditions, glendonites, ice-rafted debris, and intensified hydrological cycling associated with the late Aptian Equatorial Humid Belt, corroborate this transition (Hochuli, 1981; Krassilov, 1973; Leckie, 1989; Kemper, 1987; Herrle et al., 2015; Santos et al., 2022; Ramos et al., 2025). Tethyan records further indicate reduced siliciclastic input, turnover within the G. algerianus Zone, and a pronounced global sea-level fall (Weissert and Lini, 1991). This cooling, often termed the Aptian “Cold Snap” (McAnena et al., 2013), is commonly attributed to declining atmospheric  $\text{CO}_2$  levels, likely driven by enhanced burial of organic carbon and pyrite, which slowed carbon cycling and promoted polar ice growth (Weissert and Lini, 1991; Leandro et al., 2022). Large Igneous Province (LIP) emplacement, particularly the Kerguelen Plateau, may have contributed to this climate shift by perturbing the carbon cycle and triggering episodic cooling (Coffin & Eldholm, 1994; Percival et al., 2024). Geochemical proxies, including benthic and planktonic  $\delta^{18}\text{O}$ , indicate that Aptian bottom waters were up to  $\sim 10^\circ\text{C}$  cooler than those of the Albian, highlighting a rapid warming of both surface and deep waters across the boundary (Huber et al., 2011; Kochhann et al., 2023). Under typical Cretaceous greenhouse conditions, high-latitude regions were unlikely to generate dense, oxygenated deep waters, leading to sluggish deep-ocean ventilation (Schlanger & Jenkyns, 1976; Hay, 2008, 2009). The Aptian Cold Snap temporarily disrupted this mode, enhancing thermohaline circulation through increased oxygen solubility in colder waters and possibly the presence of polar ice. This circulation regime promoted deep-water renewal and organic matter oxidation, processes that facilitated CORB formation, as evidenced by widespread hardgrounds, intensified bottom currents, and a basin-wide shift from grey-green to red-brown sediments (Premoli Silva et al., 1989; Weissert and Lini, 1991).”* (Lines 329–349 of the revised manuscript).

To address the reviewers' comments and suggestions, it was necessary to expand and subdivide the Discussion section to improve clarity and readability. We believe that the revised manuscript, although denser, is now considerably more robust. Thank you very much for all the suggestions.

**Comment 3:**

*Geological setting*

*Line 93 Carbonate Compensation Depth CCD, I prefer Calcite Compensation Depth sensu Bramlette 1961 (in contrast to Aragonite Compensation Depth, ACD)*

**Response:**

We used the term *Carbonate Compensation Depth* to preserve the original terminology adopted by Norris et al. (1998) and subsequently maintained by Li et al. (2011), both based on studies at ODP Site 1049. However, we agree that the use of *Calcite Compensation Depth* is more appropriate. This clarification has been incorporated into the revised manuscript (Line 103). Thank you for the suggestion.

**Comment 4:**

*Line 94 -97 Composition of sediment: you write correctly that the sediment is a clayey calcareous nannofossil chalk and claystone, but you also write that the sediment is composed of quartz, limestone clasts, dolomite etc. Please clarify.*

**Response:**

Indeed, this description is not correct, and we thank the reviewer for pointing out this issue. In the revised version of the manuscript, we now use the original description provided by Norris et al. (1998), which states: “Nannofossil chalk, clayey nannofossil chalk, nannofossil clay, clay, and an organic-rich black shale” (Norris et al., 1998), as reported in Lines 104-105 of the revised manuscript.

**Comment 5:**

*Line 105 please cite earlier literature on this topic which has been investigated over the last 40 years (see works by Premoli Silva etc, or, a younger article, Giorgioni et al, 2017 among others).*

**Response:**

Indeed, it was an oversight not to include these earlier references, which underpin much of the current research. We have now incorporated these citations throughout the revised manuscript. Thank you for bringing this point to our attention.

**Comment 6:**

*Figure 3 please define PLG when you use the term for the first time. I recommend to add a graph of the PLG core plotted against depth in meters (you may add this in figure 2 ?).*

**Response:**

Thank you for pointing out this lack of information. We have updated Fig. 2 so that both scales are presented in meters. We also incorporated geochemical proxies from Li et al. (2011) and Hu et al. (2012) to better address the differences between the Aptian and Albian intervals at ODP Site 1049.

