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1 Tracking Cretaceous to present day deep-sea sedimentary

2 hiatuses driven by intensified bottom-water currents

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Abstract

Increased deep-sea paleocurrents are thought to be intimately associated with sedimentary hiatuses, which result in missing or mixed information on sediment ages, paleoproductivity, and marine chemistry and redox conditions. However, tracing paleocurrent evolution based on sedimentary hiatuses is challenging due to poor age constraints and the limited archive. Here, we investigate authigenic carbonate fluorapatite (CFA) grains from winnowed foraminiferal sand on Western Pacific guyots. The CFA grains are distinct from heavily reworked, cryptocrystalline continental margin phosphorites, exhibiting well-preserved euhedral crystals that indicate *in-situ* seamount formation. We apply LA-ICP-MS U-Pb dating to these CFA grains, revealing discrete ages from the Cretaceous to Oligocene (139.3 to 21.7 Ma), in contrast to the previously identified maximum age of seamount CFA of ~72 Ma. This fills a temporal gap in seamount phosphogenesis from ~140–80 Ma, representing the oldest and longest record of seamount phosphogenesis events yet documented. The pulsed enhancement of CFA formation temporally corresponds to both sedimentary disconformities at the nearby ODP Site 866, and global oceanic sedimentary hiatuses. Our results suggest that CFA forms episodically when climate-driven paleocurrents accelerate abruptly, preventing sediment accumulation in the deep ocean but promoting nutrient upwelling to the seamount top. Our data thus highlight the utility of seamount CFA as a tracer for documenting the timescales of enhanced paleocurrents and consequent sedimentary hiatuses.

Keywords: Depositional hiatuses; Paleocurrents; Authigenic carbonate fluorapatite

1. Introduction

Ocean bottom currents play a vital role in sediment accumulation, shaping the morphology of the ocean floor (Dutkiewicz and Müller, 2022) and driving geochemical cycles during early diagenesis (Robinson et al., 2010). Ocean currents are considered a primary driver for modulating the distribution of nutrients, as well as meridional heat transport (Lamy et al., 2024). Thus, increased current intensities not only enhance biological productivity (Kaneko et al., 2025), but may also alter marine redox conditions by increasing oxygen supply or consumption.

During transitions toward global cooling, the equator-to-pole temperature gradient intensifies. The expansion of polar ice sheets increases the density of high-latitude surface waters, facilitating the subduction and dramatically invigorating deep-ocean bottom currents (Rodrigues de Faria et al., 2024). In addition, high-latitude winter monsoons and westerlies are likely enhanced, driven by stronger cold air masses and increased atmospheric pressure gradients (Crichton et al., 2021). This strengthens upper-ocean circulation and vertical mixing, promoting the formation of high-latitude deep water, thereby generating feedback mechanisms that further influence climatic conditions.

Conversely, while it has traditionally been assumed that deep-sea circulation becomes sluggish or stagnant during warming periods, recent studies indicate that transient warming events (e.g., modern anthropogenic forcing) can also alter and accelerate deep-water circulation (Hu et al., 2020). This acceleration may be driven by increased global mean wind speeds resulting from elevated greenhouse gas emissions, which subsequently accelerate global mean ocean currents. Notably, in tropical oceans, this enhanced kinetic energy can propagate down to depths of several thousand meters (Hu et al., 2020). Alternatively, intensified local evaporation during warming can create pronounced salinity gradients, triggering deep convection and resulting in vigorous deep-sea circulation (Tripathi and Elderfield, 2005).

Consequently, investigating paleocurrent intensification during past climate shifts can provide valuable insights into future warming (Rahmstorf, 2002). However, enhanced bottom currents can disrupt the sedimentary record and cause depositional hiatuses (Bralower et al., 2002). Deep-sea stratigraphic records thus contain gaps that preclude the ability to track changes in ocean circulation (Dutkiewicz and Müller, 2022). Thus, our knowledge of the evolution of paleocurrents (in particular bottom currents) is hindered by an incomplete stratigraphic record (Chenot et al., 2021).

Although bottom currents affect the sedimentary record, their interaction with seamounts can also form authigenic minerals (e.g., carbonate fluorapatite; CFA) which have the potential to record paleoceanographic conditions, including primary productivity and marine redox conditions (Frontin-Rollet et al., 2022). Seamount-current interactions are widespread (Park et al., 2023), but most currents are not strong enough to transport nutrients up the steep slopes of seamounts, such that CFA does not typically form on guyot summits unless the bottom current abruptly intensifies (Hein et al., 1993; Peng et al., 2024). Therefore, guyot summits are favorable locations to study phases of enhanced bottom current activity.

The western Pacific hosts the oldest oceanic crust, with numerous ancient seamounts (Koppers et al., 2003; Kendrick et al., 2022; Fig. 1). Consequently, this region may preserve longer timescale information on enhanced paleocurrents. However, our ability to track these long-term sedimentologic relationships is inherently limited by the Wilson Cycle. Because older oceanic crust is continuously recycled and destroyed via subduction, this process would impose an upper age limit on the deep-sea authigenic sedimentary record (up to ~160 Ma in the western Pacific; Seton et al., 2020).

Seamounts obstruct the forward flow of ocean currents, inducing upwelling and causing the currents to gradually divide into multiple high-velocity bottom currents (Lusty et al., 2018; Rebesco et al., 2014). As seamount topography forces currents and suspended sediments

upwards, they bring nutrient-rich deep waters to shallower settings, thereby enhancing biological productivity in the photic zone (Leitner et al., 2020). Enhanced primary productivity and phosphorus supply from upwelling can subsequently promote phosphogenesis on seamounts (Hein et al., 1993). However, well-preserved authigenic CFA grains within winnowed foraminifera sands on seamount summits are poorly studied, limiting understanding of paleocurrent-seamount interactions, particularly for seamount CFA older than ~80 Ma (Peng et al., 2024).

Here, we examine well-preserved authigenic CFA grains collected from the Niulang and Weijia guyots in the oldest western Pacific region (Fig. 1). By integrating U-Pb ages of CFA with trace element, carbon isotope and sedimentary hiatus records, we show that since the Cretaceous, CFA has precipitated on these guyots due to enhanced nutrient upwelling during periods of paleocurrent intensification. This provides a novel tracer of circulation intensification, bridging gaps that are otherwise undocumented due to current-driven sedimentary hiatuses. Crucially, the application of CFA for absolute dating constrains both the timing of intensified circulation and associated variability in primary productivity.

2. Material and methods

2.1 Sampling and preparation

We collected surface sediment cores (~1 m long) using a box corer from the R/V Xiangyanghong 10 on the Niulang (160.87°E, 20.46°N, water depth = ~1600 m) and Weijia (156.58°E, 12.66°N, water depth = ~1400 m) guyots in the Northwest Pacific within the oldest region of oceanic crust, whose summits are located near the oxygen minimum zone (OMZ), where phosphate contents are generally high (Figs. 1 and S1). The age of the seamounts is uncertain, as the altered lava substrate of the guyot precludes reliable $^{40}\text{Ar}/^{39}\text{Ar}$ dating (Wei et al., 2022). The sediment is composed of foraminiferal sand with apatite (CFA), zeolites, iron

(oxyhydr)oxides and silicates (Figs. 2 and S2). The CFA was hand-picked and cleaned with deionized water and mounted for subsequent analysis.

2.2 Analytical methods

2.2.1 Scanning electron microscopy (SEM)

The mount was platinum-coated and imaged for micro-/nano-textures with a Tescan MIRA scanning electron microscope (SEM) at the School of Marine Sciences, Sun Yat-sen University (SYSU). The operating voltage was set to 15 kV and the beam current was 1 nA for imaging in backscattered electron mode.

2.2.2 Trace elements and U-Pb dating of CFA using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS)

Trace element analyses and U-Pb age screening of authigenic apatite were conducted simultaneously at the School of Marine Sciences, SYSU, using an Agilent 7900 Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) coupled to a 193 nm Coherent GeolasPro laser. The apatite unknowns and standards were ablated using a 32 μm spot size, 5 J/cm^2 energy density, a 5 Hz repetition rate, and a total shot count of 225. Trace element compositions were calibrated against NIST 612 standard glass, and a Ca content for CFA of 41 wt% (<http://webmineral.com/data/Carbonate-fluorapatite.shtml>) was used as the internal elemental standard (Dataset S1).

