

Response to Reviewer 1 – Baptiste Suchéras-Marx

Manuscript: “Orbital pacing, climate change, and the evolution of Maastrichtian upwelling along the southern Neo-Tethyan margin (Jordan)”

We thank Reviewer 1 for emphasizing figure readability, stratigraphic precision, methodological reproducibility, and the need to distinguish observation from interpretation. These comments led to a broad revision of the manuscript, particularly the figures, cyclostratigraphic section, MME correlation, sequence-stratigraphic terminology, and paleoenvironmental discussion.

Comment 1

Reviewer comment: General – figures are barely readable

Response: We agree. All figures will be regenerated/re-exported at publication resolution with substantially larger fonts, labels, symbols and scale bars. Rasterized text will be avoided wherever possible, and multi-panel figures will be simplified so that all information remains legible at final page size.

Comment 2

Reviewer comment: General – uncertainties make parts of the study difficult to understand

Response: We agree and have revised the manuscript to make the analytical workflow and stratigraphic reasoning explicit. In particular, we will expand the cyclostratigraphic Methods, clarify the nannofossil counting/percentage approach and uncertainty, distinguish observation from interpretation, and explain how the age model, biostratigraphy and chemostratigraphy are integrated.

Comment 3

Reviewer comment: Figure 1 – unreadable text/names; missing facies legend; Group/Formation not shown

Response: We agree. Figure 1 will be redesigned with larger text and readable well/outcrop labels. A complete facies legend will be added, and the Group and Formation names referred to in the caption/text will be displayed directly on the stratigraphic panel.

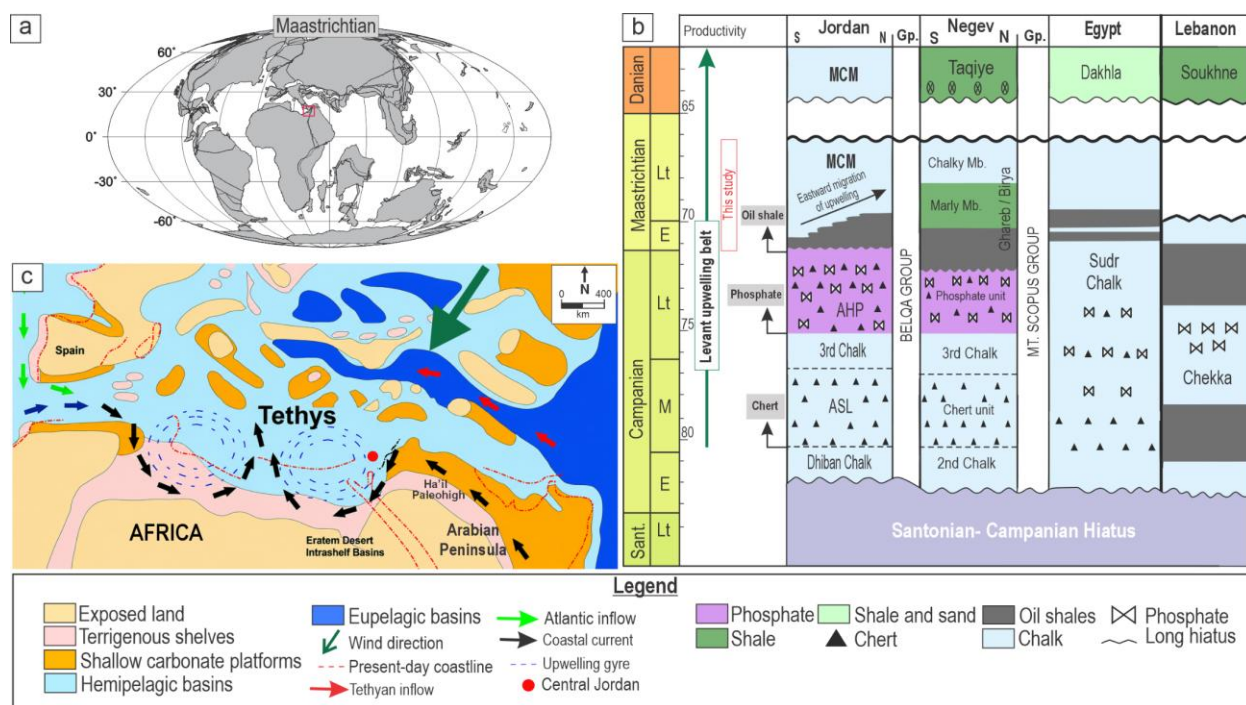


Figure 1. Late Cretaceous paleogeographic and stratigraphic setting of the Levant upwelling system. (a) Maastrichtian paleogeography and location of central Jordan. **(b)** Regional stratigraphic correlation across Jordan, Negev, Egypt, and Lebanon, highlighting phosphorite, chert, and organic-rich deposits associated with enhanced productivity (Messaoud et al., 2025). **(c)** Maastrichtian Tethyan paleogeography showing major depositional environments, circulation, prevailing winds, and the Levant upwelling system (Guiraud et al., 2005; MacLeod et al., 2011; Soudry et al., 2006)..

Comment 4

Reviewer comment: Figure 2 – core image should be supplementary; main figure should be more like Fig. 3

Response: We thank the reviewer for this suggestion. However, we consider the core image important to retain in the main manuscript because it provides direct visual documentation of the studied succession and allows the reader to relate the geochemical, micropaleontological, and cyclostratigraphic records to the actual lithological expression of the core. In particular, the core image illustrates the vertical changes from organic-rich marl and chalky marl intervals to more carbonate-rich facies, as well as prominent lithological boundaries and cyclic variations that are central to our paleoenvironmental and cyclostratigraphic interpretations. Removing it from the main text would make it more difficult for readers to assess how the proxy variations relate to the physical sedimentary record.