Regarding the PLG core, to address this issue we have added the following text to the revised manuscript:

“The Poggio Le Guaine (PLG) core, drilled in the Umbria–Marche Basin of central Italy, includes some of the most complete Aptian and Albian sedimentary successions known from the Tethyan Realm and provides the basis for an accurate and precise calibration of the Paleogene time scale (Coccioni et al., 2012; Leandro et al., 2022). The astrochronology performed on this core, based on magnetic susceptibility, provides the most detailed zonation of OAE 1b (and its sub-events), as well as the definition of the ages of the main features of the carbon-isotope curve associated with this anoxic event (Ramos et al., 2024), sequenced using Greek letters (Figure 3). These c-marks, due to the global nature of carbon-related isotopic anomalies, constitute chemostratigraphic tie points that enable long-distance correlations between successions in different sedimentary basins (Ramos et al., 2024a).” (Lines 119–126 of the revised manuscript).

**Comment 7:**

*Figure 3 Chemostratigraphy: Most of OAE1b is missing at ODP Site 1049. Published C-isotope stratigraphy supports this observation. According to your documentation the long gap (red dots) begins at 114.5 Ma. If I look at the C-isotope stratigraphic curve below the gap, it shows a trend from more positive values less positive values (143-145m) at the ODP Site (amplitude 1permil) but a much smaller fluctuation at the PLG core (amplitude < 0.5 permil). Please comment on this discrepancy (?) in the pre-gap isotope curve (why not correlate the decreasing trend with the trend between Jacob and Kilian?). And, please use the same scale for the plot of your C-isotope data in your figure 3 (much more expanded C-isotope scale at PLG!).*

**Response:**

Indeed, there are alternative options for correlating the PLG core with ODP Site 1049. The correlation scheme suggested by the reviewer is plausible; however, in our view, it complicates the placement of some carbon-isotope stratigraphic markers within biostratigraphic zones (e.g., the  $\zeta$  marker, positioned close to the center of the *H. trocoidea* bioevent).

We believe that the new Fig. 3, with both cores shown in the depth domain, provides a clearer correlation. We greatly appreciate this comment, as it helped improve the clarity and consistency of the figure.

**Comment 8:**

*Fig 3 and Fig 6: ODP core is plotted against meters, PLG core against age. Please use meters in both records. In Fig 3 CORB A ends at level 143 m (younger than 114.6 Ma). In Fig 6 you end CORB A near 114.6 Ma, if I am correct (it is difficult to switch from meters to age in the two sections).> I recommend to also mark the end-Aptian gap in fig 6, this makes reading of the figure easier. ("A" ends at the unconformity, if I am correct).*

**Response:**

We have revised Figures 3 and 6. We used the same depth scale (in meters) for both records in Figure 3 and also marked the end-Aptian gap in Figure 6. In addition, we incorporated the predominant colors of the PLG succession to allow a visual comparison of oxidation states, reflecting paleoceanographic differences linked to the paleogeography of the different basins (Trabucho Alexandre et al., 2010) over the same time interval.

We believe that the reviewer's observations significantly improved the visual quality and interpretability of the revised manuscript.

**Comment 9:**

*Line 257 Please provide a more detailed description of the eight reddish levels, including the thickness of the beds, the characteristics of the sediments between the reddish beds, carbonate content, and other relevant details. Additionally, clarify the duration of these "levels", shown in your figure 6, which is presumed to be measured in thousands of years (not in Ma as indicated in "duration" in your fig. 6).*

**Response:**

Thank you for carefully reading our manuscript, and we apologize for the error in Fig. 6. Indeed, the duration of the CORB levels should be expressed in kyr, and this mistake has now been corrected.

We visited the Bremen Core Repository and, unfortunately, only a few samples from ODP Site 1049C are available for additional geological analyses. We also added a detailed description in the text specifying the thicknesses of the CORB levels and their corresponding durations, as well as those of the intervening lithologies:

*"The eight main CORB levels composing CORB B (Figure 6) have the following thicknesses and estimated durations (from oldest to youngest): ~55 cm / 125 kyr; 12 cm / 39 kyr; 7 cm / 23 kyr; 34 cm / 95 kyr; 12 cm / 39 kyr; 5 cm / 18 kyr; 6 cm / 22 kyr; and 5 cm / 18 kyr. For CORB C, from oldest to youngest, the values are: ~12 cm / 39 kyr; 5 cm / 18 kyr; 5 cm / 18 kyr; 5 cm / 18 kyr; 7 cm / 23 kyr; 12 cm / 39 kyr; 7 cm / 23 kyr; 34 cm / 95 kyr; and 12 cm / 39 kyr. It should be noted that these values are approximate, as some red beds appear (and disappear) abruptly, whereas others show more gradational boundaries."* (Lines 301–306 of the revised manuscript).