U-Pb age determinations of authigenic apatite were conducted at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China, using an Element XRTM High Resolution ICP-MS coupled to a 193 nm Coherent GeolasPro laser. The apatite unknowns and standards were ablated using a 90 μm spot size, 5 J/cm^2 energy density, a 5 Hz repetition rate, and a total shot count of 225. An in-house smoothing device was employed to ensure smooth signals. Nitrogen gas (3 ml min^{-1})

was introduced to enhance sensitivity and reduce matrix effects. Each analysis consisted of a 20 s background measurement (laser-off) followed by 45 s of data acquisition ([Dataset S2](#)). For U-Pb dating, each U-Pb age was derived from a single CFA grain. We placed our laser ablation spots exclusively on pure apatite domains to avoid any potential admixtures of calcium carbonate in the U-Pb dataset. Madagascar apatite 2 (MAD2) was used as the primary age reference material, and Durango apatite (Durango) used as a secondary age reference material. Full procedural details are provided in the Supplementary Materials.

3. Results and discussion

3.1 Evidence for *in situ* CFA crystallization

The main components of sediment samples are foraminifera, zeolites, Fe (oxyhydr)oxides and apatite ([Fig. 2a](#)). The apatite grains resemble peloids with well-developed euhedral crystal morphologies, which are typical of authigenic CFA previously observed on other seamounts ([Pufahl and Groat, 2017](#)). The similarity in REE distribution between CFA samples and those of seawater and seamount phosphorites strongly support their *in-situ* authigenic formation ([Hein et al., 2016](#); [Fig. S3](#)).

The close spatial association of the CFA grains with biogenic calcium carbonate (primarily foraminiferal tests) and zeolites ([Fig. 2a](#)), likely created a microenvironment that played a critical role in authigenesis. SEM imaging reveals that CFA frequently infills the foraminiferal cavities ([Fig. S4](#)). This localized precipitation is primarily driven by pulsed, upwelling-enhanced primary productivity, which releases abundant dissolved inorganic phosphorus near the OMZ. Foraminifera may also actively enrich phosphate in their surrounding environment through enzymatic metabolism, particularly near the OMZ as an alternative adaptive response to oxygen depletion, thereby elevating phosphorus concentrations ([Glock et al., 2025](#)). Organic matter mineralization and localized acidification promote the

dissolution of calcareous tests (especially nannofossils), supplying the abundant calcium ions necessary for CFA precipitation.

SEM observations further demonstrate extensive CFA crystallization directly on zeolite surfaces (Fig. S4). During periods of intensified ocean currents, reduced sedimentation prolongs zeolites exposure at the sediment-water interface. Subsequent weathering and localized acidification mobilize calcium ions from the porous zeolite channels to the mineral surface, where they combine with dissolved inorganic phosphorus from pore waters to precipitate CFA (Fan et al., 2025). Because this mineralization is closely linked to these current-driven microenvironmental changes *in-situ*, the U-Pb geochronology of these CFA grains serves as a robust proxy for reconstructing shifts in paleocurrent intensity.

The ovoid apatite likely formed by direct precipitation from seawater (Benninger and Hein, 2000; Fig. 2b), and the concentric banding structure indicates *in-situ* authigenic formation (Compton and Bergh, 2016; Fig. 2c). These concentric micro-particles (at the micron scale) likely reflect a rapid, high-energy precipitation event (Föllmi, 1996). Sequential ablation analysis from the core to the outer layers of the concentric rings show they are contemporaneous within the U-Pb analytical uncertainty. This lack of age zonation indicates that crystallization occurred as rapid, discrete bursts rather than continuous overgrowths which would produce dispersed data on a Tera-Wasserburg diagram and a mixed-age signature (Pufahl and Groat, 2017). This supports the accuracy and robustness of our single-grain U-Pb dating. We also found some pebble-like concretionary CFA, which may result from apatite infilling the cavities of foraminifera or replacing pre-existing calcite via dissolution (Benites et al., 2021; Fig. 2d and 2e). The CFA samples likely crystallized on the seamount top, as all CFA grains exhibit a well-defined euhedral morphology (Fig. 2f), unlike cryptocrystalline CFA in phosphorites from continental margins (Compton and Bergh, 2016).

Furthermore, the positive correlation between U and Ca indicates that these elements were incorporated concurrently into CFA during crystallization, maintaining a closed isotopic system (O'Sullivan et al., 2020; Fig. S4). This contrasts with marine bioapatite (e.g., fish teeth), which commonly acquires U through secondary diagenetic uptake during the microbial degradation of organic matter and often shows open-system behavior. Furthermore, each CFA grain defines a robust discordia regression line in Tera-Wasserburg space (Fig. 3), with no evidence of U or Pb loss or gain (Schoene, 2014). Therefore, the CFA is authigenic and records a closed U-Pb system with an *in-situ* formation age. Notably the unconstrained initial $^{207}\text{Pb}/^{206}\text{Pb}$ intercepts for most CFA grains are ~ 0.84 (consistent with seawater/crustal Pb evolution models), while three samples exhibit anomalous initial $^{207}\text{Pb}/^{206}\text{Pb}$ values. Variations in initial $^{207}\text{Pb}/^{206}\text{Pb}$ ratios likely reflect local heterogeneity in the Pb composition of paleo-seawater (Fig. 3; see Supplementary Information for a detailed interpretation).

3.2 Pulsed bottom-water currents in the Pacific Ocean

We obtained U-Pb ages by repeated ablation of single CFA grains (Fig. S5), ranging from the Early Cretaceous (139.3 ± 2.8 Ma) to the late Oligocene (21.7 ± 1.3 Ma; Fig. 3). Because each CFA grain constitutes an independent age determination, the age distribution from our randomized sampling represents the entire sediment package. Our results record the earliest phosphogenesis event preserved in modern ocean sediments (Early Cretaceous), and reveal additional phosphogenesis in the Western Pacific (Fig. 4; Peng et al., 2024). The CFA age histograms and probability density diagrams are generated by summing Gaussian distributions, each with a mean of the individual age and a standard deviation of its analytical uncertainty. They reveal distinct temporal clusters of CFA formation. Based on the frequency distribution of these randomly sampled grains, we tentatively identify five highly populated (major) and three less populated (minor) intervals of enhanced CFA precipitation since ~ 140

Ma (Fig. 4), which aligns with sedimentary disconformities at the nearby ODP Site 866 (Fig. 4a) and compiled global oceanic sedimentary hiatuses (Dutkiewicz and Müller, 2022). These data fill a key 140–80 Ma gap in Western Pacific seamount paleocurrent proxy records compared to previous studies on seamount phosphogenesis (Hein et al., 1993; Hyeong et al., 2013; Peng et al., 2024).

The oldest CFA grain in this study formed during the Berriasian–Valanginian (~139 Ma, Fig. 3). During the Berriasian–Valanginian (~143–133 Ma), substantial volcanic activity and associated CO₂ outgassing caused oceanic oxygen depletion and dissolution of carbonates, releasing calcium ions (Basilone, 2021). A brief cooling phase occurred at the Berriasian–Valanginian transition with a steepening of latitudinal temperature gradients (Percival et al., 2023), which likely enhanced ocean circulation. This coincides with CFA formation during this period (Fig. 4), as cold upwelling of nutrient-rich waters induced by intensified circum-Tethyan currents has also been documented on the continental margins of Tethys (Morales et al., 2016). Similarly, rapid fluctuations in the global $\delta^{13}\text{C}$ composition of pelagic carbonates due to accelerated burial of organic matter during episodes of enhanced productivity (Erba, 2004), and increased phosphorus accumulation rates, are recorded across all major ocean basins (Fig. 4b and c).