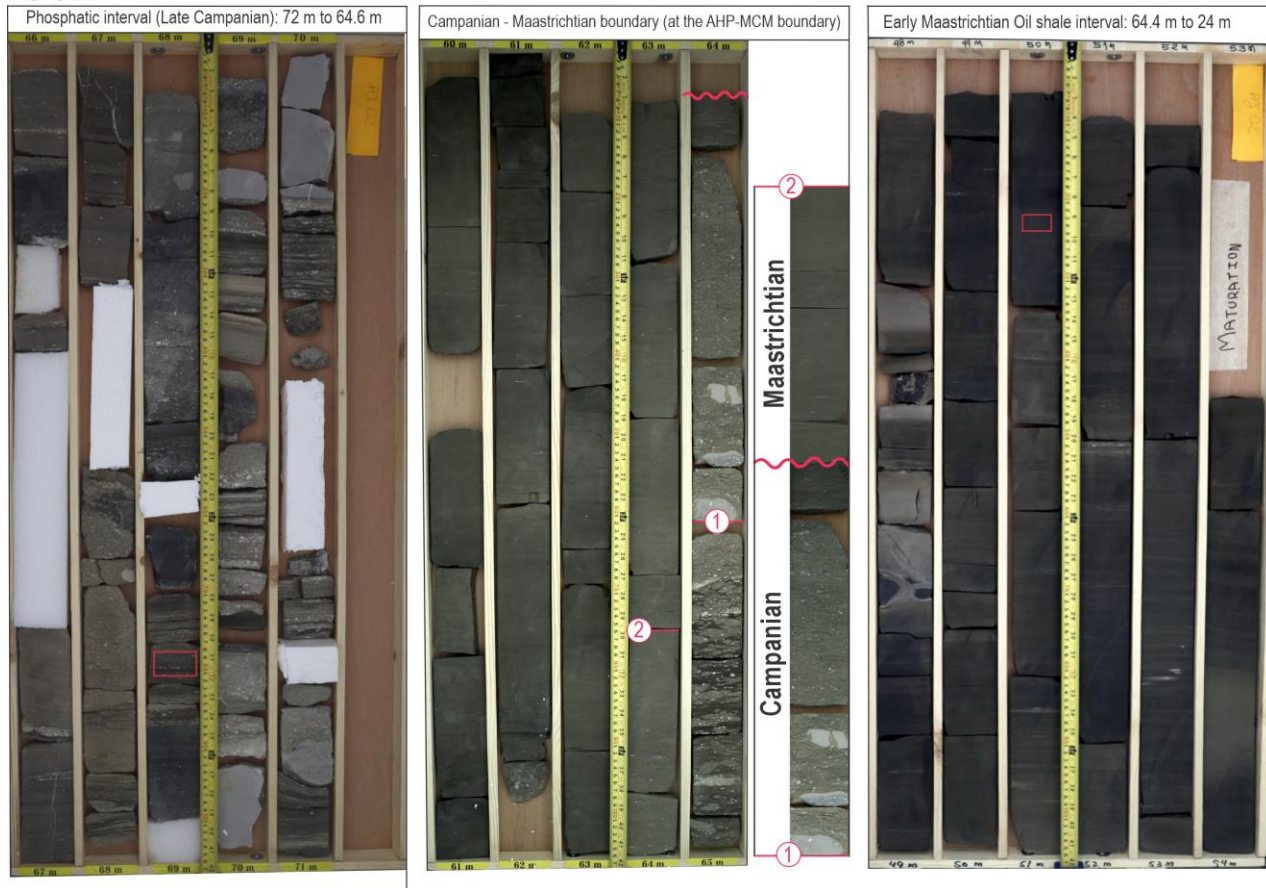


Figure 3. Representative core photographs of well 2 succession showing the lithological evolution from the late Campanian phosphatic interval (72–64.6 m), characterized by dark phosphatic and laminated organic-rich facies, through the Campanian–Maastrichtian boundary at the AHP–MCM contact, to the lower Maastrichtian oil-shale interval (64.4–24 m), dominated by dark, organic-rich fine-grained deposits. Red wavy lines mark the stratigraphic boundary and red boxes indicate selected sampling intervals.

Comment 5

Reviewer comment: Figure 3 – TS difficult to see; pixelized text; use “disconformity” rather than “sequence boundary”

Response: We agree. The TS curve and labels will be enlarged and the figure re-exported at higher quality. We will replace “sequence boundary” by the more observational term “disconformity” where the physical surface is documented, reserving sequence-stratigraphic interpretation for the text.

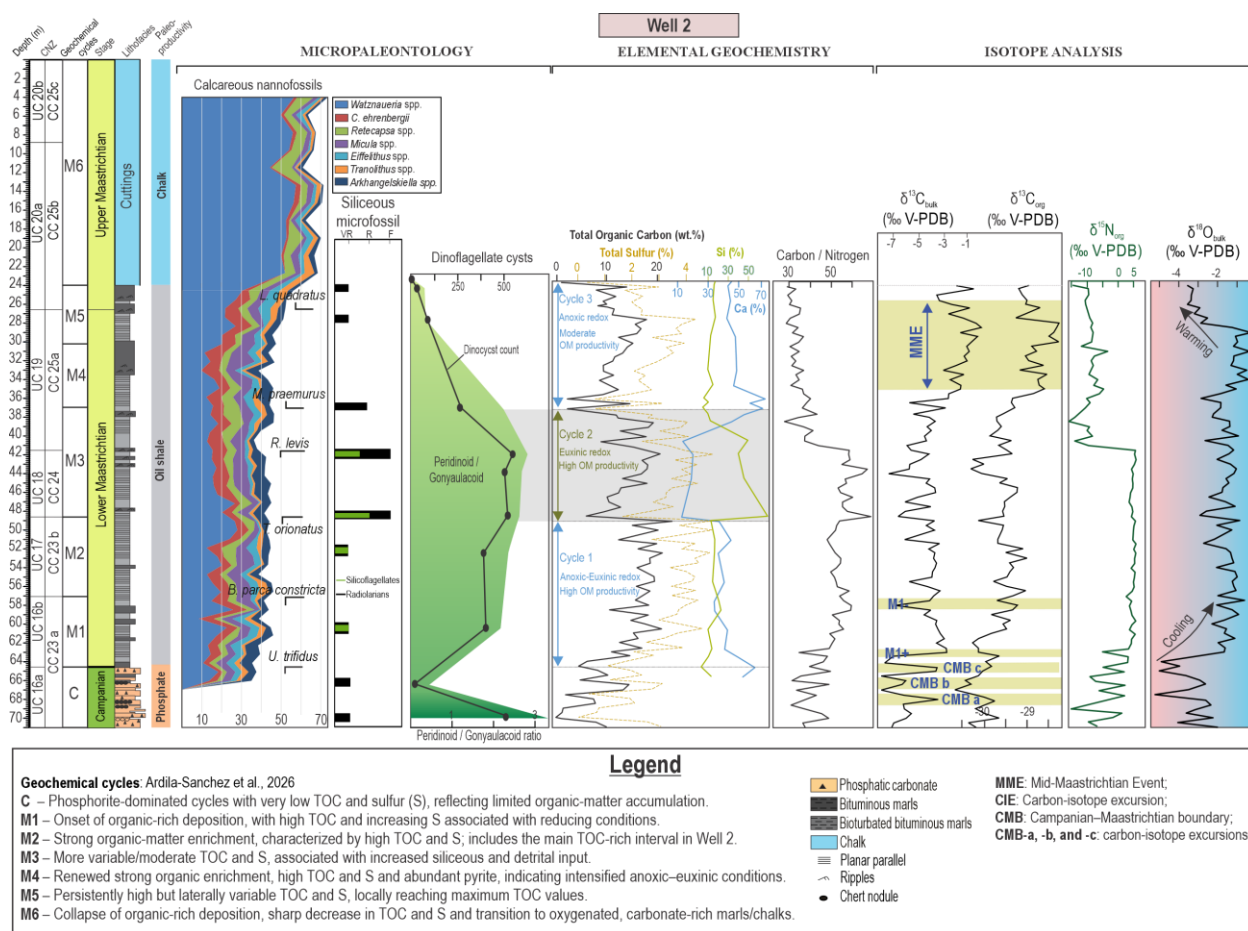


Figure 4. Integrated stratigraphic, micropaleontological, geochemical, and paleoenvironmental framework of Well 2 (upper Campanian–upper Maastrichtian). Three depositional cycles record shifts from phosphogenic upwelling and organic-matter enrichment to oligotrophic carbonate production, alongside the CMBE and MME

Comment 6

Reviewer comment: Figure 4 – unreadable; nannofossil scale unclear

Response: We agree. Figure 4 will be rebuilt with larger labels and an explicitly defined scale for nannofossil abundance/percentages. The caption and Methods will state how the values were calculated and the number of specimens counted where applicable.

