Dear Editor,
First, we would like to acknowledge your careful handling of the manuscript and the suggestions you made in your comments. Please find below our response (in black) to each point raised by you (in blue).

A. I would suggest a sedimentation rate profile to further strengthen your argument.

We agree that displaying the sedimentation rate helps to foster our arguments. We hence added sedimentations rates obtained from the Th/U-dated CWC-bearing intervals to Fig. 3, also indicating the indirectly inferred sedimentation rate for the CWC-barren interval between 200-465 cm. The figure caption has been modified accordingly.

B. Do you think a high input of nutrients during glacials will enhance the deposition of greater marine-derived organic matter? However, that signal is not strong enough!!

As we infer in the discussion the input of nutrients from run-off fertilizes the surface ocean and will likely boost surface productivity. However, the C/N ratio still indicates that most organic matter in the CWC bearing intervals derives from land, clearly dominating over marine organic matter. Hence, the potentially increased marine productivity appears secondary to the terrigenous organic matter input when it comes to fueling CWC growth.

C. The delta 13C (TOC) data does not show a sharp drop except at MIS 6!! Although it was expected during LGM due to the spreading of grassland and aridity. We see that routinely at many places. These aspects need some explanation.

We agree that MIS 6 should show a strong trend to C4-dominated vegetation as MIS 6 causing a drop in $\delta^{13}C_{org}$ comparable to that of MIS 6. However, MIS 2 is incomplete in the record due to subsequent erosion, in contrast to the more complete section comprising MIS 6. Hence, the comparatively less enriched $\delta^{13}C_{org}$ values from the LGM are likely not fully representative of the vegetation cover changes during this period.

We would also like to point out that the $\delta^{13}C_{org}$ signal is a mixture of organic matter sources, where vegetation shifts (i.e. C3 vs. C4 plants) play a an important role, but also the relative proportion of marine vs. terrestrial constituents. To emphasize the mixed nature of the $\delta^{13}C_{org}$ signal we phrase "… high $\delta^{13}C_{org}$ values as being influenced by enhanced input of POC from C4 plants… ".

D. Do you think that high bottom current itself can result in concentrating the coral pieces like a shell hash deposit, irrespective of high productivity?

It is indeed possible that winnowing due to strong bottom currents leads to the accumulation of larger particles. Winnowing is hence likely responsible for the accumulation of shells hash and coral fragments at the erosive horizons. In general, CWC bearing intervals are characterized by anomalously high bottom current speeds (Fig. 4) and are furthermore embedded in a silt-sized matrix, hence, we do not expect that the vast majority of the CWC-rich intervals have been accumulated by strong bottom current activity.

Please find below the point-by-point responses to the Referees' comments as well as a marked-up manuscript version showing the changes made to the original version of the manuscript.

Please also note that we included Andreas Koutsodendris into the co-author list as he significantly contributed to the revised version of the manuscript.

Response to Robin Fentimen (Referee 1)
First we would like to thank Robin Fentimen for his careful and supportive evaluation of our manuscript. Below we provide a point-to-point response (in black) to the original comments (in blue).

Bahr et al. set out to constrain the long-term development of Bowie Mound and to understand the environmental forcing behind its formation. They essentially conclude that an enhanced delivery of terrestrial organic matter during Heinrich Stadials (HS 1, 4 and 6) played an important role on cold-water coral growth off SE Brazil. They compare their set of sedimentological and geochemical proxies to previously published data in the area. As such, the study is based on a solid and plentiful number of proxies. The chronostratigraphy of the core is well constrained and allows, in my opinion, for a satisfying interpretation of the data. The discussion is to the point and not too lengthy, it could even go a bit more in depth (see Comment #3). The stable isotope analyses of infaunal foraminiferal tests is where the most improvement could be done. This is detailed in Specific comment #1. The conclusions drawn by the authors are arguably by the choice of method, and may have yielded more precise results and details if the approach would have been different (and more taxonomically precise; see comment #1).
As detailed below we provide more details on the stable isotope analysis. Although we are aware of the potential limitations of this method (especially of using endobenthic $\delta^{13}C$ for bottom water reconstructions due to the absence of sufficient amounts of epibenthic foraminifera) we are confident that the results provide a robust assessment of major shifts in the bottom water regime. However, we agree with the reviewer that an investigation of the benthic foraminiferal communities might provide useful insights into the changes of trophic levels and nutrient supply to the continental margin (such as done in Fentimen et al., 2020). This is clearly beyond the scope of this study but might well be tackled as part of a follow-up research.

The quality of the English in the manuscript is at times insufficient. Some corrections are listed in the section "Technical corrections". In addition to these, the manuscript would need a few extra proof readings to reach the desired quality. I am however confident that this can be done shortly and satisfyingly by the authors.
We thank both Reviewers for pointing at typos and incorrect language. They were all corrected and we also had the text proof-read by a native speaker to improve the quality of the English. Please note that we also changed the title into "Monsoonal forcing of cold-water coral growth off south-eastern Brazil during the past 160 kyrs" instead of "Monsoonal forcing controlled cold water coral growth…".

All things considered, I would be happy to recommend this manuscript for publication in Biogeosciences if the points below (plus the English in the text) are addressed by the authors. The manuscript presents a novel and interesting dataset that falls within the scope of the journal and will be of interest to its readers.
We thank R. Fentimen for his positive assessment of our study and hope that we could sufficiently address the concerns raised in the specific comments below.

Specific comments
Comment #1: My main comment concerns the grouping of different Uvigerina species for stable isotope analyses. The authors mention the genus Uvigerina spp in the material and methods. It would be good to mention here the species considered in this grouping. How many species were considered in the grouping?
We combined *U. peregrina*, and *U. proboscidae*, as now also stated in Section 3.7.1: "For each sample 1–3 tests of *Uvigerina* spp. (*U. peregrina* and *U. proboscidea*)...".

Was one species more abundant? Is one species more abundant during specific intervals (e.g. within CWC bearing intervals)?
The dominant species is *U. peregrina* constituting roughly 75 % of all species of the genus *Uvigerina* in the samples (which rarely contained more than a total of 3 *Uvigerina* specimens). Monospecific selection of *Uvigerina peregrina* would have led to significantly more gaps in the stable isotope record. To obtain enough material we therefore mostly used 3 specimens of *Uvigerina,* when necessary pooling different species for one analysis. We didn't, however, denote the number of individual tests selected from each species per sample. Based on previous inspection of the samples, there is no notable turnover in the relative proportion of the respective species throughout the core, hence, we do not expect a bias in the $\delta^{13}C$ record due to shifts in the relative abundances of those species.

Indeed, it has been demonstrated that the response to trophic conditions is species-specific for the genus Uvigerina (see for example, Theodor et al., 2016 Marine Micropaleontology). Uvigerina mediterranea is for example better suited than U. peregrina to reconstruct trophic conditions, since it is more of an opportunistic species. Uvigerinids do not share the same ecological preference (see for example Fontanier et al., 2006), thus I am quite skeptical about this grouping. In my opinion, the grouping of Uvigerinids together weakens the use of stable isotope analyses performed on their tests, since it is not monospecific (as mentioned by the authors at Line 339).

We agree with the reviewer that single-species selection would be the preferred choice for the construction of any stable isotope record, however, we opted for obtaining a record as complete as possible which limited us to combining different species as well as different genera (*Uvigerina* and *Planulina*). As mentioned before, a more in-depth study of faunal turnovers in the benthic foraminiferal communities including stable carbon isotope data from different species with different ecological preferences might be a highly valuable follow-up project but is outside the scope of this study.

We would like to point out that when discussing bottom-water variability as a potential driver of CWC growth we focus on the interpretation of the signal of epibenthic *P. wuellerstorfi* (as stated in the original manuscript text), which provides a more robust insight into bottom-water variability than infaunal species like *Uvigerina*. The higher scatter evident in the *Uvigerina* spp. $\delta^{13}C$ data compared to the data obtained on *P. wuellerstorfi* is likely due to the influence of changes in the isotopic composition of pore-water DIC but might also derive from the pooling of different species. However, in the case of *U. peregrina* and *U. proboscidae* Rathburn et al. (1996) found an offset of only 0.1–0.2 ‰. This is much smaller than the 0.8–1.4‰ offset between *U. peregrina* and *U. mediterranea* published by Theodor et al. (2016), indicating that *U. peregrina* and *U. proboscidae* occupy a similar habitat. We nevertheless now state the caveats arising from pooling the different *Uvigerina* species in the manuscript (section 5.1.1):

"The resulting normalized data exhibits a considerable scatter in the *Uvigerina* spp. record due to the pooling of different species, and hence only allows for a discussion of major shifts in the isotopic composition. However, the $\delta^{13}C$ data of *Uvigerina* spp. and *P. wuellerstorfi* do not provide compelling evidence for distinctly depleted values during phases of CWC growth compared to CWC-barren intervals (Fig. 4). Although $\delta^{13}C_{Uvi}$ might be influenced by isotopic variations of dissolved inorganic carbon of pore-water (Zahn et al., 1986) and inter-species offsets (Rathburn et al. 1996; Theodor et al., 2016), we nevertheless consider it as appropriate for reconstructing major changes in the bottom-water signature."

Hence the conclusions of section 5.1.1 are not as solid as they could be if authors considered species alone. Although I understand that this approach was chosen as a second choise because of the lack of material, I suggest that the authors should address more and discuss this point more in detail in the material and methods section and in Section 5.1.1.

As suggested, we added further details on the selection of different *Uvigerina* species in the method section and provide a discussion about the caveats in Section 5.1.1 (see comments above).

I recommend plotting the _13C of individual Uvigerina species and then to compare this to the results of the grouping (all species combined). The scatter of the normalized data may possibly be due to the effect of the grouping. This can be easily verified by isolating different Uvigerina species and adding an extra colour code to Fig. 4A. As such, the results presented by the authors would be clearer.

Unfortunately, we did not denote which species we selected for each analysis; in some samples we also had to lump different species of *Uvigerina* into one sample to accumulate enough material. We agree with the reviewer that the grouping might be at least partly responsible for the relatively large scatter of the normalized $\delta^{13}C$ data of *Uvigerina* spp.; a respective remark has been added to the discussion in Section 5.1.1 (see above).

As stated above, we nevertheless consider our results obtained from the $\delta^{13}C$ analyses to serve its purpose (i.e., tracing bottom-water variability), as we are discussing only major fluctuations in the $\delta^{13}C$ signal (not the scatter) and primarily rely on the results of single-species epibenthic *P. wuellerstorfi,* which is naturally a better tracer of bottom-water variability than any endobenthic species.

Comment #2: Although the interpretations and conclusions are in my opinion sound, the association of coral proliferation with HS 4 does not seem as clear as for HS 1 and 6. There is an offset between the Ti/Ca and

speleotherm records presented in Figure 5 with the coral proliferation phase. Is this due to an age model uncertainty? I think this offset should be discussed a bit more in detail.
We argue that the temporal offsets of CWC proliferation phases *vs*. monsoonal indicators (i.e. the Ti/Ca record and travertine/speleothem growth phases) during HS 2-5 is largely due to age model uncertainties, as the age model of the marine Ti/Ca record is based on AMS 14C dating and benthic isotope stratigraphy, introducing an error of ~2 kyrs for this interval (Campos et al., 2019). It has also to be considered that HS 1 and 6 go along with humid phases that are longer and more pronounced than HS 2-5. Hence, the expected CWC response to the increased run-off should be less pronounced during HS 2-5.

We added these aspects to the discussion of the presumed monsoonal forcing of the CWC signal in Section 5.2: "…The most distinct CWC proliferation phases in fact took place during phases of anomalously strong monsoonal precipitation during the pronounced Heinrich Stadials (HS) 1 and 6 as well as (within age model uncertainties) also during the shorter and less severe humid phases corresponding to HS 2–5 (Fig. 5F, G)."

Comment #3: It would be appreciated if the authors took the discussion one step further by comparing the environmental forcing observed in the study area to other CWC settings, e.g. along the East Atlantic margin or in the Mediterranean. This could be done in the last section of the discussion. For example, Wienberg et al. (2010) suggested that aeolian dust had a local fertilization effect on coral growth in the Gulf of Cadiz, whilst Fentimen et al. (2020) propose that fluvial input triggered coral proliferation during Greenland Interstadial 1 in the Western Mediterranean (Melilla Mound Province). Authors should also consider the work of Mienis et al. in the Western Atlantic.
We value the suggestion to broaden the discussion and now include the reference to other studies that also propose links between terrestrial input and CWC proliferation. These studies include the suggested papers by Wienberg et al. (2010) and Fentimen et al. (2020; Frontiers in Marine Science). We also reference Hanz et al. (2019) who inferred that terrestrial dissolved nutrients aided CWC growth off Angola. We added a respective statement at the end of the first paragraph of Section 5.2: "The here proposed link between Monsoonal activity and CWC growth is in line with studies from the western Mediterranean Sea (Fentimen et al., 2020), the Gulf of Cadiz (Wienberg et al., 2010) and the tropical eastern Atlantic off Angola (Hanz et al., 2019) which inferred that terrestrial input via dust or fluvial run-off ultimately fueled thriving CWC colonies." The mentioned publications of Mienis et al. only referred rather indirectly to terrigenous sediment input as a driver of CWC proliferation, thus we omitted reference to these publications in this context.

As such, the conclusions of the authors fit in with other previous observations and add new evidence. This is something that I believe should be better highlighted and deserves to be developed. The last statement of the conclusion that "This study (. . .) points at a hitherto unrecognized intimate coupling between continental hydroclimate and ecological changes in the deep ocean" is in this sense too bold and should be tempered. Indeed, previous studies already suggest this.
As suggested we toned down the respective sentence to "This study thus presents a prime example of the intimate coupling between continental hydroclimate and ecological changes in the deep ocean." In the same sense we modified the last sentence in the abstract to "Our study thus emphasizes the impact of continental climate variability on a highly vulnerable deep-marine ecosystem".