We also document CFA formation at the Barremian–Aptian (~120 Ma; Oceanic Anoxic Event 1a) and Albian–Cenomanian boundaries (~99 Ma; Oceanic Anoxic Event 1d; Fig. 4). Both periods were also characterized by intense volcanic activity and widespread oceanic anoxia, leading to enhanced nutrient input into the ocean and dissolution of carbonate, which significantly increased primary productivity and supplied sufficient Ca and P ions for CFA formation (Dumitrescu et al., 2006). When volcanism waned, 1–2 km thick ice sheets formed in Antarctica (Nordt et al., 2024), and denser water downwelling in the Antarctic region drove transiently stronger circulation. This promoted upwelling that interacted with seamounts in the

Pacific, and stimulated an increase in primary productivity (Watkins et al., 2005), consistent with rapid perturbations recorded in carbonate $\delta^{13}\text{C}$ from the Tethyan continental margin (Fig. 4b). Brief hiatuses or condensed layers at these two intervals are identified at ODP Site 866, suggesting intensified bottom current activity (Bralower et al., 2002). These intervals likely enhanced phosphorus recycling back to the water column, increasing phosphate concentrations (Peng et al., 2024). Cooling pulses during these intervals then promoted stronger ocean currents, leading to a lack of sediment deposition (Percival et al., 2023), but the currents also transported the nutrient-rich water to seamount summits, promoting the formation of CFA.

In the Late Cretaceous, we observe significantly increased CFA formation during five additional periods (Fig. 4e). During the early Campanian (~79–78 Ma), cooling drove the onset of the formation of southern component water, as recorded by ϵ_{Nd} in fish teeth (Robinson et al., 2010), resulting in intensified circulation between the major ocean basins. The number of CFA events formed on the seamount top increased relative to the Early Cretaceous (Fig. 4f). This corresponds to global oceanic sedimentary hiatuses and nearby stratigraphic disconformity at ODP Site 866 (Fig. 4a and d), and is in close agreement with records showing enhanced phosphorite formation along continental margins (Soudry et al., 2006).

The second major period of CFA formation occurred in the Maastrichtian–Paleocene (~70–65 Ma; Fig. 4). This phase coincides with long-term global cooling, which is characterized by changes in ϵ_{Nd} values in the Pacific that reflect enhanced bottom water circulation (Haynes et al., 2020). A sedimentary hiatus is also recorded at the nearby DSDP Site 199, and global compilations show increased hiatus frequency linked to enhanced bottom currents (Heezen and MacGregor, 1973; Figs. 1a and 4d). Moreover, abundant phosphorites are observed on the adjacent Pacific seamounts, linked to the strengthened Tethyan circulation (Peng et al., 2024). Unlike previous guyot-summit records indicating a discrete CFA event at ~71 Ma (Hein et al., 1993), our results yield a broader cluster of CFA ages between ~70 and

65 Ma. While the analytical precision of LA-ICP-MS U-Pb dating limits precise duration estimates, this cluster suggests that enhanced current activity persisted over a longer interval, which is also consistent with the time span (72–65 Ma) for massive phosphorite formation along Tethyan continental margins (Soudry et al., 2006).

Three other major periods of CFA formation are identified: the Paleocene to the early Eocene (57–50 Ma); the Eocene to the Oligocene (40–33.5 Ma, EOT); and the Oligocene to the Miocene (27–21 Ma, OMT) (Fig. 4). These periods occur broadly coeval with elevated global P accumulation rates (Fig. 4c). These transitions coincide with previous determinations of phosphogenesis events on seamounts due to intensification of episodic upwelling (Peng et al., 2024). However, our individual grain records show broader age distribution (Fig. 4), compared to previous studies suggesting more restricted CFA formation intervals at 56–54 Ma, 35–34 Ma and 25–23 Ma (Peng et al., 2024). Considering analytical uncertainties, these clusters suggest prolonged intensification of currents from 59 to 48 Ma, evidenced by an increase in the coarse fraction of the upper Paleocene to early Eocene sediments at nearby ODP Site 865 (Arreguín-Rodríguez et al., 2016), as well as a long-lasting increase in bottom water circulation from 40 to 33 Ma, driven by episodic Antarctic ice sheet expansion (Rodrigues de Faria et al., 2024). Global benthic foraminiferal $\delta^{18}\text{O}$ records further support long-term cooling during this interval (Westerhold et al., 2020).

Our compilation of global oceanic sedimentary hiatuses caused by enhanced bottom currents reveals an abrupt increase in the frequency of hiatuses close to 27 Ma, followed by an oscillatory upward trend that persisted until 20 Ma (Fig. 4d). This pattern suggests that oceanic current intensity began to strengthen at ~27 Ma, leading to modest but widespread sedimentary hiatuses, with peak intensity reached at ~21 Ma (Dutkiewicz and Müller, 2022). The prolonged period of enhanced current activity aligns temporally with the extended formation of CFA recorded in our study (Fig. 4f). However, CFA grains younger than the middle Miocene are

absent in our study sites, possibly due to the waning vigor of intermediate and deep ocean circulation (Dutkiewicz and Müller, 2022). This may also explain why prominent phosphogenesis during the peak of the Monterey event (16–15 Ma) is recorded along continental margins (Jacobs et al., 1996), whereas our seamount samples lack such younger records (Fig. 4). As global bottom currents waned, they were insufficiently vigorous to drive the upwelling of deep, P- and Ca-rich water masses up the steep flanks of guyots to their summits. By contrast, these weakened currents were still capable of transporting nutrient-rich waters onto the relatively gentle slopes of continental margins.

3.3 Model for pulsed paleocurrent behavior since the Early Cretaceous

The changes in global oceanic sedimentary hiatus frequency and the presence of depositional hiatuses from nearby sites can be used to infer the timing and intensity of bottom water currents (Fig. 4a and d). Our CFA U-Pb age distributions capture these pulsed changes more directly. Current activity during the Early Cretaceous was relatively weak but strengthened from the Late Cretaceous to the Cenozoic (Robinson et al., 2010), with an increase in both the frequency and duration of phases of CFA formation (Fig. 4e and f). Our results suggest that CFA formation was driven by pulsed acceleration of paleocurrents that enhanced phosphate supply (Peng et al., 2024). Accelerated currents likely generated a hydraulic jump upon encountering seamounts (Rebesco et al., 2014), inducing upwelling that delivered phosphate to the guyot summits, coincident with phases of non-deposition of deep-sea sediments (Fig. 4d and e). Meanwhile, surrounding zeolites may act as catalytic templates promoting phosphate mineral precipitation by releasing calcium cations and strongly adsorbing phosphate anions (Fan et al., 2025). Together, these localized biological and mineralogical substrate conditions likely synergized with the large-scale upwelling of nutrient-rich waters, facilitating efficient, localized precipitation of euhedral CFA. Thus, single-grain CFA ages

record the pulsed nature of current intensification and provide a complementary archive to sedimentary hiatus records.

During phases of normal current activity, seamount tops are less favorable for CFA precipitation than continental margins. CFA precipitation occurs under two main conditions associated with enhanced bottom water currents (Fig. 5). First, during warming periods (i.e., the late Paleocene to early Eocene), CFA may form when evaporation increases surface water salinity, triggering deep convection (Tripathi and Elderfield, 2005). Enhanced deep-water formation subsequently intensifies and accelerates bottom currents (Arreguín-Rodríguez et al., 2016); alternatively, acceleration may result from stronger global mean winds driven by elevated greenhouse gas emissions, which enhance large-scale ocean circulation (Hu et al., 2020), thereby reducing sediment deposition and generating hiatuses. This sediment starvation is critical, as it limits the dilution of authigenic minerals and allows their accumulation on the seafloor.

Second, CFA may form during cooling periods, when ice-sheet expansion (e.g., EOT and OMT) or short cooling events (e.g., during Oceanic Anoxic Event 1a and 1d) promote downwelling of denser water or intensified vertical mixing driven by the high-latitude winter monsoons and westerlies. This process may promote high-latitude deep water formation and strengthens vertical mixing, resulting in stronger ocean circulation (Crichton et al., 2021; Rodríguez-Cuicas et al., 2019).

Regarding local oceanographic controls, when intensified background currents interact with a seamount, this fixed three-dimensional obstacle converts horizontal kinetic energy into localized vertical motion. Current–seamount interaction generates layered wake vortices and lee waves, which promote intense turbulent mixing between the deep and upper water masses, thereby upwelling deep, nutrient-rich waters to the summit and the photic zone (Mashayek et al., 2024). The intensity of these processes typically scales non-linearly with current velocity;

stronger shear forces amplify eddy dimensions, resulting in enhanced vertical mixing and more pronounced isopycnal upwelling (Jiang et al., 2021). Meanwhile, the obstruction of bottom currents by the seamount causes flow constriction and acceleration, producing downstream high-shear zones. When the current velocity is sufficiently high, it strongly erodes and reworks previously deposited sediments, driving the development of depositional hiatuses (Juan et al., 2018). Resuspended sediments and nutrients are then entrained by the upwelling and transported to the guyot summit. Enhanced upwelling thus stimulates primary productivity and supplies abundant bioavailable phosphorus, promoting phosphogenesis on seamount tops (Fig. 5).