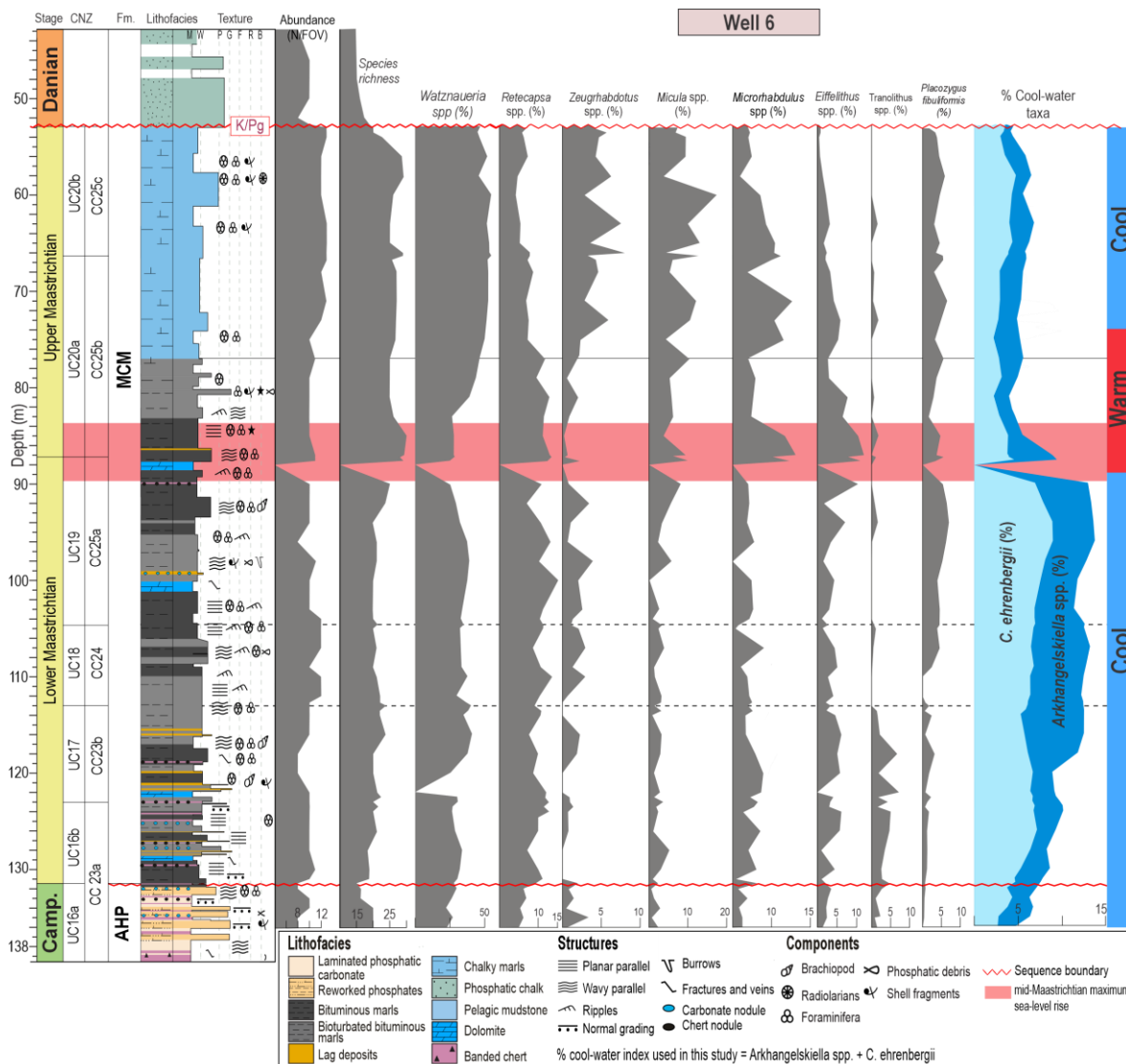


Figure 6. Integrated lithostratigraphic and calcareous nannofossil framework of well 6 core spanning the upper Campanian to lower Danian. The figure shows lithofacies, sedimentary structures, fossil components, nannofossil abundance (N/FOV), species richness, and relative abundances of selected taxa across the UC and CC biozones. Selected taxa include Watznaueria, Retecapsa, Zeughrabdodus, Micula, Microrhabdulus, Eiffellithus, Tranolithus, and Placozygus fibuliformis. The relative abundances of Arkhangelskiella spp. and Cribrosphaerella ehrenbergii are additionally presented as a cool-water index. Red wavy lines indicate the Campanian–Maastrichtian and K/Pg boundaries.

Comment 7

Reviewer comment: Figure 5 – unreadable; inconsistent with Fig. 4; cool interval questionable; blue line undefined

Response: We agree. Figures are standardized to the same graphical structure and scales. The blue curve will be explicitly defined in the legend/caption. We will reassess the lower extent of the cool interval against the actual cool-water taxon percentages and modify the shading so that it reflects the data rather than an a priori climatic subdivision.

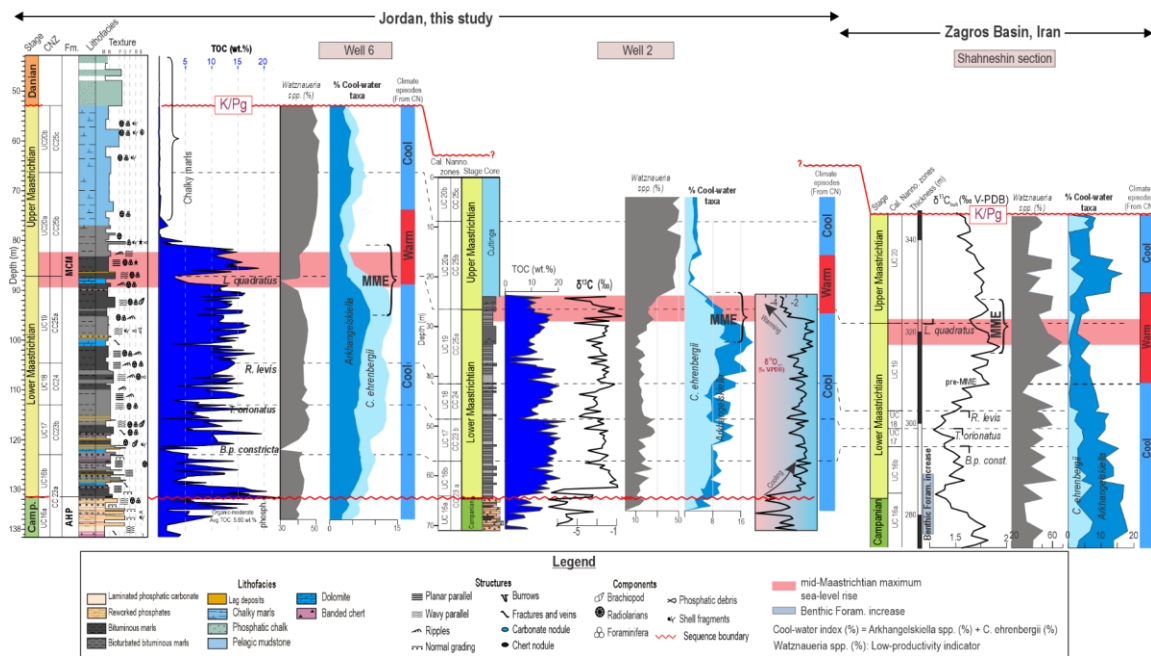


Figure. Integrated stratigraphic, geochemical, and paleoclimatic correlation of the upper Campanian–Maastrichtian to lower Danian succession from Wells 6 and 2 (Jordan) and the Shahnesht section (Zagros Basin, Iran). Records include lithostratigraphy, GR, TOC, calcareous nannofossil assemblages, cool-water index, and $\delta^{18}O$. Dashed lines mark key biostratigraphic correlations, the blue interval highlights the mid-Maastrichtian maximum transgression and MME, and red wavy lines indicate major stratigraphic boundaries, including the K/Pg boundary.