Also the link between coral growth and monsoonal forcing is only written and stated clearly in the title. No mention of the term "monsoonal forcing" is done in the discussion and conclusion. I think that if the title uses this term, it should also clearly be stated and discussed in the discussion (noticeably in section 5.2).
We now state more explicitly the connection of monsoonal forcing on CWC growth in the discussion (see also response to comment #2) and in the Conclusions ("We find that intervals of high CWC abundance are primarily related to … enhanced monsoonal precipitation in eastern Brazil."). In the abstract we now phrase: "Our results indicate a multi-factorial control on CWC growth and mound formation at Bowie Mound during the past ~160 kyrs, which reveals distinct formation pulses during glacial high northern latitude cold events (Heinrich Stadials, HS) largely associated with anomalously strong monsoonal rainfall over the continent."

Technical corrections Title: "cold-water coral", missing "-"
Corrected.

Line 25: "located at" and not "located in"

Corrected.

Line 42: “constrained” and not “constraint”
Corrected.

Lines 48 to 52: These two sentences need to be rephrased; I cannot get the meaning of the sentences as they are. Especially in the second sentence, the verb is missing (“Changes the species (. . .)”).
We thank the reviewer for pointing at this typographic mishap. These two sentences now read “The most common framework-forming CWC comprise of *Lophelia pertusa* (recently assigned to the genus *Desmophyllum* by Addamo et al., 2016), *Macropora oculata*, *Solenosmilia variabilis*, *Bathelia candida*, and *Enallopsammia profunda* (e.g., Mangini et al., 2010; Frank et al., 2011; Muñoz et al., 2012; Hebbeln et al., 2014; Raddatz et al., 2020).”

Line 53: Explain the abbreviations POC and DOC the first time you introduce them, some readers may not be acquainted with these.
Done.

Line 55: This sentence needs to be reworked, it is not understandable as it is: “Note, however, that similar studies in the feeding in the properties (. . .)”. Do the authors mean feeding properties / feeding behaviour?
This sentence and the following now reads “However, we note that similar studies on the feeding preferences of *S. variabilis*, the dominant framework-building CWC at the herein investigated Bowie Mound (Raddatz et al. 2020) are still missing. Additionally, changes in the properties and spatial configuration of ambient intermediate- or deep-water masses may also strongly impact CWC through changes in the dissolved oxygen concentration and the seawater parameters pH, alkalinity and carbonate-ion concentration.”

Line 58: In the sentence: “All affect the capacity (. . .)” I would suggest repeating the word parameters or variables, i.e. “All these parameters (or environmental variables) affect the capacity (. . .)”.
The sentence has been revised to “All these parameters affect…”.

Line 61: check the grammar: “to play a role in” not “to play a role for”
Corrected.

Lines 62 to 64: The end of this sentence is not clear, consider reworking it. For example: “(. . .) importance of surface productivity in providing food to the deep ocean”.
We rephrased the sentence according to the suggestion of the reviewer.

Line 70: I would suggest not to start the sentence with an abbreviation (Here CWC).
We changed the start of the sentence to “The presence of CWC-bearing mounds…”.

Line 72: “Adapted” and not “adopted”
Corrected.

Line 82: rephrase the sentence: “demonstrates for the first time” instead of “for the first time demonstrates”.
C4
Corrected.

Lines 81 to 83: The combined use in this sentence of “for the first time” and “a so far underestimated” is possibly a bit redundant. I would recommend less emphasizing in this sentence. There is no need to say it is “so far underestimated” if it is the first time it has been observed.
We deleted “for the first time” to avoid redundancy.

Figure 1: Numbers on the hydrographic section (top left) are barely readable. I would suggest increasing the size of these.
Done.

Line 133: Spelling: “half” not “halve”
Corrected.

Line 137: Correct the beginning of the sentence: “Core M125-34-2” instead of “The core (. . .)”
Corrected.

Line 145: Correct the beginning of the sentence: “To constrain” instead of “for constraining”
Corrected.

Line 146: Correct the English: “was sampled at (or sampled every 10 cm)”, instead of “was sampled in”
Corrected.

Line 168: “Half” instead of “halve”
Corrected.

Line 181: “at Heidelberg University” instead of “at the Heidelberg University”, or rephrase: “at the Department of Geosciences, Heidelberg University”.
Corrected.

Line 184: “were analysed with the Diffract Suite (. . .)” instead of “was analysed with Diffract Suite (. . .)”
Corrected.

Line 185: Avoid using the passive form to often when possible. For example here, rather write: “The Rietveld refinement program DIFFRAC.TOPAS (Bruker Software) was used to perform quantitative phase analysis”.
Corrected as suggested.

Line 195: “Weighed” instead of “weighted”. The verb is “to weigh” (thus weighed in the past tense), the noun is “weight”.
Corrected.

Line 195: I would suggest rather writing “filled to the top” instead of “filled until capacity”.
Corrected.

Line 198: correct: “(. . .) and put into an ultrasonic bath”, instead of “(. . .), put into an (. . .)”
Corrected.

Lines 204 and 205: Is there a mistake here: “The high number of replicates resulted from”. Do you mean: “resulted in” ?
We changed the sentence into “The relatively large inter-sample variability that is likely caused by…”.

Line 257 and 258: No capital letter given to “core” (write “core”)
Corrected.

Figure 3: The symbol (white diamond) of Uvigerina spp. appears to be missing on the figure.
We added the diamond (symbol for *P. wuellerstorfi*) to the legend.

Line 369: correct to “seemed to have”
Corrected.

Line 382 to 384: Check the sentence for grammar: “increasing” instead of “increase”, “suggests” instead of “suggest”.
We did not apply these suggested changes, as “increasing” does not fit into the sentence’s structure and “data”, the reference of “suggest” is in plural.

Line 483: The sentence needs to be rephrased, it reads: “Due to their baffling capacity, the additional sedimentary input would have aided mound formation”. I would recommend rather writing: “Due to the baffling capacity of CWCs, the (. . .)”. As it is, the sentence suggests that the mound baffles sediment, whilst it is the corals not the mound in itself.

We thank the reviewer for pointing out this ambiguity. We rephrased the sentence as suggested.

Response to Referee 2

First we would like to acknowledge Reviewer 2 for his/her constructive evaluation of our manuscript. Below we provide a point-to-point response (in black) to the original comments (in blue).

The manuscript submitted here investigates the impact of monsoonal variability on CWC growth in last 160 Kyrs. While the authors present a manuscript with compelling arguments; that is likely to be of interest to readers of Biogeosciences, I have a few of concerns that should be addressed before publication.

1. Authors try to show how the monsoon impacted CWC growth without providing any direct correlation between the two, which is a simple statistical analysis to do.

We thank Reviewer 2 for the suggestion of performing a statistical test to validate the proposed monsoonal impact on the CWC growth. For this purpose we computed the linear correlation between CWC occurrences (as shown in Figure 5H) and the Ti/Ca ratio of Core M125-95-3 using the Monte-Carlo-based SurrogateCor function implemented in the “astrochron” package in R (Meyers, 2014), which has been specifically designed for correlation of time series with a different temporal resolution. The resultant correlation coefficient r = 0.56 (p=0.01) corroborates a significant correlation even considering potential mismatches due to age model uncertainties and non-linear proxy behavior. We include these new statistical results in the caption of Fig. 5: “Note the good match between CWC occurrences and enhanced monsoonal activity on the continent (correlation between Ti/Ca and CWC frequency: r = 0.56, p = 0.02; computed using the SurrogateCor function of the R-package “astrochron”; Meyers, 2014)”.

Notably, these results also support the already stated results of a discriminant analysis which showed that proxies reflecting terrigenous run-off (C_{org}/N_{total}) and weathering (albite/kaolinite) are good predictors for CWC occurrences (cf. end of Section 5.1.3 “Influence of the continental hydrological cycle”).

2. The discussion section needs to be streamlined towards the main objective of the manuscript, which now rather seems to be a collection of different points without the central theme. It’s difficult for a reader to go through the whole discussion and find exactly where the authors prove their central claim. While discussing many proxies is necessary for a paper like this, it’s also important to stress how these proxies help to prove your central claim, which is something lacking in the manuscript.

We recognize the concern by Reviewer 2 (partly also raised by Reviewer 1), and put more emphasis on the main message of the paper, i.e. the direct link between continental hydroclimate and CWC growth at the continental slope. We now stress this link right at the onset of Section 5 “Results and Discussion”: “…We argue that the most dominant environmental factor for triggering CWC growth was elevated river run-off during periods of strong monsoonal rainfall in the coastal hinterland, which provided nutrients and organic matter that enhanced the food supply of CWC colonies.” We further emphasize the role of monsoonal rainfall as a decisive factor for CWC growth as also requested by Reviewer 1 (this affects Abstract, Section 5.2, and Conclusions).

3. While the growth of CWC during HS events is very evident visually, why the CWC growth was not observed during MIS3 and MIS4 is still not clearly explained. While TOC is the only proxy that was different during these stages but high TOC didn’t promote CWC growth at 20-40m [REMARK: this likely refers to 20-40 cm] depth. So it seems that TOC is not a singular factor affecting CWC growth. While authors have explained water currents and terrigenous input as some other proxies to impact CWC growth, they seem to be fluctuating a lot in all the MIS stages and hence fail to shed any light on what stopped CWC from growing during MIS3 and MIS4.

The Reviewer refers here to the CWC barren interval between 20–40 cm core depth. We note that this interval is characterized by intermediate TOC contents that are not as high as during the main CWC growth phases between 70-180 cm and below 530 c (Fig. 6A). As already stated in the original text (see section 5.1.2: “However, as suggested in the previous section, there are multiple factors necessary for stimulating coral growth at Bowie Mound”), we assume a multi-factorial control of CWC proliferation phases. Organic matter supply likely played a major role but other factors such as hydrodynamic conditions might have interfered as well.

In this line the absence of CWC during large portions of MIS 4 could be well explained by the generally low TOC contents that point to the lack of organic matter supply inhibiting CWC growth. We now state this connection explicitly in Section 5.1.2: “…while the long CWC-barren interval between 200–460 cm is characterized by relatively low TOC contents…”. According to the stratigraphic assignment this specific

interval encompasses early MIS 4, not MIS 3; to make this distinction clearer we modified the age assignments in Figures 4 and 6 and modified the respective paragraph in Section 4:
"The section between E_{II} and E_{III} on the other hand has relatively uniform $\delta^{18}O$ values around 4.3 ‰ ($\delta^{18}O_{Uvi}$) and 3.4 ‰ ($\delta^{18}O_{Plan}$), respectively, which matches M125-50-3 $\delta^{18}O_{Uvi}$ values during MIS 4 to 2. A Th/U date at the top of this section at 117 cm reveals an age of 34 ka, while CWC ages from slightly deeper in the core (between 131-190 cm) fall within the range of 60–63 ka (MIS 4). As $\delta^{18}O_{Uvi}$ values between E_{II} and E_{III} are less depleted than MIS 5 samples of reference site M125-50-3, we infer that those sediments were most likely deposited during MIS 4 and did not reach into MIS 5. Hence, it hence appears that deposits of MIS 2 and large parts of MIS 3 are not present in core M125-34-2, either due to non-deposition or subsequent erosion (note the prominent erosive surface E_{II}). This age assignment would also imply that the extended CWC-free portion from 200 to 465 cm was deposited within a short period of approximately 8 kyr during MIS 4 (62.2 ka as the oldest Th/U dates and ~70 ka as the MIS 4/5 boundary)."

4. The figures captions throughout the manuscript describe what is shown in the figure, but don't provide the reader with any additional information such as calling attention to the significant result. The message shown by the figure is left entirely up to the reader to decipher.
We are aware that the figures and the associated discussion of the factors influencing CWC growth phases are quite complex. We therefore acknowledge the suggestion by Reviewer 2 to provide more information on the interpretation of a Figure's content in the respective caption. We hence added the following sentences to the captions:
Fig. 4: "Phases of CWC proliferation appear to require background state of high hydrodynamics conditions (elevated ln(Zr/Al) and $\overline{SS}$) but do not show an influence of deep-water mass variability (□^{13}C).."
Fig. 5: "Note the good match between CWC occurrences and enhanced monsoonal activity on the continent (correlation between ln(Ti/Ca) and CWC frequency: $r = 0.56$, $p = 0.02$; computed using the SurrogateCor function of the R-package "astrochron"; Meyers, 2014)."
Fig. 6: "Note that high CWC abundances fall into intervals of high TOC and increased weathering due to an intensified continental hydrological cycle."

Moreover, in some figures authors have added depth and in some age. It would be best if authors add age and depth in all the figures.
We would like to note that we already provide depth and age scales on Figures, when appropriate (Figs. 3, 4, 6). For Figure 5 we followed the reviewer's suggestion and added the depths intervals denoting the phases of CWC proliferation at Bowie Mound on top of the figure; a respective comment has been added to the caption ("Red bars indicate periods of enhanced CWC growth at Bowie Mound, with the respective depths in Core M125-34-2 annotated").

5. Line 48: "The most common framework-forming CWC comprise. "This sentence doesn't make sense. It is either incomplete or needs to be restructured.
This sentence has been rephrased (see also reply to respective comment by Reviewer 1).

6. The next sentence in line 49 "Changes the species. . .." Is also incomplete and hence doesn't provide context.
This sentence has been rephrased (see also reply to respective comment by Reviewer 1).

7. Line 55: "in" repeated "similar studies in the feeding in the properties. . ."
We rephrased the sentence to "… similar studies on the feeding preferences of *S. variabilis*, the dominant framework-building CWC discussed in this study, are still pending".