To synthesize, the episodic formation of CFA on these guyots is driven by a complex synergy of global biogeochemical cycles and local oceanographic and mineralogical factors. We propose that these varied factors interact through a multi-stage mechanism encompassing priming, delivery and precipitation. First, the global ocean is frequently primed with excess nutrients during extreme climatic states; substantial volcanic activity and consequent CO₂ outgassing drive oceanic oxygen depletion and the dissolution of pelagic carbonates, releasing abundant calcium ions into the water column. Concurrently, widespread anoxia increases phosphorus recycling back to the water column, leading to particularly high deep-sea phosphate concentrations. Second, enhanced currents driven by climatic transitions and local barriers serve as the physical delivery mechanism. Surface denser water downwelling leads to the abrupt intensification of deep-ocean circulation. These accelerated currents encounter the seamount, delivering the P- and Ca-rich waters mentioned above directly to the guyot summits. Finally, precipitation is facilitated by the localized seamount summit environment (near the OMZ). Enhanced nutrient delivery boosts primary productivity, exporting bioavailable phosphorus back to the substrate. Here, local microenvironments, specifically the presence of

phosphate-enriching foraminifera and catalytic zeolite templates, facilitate localized phosphate formation and *in-situ* crystallization of euhedral CFA.

CFA grains on seamount summits may record changes in ocean currents more sensitively than continental margin phosphorites. Gentle continental slopes easily facilitate prolonged phosphorite formation over broad areas, blurring multiple short-term changes (Soudry et al., 2006). We therefore propose that seamount CFA from seamounts serves as a robust tracer of enhanced ocean circulation during abrupt climate shifts. This approach overcomes limitations imposed by sedimentary hiatuses that often hinder reconstructions of such intervals and establishes a new archive for investigating paleoproductivity linked to climate perturbations. Although the resolution of our approach, currently limited by sample size, may not capture weaker circulation intensifications (e.g., during Oceanic Anoxic Event 2), it nonetheless reveals principal trends since the Cretaceous. Collecting additional samples from this and other seamounts will provide an important avenue for future validation and refinement of this proxy.

4. Conclusion

We demonstrate that authigenic CFA micro-particles from Western Pacific guyots serve as robust chronometers for reconstructing paleocurrent dynamics and complementing deep-sea sedimentary hiatus records. Our U-Pb dating reveals multiple temporal clusters of enhanced CFA authigenesis from the Early Cretaceous (~140 Ma) to the early Miocene (~21 Ma) that tightly correlate with periods of profound global deep-sea sedimentary hiatuses. We propose that this episodic phosphogenesis is driven by a coupled macro- and micro-scale mechanism. Globally, climate-driven intensifications of deepwater circulation collide with steep seamount topography, generating robust localized upwelling and turbulent mixing that severely scour the seafloor to create depositional hiatuses. Simultaneously, these nutrient-rich

upwelling waters are delivered to the guyot summits, where specific microenvironments, facilitated by dissolving calcareous foraminifera and catalytic zeolite templates, trigger rapid *in-situ* CFA crystallization. Ultimately, these authigenic micro-records provide a precise temporal framework for deciphering the complex feedbacks between Earth's long-term climate states, deep-ocean circulation, and localized marine biogeochemistry.

CRedit authorship contribution statement

Jiewei Hu: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Dengfeng Li:** Writing – review & editing, Conceptualization, Funding acquisition, Supervision. **David Chew:** Review and editing, Funding acquisition. **Simon Poulton:** Review and editing. **Yanhui Dong:** Resources, Investigation. **Jinzhou Peng:** Methodology, Review and editing. **Yu Fu:** Data curation, Validation. **Xiaoming Sun:** Supervision.

Declaration of competing interest

The authors declare no competing interests.

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Data availability

All data in this study are available in the main manuscript or supporting information. There are two datasets uploaded with the submission.

References

- Arreguín-Rodríguez, G.J., Alegret, L., Thomas, E., 2016. Late Paleocene-middle Eocene benthic foraminifera on a Pacific seamount (Allison Guyot, ODP Site 865): Greenhouse climate and superimposed hyperthermal events. *Paleoceanography* 31, 346–364. <https://doi.org/10.1002/2015PA002837>
- Basilone, L., 2021. Valanginian cold/warm climatic oscillation and synsedimentary tectonic interaction for drowning the carbonate platform of Southern Tethys (Sicily). *Sedimentary Geology* 423, 105991. <https://doi.org/10.1016/j.sedgeo.2021.105991>
- Benites, M., Hein, J.R., Mizell, K., Jovane, L., 2021. Miocene phosphatization of rocks from the summit of Rio Grande Rise, southwest Atlantic Ocean. *Paleoceanography and Paleoclimatology* 36, e2020PA004197. <https://doi.org/10.1029/2020PA004197>
- Benninger, L.M., Hein, J.R., 2000. Diagenetic evolution of seamount phosphorite, in: Glenn, C.R., Prévôt-Lucas, L., Lucas, J. (Eds.), *Marine Authigenesis: From Global to Microbial*. SEPM Society for Sedimentary Geology, pp. 245–256. <https://doi.org/10.2110/pec.00.66.0245>
- Bralower, T.J., Premoli Silva, I., Malone, M.J., et al. (Eds.), 2002. Shipboard Scientific Party, 2002. Leg 198 summary, in: *Proceedings of the Ocean Drilling Program, 198 Initial Reports*. Ocean Drilling Program, pp. 1–148. <https://doi.org/10.2973/odp.proc.ir.198.2002>
- Chenot, E., Pucéat, E., Freslon, N., Deconinck, J.-F., Razmjooei, M.J., Thibault, N., 2021. Late Cretaceous changes in oceanic currents and sediment sources in the eastern Tethys: insights from Nd isotopes and clay mineralogy. *Global and Planetary Change* 198, 103353. <https://doi.org/10.1016/j.gloplacha.2020.103353>
- Compton, J.S., Bergh, E.W., 2016. Phosphorite deposits on the Namibian shelf. *Marine Geology* 380, 290–314. <https://doi.org/10.1016/j.margeo.2016.04.006>
- Crichton, K.A., Ridgwell, A., Lunt, D.J., Farnsworth, A., Pearson, P.N., 2021. Data-constrained assessment of ocean circulation changes since the middle Miocene in an Earth system model. *Climate of the Past* 17, 2223–2254. <https://doi.org/10.5194/cp-17-2223-2021>
- Dumitrescu, M., Brassell, S.C., Schouten, S., Hopmans, E.C., Sinninghe Damsté, J.S., 2006. Instability in tropical Pacific sea-surface temperatures during the early Aptian. *Geol* 34, 833. <https://doi.org/10.1130/G22882.1>
- Dutkiewicz, A., Müller, R.D., 2022. Deep-sea hiatuses track the vigor of Cenozoic ocean bottom currents. *Geology* 50, 710–715. <https://doi.org/10.1130/G49810.1>
- Erba, E., 2004. Calcareous nannofossils and Mesozoic oceanic anoxic events. *Marine Micropaleontology*.
- Fan, W., Zhou, J., Jiang, X., Zhang, H., Mi, M., Yuan, P., Dong, Y., Liu, D., Wei, Y., Peckmann, J., 2025. Carbonate fluorapatite coatings on phillipsite represent a significant sink of phosphorus in abyssal plains of the western Pacific Ocean. *Proceedings of the National Academy of Sciences* 122, e2407683122. <https://doi.org/10.1073/pnas.2407683122>

Föllmi, K.B., 1996. The phosphorus cycle, phosphogenesis and marine phosphate-rich deposits. *Earth-Science Reviews* 40, 55–124. [https://doi.org/10.1016/0012-8252\(95\)00049-6](https://doi.org/10.1016/0012-8252(95)00049-6)