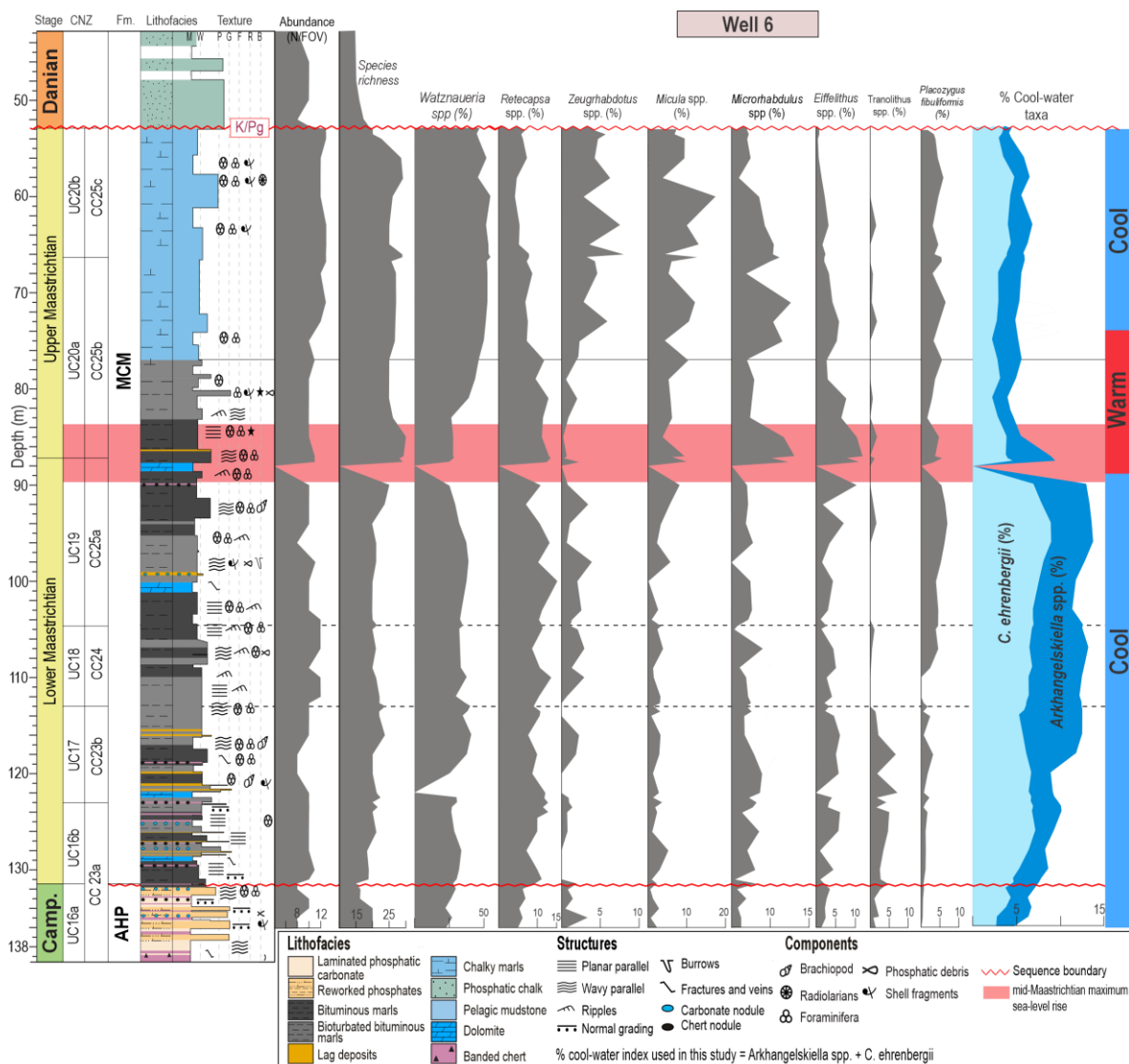
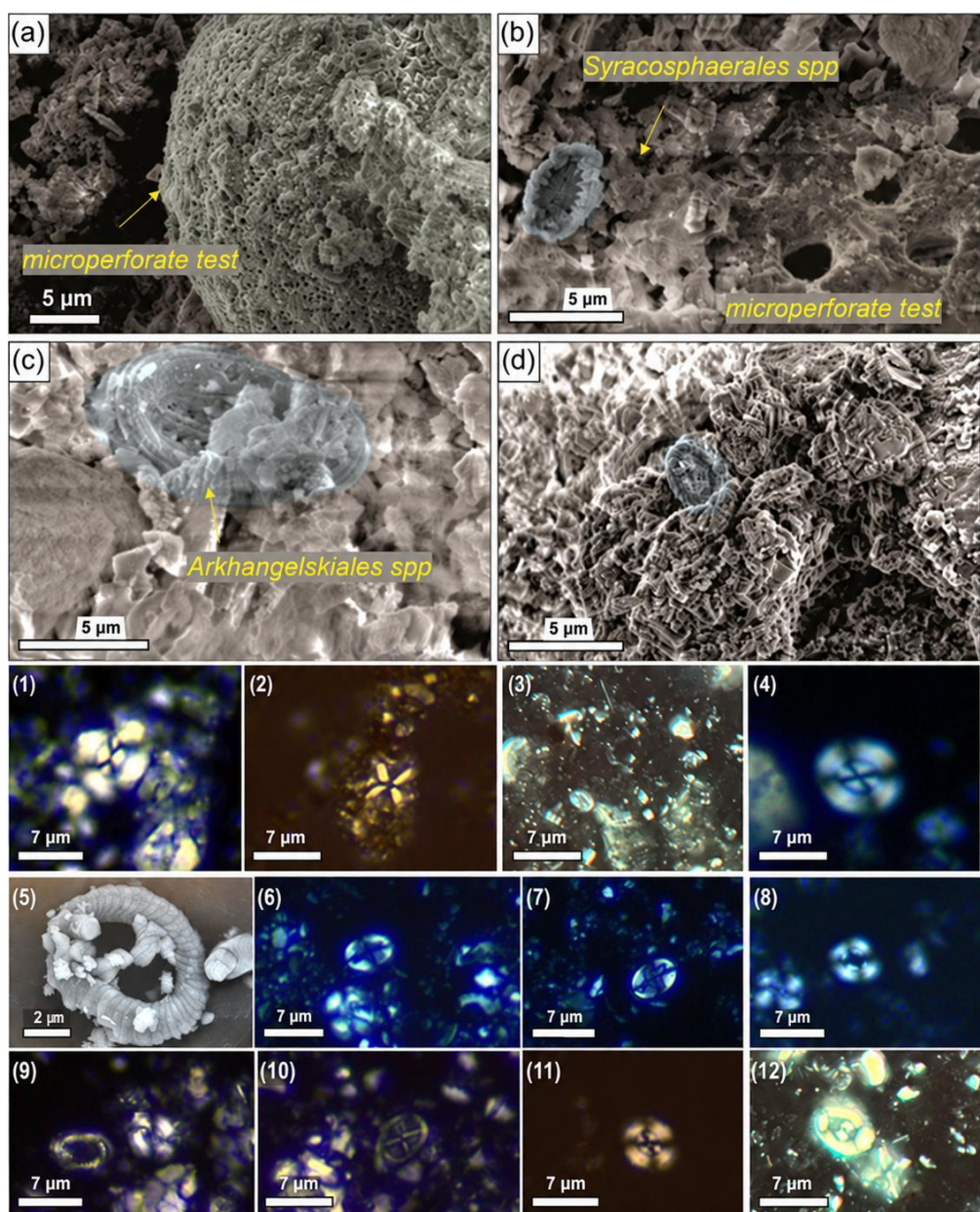


Figure. Integrated lithostratigraphic and calcareous nannofossil framework of well 6 core spanning the upper Campanian to lower Danian. The figure shows lithofacies, sedimentary structures, fossil components, nannofossil abundance (N/FOV), species richness, and relative abundances of selected taxa across the UC and CC biozones. Selected taxa include *Watznaueria*, *Retecapsa*, *Zeughrabdodus*, *Micula*, *Microhabdulus*, *Eiffellithus*, *Tranolithus*, and *Placozygus fibuliformis*. The relative abundances of *Arkhangelskiella* spp. and *Cribrosphaerella ehrenbergii* are additionally presented as a cool-water index. Red wavy lines indicate the Campanian–Maastrichtian and K/Pg boundaries.