8. Line 72: It should be "adapted" instead of "adopted".
Corrected.

9. Line 77 -79: "This setting allows us. . ... growth at Bowie mound". It is a repetition of what has been already said in previous sentences.
This sentence has been removed (see also reply to respective comment by Reviewer 1).

10. Line 369: “AAIW seemed to had an insignificant” It should be “to have had” or “AAIW had” depending on what authors want to say exactly.
Corrected to “seemed to have”.

11. Line 384: “does not necessarily led to”. It should be “lead”
Corrected.

Monsoonal forcing ~~controlled~~ of cold-~~–~~water coral growth off south-eastern Brazil during the past 160 kyrs

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Abstract. Cold-water corals (CWC) constitute important deep-water ecosystems that are ~~increasingly~~ under increasing environmental pressure due to ocean acidification and global warming. The sensitivity of these deep-water ecosystems to environmental change is demonstrated by abundant paleo-records drilled through CWC mounds that reveal ~~a~~ characteristic alterations between rapid formation and dormant or erosive phases. Previous studies have identified several central parameters for driving or inhibiting CWC growth ~~parameters~~ such as food supply, oxygenation, and the carbon saturation state of bottom water ~~as central for driving or inhibiting CWC growth~~, yet there ~~is~~ are still ~~a~~ large uncertainties~~y~~ about the relative importance of the different environmental parameters. To advance this debate we have performed a multi-proxy study on a sediment core retrieved from the 25 m high Bowie Mound, located at 866 m water depth on the continental slope off south-eastern Brazil, a structure built up mainly by the CWC *Solenosmilia variabilis.* Our results indicate a multi-factorial control on CWC growth ~~and mound formation~~ at Bowie Mound during the past ~160 kyrs, which reveals distinct formation pulses during northern high latitude glacial ~~high northern latitude~~ cold events (Heinrich Stadials, HS) largely associated with anomalously strong monsoonal rainfall ~~continental wet periods~~ over the continent. The ensuing enhanced run-off elevated the terrigenous nutrient and organic matter supply to the continental margin, and ~~might~~ likely have boosted marine productivity. The dispersal of food particles towards the CWC colonies during HS was facilitated by the highly dynamic hydraulic conditions along the continental slope that prevailed throughout glacial periods. These conditions caused the emplacement of a pronounced nepheloid layer above Bowie Mound thereby aiding the concentration and along-slope dispersal of organic matter. Our study thus ~~demonstrates a yet unrecognized~~emphasizes the impact of continental climate variability on a highly vulnerable deep-marine ecosystem.

1 Introduction

Cold-water corals (CWC) are hotspots of biodiversity in the deep-sea (Roberts and Cairns, 2014), important constituents of the deep water carbon cycle (Lindberg and Mienert, 2005; Titschack et al., 2009; White et al., 2012; Cathalot et al., 2015; Titschack et al., 2015, 2016), and potent bio-engineers due to their sediment baffling capacity that allows for enormous sediment accumulation rates of up to 1500 cm/kyr during maximum CWC mound formation phases (Titschack et al., 2015; Wienberg and Titschack, 2017, Wienberg et al., 2018). Yet the ~~fate~~ impact of global climate change on CWC reefs and the associated ecosystems under ~~global climate change~~ is poorly constrained, because the factors driving or inhibiting their ~~formation~~ occurrence ~~as well as~~and the potential thresholds in their resilience to environmental change are still under debate (Hebbeln et al., 2019; Raddatz and Rüggeberg, 2019). Geological records reveal that coral mounds typically exhibit distinct phases of formation, often intercalated by intermitte~~nt~~d periods of non-deposition and/or potentially erosion, ~~pointing at~~indicating a high sensitivity of CWCs to changing boundary conditions (e.g., Rüggeberg et al., 2005; Kano et al., 2007; Frank et al., 2011; Raddatz et al., 2014, 2016; Wienberg and Titschack, 2017; Wienberg et al., 2018).

The most common framework-forming CWC comprise of ~~preferences of *S. variabilis*, the dominant framework-building CWC discussed in this study, are still pending. Changes the species~~ *Lophelia pertusa* (recently assigned to the genus *Desmophyllum* by Addamo et ~~l~~al., 2016), *Macropora oculata*, *Solenosmilia variabilis*, *Bathelia candida*, and *Enallopsammia profunda* (e.g., Mangini et al., 2010; Frank et al., 2011; Muñoz et al., 2012; Hebbeln et al., 2014; Raddatz et al., 2020). Field and laboratory studies of *L. pertusa*, the most intensively investigated species, suggest that scleractinian CWC are non-specialists regarding food sources, which ~~may~~ range from particulate to dissolved organic carbon (~~-~~POC and~~to~~ DOC, respectively) (Kiriakoulakis et al., 2005; Duineveld et al., 2007; Gori et al., 2014; van Oevelen et al., 2016), algae, bacteria, and zooplankton (Gori et al., 2014; Mueller et al., 2014~~; Wienberg and Titschack, 2017~~). However, we note that similar studies on the feeding preferences of *S. variabilis*, the dominant framework-building CWC at the herein investigated Bowie Mound (Raddatz et al. 2020) are still missing. Additionally, changes in the properties and spatial configuration of ambient intermediate- or deep-water masses may also strongly impact CWC through changes in the dissolved oxygen concentration and the seawater parameters pH, alkalinity and carbonate-ion concentration. ~~Note, however, that similar studies in the feeding in the properties and spatial configuration of ambient intermediate- or deep water masses might have a strong impact on CWC as they alter the dissolved oxygen concentration and also the seawater parameters pH, alkalinity and carbonate-ion concentration.~~ All these parameters affect the capacity of CWC to build their aragonitic framework (e.g., Form and Riebesell, 2012; Maier et al., 2012; Lunden et al., 2014; Hennige et al., 2015; Büscher et al., 2017; Auscavitch et al. 2020). Spatial fluctuations of intermediate- to deep-water masses further influence the depth and strength of pycnoclines, which are thought to play an important role ~~for~~ in the concentration and dispersal of nutrients and food utilized by CWC (Frederiksen et al., 1992; Duineveld et al., 2007; Mienis et al., 2007; Rüggeberg et al., 2016). Aside ~~of~~ from processes directly affecting the water-mass properties bathing CWC, several studies also point ~~at~~ to the importance of sea surface productivity in providing food to the deep ocean ~~importance of surface productivity in providing food that is transported to the deep ocean~~ (Davies et al., 2009; Soetaert et al., 2016). However, despite the proximity of CWC mounds situated on the continental slope to adjacent continents, the role of terrestrial nutrient and POC input is still a matter of debate (Wienberg et al., 2010; Hanz et al., 2019; Fentimen et al., 2020).~~The role of adjacent continents via~~

~~the input of terrestrial nutrients and POC is still a matter of debate considering the proximity of CWC situated on the continental slope to land.~~

To systematically test the relative importance of the diverse factors potentially influencing CWC growth and mound formation, we investigated the response of CWC at Bowie Mound, a coral-bearing mound in the Campos Basin on the continental slope offshore south-eastern ~~SE~~ Brazil (Bahr et al., 2016; Raddatz et al., 2020) to changes in paleoenvironmental conditions. The presence of CWC-bearing mounds off Brazil ~~were~~ was first reported by Viana et al. (1998) and Sumida et al. (2004) along the continental slope at intermediate water depths between 500 to 1000 m, bathed by ~~within the~~ Antarctic Intermediate Water (AAIW). At Bowie Mound, the dominating species is *S. variabilis*, which is ~~adopted~~ adapted to colder (as low as 3-4°C; Fallon et al., 2014; Flögel et al., 2014; Gammon et al., 2018) and less aragonite saturated waters than ~~mounds formed by~~ *L. pertusa* (Thresher et al., 2011; Flögel et al., 2014; Bostock et al., 2015; Gammon et al., 2018).

The selected location at Bowie Mound is ideally suited to ~~test~~ assess~~for~~ a variety of external factors ~~potentially~~ capable of driving CWC growth dynamics as it is situated at the interface of distinctly different water masses (cf. Section 2) and is strongly influenced by terrigenous input from land and the broad shelf off Cabo Frio, which experiences ~~with~~ intense seasonal upwelling. This setting allows us to test the relative importance of different factors that are potentially crucial for the CWC growth at Bowie Mound, in particular (i) intermediate water-mass variability ~~and~~ via its impact on nutrient (e.g., Fe, P, N) concentration, food availability, and local hydrodynamics ~~as well as~~and (ii) variations in nutrient~~s~~ -and organic matter fluxes derived from upwelling and terrestrial input in the context of global climatic changes. Our unique set of multi-proxy data combined with Th/U-dated CWC demonstrates ~~for the first time demonstrates~~ that an invigorated continental hydroclimate played a ~~so~~ thus far underestimated role in triggering CWC growth at the south-eastern ~~SE~~ Brazilian margin – a scenario that is likely affecting CWC-mounds worldwide.

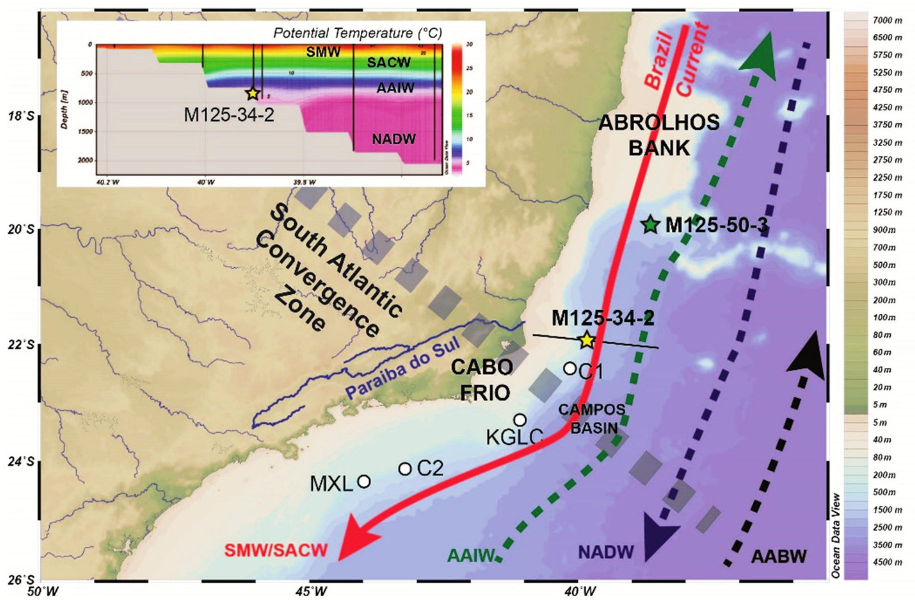
2 Hydrological, climatological and geological setting

The (sub)surface circulation in the western Tropical South Atlantic at the Campos Basin off southeast Brazil is dominated by the southward flowing, warm Brazil Current (BC; Fig. 1). The BC forms the western portion of the anticyclonic subtropical gyre (Stramma and England, 1999), which is characterized by high evaporation rates that ~~lead to the formation of~~ produced the Salinity Maximum Water (SMW, 24ºC, $\sigma_\theta \sim 25.2$) ~~occupying~~ in the upper 200 m of the water column. The interaction of the BC with the coastal hydrographic system promotes subsurface upwelling of South Atlantic Central Water (SACW) on the shelf edge and on the shelf (Roughan and Middleton, 2002; Aguiar et al., 2014). Upwelling is particularly strong during austral spring and summer when northeasterly winds generating upward Ekman pumping on the mid shelf (Castelao and Barth, 2006; Castelao, 2012), which fuels productivity due to the subsurface encroachment of nutrient-rich SACW. ~~Below the SMW, the~~The SACW is found from below the SMW up to ~~until~~ 500 m water depth and is~~,~~ characterized by decreasing temperatures and salinities (20ºC, 36.0 psu to 5ºC, 34.3 psu; Fig. 1) (Raddatz et al., 2020) owing to its formation in the southwest Atlantic and the South Indian Ocean (Sverdrup et al., 1942; Stramma and England, 1999). The ~~The SACW is underlain by the Antarctic Intermediate Water (~~AAIW (~~;~~ ~34.3 PSU, ~4°C; Fig. 1) lies below the SACT and above ~~(Fig. 1).~~ North Atlantic Deep Water (NADW) which is present~~is found~~ below 1100 m water depth and has~~with~~ higher oxygen concentrations and salinities compared to AAIW (Mémery et al., 2000). Below ~2500 m the Antarctic Bottom Water (AABW) constitutes the deepest and most dense water mass in this region (Stramma and England, 1999)~~ in this region~~.

The interaction between the north- or southward-directed flow of the different water masses with the morphology of the slope at Campos Basin ~~causes the formation of~~froms strong geostrophic currents (Viana and Faugères, 1998; Viana et al., 1998; Viana, 2001). These currents are responsible for enhanced sediment focusing leading to the formation of drift bodies, while internal waves at the boundary between different water masses create wide-spread erosional surfaces (Viana et al., 1998, 2001).

Bowie Mound itself has a total elevation of 25 m and is situated~~ s~~ within a field of mound-like structures, which are ~~at~~ presently barren of living framework-forming CWC ~~colonies~~ (Bahr et al., 2016). Located ~~With~~ at~~a water depth of~~ 866 m water depth, it lies within the core of the AAIW. Hence, it can be expected that changes in the nutrient and organic matter inventory of the AAIW (Poggemann et al., 2017) and/or displacement of the intermediate water mass may have had a direct impact on the hydrodynamic conditions at Bowie Mound.

The Campos Basin receives freshwater and sediment input primarily from the Paraíba do Sul River, which delivers between 180 to 4400 $m^3 s^{-1}$ water (Carvalho et al., 2002) and 30 t yr^{-1} of sediment ~~load~~ (Jennerjahn et al., 2010) to the study area. Most precipitation in the hinterland of the Paraíba do Sul River occurs during austral summer, when strong atmospheric convection forms the South Atlantic Convergence Zone, an elongated band of heavy precipitation that reaches from central Amazonia into the tropical South Atlantic (Carvalho et al., 2004; Marengo et al., 2012) (Fig. 1).