Frontin-Rollet, G.E., Handler, M.R., Wysoczanski, R.J., Gazley, M.F., Hickey, C.W., 2022. Geochemical characterisation of offshore New Zealand phosphorites, and mechanisms for their formation. *Marine Geology* 445, 106751. <https://doi.org/10.1016/j.margeo.2022.106751>

Glock, N., Richirt, J., Woehle, C., Algar, C., Armstrong, M., Eichner, D., Firrincieli, H., Makabe, A., Govindankutty Menon, A., Ishitani, Y., Hackl, T., Hubert-Huard, R., Kienast, M., Milker, Y., Mutzberg, A., Ni, S., Okada, S., Rakshit, S., Schmiedl, G., Steiner, Z., Tame, A., Zhang, Z., Nomaki, H., 2025. Widespread occurrence and relevance of phosphate storage in foraminifera. *Nature* 638, 1000–1006. <https://doi.org/10.1038/s41586-024-08431-8>

Haynes, S.J., MacLeod, K.G., Ladant, J.-B., Guchte, A.V., Rostami, M.A., Poulsen, C.J., Martin, E.E., 2020. Constraining sources and relative flow rates of bottom waters in the Late Cretaceous Pacific Ocean. *Geology* 48, 509–513. <https://doi.org/10.1130/G47197.1>

Heezen, B.C., MacGregor, I.D., 1973. Mesozoic chalks beneath the caroline abyssal plain: DSDP site 199, in: Initial Reports of the Deep Sea Drilling Project, 20, Initial Reports of the Deep Sea Drilling Project. U.S. Government Printing Office, pp. 65–87. <https://doi.org/10.2973/dsdp.proc.20.1973>

Hein, J., Koschinsky, A., Mikesell, M., Mizell, K., Glenn, C., Wood, R., 2016. Marine phosphorites as potential resources for heavy rare earth elements and yttrium. *Minerals* 6, 88. <https://doi.org/10.3390/min6030088>

Hein, J.R., Yeh, H.-W., Gunn, S.H., Sliter, W.V., Benninger, L.M., Wang, C.-H., 1993. Two major Cenozoic episodes of phosphogenesis recorded in equatorial Pacific seamount deposits. *Paleoceanography* 8, 293–311. <https://doi.org/10.1029/93PA00320>

Hu, S., Sprintall, J., Guan, C., McPhaden, M.J., Wang, F., Hu, D., Cai, W., 2020. Deep-reaching acceleration of global mean ocean circulation over the past two decades. *Science Advances* 6, eaax7727. <https://doi.org/10.1126/sciadv.aax7727>

Huber, B.T., MacLeod, K.G., Watkins, D.K., Coffin, M.F., 2018. The rise and fall of the Cretaceous Hot Greenhouse climate. *Global and Planetary Change* 167, 1–23. <https://doi.org/10.1016/j.gloplacha.2018.04.004>

Hyeong, K., Kim, J., Yoo, C.M., Moon, J.-W., Seo, I., 2013. Cenozoic history of phosphogenesis recorded in the ferromanganese crusts of central and western Pacific seamounts: Implications for deepwater circulation and phosphorus budgets. *Palaeogeography, Palaeoclimatology, Palaeoecology* 392, 293–301. <https://doi.org/10.1016/j.palaeo.2013.09.012>

Jacobs, E., Weissert, H., Shields, G., Stille, P., 1996. The Monterey Event in the Mediterranean: A record from shelf sediments of Malta. *Paleoceanography* 11, 717–728. <https://doi.org/10.1029/96PA02230>

Jiang, X., Dong, C., Ji, Y., Wang, C., Shu, Y., Liu, L., Ji, J., 2021. Influences of Deep-Water Seamounts on the Hydrodynamic Environment in the Northwestern Pacific Ocean. *Journal of Geophysical Research: Oceans* 126, e2021JC017396. <https://doi.org/10.1029/2021JC017396>

Juan, C., Van Rooij, D., De Bruycker, W., 2018. An assessment of bottom current controlled sedimentation in Pacific Ocean abyssal environments. *Marine Geology* 403, 20–33. <https://doi.org/10.1016/j.margeo.2018.05.001>

Kaneko, H., Tanaka, T., Wakita, M., Sasaki, K., Okunishi, T., Miyazawa, Y., Zhang, R., Tatamisashi, S., Sato, Y., Hashimukai, T., Chiba, T., Takada, M., Yoshino, J., 2025.

- Topographically driven vigorous vertical mixing supports mesoscale biological production in the Tsugaru Gyre. *Nat Commun* 16, 3656. <https://doi.org/10.1038/s41467-025-56917-4>
- Kendrick, M.A., Zhao, J., Feng, Y., 2022. Early accretion and prolonged carbonation of the Pacific Ocean's oldest crust. *Geology* 50, 1270–1275. <https://doi.org/10.1130/G49985.1>
- Koppers, A.A.P., Staudigel, H., Pringle, M.S., Wijbrans, J.R., 2003. Short-lived and discontinuous intraplate volcanism in the South Pacific: Hot spots or extensional volcanism? *Geochem Geophys Geosyst* 4, 2003GC000533. <https://doi.org/10.1029/2003GC000533>
- Lamy, F., Winckler, G., Arz, H.W., Farmer, J.R., Gottschalk, J., Lembke-Jene, L., Middleton, J.L., van der Does, M., Tiedemann, R., Alvarez Zarikian, C., Basak, C., Brombacher, A., Dumm, L., Esper, O.M., Herbert, L.C., Iwasaki, S., Kreps, G., Lawson, V.J., Lo, L., Malinverno, E., Martinez-Garcia, A., Michel, E., Moretti, S., Moy, C.M., Ravelo, A.C., Riesselman, C.R., Saavedra-Pellitero, M., Sadatzki, H., Seo, I., Singh, R.K., Smith, R.A., Souza, A.L., Stoner, J.S., Toyos, M., de Oliveira, I.M.V.P., Wan, S., Wu, S., Zhao, X., 2024. Five million years of Antarctic Circumpolar Current strength variability. *Nature* 627, 789–796. <https://doi.org/10.1038/s41586-024-07143-3>
- Leitner, A.B., Neuheimer, A.B., Drazen, J.C., 2020. Evidence for long-term seamount-induced chlorophyll enhancements. *Sci Rep* 10, 12729. <https://doi.org/10.1038/s41598-020-69564-0>
- Lusty, P.A.J., Hein, J.R., Josso, P., 2018. Formation and occurrence of ferromanganese crusts: Earth's storehouse for critical metals. *Elements* 14, 313–318. <https://doi.org/10.2138/gselements.14.5.313>
- Mashayek, A., Gula, J., Baker, L.E., Naveira Garabato, A.C., Cimoli, L., Riley, J.J., De Lavergne, C., 2024. On the role of seamounts in upwelling deep-ocean waters through turbulent mixing. *Proc. Natl. Acad. Sci. U.S.A.* 121, e2322163121. <https://doi.org/10.1073/pnas.2322163121>
- Morales, C., Spangenberg, J.E., Arnaud-Vanneau, A., Adatte, T., Föllmi, K.B., 2016. Evolution of the northern Tethyan Helvetic Platform during the late Berriasian and early Valanginian. *The Depositional Record* 2, 47–73. <https://doi.org/10.1002/dep2.13>
- Nordt, L., Breecker, D., White, J., 2024. The early Cretaceous was cold but punctuated by warm snaps resulting from episodic volcanism. *Commun Earth Environ* 5, 1–10. <https://doi.org/10.1038/s43247-024-01389-5>
- O'Sullivan, G., Chew, D., Kenny, G., Henrichs, I., Mulligan, D., 2020. The trace element composition of apatite and its application to detrital provenance studies. *Earth-Science Reviews* 201, 103044. <https://doi.org/10.1016/j.earscirev.2019.103044>
- Park, J., Jung, J., Ko, Y., Lee, Y., Yang, K., 2023. Reconstruction of the paleo-ocean environment using mineralogical and geochemical analyses of mixed-type ferromanganese nodules from the tabletop of western Pacific Magellan seamount. *Geochemistry, Geophysics, Geosystems* 24, e2022GC010768. <https://doi.org/10.1029/2022GC010768>
- Peng, J., Li, D., Poulton, S.W., O'Sullivan, G.J., Chew, D., Fu, Y., Sun, X., 2024. Episodic intensification of marine phosphorus burial over the last 80 million years. *Nat Commun* 15, 7446. <https://doi.org/10.1038/s41467-024-51598-x>
- Percival, L.M.E., Ownsworth, E., Robinson, S.A., Selby, D., Goderis, S., Claeys, P., 2023. Valanginian climate cooling and environmental change driven by Paraná-Etendeka basalt erosion. *Geology* 51, 753–757. <https://doi.org/10.1130/G51202.1>