Comment 8

Reviewer comment: Figure 6 – missing scales; photo 3 coccolith unclear; *Watznaueria biporta* identification questioned

Response: We agree. Scale bars and numerical scale values will be added to photographs 1–12. Photo 3 will be replaced by a clearer image or removed if the coccolith cannot be demonstrated unambiguously. The specimen assigned to *Watznaueria biporta* in photo 5 will be re-examined and relabelled or removed if the identification cannot be confirmed.



Comment 9

Reviewer comment: Figure 7 – species names and scale-bar numbers too small

Response: We agree. Species names and scale-bar values will be enlarged and the plate reorganized if necessary to maintain readability at publication size.

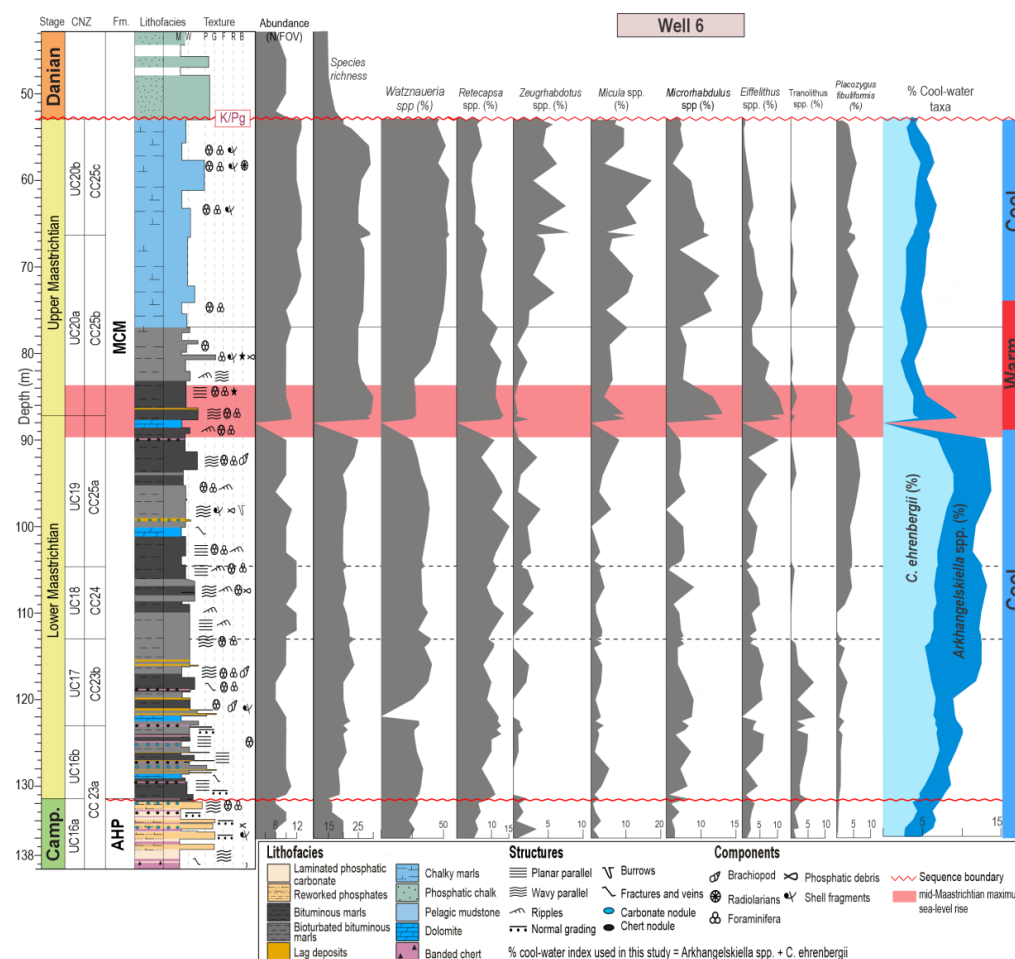


Figure 6. Integrated lithostratigraphic and calcareous nannofossil framework of well 6 core spanning the upper Campanian to lower Danian. The figure shows lithofacies, sedimentary structures, fossil components, nannofossil abundance (N/FOV), species richness, and relative abundances of selected taxa across the UC and CC biozones. Selected taxa include Watznaueria, Retecapsa, Zeughrabdotus, Micula, Microrhabdulus, Eiffellithus, Tranolithus, and Placozygus fibuliformis. The relative abundances of Arkhangelskiella spp. and Cribrosphaerella ehrenbergii are additionally presented as a cool-water index. Red wavy lines indicate the Campanian–Maastrichtian and K/Pg boundaries.

Comment 10

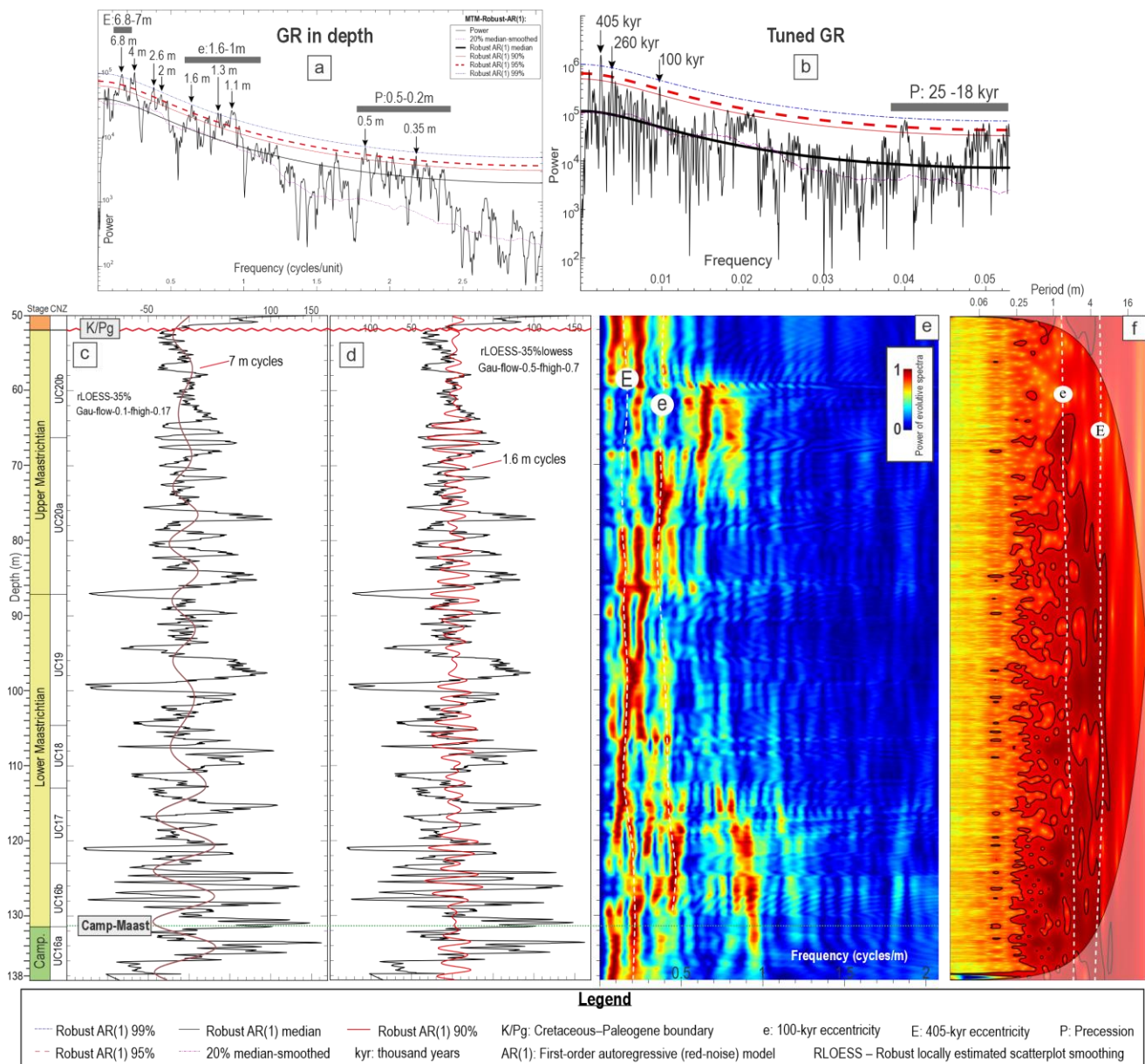
Reviewer comment: Figure 8 – text and scales too small