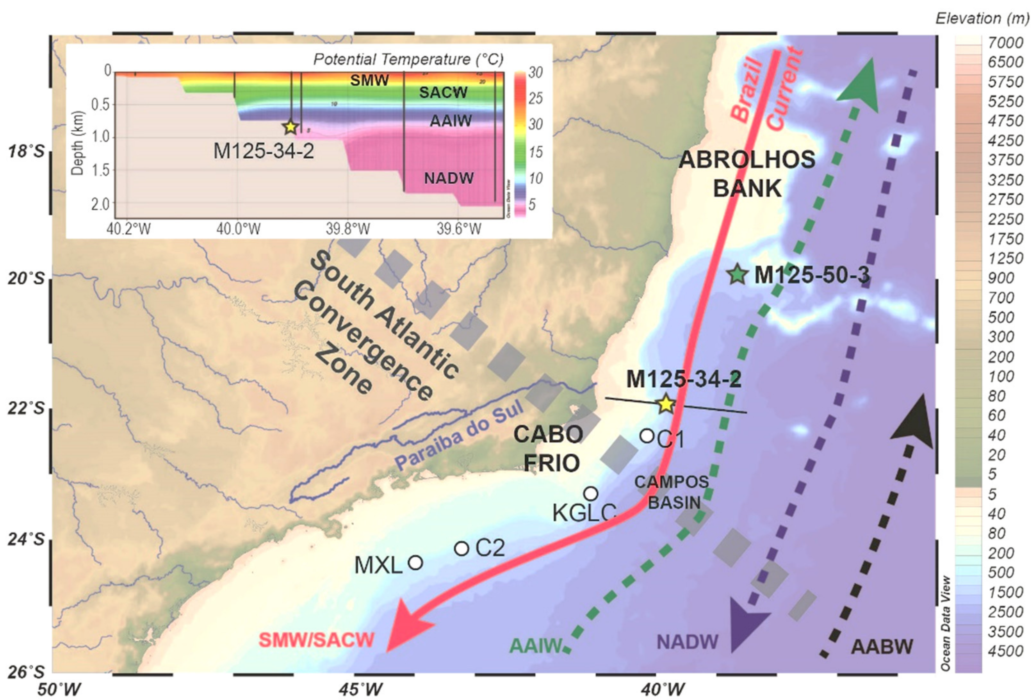


Fig. 1 Location of core M125-34-2 (yellow star) on Bowie Mound, reference core M125-50-3 (green star) and other CWC records published in Mangini et al. (2010) and Ruckelshausen (2013) (white dots). Major surface (red line), intermediate (green) and deep-water circulation features (blue) and water masses are indicated as well as the approximate location of the South Atlantic Convergence Zone (stippled line) as the main atmospheric feature. Inset shows a hydrographic section crossing the location of Bowie Mound core M125-34-2 with potential temperatures as measured via CTD (black lines) during R/V METEOR Expedition M125 (Bahr et al., 2016; Raddatz et al., 2020); the location of the hydrographic section is indicated by a black line in the map. Figure modified after Raddatz et al. (2020). AABW – Antarctic Bottom Water, AAIW – Antarctic Intermediate Water, NADW – North Atlantic Deep Water, SACW – South Atlantic Central Water, SMW – Salinity Maximum Water.

3 Material and Methods

3.1 Material

Gravity core M125-34-2 was retrieved during R/V METEOR cruise M125 from the top of the 25 m high Bowie Mound in 866 m water depth at 21°56.957'S and 39°53.117'W (exact positioning was secured by the Ultra-Short-Baseline system POSIDONIA; Fig. 1;~~,~~ Bahr et al., ~~2017~~2016). The core was cut into 1 m segments onboard and stored unopened at -20°C. After CT-scanning, the core was opened in the frozen state (for details on the CT-scanning cf. Skornitzke et al., 2019; Raddatz et al., 2020). Discrete samples for X-ray d~~D~~iffractometry (XRD), grain-size analyses, C and N content, and stable carbon and oxygen isotope analyses of foraminifera and organic matter were taken from the sediment matrix avoiding the sampling of coral fragments. X-ray ~~F~~fluorescence (XRF) scanning was performed on the archive halves~~ve~~, while avoiding coral segments when defining the sampling path of the detector.

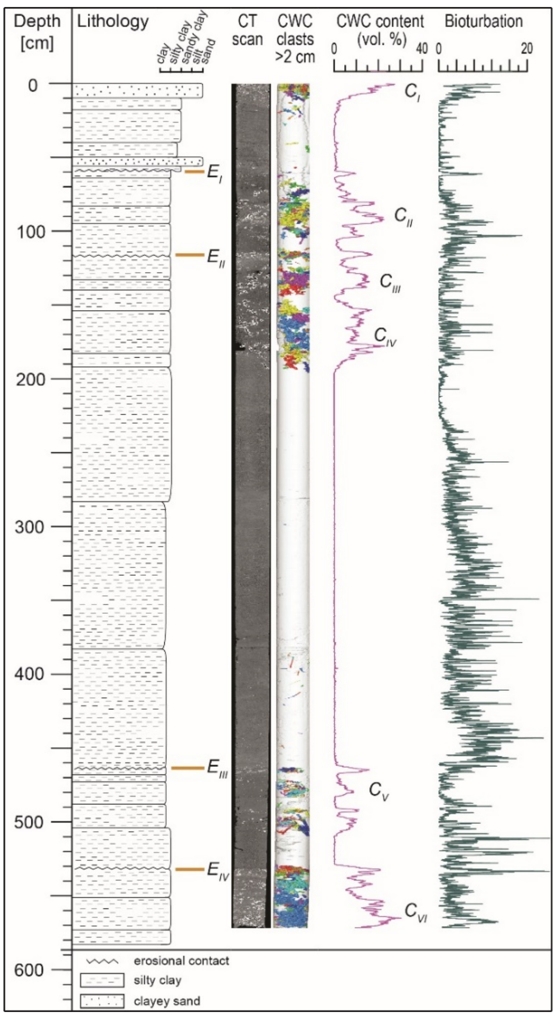


Fig. 2. Lithological log of Core M125-34-2 (21°56.957'S, 39°53.117'W, 866 m water depth) including CT-scanning image and CWC clasts >2 cm, CWC content and bioturbation index. Erosional surfaces E_I–E_{IV} are indicated as well as CWC-bearing intervals C_I–C_{VI} after Raddatz et al. (2020).

~~The C~~Core M125-34-2 (Fig. 2) consists of moderately to strongly bioturbated olive grey to dark grey, silty clayey sand with ~~an~~ alternating~~ of~~ coral-bearing and coral-free zones (Raddatz et al., 2020). The sediments are rich in micro- and macrofossils including pteropods, bivalves as well as benthic and planktonic foraminifers. Six intervals (C_I–C_{VI}) ~~with~~ of particularly high coral contents of up to 31 vol.% were identified within the core ~~located between~~at 0–13 cm, 80–

105 cm, 131.5–138 cm, 157–190 cm, 479.5–480.5 cm, and 549.5–568 cm (Fig. 2; Raddatz et al., 2020)~~ (Fig. 2)~~. Coral-bearing intervals are characterized by the presence of *S. variabilis* and to a minor degree *M. oculata* as the major macrofossils (clast length >2 cm). Visual inspection and CT imaging (Appendix Figures A-F) reveal four prominent erosive surfaces (E_I–E_{IV}) with abundant coral fragments and shell debris at 58 cm, 117 cm, 465 cm, and 532 cm (Fig. 2).

~~For~~ To constrain~~ing~~ the chronostratigraphy of core M125-34-2 and to assess the intermediate-water variability, adjacent core M125-50-3 (19°56.957'S; 38°35.979'W; 904 m water depth; Fig. 1) was sampled ~~in~~ at 10 cm intervals for $\delta^{18}O$ analyses. Core M125-50-3 is barren of CWC and consists of bioturbated, greenish-grey hemipelagic mud with darker and lighter intervals. Two sandy, foraminifera-rich layers at 1226 and 1230 cm might point ~~at~~ to periods of condensed sedimentation, otherwise no unconformities or erosive surfaces could be identified.

3.2 Quantitative ~~interpretation~~ analysis of CT-scanning data

Prior to opening, the sediment core sections were scanned with a SOMATOM Definition Flash computer tomograph at the Clinic of Diagnostic and Interventional Radiology (DIR) of Heidelberg University Hospital, Heidelberg, Germany, with 140 kVp tube potential and 570 mAs tube current – time product with a pitch of 0.4 (for details see Skornitzke et al., 2019). The raw data with a resolution of 0.5 mm in z-orientation and 0.3 mm in xy-orientation was reconstructed iteratively (ADMIRE, Siemens Healthineers) using a sharp kernel (I70 h level 3) to an isotropic voxel size of 0.35 mm. Further data processing was carried out with the ZIB edition of the Amira software (Stalling et al. 2005; http://amira.zib.de). Within Amira, the core sections were virtually reunited and the core liner and marginal coring artefacts were removed (~2 mm of the core rim). Furthermore, coral clasts were segmented and separated with the ContourTreeSegmentation module (threshold: 1400; persistence value: 1150) and~~,~~ quantified. M~~ and m~~acrofossils >2 cm were visualized as surfaces in 3D following the methodology of Titschack et al. (2015). As an index for bioturbation, we determined the standard deviation of the matrix sediment X-Ray attenuation within each XY-oriented CT slice. The matrix sediment was segmented by selecting the data volume surrounding the corals, removing areas with values <500 HU (considered to represent air and water) and reducing the remaining segmented volume by three voxels to avoid marginal artefacts in the X~~x~~-R~~r~~ay attenuation caused for example by the resolution depending averaging effect.

3.3 X-Ray fluorescence (XRF) scanning

XRF core scanning was performed on the archive hal~~ves~~ve of the split ~~split~~ core. All segments of core M125-34-2 were scanned at ~~the~~ Heidelberg University, using an Avaatech ~~4th generation~~(GEN4) XRF Core Scanner. XRF core scanner data were collected every 1.0 cm down-core with a 1.2 cm cross-core slit size. The split core surface was cleaned and covered with a 4 ~~micron~~ µm thin SPEXCerti Prep Ultralene1 foil to avoid contamination of the XRF measurement unit. Core intervals with very abundant corals ~~had to~~were ~~be~~ skipped to avoid damage of~~ing~~ the foil covering the detector through sharp and rigid edges of coral fragments. Data was~~er e~~ collected in two separate runs using generator settings of 10 and 30 kV and currents of 0.2 and 1.0 mA, respectively. Sampling time was set to 20 seconds per measurement. To counteract artifacts derived from variations in sediment porosity, water content and surface roughness, element counts were normalized by dividing the value of the component (C) by the sum of the counts for each depth (Bahr et al., 2014).

3.4 X-Ray diffractometry (XRD)

About 9 g of wet material was dried in an oven at 40°C and subsequently milled in a ball mill (Pulverisette, FRITSCH), with 300 cycles per sec for 3 minutes to obtain a powder with a grain size of 1-3 micrometresµm. The XRD measurements were done carried out at the Heidelberg Universitythe, Department Institute of Earth Sciencesof Geosciences, Heidelberg University, using a Bruker, D8 ADVANCE Eco diffractometer (40 kV, 25mA) with a Cu Kα diode. The samples were measured in rotating, circular, synthetic sample holders. An angular range of 2θ from 5° to 70° was measured with a step size of 0.02 increments (3338 steps per sample) for 1 sec per step. Peak positions and intensity of data wereas analyzed with Diffract Suite EVA (Bruker Software). The Rietveld refinement program DIFFRAC.TOPAS (Bruker Software) was used to perform quantitative phase analysisFor quantitative phase analysis the Rietveld refinement program DIFFRAC.TOPAS (Bruker Software) was used.

3.5 Grain-size analysis (Sortable Silt, $\overline{SS}$)

The preparation of the samples for the $\overline{SS}$ analyses followed Bianchi et al. (2001) and Stuut et al. (2002). Wet samples with a weight between 0.3 and 1 g were dried over night at 40 °C. Macroscopically visible coral fragments were removed. After weighting the dry samples, 10 ml of 30 % H_2O_2 were added to each sample to dissolve the organic material under sub-boiling conditions on a heating plate until the reaction ceased. To remove carbonates, 5 ml HCl (10 %) were added to each sample under sub-boiling conditions for at least 10 minutes until the end of the reaction. Samples were washed through standard sieves (63 µm mesh size) to remove the sand and coarser fraction. The fraction >63 µm was dried at 40°C and weightted. The material <63 µm was transferred into 1 L beakers and, filled until capacityto the top with demineralized water. After a settling period of at least 8 hours (h), the supernatant water was decanted, and the sample transferred into a 200 mL beaker, topped with demineralized water and settled for 8 h. After decanting supernatant water, the sampled wereas transferred into a 50 mL plastic beakers and, put into an ultrasonic bath to disintegrate aggregated sediment particles. Afterwards, 35 ml Na-Pyrophosphate wasere added to prevent particles from forming new aggregates and 2 ml isopropyl alcohol to keepminimize the formation of air bubbles in the liquid to a minimum. Samples were measured with a Laser Particle Sizer (LPS) ANALYSETTE 22 by FRITSCH™ at the Institute of Earth Sciences, Heidelberg University, in wet dispersion covering the range 0.08-2000 µm with 99 size classes. For analysisT of the raw data was analyzed with the software MaScontrol (FRITSCH™) was byused applying a Fraunhofer model. Results are derived from a total of five analytical runs à with 100 scans per sample. Up to seven replicate samples were performed for each depth to minimize the natural variability of the samples. While there isThe high number of replicates resulted from a relatively large inter-sample variability that is likely caused by the high amount of mica flakes present in the sediment distorting the laser beam, w. We nevertheless consider the results retrieved via the ANALYSETTE 22 as reliable (for an in-depth discussion see Jonkers et al., 2009).