552 Pufahl, P.K., Groat, L.A., 2017. Sedimentary and igneous phosphate deposits: formation and
553 exploration: An invited paper. *Economic Geology* 112, 483–516.
554 <https://doi.org/10.2113/econgeo.112.3.483>

555 Rahmstorf, S., 2002. Ocean circulation and climate during the past 120,000 years. *Nature*
556 419, 207–214. <https://doi.org/10.1038/nature01090>

557 Rebesco, M., Hernández-Molina, F.J., Van Rooij, D., Wåhlin, A., 2014. Contourites and
558 associated sediments controlled by deep-water circulation processes: State-of-the-art
559 and future considerations. *Marine Geology*, 50th Anniversary Special Issue 352, 111–
560 154. <https://doi.org/10.1016/j.margeo.2014.03.011>

561 Rella, S.F., Uchida, M., 2014. A Southern Ocean trigger for Northwest Pacific ventilation
562 during the Holocene? *Sci Rep* 4, 4046. <https://doi.org/10.1038/srep04046>

563 Robinson, S.A., Murphy, D.P., Vance, D., Thomas, D.J., 2010. Formation of “Southern
564 Component Water” in the Late Cretaceous: Evidence from Nd-isotopes. *Geology* 38,
565 871–874. <https://doi.org/10.1130/G31165.1>

566 Rodrigues de Faria, G., Lazarus, D., Renaudie, J., Stammeier, J., Özen, V., Struck, U., 2024.
567 Late Eocene to early Oligocene productivity events in the proto-Southern Ocean and
568 correlation to climate change. *Climate of the Past* 20, 1327–1348.
569 <https://doi.org/10.5194/cp-20-1327-2024>

570 Rodríguez-Cuicas, M.-E., Montero-Serrano, J.-C., Garbán, G., 2019. Paleoenvironmental
571 changes during the late Albian oceanic anoxic event 1d: An example from the
572 Capacho Formation, southwestern Venezuela. *Palaeogeography, Palaeoclimatology,*
573 *Palaeoecology* 521, 10–29. <https://doi.org/10.1016/j.palaeo.2019.02.010>

574 Sager, W.W., Winterer, E.L., Firth, J.V., et al. (Eds.), 1993. Shipboard Scientific Party, 1993.
575 Site 866, in: *Proceedings of the Ocean Drilling Program*, 143 Initial Reports,
576 *Proceedings of the Ocean Drilling Program. Ocean Drilling Program*, pp. 181–271.
577 <https://doi.org/10.2973/odp.proc.ir.143.1993>

578 Schoene, B., 2014. U–Th–Pb Geochronology, in: *Treatise on Geochemistry*. Elsevier, pp.
579 341–378. <https://doi.org/10.1016/B978-0-08-095975-7.00310-7>

580 Seton, M., Müller, R.D., Zahirovic, S., Williams, S., Wright, N.M., Cannon, J., Whittaker,
581 J.M., Matthews, K.J., McGirr, R., 2020. A global data set of present-day oceanic
582 crustal age and seafloor spreading parameters. *Geochemistry, Geophysics,*
583 *Geosystems* 21, e2020GC009214. <https://doi.org/10.1029/2020GC009214>

584 Soudry, D., Glenn, C.R., Nathan, Y., Segal, I., VonderHaar, D., 2006. Evolution of Tethyan
585 phosphogenesis along the northern edges of the Arabian–African shield during the
586 Cretaceous–Eocene as deduced from temporal variations of Ca and Nd isotopes and
587 rates of P accumulation. *Earth-Science Reviews* 78, 27–57.
588 <https://doi.org/10.1016/j.earscirev.2006.03.005>

589 Stille, P., Steinmann, M., Riggs, S.R., 1996. Nd isotope evidence for the evolution of the
590 paleocurrents in the Atlantic and Tethys Oceans during the past 180 Ma. *Earth and*
591 *Planetary Science Letters* 144, 9–19. [https://doi.org/10.1016/0012-821X\(96\)00157-4](https://doi.org/10.1016/0012-821X(96)00157-4)

592 Tozer, B., Sandwell, D.T., Smith, W.H.F., Olson, C., Beale, J.R., Wessel, P., 2019. Global
593 bathymetry and topography at 15 arc sec: SRTM15+. *Earth and Space Science* 6,
594 1847–1864. <https://doi.org/10.1029/2019EA000658>

595 Tripathi, Elderfield, 2005. Deep-Sea Temperature and Circulation Changes at the Paleocene-
596 Eocene Thermal Maximum. *Science*. <https://doi.org/10.1126/science.1109202>

597 Watkins, D.K., Cooper, M.J., Wilson, P.A., 2005. Calcareous nannoplankton response to late
598 Albian oceanic anoxic event 1d in the western North Atlantic. *Paleoceanography* 20,
599 1–14. <https://doi.org/10.1029/2004PA001097>

600 Wei, X., Shi, X.-F., Xu, Y.-G., Castillo, P.R., Zhang, Y., Zhang, L., Zhang, H., 2022. Mid-
601 Cretaceous Wake seamounts in NW Pacific originate from secondary mantle plumes

with Arago hotspot composition. *Chemical Geology* 587, 120632.
<https://doi.org/10.1016/j.chemgeo.2021.120632>
Westerhold, T., Marwan, N., Drury, A.J., Liebrand, D., Agnini, C., Anagnostou, E., Barnett,
J.S.K., Bohaty, S.M., De Vleeschouwer, D., Florindo, F., Frederichs, T., Hodell, D.A.,
Holbourn, A.E., Kroon, D., Lauretano, V., Littler, K., Lourens, L.J., Lyle, M., Pälike,
H., Röhl, U., Tian, J., Wilkens, R.H., Wilson, P.A., Zachos, J.C., 2020. An
astronomically dated record of Earth's climate and its predictability over the last 66
million years. *Science* 369, 1383–1387. <https://doi.org/10.1126/science.aba6853>

Figure 1. Geological map of the sampling location and its present-day bathymetry and oxygen profiles. (a) Seafloor crustal age map of the Pacific. Grey line represents the pathway of the Lower Circumpolar Deep Water (LCDW) (Rella and Uchida, 2014). Seafloor crustal age data are from ref (Seton et al., 2020). Orange dots represent nearby ODP/DSDP sites. **(b)** The bathymetry of the Western Pacific seamounts, with the transect of the depth-latitude profile in (c) illustrated. Bathymetry data are from ref (Tozer et al., 2019). Parts a and b were created by GMT V6.4. **(c)** Depth-latitude profiles for oxygen contents in the water column generated with Ocean Data View (Schlitzer, R., Ocean Data View, odv.awi.de, 2023). OMZ = oxygen minimum zone.