Response: We agree. Figure 8 will be re-exported with larger text, axis labels and scales, and unnecessary graphical elements will be reduced.

Comment 11

Reviewer comment: Figure 9 – tuned shown before untuned; no panel letters

Response: We agree. The figure will be reordered so that the untuned depth-domain analysis is presented first, followed by the tuned time-domain analysis. All panels will be labelled (a–d or as appropriate) and referred to explicitly in the caption and Results.



Comment 12

Reviewer comment: Figure 10 – dark band confusing; text too small; specify $\delta^{13}\text{C}$ material

Response: We agree. The dark band will be removed or redesigned so that it cannot be mistaken for a time scale or the Campanian–Maastrichtian boundary. Text will be enlarged. We will explicitly identify each isotope dataset as $\delta^{13}\text{C}_{\text{org}}$ and $\delta^{13}\text{C}_{\text{carb}}$ and state the analyzed material/method in the Methods and caption. The revised correlation figure will also make the stratigraphic position of the MME clearer.

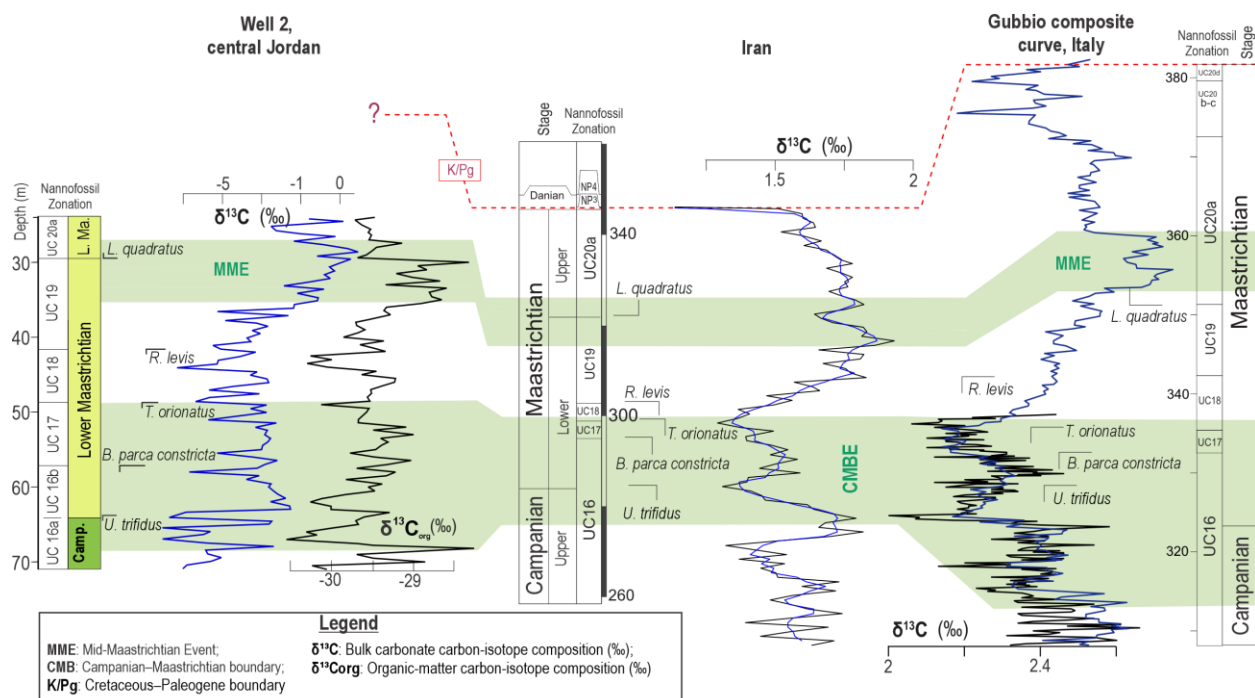


Figure. Carbon-isotope stratigraphic correlation of Well 2 (central Jordan) with the Shahneshin section, Iran (Razmjooei et al., 2020), and the Gubbio composite curve, Italy. $\delta^{13}\text{C}$ records and key calcareous nannofossil bioevents constrain the correlations across the Campanian–Maastrichtian interval. Green shading highlights the correlated carbon-isotope excursions, including the Campanian–Maastrichtian Boundary Event (CMBE) and Mid-Maastrichtian Event (MME). The red dashed line indicates the inferred correlation toward the K/Pg boundary.

Comment 13

Reviewer comment: Figure 11 – not cited in text

Response: We agree. The figure will either be explicitly introduced and described in the Results where its dataset is discussed or removed/merged if it does not add independent information.

Comment 14

Reviewer comment: Figure 12 – hiatus not discussed

Response: We agree. The hiatus/condensed interval shown in the figure will be described in the Results and its implications for sedimentation and stratigraphic completeness discussed. This will be integrated with the reconstructed sedimentation-rate evolution and sequence-stratigraphic framework.

Comment 15

Reviewer comment: All figures – captions too interpretative

Response: We agree. All captions will be shortened and restricted to panel identification, plotted datasets, symbols, abbreviations, analytical material and essential stratigraphic information. Interpretations concerning orbital forcing, climate, redox, productivity and sea level will be moved to the Results or Discussion as appropriate.

Comment 16

Reviewer comment: Terminology – Middle Maastrichtian; Early/Late vs Lower/Upper

Response: We agree and will standardize terminology throughout. “Middle Maastrichtian” will be replaced by “mid-Maastrichtian”. Early/Late will be used for geochronologic time, Lower/Upper for formally defined

chronostratigraphic subdivisions where appropriate, and lower/upper descriptively for stratigraphic position.

Comment 17

Reviewer comment: Methods – add cyclostratigraphic subsection

Response: We agree. A dedicated Cyclostratigraphic analysis subsection will be added. It will specify software, data preparation and interpolation, detrending, MTM configuration, noise model and confidence levels, filtering, amplitude-modulation analysis, wavelet/evoFFT settings, astronomical target periods, tuning procedure and age-model construction.

Comment 18

Reviewer comment: Methods §3.2 – identify well/core and magnification

Response: We agree. Section 3.2 will explicitly identify the core/well analyzed and state the microscope magnification(s) used for the nannofossil observations/counts.

Comment 19

Reviewer comment: Results §4.1.1 – mostly from published work

Response: We agree. Background information derived primarily from previous studies will be moved to the Geological Setting/Stratigraphy section. The Results will retain only observations generated or compiled directly for the present study.