3.6 Carbon and nitrogen content

Sediment samples were homogenized with a mortar and pestle and then weighted (0.5 mg for each analyses). The total organic carbon (TOC) and inorganic carbon (TIC, together TC) content was analyzed with a LECO RC-412 (Institute of Geoscience, Goethe University Frankfurt). The reproducibility of the replicate analyses was < ± 0.1 %. The total nitrogen (TN) content was analysed with a LECO TruSpec Macro (Institute of Geoscience, Goethe University Frankfurt).

3.7 Stable oxygen and carbon analysis

3.7.1 Stable isotope analysis of foraminiferal calcite

For stable isotope analyses of core M125-34-2, samples were taken at 5–10 cm intervals, wet-sieved (>63 µm) and then dried afterwards. For each sample 1–3 tests of *Uvigerina* spp. (*U. peregrina* and *U. proboscidea*) or *Planulina wuellerstorfi* were selected from the size fraction >125 µm, depending on availability. Stable carbon and oxygen isotope ratios were measured on a Thermo Fischer MAT 253 Plus IRMS gas isotope ratio mass spectrometer with coupled Kiel IV automated carbonate preparation device at the Institute of Earth Sciences, Heidelberg University. The instrument was calibrated using the in-house standard (Solnhofen limestone), itself which is calibrated against the IAEA-603. V; values are reported versus the VPDB (Vienna Peedee Belemnite) standard. Standard deviations derived from repeated measurements of the internal standard are ±0.06 ‰ for stable oxygen isotopes (-$\delta^{18}O$) and ±0.03 % for stable carbon isotopes ($\delta^{13}C$).

The ~13 m long core M125-50-3 was sampled each every ~10 cm for benthic foraminiferal isotope studiesanalysis. The samples were freeze-dried and washed through a >63 µm sieve to separate the coarse fraction fromand the fine fractions. Specimens of the benthic genera *Uvigerina* spp. were hand-picked from the size fraction 315–400 µm. Stable oxygen ($\delta^{18}O$) isotope analyses were performed on a ThermoScientific MAT 253 mass spectrometer with an automated Kiel IV Carbonate Preparation Device at GEOMAR. The isotope values are calibrated versus the NBS19 (National Bureau of Standards) carbonate standard and the in-house "Standard Bremen" (Solnhofen limestone). Isotope values presented in the delta-notation are reported in permil (‰) relative to the VPDB scale. The analytic error is ±0.06 ‰ for $\delta^{18}O$ and ±0.03 ‰ for $\delta^{13}C$.

3.7.2 Stable isotope analysis of organic matter

Previously homogenized samples were decarbonized with 10 % HCl to remove all inorganic carbon. Afterwards, the samples were centrifuged and washed several times with deionized water in order to remove residual HCl. The samples were then dried in an oven at 50 °C. Subsequent analyses of the carbon isotopic composition of organic carbon ($\delta^{13}C_{org}$) was performed by a Flash Elemental Analyzer 1112, connected to the continuous flow inlet system of a MAT 253 gas source mass spectrometer (Institute of Geosciences, Goethe University Frankfurt). Samples and standards both reproduced within ±0.2‰ and are reported relative to the VPDB standard.

3.7 Statistical analysis

Correlation coefficients and associated p-values were calculated using the Monte-Carlo-based SurrogateCorr function implemented in the "astrochron" package in R (Meyers, 2014) with 1000 iterations. This method has been particularly

developed to assess the correlation of parameters sampled on different down-core resolutions (e.g. XRF scanning data *vs*. discrete grain size measurements;~~) (~~ Meyers, 2014).
Discriminant analysis was performed with the program PAST (v3.15) (Hammer et al., 2001). Prior to analysis, the data was detrended and normalized to the mean and standard deviation.

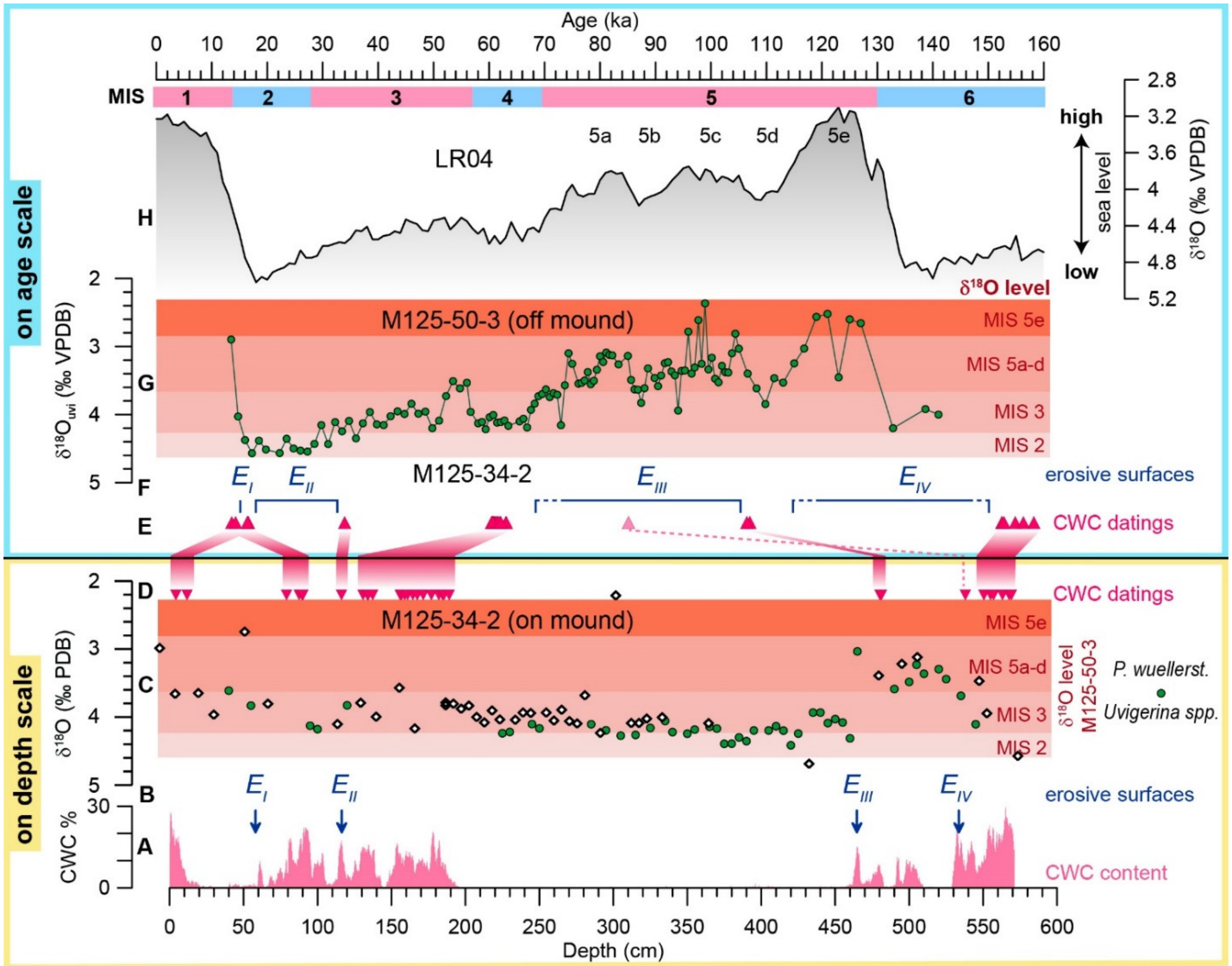
4. Age model refinement

The age model of core M125-34-2 used in this study represents a refined version of the stratigraphy published in Raddatz et al. (2020), which is based on ^{230}Th/U dates of CWCs. The six coral-bearing intervals, as described in Section 3.1, exhibited a mean accumulation rate of 30 cm kyr^{-1} with an overall range from 2 cm kyr^{-1} (C_V) to 80 cm kyr^{-1} (C_{III}) (Raddatz et al., 2020).
To better constrain the age of CWC-barren intervals and evaluate the chronostratigraphic duration of potential hiatuses, we compared the $\delta^{18}O$ record of c~~C~~ore M125-34-2 with the benthic isotope record of adjacent c~~e~~ore M125-50-3. The clear glacial-interglacial pattern of $\delta^{18}O_{Uvi}$ in ~~Core~~ core M125-50-3 allows ~~to construct~~for the construction of a robust age model for this site by tuning its benthic isotope record to the LR04 benthic stack (Lisiecki and Raymo, 2005) and ~~,~~ indicat~~es~~ing that it extends~~reaches down~~ to ~135 ka (Fig. 3). Its stratigraphic range is thus only slightly shorter than the one of M125-34-2 (158 ka based on Th/U dates) and is therefore suitable as an off-mound reference site. As both cores are situated in similar water depths and are thus bathed by the same water mass (today the AAIW, see Section 2), we expect the respective $\delta^{18}O$ values ~~not only~~ to not only follow a common glacial/interglacial pattern but also to be comparable in their absolute values, allowing for~~to~~ further constraining the chronostratigraphy of M125-34-2.

As neither shallow infaunal *Uvigerina* spp. and epibenthic *P. wuellerstorfi* were consistently present throughout core M125-34-2, we generated a spliced record of both species. For the $\delta^{18}O$ splice we corrected values of *P. wuellerstorfi* by adding the correction factor of +0.47 ‰ according to Marchitto et al. (2014). The resulting ~~ant~~ combined $\delta^{18}O$ record of M125-34-2 exhibits a considerable scatter ~~in lithological Unit 1~~from the top to erosive horizon E_I including relatively depleted ~~$\delta^{18}O_{cib}$~~ $\delta^{18}O_{Plan}$ values as low as 2.5 ‰ (Fig. 3), which puts this ~~unit~~ interval into a transitional phase between glacial and interglacial $\delta^{18}O$ levels. Neither $\delta^{18}O$ values nor absolute dating supports the preservation of Holocene deposits at the top of the gravity core. A deglacial age for the deposition of this interval ~~Unit 1~~ is further corroborated by Th/U dates of 13.7 to 14.3 ka, respectively. Samples from between E_I and E_{II} ~~Unit 2 has~~show slightly heavier $\delta^{18}O$ values ~~than Unit 2~~ and Th/U dates clustering around 16.5 ka, which indicates a post-LGM deposition. The existing Th/U dates suggest that the hiatus represented by the erosive unconformity ~~between Units 1 and~~E_{I}~~-2~~ is most likely shorter than 2 kyr. ~~Unit 3~~The section between E_{II} and E_{III} on the other hand has relatively uniform $\delta^{18}O$ values ~~that cluster~~ around 4.3 ‰ ($\delta^{18}O_{Uvi}$) and 3.4 ‰ ($\delta^{18}O_{Planeib}$), respectively, which matches M125-50-3 $\delta^{18}O_{Uuvi}$ values during MIS 4~~2~~ to 2~~4~~. ~~The age of the top of Unit 3 is relatively well defined by~~A Th/U dates at the top of this section at 117 cm reveals an age of 34 ka, while CWC ages from slightly deeper in the core (between 131-190 cm) fall within the range of 60–63 ka (MIS 4). ~~and older while its base lacks any absolute dating.~~ As ~~values of~~ $\delta^{18}O_{Uuvi}$ ~~o~~values between E_{II} and E_{III} ~~f Unit 3~~ are ~~more~~ less depleted than ~~MIS 2 values but less than~~ MIS 5 samples of reference site M125-50-3, we infer that ~~lithological Unit 3~~those sediments were ~~was~~ most likely deposited during ~~MIS 3 and potentially~~ MIS 4 ~~but~~ and did not reach into MIS 5. Hence, i~~I~~t hence appears that ~~MIS 2~~ deposits of MIS 2 and large parts of MIS 3 are not present in core M125-34-2, either due to non-deposition or subsequent erosion (note the prominent erosive surface ~~between Units 2 and 3~~E_{II}). This age assignment would also imply that the extended CWC-free portion ~~of Unit 3~~ from 200 to 465 cm ~~has been~~was deposited within a short period of approximately 8 kyr during MIS 4 (62.2~~0~~ ka as the oldest Th/U dates and ~70 ka as the MIS 4/5 boundary). This would yield a sedimentation rate of 33 cm kyr^{-1} (Fig. 3A), which is typical for contouritic sediments ~~as common~~ at the south-eastern Brazilian margin (Viana et al., 1998; Hernández-Molina et al., 2014; Rebesco et al., 2014). The following interval between E_{III} and E_{IV} ~~Unit 4~~ has relatively~~distinctively more~~ depleted $\delta^{18}O_{Uvi}$ values that fall into ~~values in~~ the range of MIS 5a–d values in reference core M125-50-3~~, but less depleted as those of MIS 5e.~~. Th/U dates of ~107 ka for~~of~~ CWC ~~at the top of Unit 4~~below E_{III} support a deposition during~~of this Unit in~~ MIS 5d and further indicate a prolonged interval of non-deposition or erosion leading to the absence of MIS 5a-c in core M125-34-2. As $\delta^{18}O$ values below E_{IV} ~~of Unit 5~~ are again on glacial levels, this ~~unit~~ section can be assigned to MIS 6 which is in line with Th/U dates of 152.6–158.4 ka. Hence the penultimate interglacial MIS 5e is likely not recovered and falls into the hiatus ~~between Units 4 and 5~~represented by E_{IV}.

In summary, deposition at Bowie Mound site M125-34-2 appears to be concentrated during glacial intervals of intermediate ice volume and reduced during interglacial periods~~In summary, deposition at Bowie Mound core M125-34-2 appears to be focused on glacial intervals of intermediate ice volume, such as MIS 3, contrary to the reduced presence in interglacial deposits~~.