**Comment 10:***Origin of CORBs*

*This discussion is rather long and it summarizes, in part, quite well-established interpretations of the link between red sediments and cold snap(s) > cite relevant literature. CO<sub>2</sub> reductions and Aptian “Ice Age” (see for early literature e.g. Weissert and Lini, 1991 and earlier literature therein).*

**Response:**

Thank you for highlighting the need to further develop the role of CO<sub>2</sub> in relation to the cold snap. Indeed, the inclusion of Weissert and Lini (1991)—among other key references—was fundamental in strengthening the theoretical and historical framework of the manuscript.

To expand the discussion on the origin of CORBs, it was necessary to undertake an in-depth discussion of the Aptian–Albian paleoclimatic reorganization of ocean circulation, based on the studies suggested by the reviewer (e.g., Weissert and Lini, 1991; Hay, 2008, 2009; Trabucho Alexandre et al., 2010; Gambacorta et al., 2016; Giorgioni et al., 2016). Regarding CO<sub>2</sub> reductions and the Aptian “Ice Age” and their causes, we wrote in the revised manuscript:

*“A major paleoclimatic transition across the Aptian–Albian boundary is recorded by long-term fluctuations in the carbon isotope record, reflecting changes in the global carbon cycle linked to ocean circulation and productivity (Weissert, 1989). At ODP Site 1049,  $\delta^{13}\text{C}$  values shift abruptly from ~4‰ to ~2‰ VPDB, providing clear evidence for a fundamental climatic reorganization (Huber et al., 2011).” (Lines 329–332).*

*“Large Igneous Province (LIP) emplacement, particularly the Kerguelen Plateau, may have contributed to this climate shift by perturbing the carbon cycle and triggering episodic cooling (Coffin & Eldholm, 1994; Percival et al., 2024).” (Lines 339–341).*

*“High-frequency Milankovitch-scale cyclicity is widely recorded in Lower Cretaceous pelagic successions and is expressed in variations of CaCO<sub>3</sub> and SiO<sub>2</sub> contents (Herbert et al., 1986), carbon isotopes, and magnetic susceptibility (Leandro et al., 2022). These cycles are superimposed on a long-term perturbation of the global carbon cycle (Weissert, 1989), characterized by reduced carbon turnover and multi-million-year cold interludes (Leandro et al., 2022), potentially associated with polar ice-sheet growth (Trabucho Alexandre et al., 2010) and eustatic sea-level fall (Weissert & Lini, 1991).” (Lines 419–423).*

These additions improve the discussion of the CO<sub>2</sub>–climate link during the Aptian cold snap and reinforce the paleoceanographic interpretation presented in the manuscript.

**Comment 11:**

325 *Your discussion on deep-water oxygenation remains rather general: “sustained and effective thermohaline circulation”, where were sources of deep-water formation, during greenhouse times and during cold snaps, was evaporation a possible way to form dense water e.g. on Arabian platform as suggested by Nd-Isotope data for the Late Cretaceous etc. See also early discussions on Cretaceous paleoceanography at times of no major polar ice caps in several papers by William (Bill) Hay. There are also several studies on Albian cyclostratigraphy and paleoceanography available in the literature (e.g. Giorgioni and others).*

**Response:**

To strengthen the plausibility of effective thermohaline circulation during the Cold Snap, it was necessary to expand the Discussion section, initially emphasizing how Aptian–Albian paleoclimatic change enabled a transition from a greenhouse mode of ocean circulation to a mode relatively more comparable to that of the Cenozoic, in which thermohaline circulation plays a primary role in oxygenating the deep ocean. We therefore inserted the following text:

*“A major paleoclimatic transition across the Aptian–Albian boundary is recorded by long-term fluctuations in the carbon isotope record, reflecting changes in the global carbon cycle linked to ocean circulation and productivity (Weissert, 1989). At ODP Site 1049,  $\delta^{13}\text{C}$  values shift abruptly from  $\sim 4\text{‰}$  to  $\sim 2\text{‰}$  VPDB, providing clear evidence for a fundamental climatic reorganization (Huber et al., 2011). Independent proxies, including floral and faunal turnover, plant fossils indicating cooler conditions, glendonites, ice-rafted debris, and intensified hydrological cycling associated with the late Aptian Equatorial Humid Belt, corroborate this transition (Hochuli, 1981; Krassilov, 1973; Leckie, 1989; Kemper, 1987; Herrle et al., 2015; Santos et al., 2022; Ramos et al., 2025). Tethyan records further indicate reduced siliciclastic input, turnover within the G. algerianus Zone, and a pronounced global sea-level fall (Weissert and Lini, 1991). This cooling, often termed the Aptian “Cold Snap” (McAnena et al., 2013), is commonly attributed to declining atmospheric  $\text{CO}_2$  levels, likely driven by enhanced burial of organic carbon and pyrite, which slowed carbon cycling and promoted polar ice growth (Weissert and Lini, 1991; Leandro et al., 2022). Large Igneous Province (LIP) emplacement, particularly the Kerguelen Plateau, may have contributed to this climate shift by perturbing the carbon cycle and triggering episodic cooling (Coffin & Eldholm, 1994; Percival et al., 2024). Geochemical proxies, including benthic and planktonic  $\delta^{18}\text{O}$ , indicate that Aptian bottom waters were up to  $\sim 10^\circ\text{C}$  cooler than those of the Albian, highlighting a rapid warming of both surface and deep waters across the boundary (Huber et al., 2011; Kochhann et al., 2023). Under typical Cretaceous greenhouse conditions, high-latitude regions were unlikely to generate dense, oxygenated deep waters, leading to sluggish deep-ocean ventilation (Schlanger & Jenkyns, 1976; Hay, 2008, 2009). The Aptian Cold Snap temporarily disrupted this mode, enhancing thermohaline circulation through increased oxygen solubility in colder waters and possibly the presence of polar ice. This circulation regime promoted deep-water renewal and organic matter oxidation, processes that facilitated CORB formation, as evidenced by widespread hardgrounds, intensified bottom currents, and a basin-wide shift from grey-green to red-brown sediments*

*(Premoli Silva et al., 1989; Weissert and Lini, 1991). During the Albian, renewed greenhouse conditions suppressed deep-water formation by reducing latitudinal thermal gradients, with ocean heat transport dominated by mesoscale eddies and low-latitude sinking of warm, saline waters (Hay, 2008, 2009; Gambacorta et al., 2016). This shift is reflected in clay-mineral assemblages and geochemical proxies: Aptian Ca-rich CORBs formed under drier conditions with limited terrigenous input, whereas Albian Al-rich CORBs indicate more humid climates, greater paleoceanographic variability, and orbitally paced alternations in ventilation (Li et al., 2011; Hu et al., 2012). The slightly higher illite concentrations in the Aptian CORBs—reflecting moderate to weak weathering under relatively dry conditions—suggest that the atypical conditions of the Aptian Cold Snap interlude were characterized by lower terrigenous input than that experienced during the Albian (Fig. 3). Although the CaCO<sub>3</sub> content of the white layers interbedded with the red beds is similar in the Aptian and Albian intervals, the markedly low CaCO<sub>3</sub> values in the Albian CORBs are noteworthy (Li et al., 2011). This observation indicates substantial paleoceanographic variability (instability) during the Albian compared to the Aptian stage. Low CaCO<sub>3</sub> content may be related to: (a) reduced primary productivity, (b) higher dissolved CO<sub>2</sub> concentrations, (c) increased terrigenous input, and (d) water-column stagnation with the absence of younger waters. Because terrigenous input at ODP Site 1049 remained stable throughout the Albian (Cheng, 2008), we propose that alternation between intervals of active water bottom oxygenation and intervals of ocean stagnation (white and green beds) provides a more plausible explanation. Variations in the Ba/Al ratio and in SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> concentrations between the Albian red and white beds (Fig. 3) further support the presence of cyclical changes in productivity (Hu et al., 2012). In contrast, the absence of such abrupt CaCO<sub>3</sub> variability during the Aptian suggests more stable paleoceanographic conditions, with limited fluctuations in paleoproductivity and ocean circulation.” (Lines 329–367 of the revised manuscript)*

To introduce the topic *Circulation regimes and CORB formation*, which addresses the different circulation modes that may have operated during Aptian–Albian times. We hope that this broader discussion strengthens the hypothesis proposed in this manuscript.