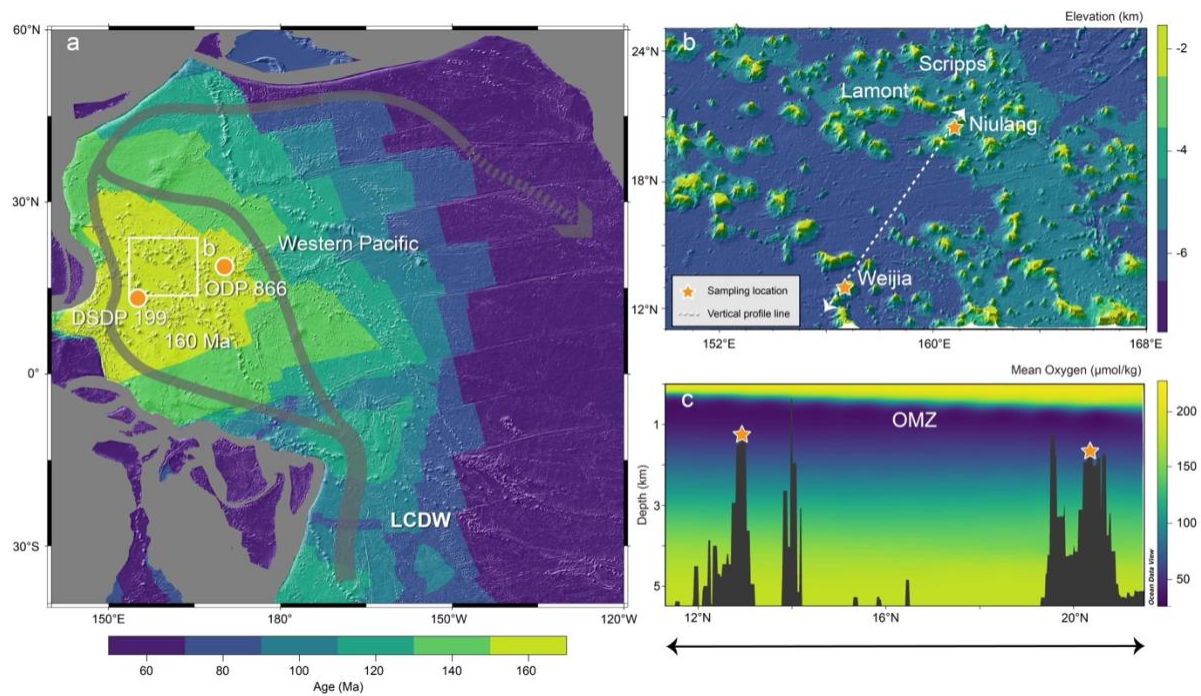


Figure 2. Scanning electron microscopy (SEM) images of sediments from the Niulang and Weijia guyots. (a) Main components in the winnowed sediments. (b) Ovoid CFA with porous microstructure. (c) CFA with concentric banding structure. (d) Pebble-like concretionary CFA with foraminifera remains. (e) Hexagonal apatite and interwoven prismatic calcite. (f) Euhedral hexagonal crystal structure of CFA. CFA = carbonate fluorapatite; Zeo = zeolite; Fora = foraminifera; Ap = apatite; Cal = calcite. All images were created in backscattered electron mode.

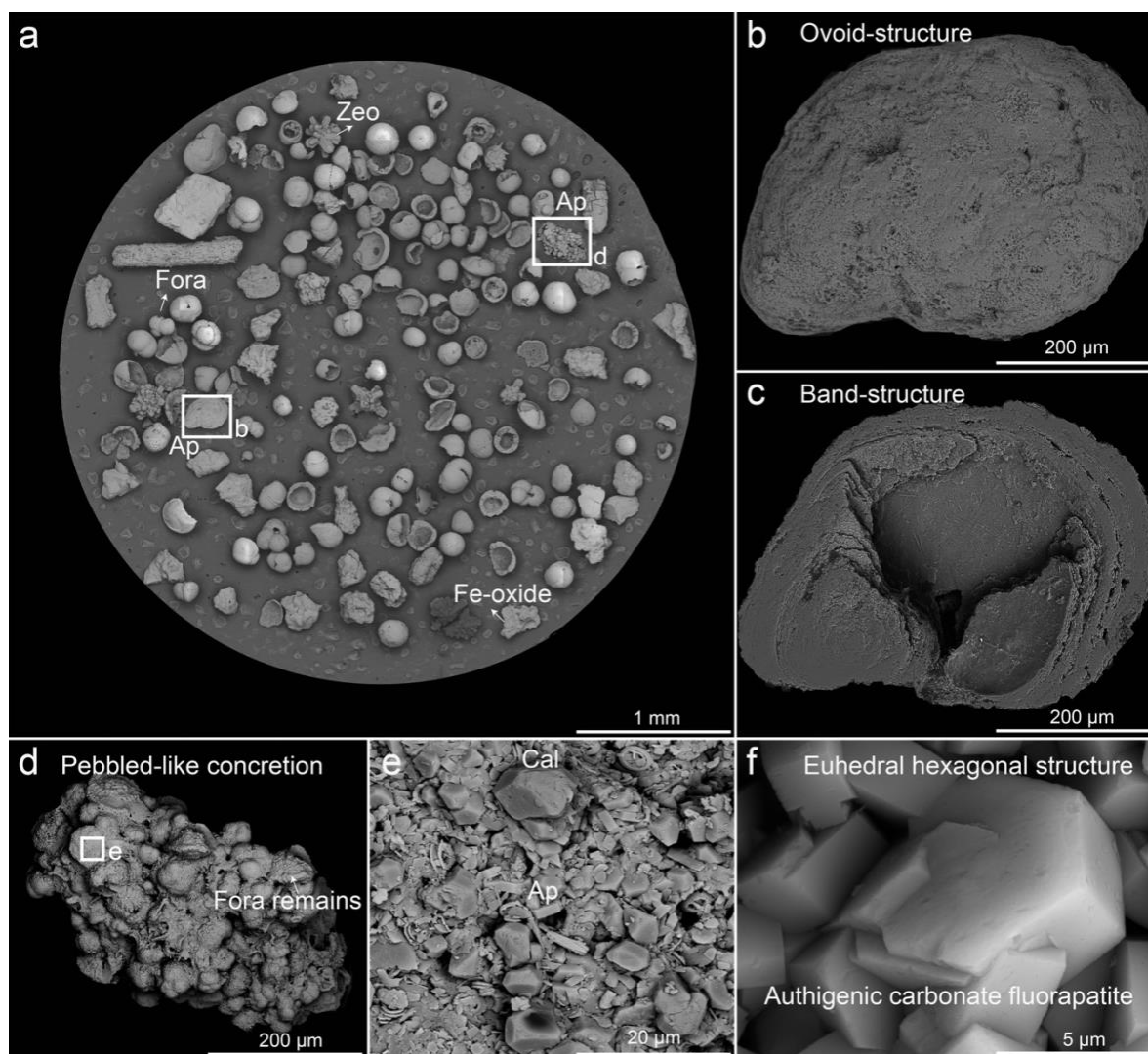
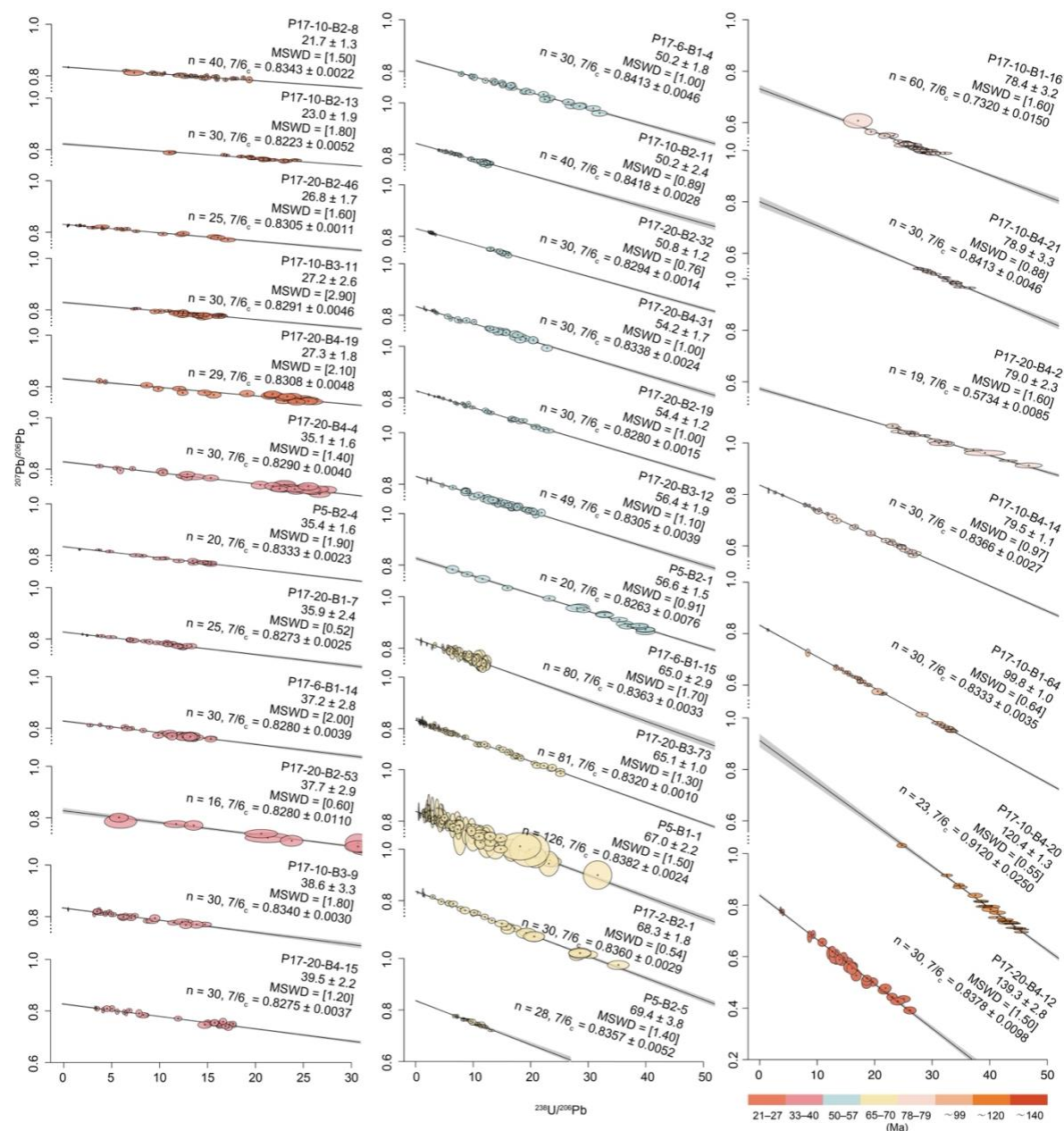
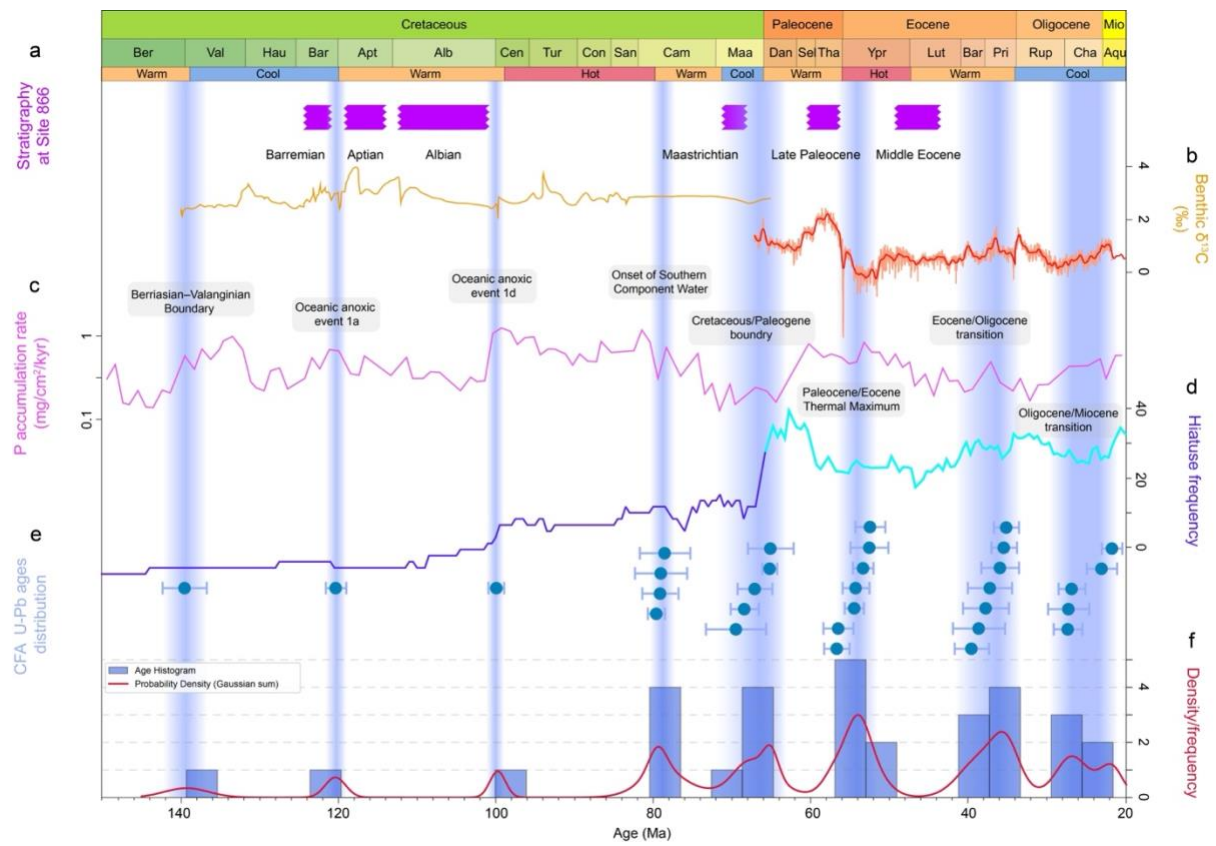