The erosive horizons present in core M125-34-2 caused by winnowing due to strong current activity and internal waves provide evidence for extreme variability in the hydrological regime at the south-eastern Brazilian Margin (Viana and Faugères, 1998; Viana et al., 1998; Viana, 2001)~~, produced by winnowing due to strong current activity and internal waves~~. While winnowing has the capacity to remove the sediment matrix leading to lag deposits, it is rather unlikely that it would also remove coral fragments. Hence, it is feasible to assume that the dated intervals of CWC presence represent the complete sequence of CWC presence at this part of Bowie Mound.



on age scale
on depth scale
Age (ka)
MIS
1
2
3
4
5
6
LR04
5a
5b
5c
5d
5e
high
low
sea level
δ18O (‰ VPDB)
δ18O level
H
G
M125-50-3 (off mound)
MIS 5e
MIS 5a-d
MIS 3
MIS 2
δ18Ouvi (‰ VPDB)
F
E
M125-34-2
erosive surfaces
CWC datings
D
C
M125-34-2 (on mound)
δ18O (‰ PDB)
δ18O level M125-50-3
P. wuellerst.
Uvigerina spp.
B
A
CWC %
CWC content
Depth (cm)

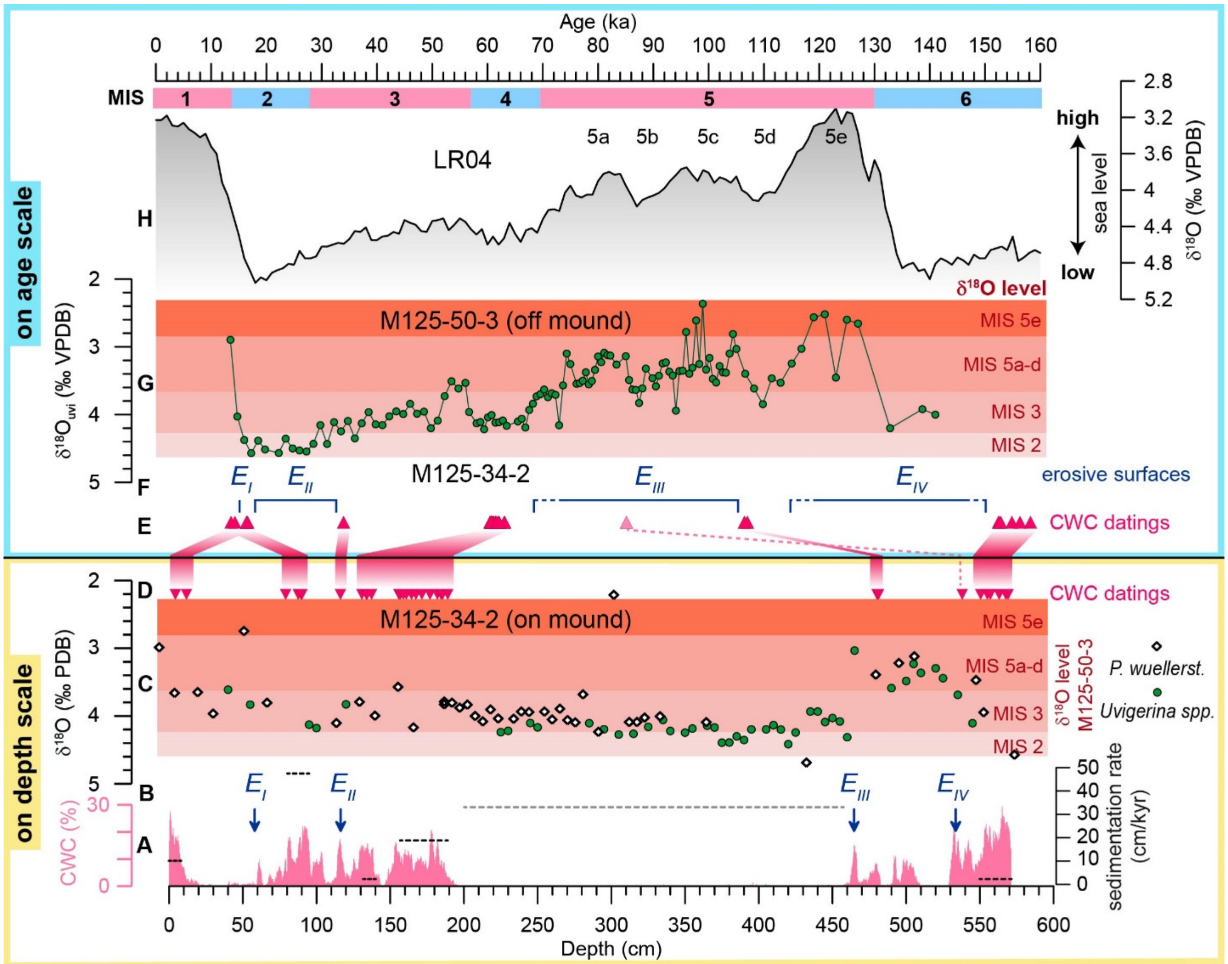


Fig. 3 Refined age model of cCore M125-34-2 from Bowie Mound. Lower panel displays data from M125-34-2 on depth scale, comprising (A) CWC abundances (%; magenta) based on CT-scanning and accumulation rates for both, the Th/U-dated CWC bearing intervals (black dashed lines; cf. Raddatz et al., 2019) and the CWC-barren interval between 200–465 cm (grey dashed line);; (B) blue arrows denote erosive horizons (hiatuses); (B) erosive horizons E_I–E_{IV} (cf. Fig. 2); (C) benthic $\delta^{18}O$ data from *Uvigerina* spp. (green dots) and *P. wuellerstorfi* (white diamonds; elevated by +0.47 to adjust for the interspecies offset to *Uvigerina* spp. after(Marchitto et al., 2014)); red horizontal shadings indicate reference $\delta^{18}O$ levels for the respective Marine Isotope Stages (MIS) taken from off-mound core M125-50-3 (see panel G); (D) red triangles mark Th/U datings. The upper panel displays data in the time domain, with (E) Th/U dates of M125-34-2; (F) the inferred duration of hiatuses reflected by erosive horizons E_I–E_{IV} of core M125-34-2; (G) the $\delta^{18}O$ record on *Uvigerina* spp. on off-mound core M125-50-3 with red horizontal shadings illustrating the $\delta^{18}O$ level during different isotope stages as used in panel (C); (H) the LR04 benthic stack (Lisiecki and Raymo, 2005) as an approximation for eustatic sea-level changes; Marine Isotope Stages (MIS) are indicated by pink and blue bars signifying relatively warm and cold periods, respectively.

5. Results and Discussion

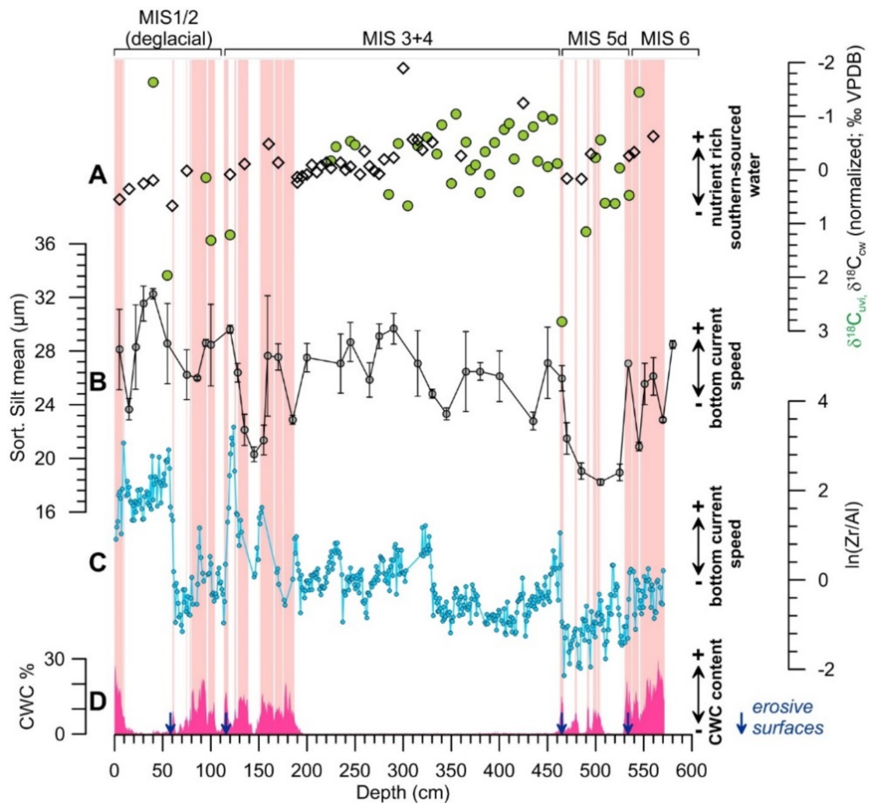
In the following we discuss if and how changes in environmental parameters might have enhanced or prohibited CWC growth at Bowie Mound, focusing on the role of intermediate water-mass variability and varying terrigenous sediment supply. We argue that the most dominant environmental factor for triggering CWC growth was elevated river run-off during ~~-~~periods of strong monsoonal rainfall in the coastal hinterland, which provided nutrients and organic matter that enhanced the food supply of CWC colonies.

5.1 Drivers and inhibitors of CWC growth at Bowie Mound

5.1.1 Intermediate water mass properties and hydraulic dynamics

Intermediate water-~~-~~mass properties ~~might~~ may have played a crucial role for the development of Bowie Mound. First, Bowie Mound lies within the ~~nutrient-rich~~ AAIW, which ~~might~~ probably~~have~~ boosted CWC growth at the East Brazilian slope. Secondly, nutrients and POC typically concentrate within nepheloid layers at water mass boundaries and provide a prolific food source for CWCs (Mienis et al., 2007; Dullo et al., 2008; Raddatz et al., 2014; Rüggeberg et al., 2016; Magill et al., 2018). In the case of Bowie Mound, it is possible ~~might thus be suspected~~ that enhanced production (Pahnke and Zahn, 2005; Pahnke et al., 2008) and/or nutrient-enrichment ~~(i.e~~(e.g.~~,~~ increasing phosphate and nitrate concentration) of the AAIW (Poggemann et al., 2017) during phases of weak Atlantic Meridional Overturning Circulation (AMOC) could have triggered its episodic formation phases. A more prominent AAIW ~~might have further~~likely also strengthened internal waves hitting the slope at the AAIW/SACW boundary in the Campos Basin (Viana et al., 1998; Viana, 2001) and thus fueled the nepheloid layer by enhanced resuspension.

Here, we use the benthic $\delta^{13}C$ obtained on M125-34-2 as an indicator of the relative contribution of~~nutrient-rich (hence,~~ ^{13}C depleted~~)~~ southern-sourced intermediate water masses (Kroopnick, 1985; Curry and Oppo, 2005). As we had to use different species (shallow infaunal *Uvigerina* spp. and epibenthic ~~C~~*P. wuellerstorfi*), we combined both records. To adjust for intra-species offsets, we followed the approach of Kaboth et al. (2017) and normalized the $\delta^{13}C$ values of each species to the respective mean and standard deviation. The resulting~~ant~~ normalized data exhibits a considerable scatter in the *Uvigerina* spp. record due to the pooling of different species, and hence only allows for a discussion of major shifts in the isotopic composition. However, ~~, although exhibiting a considerable scatter,~~the $\delta^{13}C$ data of *Uvigerina* spp. and *P. wuellerstorfi* do not provide compelling evidence for distinctly depleted values during phases of CWC growth compared to CWC-barren intervals (Fig. 4). ~~Albeit~~ Although ~~the~~ $\delta^{13}C_{Uvi}$ ~~of *Uvigerina* spp.~~ might be influenced by isotopic variations of dissolved inorganic carbon of pore-water (Zahn et al., 1986) and inter-species offsets (Rathburn et al. 1996; Theodor et al., 2016), we nevertheless consider it as appropriate ~~to~~ for reconstructing ~~profound~~ major changes in the bottom-water signature. Even when only considering ~~the~~ $\delta^{13}C_{Plan}$ ~~values obtained on epibenthic *C. wuellerstorfi*~~, there are no apparent systematic difference between CWC-bearing and CWC-barren intervals~~becomes apparent~~. The continuous, monospecific~~*Uvigerina* spp.~~ $\delta^{13}C_{Uvi}$ record obtained on off-mound core M125-50-3 ~~also~~ likewise lacks negative excursions during times of CWC growth at Bowie Mound (Fig. 5C). Hence, it appears that changes in the nutrient or organic matter content of the AAIW as observed during the last deglaciation (Poggemann et al., 2017) did not significantly affect CWC growth.