**Comment 12:**

*336 Here you list several processes which may or may not have influenced deep water circulation in the Cretaceous. Please consider the time frame for these processes, storms and cyclones, for example, had an impact which is most probably not recorded in oxygenation state of Cretaceous pelagic sediments, and so on. > Please shorten or discuss more accurately.*

**Response:**

Indeed, we thank the reviewer for drawing our attention to this issue. We removemos essa parte no novo manuscrito.

**Comment 13:***Unconformity*

*Unconformities remain a significant topic in Cretaceous paleoceanography. The correlation of gaps between ocean basins will require further studies. At Blake Nose, the gap spans the Late Aptian, while other notable pelagic gaps, such as at the Cismon Site in northern Italy (Tethys), began earlier and ended later. And, look also at discussion of Albian to Turonian Ocean circulation and deep-water currents in the Tethys, including discussion of red beds in Gambacorta et al., 2016.*

**Response:**

Regarding the unconformity, other reviewers also pointed out that we should better describe its causes, particularly those related to bottom currents. Accordingly, we decided to include the following text in the Discussion section: “*The unconformity observed at ODP Site 1049 is consistent with the local geological setting of the Blake Escarpment, a continental-slope environment characterized by persistent bottom-current activity and high erosional potential (Benson et al., 1978; Li et al., 2011). Along continental margins in both the Tethyan Ocean and the North Atlantic, buried contourite drifts and stratigraphic gaps are common features and are widely attributed to variations in bottom-current strength and reorganizations of deep-water circulation, frequently linked to OAEs and major paleoceanographic transitions (Gambacorta et al., 2016; Liu et al., 2023).*

*However, hiatuses of comparable duration have been documented at multiple sites, including DSDP Sites 511, 545, 763B, and 392A (Huber and Leckie, 2011), as well as at DSDP Site 545 off Morocco and ODP Site 1276 in the Newfoundland Basin (Trabucho Alexandre et al., 2010). The recurrence of similarly timed unconformities across different ocean basins indicates that the discontinuity at Site 1049 reflects a regional to global paleoceanographic signal rather than a purely local phenomenon. Incomplete stratigraphic records near the Aptian–Albian boundary—commonly associated with OAE 1b (Ramos et al., 2024b)—are therefore not unusual; several drill sites, including DSDP Sites 390, 392A, and 511, show partial or complete removal of upper Aptian and lower Albian successions (Huber et al., 2011).*

*Independent support for an erosional surface at ODP Site 1049 is provided by abrupt shifts in  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, coincident with the major planktic foraminiferal extinction at the Aptian–Albian boundary and expressed lithologically as a sharp contact. In addition, the  $\text{CaCO}_3$  record shows a pronounced decrease indicative of dissolution and/or sediment removal (Li et al., 2011), further supporting the presence of a depositional hiatus. While initial estimates placed the duration of this gap at  $\sim 0.8$ – $1.4$  Myr (Huber et al., 2011), astrochronological constraints indicate that the absence of the *Microhedbergella renilaevis* and *M. miniglobularis* zones corresponds to  $\sim 0.76$ – $0.84$  Myr (Ramos et al., 2024). Because the overlying *M. rischi* zone may also be incomplete at Site 1049, the total duration of the unconformity likely exceeded 2 Myr.*

*This extended depositional gap has contributed to discrepancies in the estimated amplitude and duration of OAE 1b (Ramos et al., 2024b) and complicates global correlations based on carbon-isotope excursions or the nomenclature of organic-rich sub-events. In the Vocontian*

*Basin, up to four organic-rich horizons—Jacob, Kilian, Paquier, and Leenhardt (Bréhéret, 1994)—have been attributed to OAE 1b, whereas other studies recognize fewer levels (Herrle et al., 2004; Trabucho-Alexandre et al., 2011). Consequently, the expression of OAE 1b in complete Tethyan sections (Coccioni et al., 2012, 2014) cannot be straightforwardly correlated with the incomplete records of the North and South Atlantic basins, including ODP Site 1049 and DSDP Site 511.*