Figure 3. Tera-Wasserburg concordia diagrams of CFA samples from the Niulang and Weijia guyots. Data ellipses and calculated ages are at the 2σ level ($\pm$ sign represents the standard error). n = total number of ablation spots; MSWDs are presented within square brackets; $7/6_c$ = the $^{207}\text{Pb}/^{206}\text{Pb}$ initial ratio. See Dataset S2 for detail information of parameters. CFA = carbonate fluorapatite.



637 **Figure 4. Comparison of CFA ages with other geochemical and stratigraphic data. (a)**
638 Stratigraphic records from ODP Hole 866B site report. Pink bars represent the stratigraphic
639 range suggested by the fossils, and sawtooth symbols indicate disconformities (Sager et al.,
640 1993). **(b)** Carbon isotope records for the Cenozoic are from benthic foraminifera in global
641 ocean drilling sites (Westerhold et al., 2020), with data for the Cretaceous derived from bulk
642 carbonate in various continental margin settings (selected from Erba, 2004). Carbon isotope
643 data document a distinct excursion, providing a record of climate change and perturbations to
644 the global carbon cycle during these intervals. **(c)** Phosphorus accumulation rate from 145 to
645 20 Ma (Föllmi, 1996). **(d)** Distribution characteristics of deep-sea hiatuses from hundreds of
646 scientific ocean drilling sites (Dutkiewicz and Müller, 2022). **(e)** Tera-Wasserburg lower
647 intercept ages of the CFA samples (error bars are two standard errors). **(f)** Age-frequency
648 distribution and probability density plot. The histogram displays data in 3 Myr bins, while the
649 curve represents a kernel density estimate (KDE), generated by summing Gaussian
650 distributions (each with a mean of the individual age and a standard deviation of its analytical
651 uncertainty), to identify major and minor episodes of CFA formation. Climate states after
652 Westerhold et al. (2020) for the Cenozoic, and Stille et al. (1996) and Huber et al. (2018) for
653 145–66 Ma. Light blue shading highlights intervals of CFA enhancement. CFA = carbonate
654 fluorapatite. Mio = Miocene, Aqu = Aquitanian, Cha = Chattian, Rup = Rupelian, Pri =
655 Priabonian, Bar = Bartonian, Lut = Lutetian, Ypr = Ypresian, Tha = Thanetian, Sel = Selandian,
656 Dan = Danian, Maa = Maastrichtian, Cam = Campanian, San = Santonian, Con = Coniacian,
657 Tur = Turonian, Cen = Cenomanian, Alb = Albion, Apt = Aptian, Bar = Barremian, Hau =
658 Hauterivian, Val = Valanginian, Ber = Berriasian



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Figure 5. Schematic illustrating intensified paleocurrent and sediment accumulation scenarios on Pacific guyots. During warming periods (i.e. the late Paleocene to early Eocene), surface water either becomes more saline through evaporation, causing it to sink, or during cooling periods, colder temperatures and/or ice formation makes surface water denser. Both states enhance deep water formation, which intensifies and accelerates bottom currents, preventing sediment deposition (causing extensive hiatuses) but generating upwelling that transported nutrients (e.g., phosphate) to the summit. This results in enhanced primary productivity, and the consequent sufficient phosphate facilitates extensive CFA formation that traces phases of enhanced currents and consequent hiatuses. CFA = carbonate fluorapatite.