MIS1/2
(deglacial)
MIS 3+4
MIS 5d
MIS 6
A
B
C
D
Sort. Silt mean (µm)
CWC %
nutrient rich southern-sourced water
bottom current speed
bottom current speed
CWC content
erosive surfaces
$\delta^{18}C_{uvi}$, $\delta^{18}C_{cw}$ (normalized; ‰ VPDB)
ln(Zr/Al)
Depth (cm)

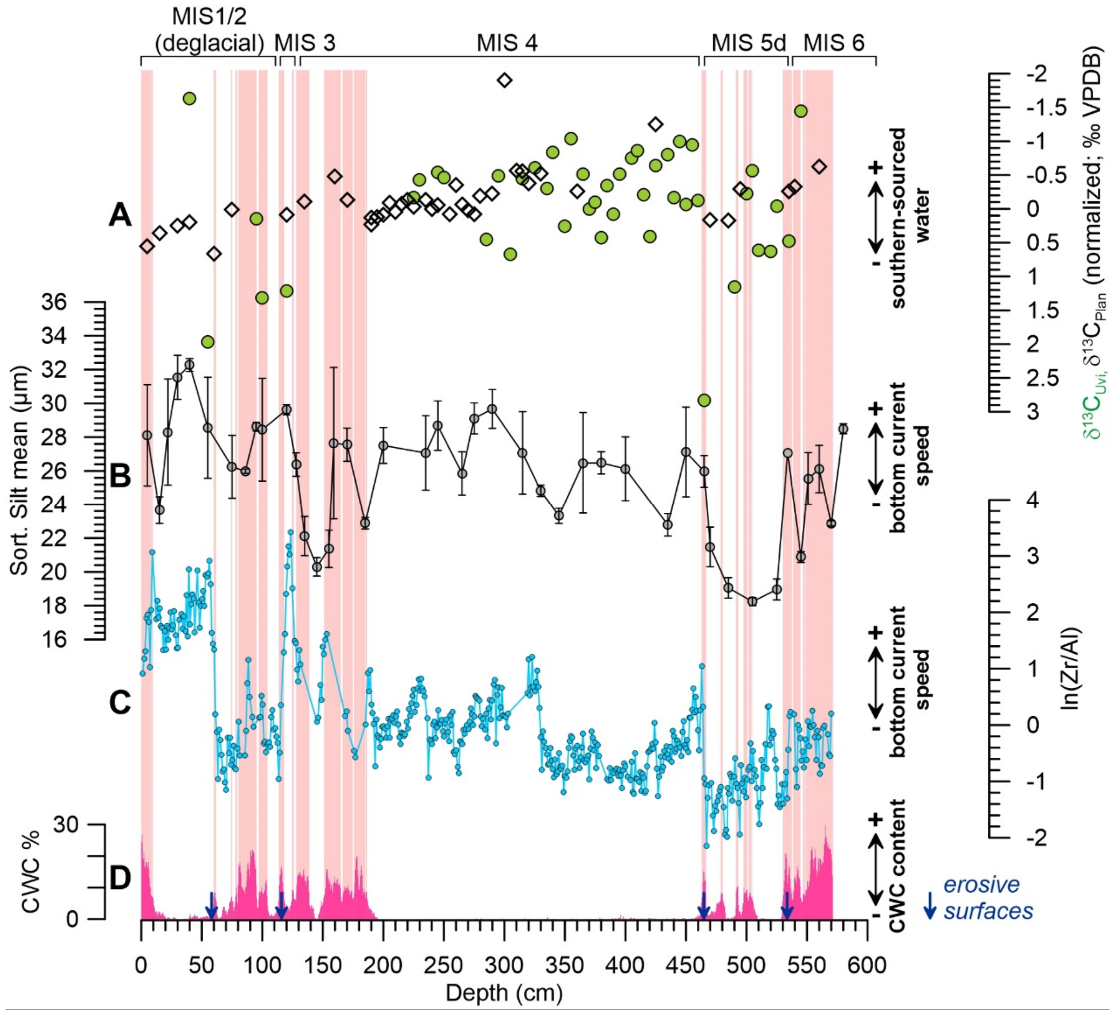
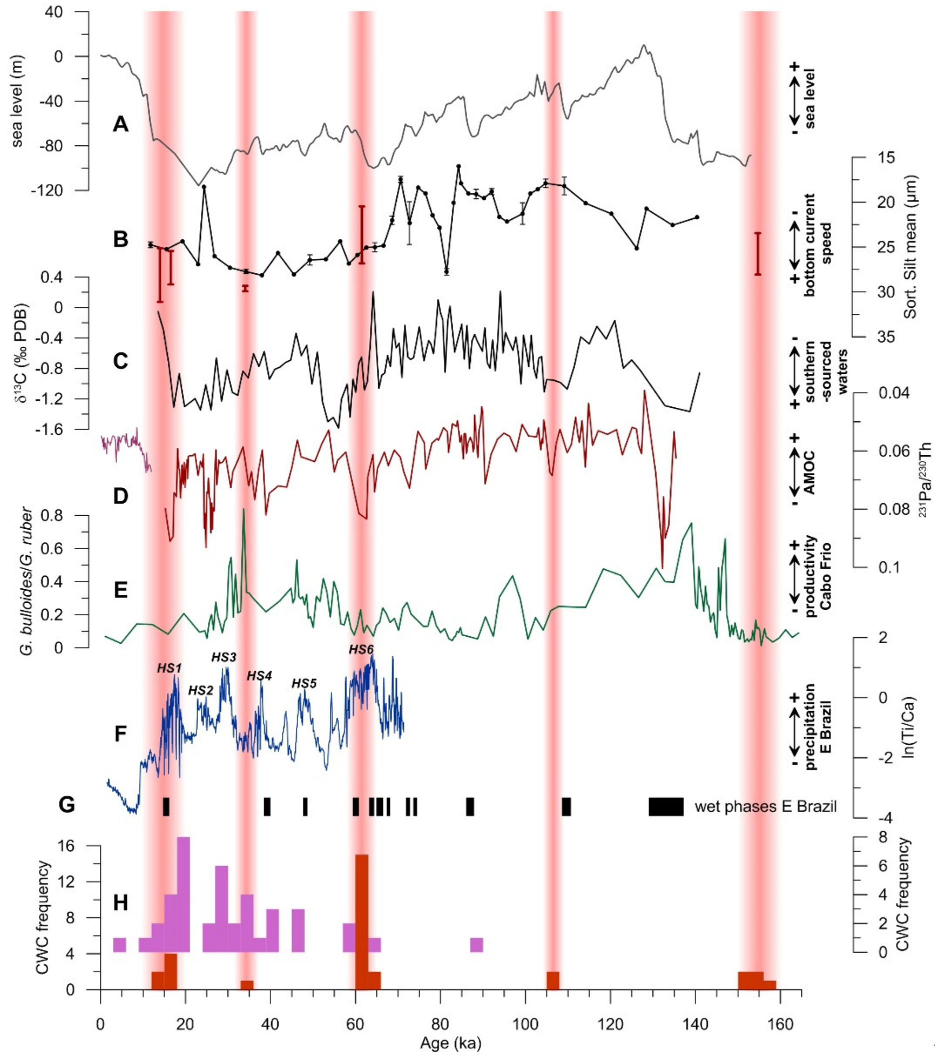


Fig. 4 Proxies of intermediate water mass variability *vs*. phases of mound formation obtained on Core core M125-34-2. (A) normalized δ^{13}C of *Uvigerina* spp. (green dots) and *P. wuellerstorfi* (white diamonds) as a proxy for bottom water--mass origin and nutrient level, (B) mean sortable silt ($\overline{SS}$) reflecting bottom current speed, (C) XRF-derived sedimentary ln(Zr/Al) ratio which are dependentss on bottom current speed (Bahr et al., 2014) and advection of fine-grained material from the nepheloid layer, and (D) CWC abundances based on CT-scanning. Phases of CWC proliferation appear to require background state of high hydrodynamics conditions (elevated ln(Zr/Al) and $\overline{SS}$) but do not show an influence of deep-water mass variability (δ^{13}C). -Light red shadings denote intervals with coral contents >7 % used for discriminant analysis; blue arrows indicate erosive unconformities.


sea level (m)
A
sea level
B
bottom current speed
Sort. Silt mean (µm)
δ13C (‰ PDB)
C
southern -sourced waters
D
AMOC
231Pa/230Th
G. bulloides/G. ruber
E
productivity Cabo Frio
HS1
HS2
HS3
HS4
HS5
HS6
F
precipitation E Brazil
ln(Ti/Ca)
G
wet phases E Brazil
H
CWC frequency
CWC frequency
Age (ka)

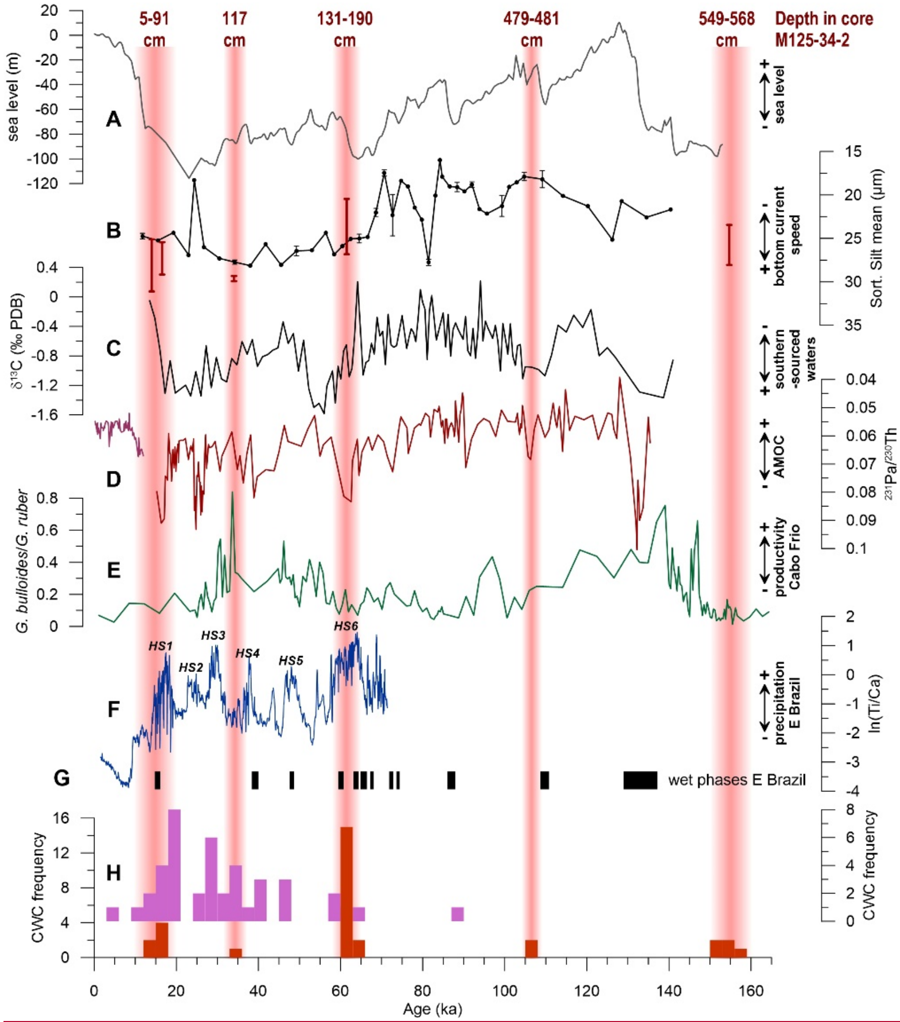
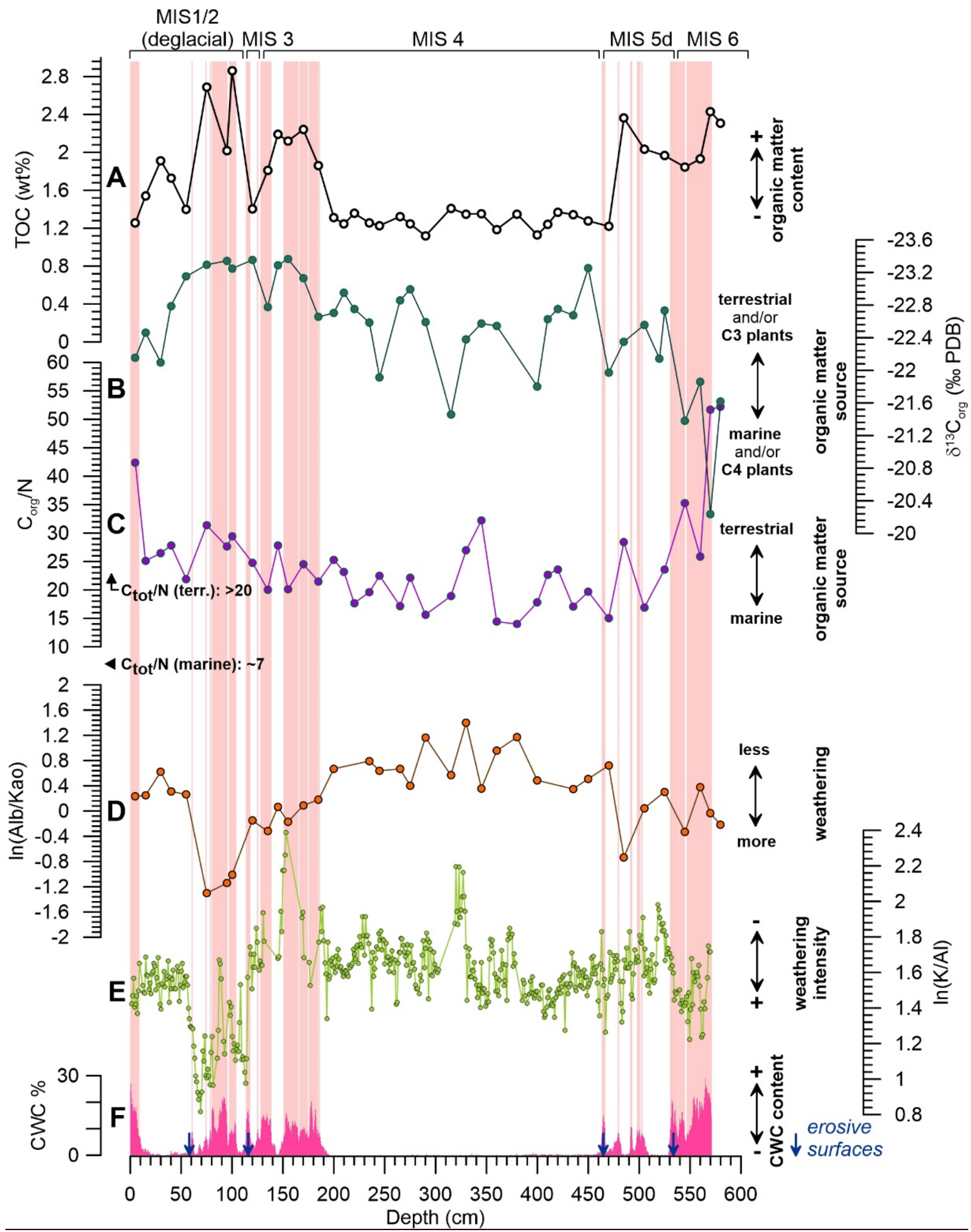