Comment 20

Reviewer comment: Line 330 – define “low to moderate” quantitatively

Response: We agree. Qualitative wording will be replaced by the corresponding numerical range so that the reader can evaluate the magnitude directly.

Comment 21

Reviewer comment: Lines 356–357 – oligotrophic conditions?

Response: Yes. Where this is the intended interpretation, we will state “oligotrophic conditions” explicitly and ensure that it is supported by the assemblage data.

Comment 22

Reviewer comment: Cool-water taxa – add percentage uncertainties

Response: We agree. We will add uncertainty estimates to the cool-water taxon percentages and describe their calculation in the Methods, allowing the significance of changes between intervals to be evaluated.

Comment 23

Reviewer comment: Results §4.3 – sample names inconsistent

Response: We agree. Sample identifiers will be reported consistently for all specifically discussed levels, or removed from the prose where they are not needed.

Comment 24

Reviewer comment: Line 434 – define AOM

Response: We agree. AOM will be defined at first use as “amorphous organic matter (AOM)”.

Comment 25

Reviewer comment: Line 494 – “Late Campanian” may contradict figures

Response: We will re-check the age assignment against the revised biostratigraphic and cyclostratigraphic framework and correct the text/figure as required. The revised high-resolution figures should remove the ambiguity that was present in the submitted version.

Comment 26

Reviewer comment: Results §4.8 – cyclostratigraphy/tuning insufficiently explained; 6.8 m not always persistent

Response: We agree. The analytical and tuning procedure will be moved/expanded in Methods, including how the sedimentation-rate range was obtained. In Results, we will revise the description of the ~6.8 m cycle: rather than calling it uniformly persistent, we will state that eccentricity-band power is expressed through much of the succession but varies in strength and apparent wavelength, locally splits, and becomes weak in the chalk interval. These changes will be discussed in terms of sedimentation dynamics and changing accumulation rates.

Comment 27

Reviewer comment: Discussion – warmer interval, oxygenation, runoff and stratification appear contradictory

Response: We agree that the original explanation was insufficient. We will expand this discussion and separate the controls on surface-water productivity/stratification from those governing bottom-water ventilation and organic-carbon burial. Warmer conditions and enhanced runoff do not by themselves require poorer bottom-water oxygenation if changes in sea level, circulation, water-mass exchange, nutrient regime and sedimentation alter ventilation and organic-matter remineralization. We will explicitly explain why organic-carbon accumulation was greater during the cooler interval and evaluate the relative roles of productivity, preservation, dilution and sedimentation rate.

Comment 28

Reviewer comment: Discussion §5.2 – show dinocyst assemblages and P/G ratio

Response: We agree. The dinocyst assemblage data and peridinioid/gonyaulacoid ratio used in the interpretation will be added to a main or supplementary figure and described in Results before being discussed.

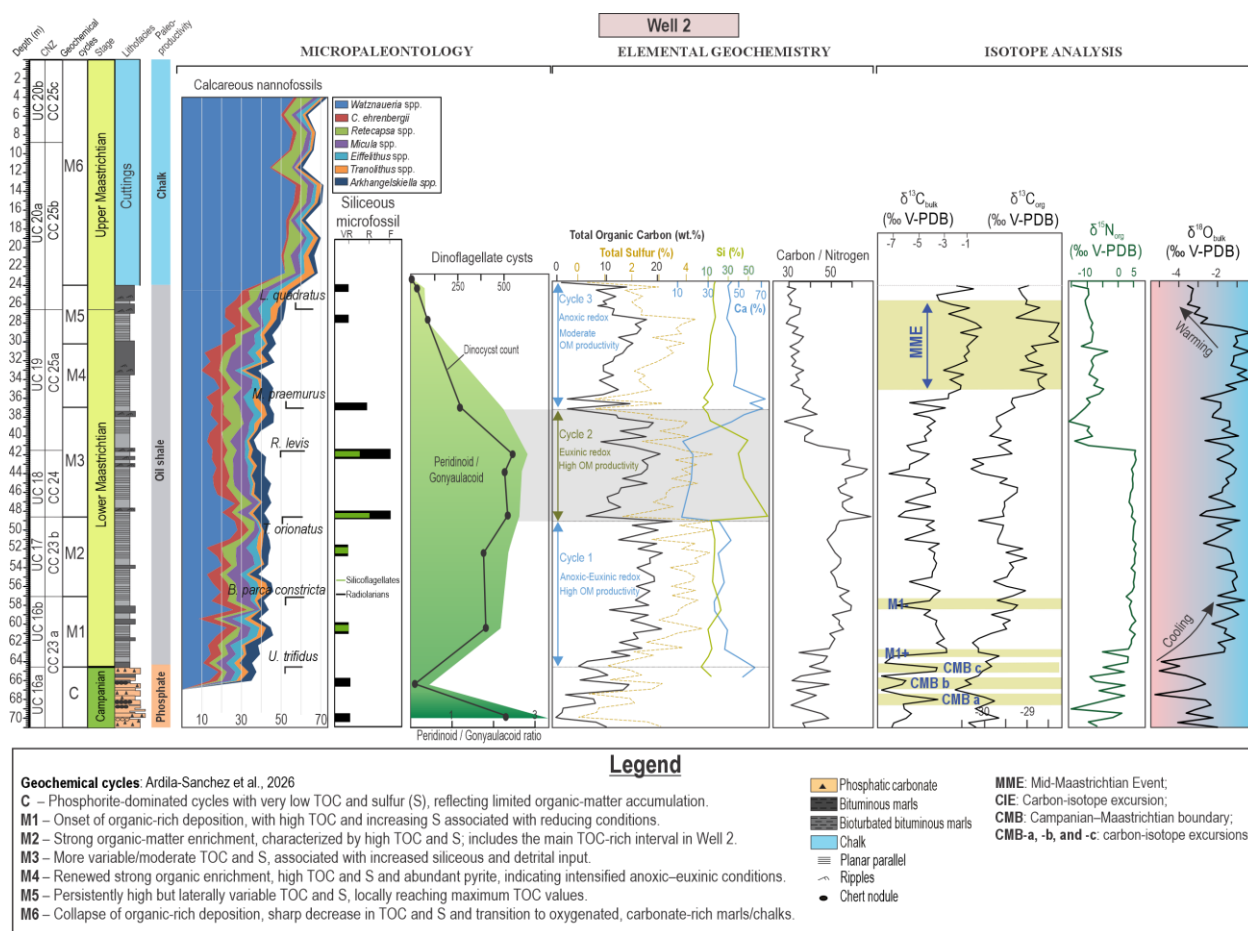


Figure 4. Integrated stratigraphic, micropaleontological, geochemical, and paleoenvironmental framework of Well 2 (upper Campanian–upper Maastrichtian). Three depositional cycles record shifts from phosphogenic upwelling and organic-matter enrichment to oligotrophic carbonate production, alongside the CMBE and MME

Comment 29

Reviewer comment: Line 720 – Early-Middle Maastrichtian boundary

Response: We agree. This terminology will be removed. The interval will be described using an appropriate numerical age, biozone/event, or as early to mid-Maastrichtian depending on context.

Comment 30

Reviewer comment: Line 726 – nutrient “enrichment” vs source

Response: We agree. The sentence will be rewritten to distinguish nutrient source/supply from nutrient enrichment or concentration in the depositional system.