*Multiple processes likely contributed to the development of the Aptian–Albian unconformity. Paleoclimatic reconstructions indicate cooler temperatures and reduced humidity during this transition, coincident with high-latitude cooling and a global sea-level fall, consistent with the buildup of polar ice caps (Weissert and Lini, 1991). Carbon-cycle perturbations during the Aptian closely track eustatic variations (Haq et al., 1987), and the pronounced negative  $\delta^{13}\text{C}$  excursion at the base of the Albian (C-mark v; Ramos et al., 2024) coincides with a lowstand. We therefore propose that eustatic sea-level fall was a primary control on sediment removal at ODP Site 1049, while bottom-current activity acted as an amplifying mechanism rather than the initial driver of erosion.*

*Although the progressive opening of the Equatorial Atlantic Gateway during the Albian may have strengthened contour currents along continental slopes (Duarte et al., 2025), the presence of a comparable unconformity at DSDP Site 511 in the southern South Atlantic suggests that intensified bottom currents were a response to global sea-level change rather than a purely gateway-driven process. Transient bottom currents, potentially modulated by orbital forcing, may have further promoted episodic seafloor erosion and reoxygenation (Gambacorta et al., 2016). The estimated duration of ~2.56 Myr for the unconformity at ODP Site 1049 is compatible with long-period (~2.4 Myr) eccentricity modulation, supporting recent suggestions that grand orbital cycles exerted a first-order control on global deep-water circulation and sediment preservation prior to 70 Ma (Dutkiewicz et al., 2024).*

*Overall, the long duration and widespread expression of the Aptian–Albian unconformity likely reflect the superposition of eustatic, climatic, and circulation-driven processes operating under distinct mid-Cretaceous boundary conditions.” (Lines 441–485, new manuscript).*

We thank the reviewer for this valuable suggestion.

**Comment 14:**

*The 356 and 366 prominent gaps in shelf successions likely indicate stronger currents during greenhouse climate periods (see current patterns during OAE2, Wohlwend et al. 2015). Both orbital changes and significant mid-Cretaceous climate fluctuations appear to have greatly influenced deep-water and shelf current strength. I suggest discussing additional factors that may affect erosive currents and referencing literature that highlights the complexity of gap stratigraphy beyond what is presented in this study.*

**Response:**

Thank you for reading our manuscript and for suggesting so many points with great potential to improve the revised version. The discussion of stronger currents was incorporated into the new manuscript at specific points, such as:

*“This circulation regime promoted deep-water renewal and organic matter oxidation, processes that facilitated CORB formation, as evidenced by widespread hardgrounds, intensified bottom currents, and a basin-wide shift from grey-green to red-brown sediments (Premoli Silva et al., 1989; Weissert and Lini, 1991).” (Lines 347–349). “Episodic saline incursions and astronomically paced bottom currents may have intermittently enhanced deep-water renewal and seafloor reoxygenation without requiring major reorganization of global circulation (Friedrich et al., 2008; Gambacorta et al., 2016).” (Lines 429–431). “Although the progressive opening of the Equatorial Atlantic Gateway during the Albian may have strengthened contour currents along continental slopes (Duarte et al., 2025), the presence of a comparable unconformity at DSDP Site 511 in the southern South Atlantic suggests that intensified bottom currents were a response to global sea-level change rather than a purely gateway-driven process. Transient bottom currents, potentially modulated by orbital forcing, may have further promoted episodic seafloor erosion and reoxygenation (Gambacorta et al., 2016). The estimated duration of ~2.56 Myr for the unconformity at ODP Site 1049 is compatible with long-period (~2.4 Myr) eccentricity modulation, supporting recent suggestions that grand orbital cycles exerted a first-order control on global deep-water circulation and sediment preservation prior to 70 Ma (Dutkiewicz et al., 2024).” (Lines 475–482).*

Although this discussion of erosive currents is extremely interesting, it would be more appropriate for a review paper, and our manuscript—which aims to be a magneto-cyclostratigraphic study—would risk becoming unfocused. Thank you for reviewing our manuscript so thoroughly and insightfully, and for providing key references that were fundamental in strengthening the revised manuscript and making it suitable for publication in *Climate of the Past*.