Comment 31

Reviewer comment: Line 748 – weak $\delta^{13}\text{C}_{\text{carb}}$ – $\delta^{13}\text{C}_{\text{org}}$ correlation vs diagenesis

Response: We agree. The original inference of carbon-reservoir decoupling was too strong because $\delta^{13}\text{C}_{\text{carb}}$ is demonstrably susceptible to diagenetic modification. We will rewrite this section so that the weak correlation is treated primarily as evidence that $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{13}\text{C}_{\text{org}}$ did not respond identically, while acknowledging that alteration of the carbonate signal prevents a simple interpretation in terms of primary reservoir decoupling.

Comment 32

Reviewer comment: Line 840 – unclear sentence

Response: We agree and will rewrite the sentence for clarity after checking its intended meaning and surrounding argument.

Comment 33

Reviewer comment: Line 841 – “exceptional preservation” inconsistent with N loss

Response: We agree. “Exceptional preservation” will be replaced by more precise wording such as “enhanced net organic-carbon burial/accumulation” or “favorable preservation of a substantial fraction of marine organic carbon”. This acknowledges substantial transformation and nitrogen loss during early diagenesis.

Comment 34

Reviewer comment: Lines 894–909 – important explanation

Response: We thank the reviewer for this positive comment. We will retain this section and use it as a basis for clarifying the broader paleoceanographic mechanism elsewhere in the Discussion.

Comment 35

Reviewer comment: Use of “K/Pg boundary” where a disconformity is present

Response: We agree. Because the studied succession does not preserve the K/Pg boundary continuously, we will not refer to the disconformity itself as the K/Pg boundary. We will instead describe the upper surface as a disconformity/hiatus and specify its stratigraphic relationship to the K/Pg boundary only where supported by independent age constraints. Suggested revision of the MME paragraph To address the reviewer's concern about stratigraphic clarity, we recommend explicitly distinguishing the short carbon-isotope MME from the broader mid-Maastrichtian climatic perturbation. Following Dubicka et al. (2024), the broader warming/paleoceanographic interval spans approximately 69.5–67.5 Ma, whereas the MME sensu stricto is the shorter (~570 kyr) carbon-isotope interval characterized by the MME1–MME3 succession. In AJ-02, its placement should be presented as an integrated correlation rather than a single-datum assignment: the carbon-isotope pattern is evaluated together with the high-resolution calcareous nannofossil succession, particularly the position of the FO of *Lithraphidites quadratus*, and the cyclostratigraphic age model. This agreement provides the basis for positioning the MME in the Jordan record and should be made visually explicit in the revised correlation figure. Final pre-submission checklist All figure text readable at final journal page size. Every figure called in the text in numerical order. All panels lettered and captions descriptive rather than interpretative. All isotope notation identifies the analyzed pool/material (e.g., $\delta^{13}\text{C}_{\text{org}}$, $\delta^{13}\text{C}_{\text{carb}}$). Figures 4 and 5 use consistent architecture/scales and define all curves. Cool-water taxa include counting/percentage uncertainty. Cyclostratigraphy Methods are reproducible and tuning procedure is explicit. Untuned analyses precede tuned analyses. 405-kyr signal is not described as uniformly persistent; variable power/splitting and chalk weakening are discussed. ~100-kyr eccentricity expression is documented consistently across proxies where supported by the spectra. MME is defined consistently with Dubicka et al. (2024), separating the short CIE from broader warming. Hiatus/disconformity and condensation are discussed together with sedimentation-rate and sea-level reconstruction. Dinocyst assemblages/P:G ratio shown if used as a central discussion argument. “Middle Maastrichtian” removed; stratigraphic/time terminology standardized. “K/Pg boundary” removed where the boundary interval is not preserved. Claims of “exceptional preservation” replaced by organic-carbon accumulation/burial where appropriate. Geological-setting material removed from Results.

Additional clarification on the MME

To address the reviewer's concern about stratigraphic clarity, we recommend explicitly distinguishing the short carbon-isotope MME from the broader mid-Maastrichtian climatic perturbation. Following Dubicka et al. (2024), the broader warming/paleoceanographic interval spans approximately 69.5–67.5 Ma, whereas the MME sensu stricto is the shorter (~570 kyr) carbon-isotope interval characterized by the MME1–MME3 succession. In AJ-02, its placement should be presented as an integrated correlation rather than a single-datum assignment: the carbon-isotope pattern is evaluated together with the high-resolution calcareous nannofossil succession, particularly the position of the FO of *Lithraphidites quadratus*, and the cyclostratigraphic age model. This agreement provides the basis for positioning the MME in the Jordan record and should be made visually explicit in the revised correlation figure.

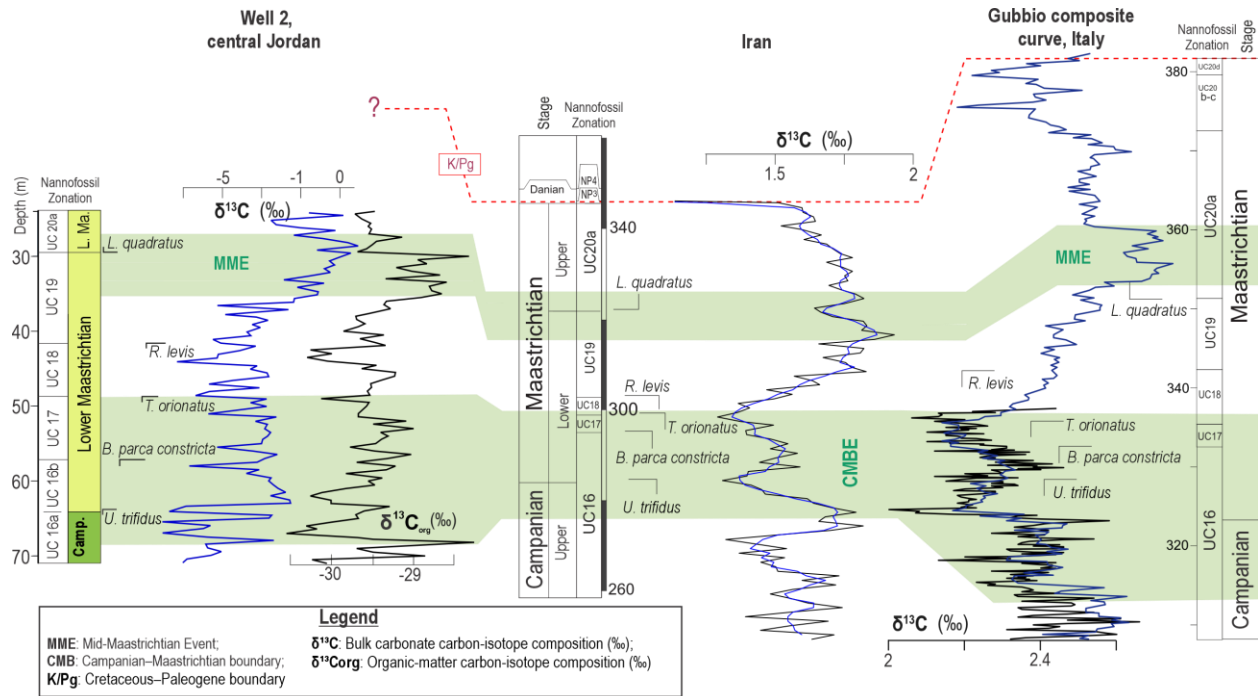


Figure 14. Carbon-isotope stratigraphic correlation of Well 2 (central Jordan) with the Shahneshin section, Iran (Razmjooei et al., 2020), and the Gubbio composite curve, Italy. $\delta^{13}\text{C}$ records and key calcareous nannofossil bioevents constrain the correlations across the Campanian–Maastrichtian interval. Green shading highlights the correlated carbon-isotope excursions, including the Campanian–Maastrichtian Boundary Event (CMBE) and Mid-Maastrichtian Event (MME). The red dashed line indicates the inferred correlation toward the K/Pg boundary.