Fig. 5 Frequency of CWC occurrences in the time domain at Bowie Mound core M125-34-2 and adjacent cores from the south-eastern ~~SE~~ Brazilian Margin in the paleoclimatic context. (A) global sea level (Grant et al., 2012); (B) mean sortable silt in off-mound core M125-50-3, range of sortable silt values of CWC-bearing intervals in core M125-34-2 are indicated by red ~~error~~ bars; (C) benthic $\delta^{13}C$ of *Uvigerina* spp. in off-mound core M125-50-3 reflecting the portion of ~~nutrient-rich~~ southern-sourced waters (AAIW) at the south-eastern ~~SE~~ Brazilian Margin; (D) variability of ~~deep~~ Atlantic Meridional Overturning Circulation~~oceanic overturning circulation~~ (AMOC; dark red line: Böhm et al., 2015; purple: Lippold et al., 2019); (E) upwelling intensity at Cabo Frio reflected by the ratio between upwelling-related planktonic foraminifer *Globigerinoides bulloides* and oligotrophic *Globigerinoides ruber*; (F) ln(~~–~~Ti/Ca) ratio reflecting terrigenous input to the ~~E~~ eastern Brazilian margin off the Sao Francisco River (core M125-95-3; Campos et al., 2019); (G) growth periods of travertine and speleothems in E Brazil during anomalous wet periods, indicated by black bars (Wang et al., 2004); (H) frequency of CWC Th/U dates per 3 kyrs bins at Bowie Mound (core M125-34-2; red bars) and in cores at the south-eastern ~~SE~~ Brazilian Margin (violet) (Mangini et al., 2010; Ruckelshausen, 2013) (Fig. 1). Note the good match between CWC occurrences and enhanced monsoonal activity on the continent (correlation between ln(Ti/Ca) and CWC frequency: r = 0.56, p = 0.02; computed using the SurrogateCor function of the R-package "astrochron"; Meyers, 2014). Red bars indicate periods of enhanced CWC growth at Bowie Mound, with the respective depths in core M125-34-2 annotated.

While nutrient and/or food delivery by the AAIW seemsed to haved had an insignificant effect on CWC growth at Bowie Mound, changes in the hydrodynamics regime altering affecting the depth and strength of the nepheloid layer might have influenced mound formationhad an impact of CWC proliferation. Hydrodynamic conditions at core M125-34-2 can be reconstructed by using the variation in $\overline{SS}$, a well-established proxy for bottom current speed reflected by the mean grain size of the 10-63 µm fraction (McCave et al., 1995), and the sedimentary ln(-Zr/Al) ratio (Fig. 4). The latter proxy follows the rationale that heavy minerals accumulate relative to aluminosilicates during when the high bottom current flow speed is high (e.g., Turnewitsch et al., 2004; Bahr et al., 2014; Miramontes et al., 2019). The significant correlation (r=+0.49; p<0.05) of both proxies may therefore predominantly reflects the hydraulic regime at Bowie Mound, despite certain intervals where both parameters deviate (e.g. between 60 and –115 cm with high $\overline{SS}$ and low ln(Zr/Al) values), which might be due to small-scale hydraulic effects created by the CWC branches themselves (Mienis et al., 2019). Based on both hydrodynamic proxies, CWC at Bowie Mound tend to accumulate in during intervals with elevated flow speed. Phases of low flow speed are accompanied by low CWC abundances (e.g., between at 140–150 cm and 465–550 cm), in line with the notion that active bottom currents play a significant role in distributing nutrients and food towards CWC colonies (e.g., Thiem et al., 2006; Dorschel et al., 2007; Davies et al., 2009; Raddatz et al., 2011). High current speeds will also increase sediment and POC supply, thereby providing food and at the same time increasinge accumulation rates due to the baffling capacity of CWC. Our data, however, suggest that a relatively high flow speed does not necessarily lead to CWC growth as demonstrated by the extended CWC-free section between 200 and –460 cm, where ln(Zr/Al) and $\overline{SS}$ fluctuates on a relativelyreach high levels as well as betweenand at 15–60 cm where no CWC are preserved despite high TOC accumulation. Hence, the absence of CWC-bearing intervals despite persistently high bottom current speeds during most of the glacial intervals MIS 3 and 4 indicate that additional environmental drivers other than intermediate water--mass variability must have played an importantactive role for triggeringfor CWC proliferation growth at on the Brazilian Margin.

5.1.2 Terrestrial and marine organic matter supply

Having a sufficient food supply to Bowie Mound is a The prerequisite for enhanced CWC growth is sufficient food supply to Bowie Mound. To assess the potential impact of enhanced POC and/or DOC supply as an incentive for enhanced CWC growth we compared TOC measurements to CWC abundances (Fig. 6). It appears that CWC abundance is s are highest duringin intervals ofwith elevated organic matterOM presence content, while the long CWC-barren interval between 200 and 460 cm is characterized by relatively low TOC contents, thuswhich stressing thees its importance of TOC as a prerequisite for mound aggregation. While statistically significant, the down-core pattern of CWC abundances and TOC ($r = 0.55$; $p < 0.05$) also indicates that this correlation is not straight forward; an example is the coral-free, high-TOC interval between 15 and– 60 cm with high TOC contents that is barren of corals (Fig. 6). However, aAs suggested argued also in the previous section, there arehave been multiple factors necessary forto stimulatinge coral growth at Bowie Mound.


MIS1/2 (deglacial)
MIS 3
MIS 4
MIS 5d
MIS 6
TOC (wt%)
A
organic matter content
B
terrestrial and/or C3 plants
marine and/or C4 plants
organic matter source
δ13Corg (‰ PDB)
Corg/N
C
terrestrial
marine
Ctot/N (terr.): >20
Ctot/N (marine): ~7
ln(Alb/Kao)
D
less
more
weathering
E
weathering intensity
ln(K/Al)
CWC %
F
CWC content
erosive surfaces
Depth (cm)

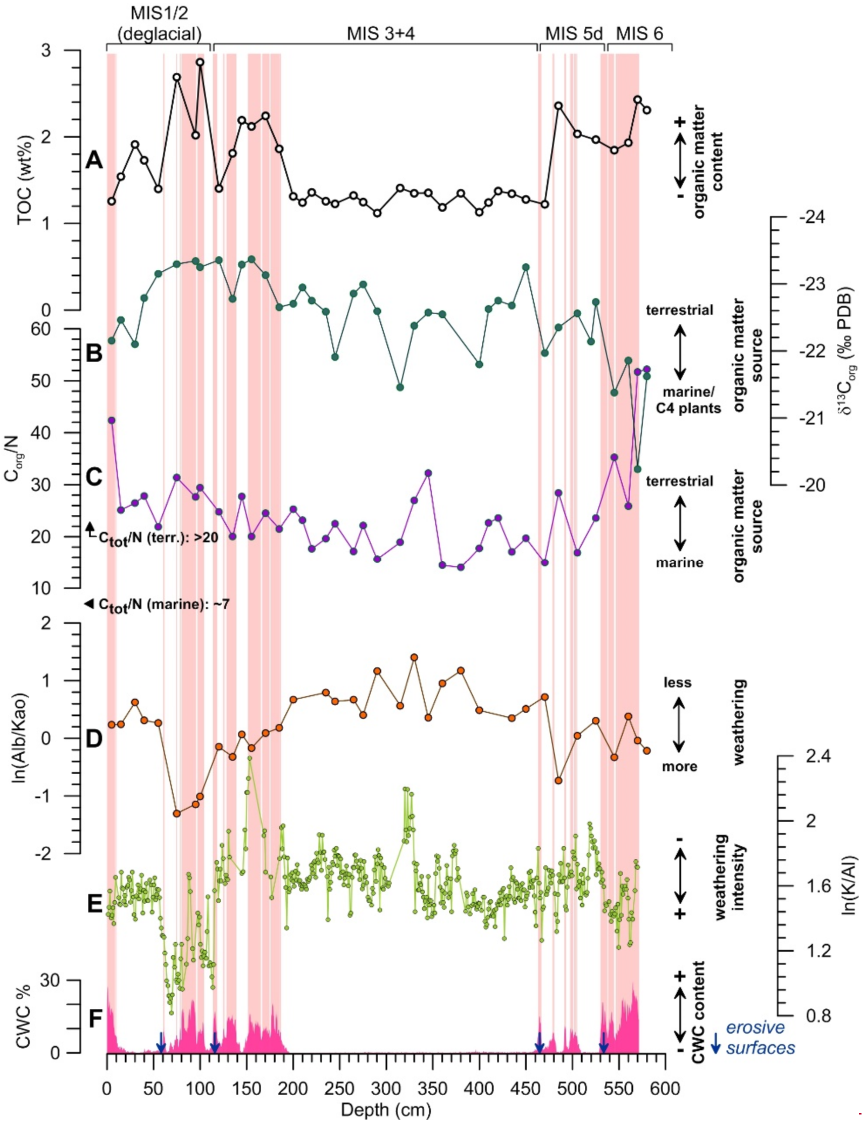


Fig. 6 Organic-matter accumulation and origin at Bowie Mound core M125-34-2 in context with continental hydroclimate and CWC occurrences. (A) Total organic carbon (TOC, white dots) reflecting organic-matter accumulation; (B) and (C) $\delta^{13}C$ and C_{org}/N_{tot} ratio of organic matter as measures for terrestrial *vs.* marine organic matter input, respectively. Marine and terrestrial endmembers are indicated (Holtvoeth et al., 2003); (D) and (E) XRD-derived ln(Albite/Kaolinite) and XRF-derived ln(K/Al) ratios, respectively, as indicators of the weathering intensity in the hinterland, reflecting the strength of the continental hydrological cycle; and (F) CWC abundances based on CT-scanning. Note that high CWC abundances fall into intervals of high TOC and increased weathering due to an intensified continental hydrological cycle. Light red shadings denote intervals with coral contents >7 % used for discriminant analysis; blue arrows indicate erosive unconformities.

To investigate the origin of the organic matter within the sediment matrix we analyzed its C_{org}/N_{total} ratio and stable carbon isotopic composition ($\delta^{13}C_{org}$). Marine organic matter has lower C_{org}/N_{total} ratios (~6.6) compared to terrestrial organic matter (>20) (Holtvoeth et al., 2003). Organic matter in core M125-34-2 exhibits C_{org}/N_{total} ratios of 14 to 52

(Fig. 6), indicating that land-derived material ~~has been~~was ~~an significant~~a dominant source of organic matter throughout the record. Intervals ~~with~~ of high CWC abundances are ~~thereby~~ characterized by elevated C_{org}/N_{total} ratios, namely at the top and at the base of the core with ratios >40~~, pointing at~~indicating an overwhelming contribution of terrigenous matter. Notably, in line with the upwelling center off Cabo Frio being confined to the shelf without reaching northward to the slope where Bowie Mound is situated (Albuquerque et al., 2014, 2016), upwelling derived organic matter with typical marine C_{org}/N_{total} ratios below 6.5 (Albuquerque et al., 2014) apparently played a subordinate role. ~~Notably, organic matter derived from upwelling on the shelf off Cabo Frio apparently plays a subordinate role as this predominantly marine organic material has low C_{org}/N_{total} ratios typically below 6.5 (Albuquerque et al., 2014) in line with the upwelling center being confined to the shelf without reaching northward to the slope where Bowie Mound is situated (Albuquerque et al., 2014, 2016).~~ A significant terrigenous admixture of terrestrial organic matter is also indicated by the relatively low $\delta^{13}C_{org}$ (-23.2 to -20.2 ‰) as terrigenous organic material has a more depleted signature (-27 ‰) compared to typical marine $\delta^{13}C_{org}$ values (-19 ‰) (Holtvoeth et al., 2003). In this regard, ~~low~~ high $\delta^{13}C_{org}$ values during CWC-bearing intervals in the upper 50 cm and below 549.5 cm ~~might~~ can be interpreted as periods of enhanced marine productivity, which ~~is in contradiction to~~ contradicts contemporaneous~~parallel~~ C_{org}/N_{total} ratios of as high as 52. This conflicting evidence might be resolved by interpreting the high $\delta^{13}C_{org}$ values as ~~representing~~ being influenced by enhanced input of POC from C4 plants (typically grasses), which are characterized by an endmember of ca. -12 ‰ (Holtvoeth et al., 2003). Palynological evidence ~~in~~ indeed~~fact~~ point to the establishment of grassland biomes in the catchment of the Paraiba do Sul during the last glacial ~~caused~~ as a result of~~by~~ generally drier conditions (Behling et al., 2002). This is in accordance with the presumed deposition of the intervals 0–50 cm and 549.5–568 cm during the last deglaciation and MIS 6, respectively (Fig. 5).

5.1.3 Influence of the continental hydrological cycle

A major source of terrigenous material and thus a potent organic-matter source for the Brazilian Margin are rivers draining the densely vegetated hinterland, especially the Paraiba do Sul (Fig. 1). To investigate if enhanced riverine input due to more humid conditions in the hinterland ~~contributed to enhanced~~increased terrestrial organic-matter supply to Bowie Mound, we studied the mineralogical and geochemical composition of the terrigenous fraction of the sediment. Changes in the water availability in the hinterland should impact the degree of weathering and thus leave an imprint in the mineralogical composition of the terrigenous sediments. The composition of the non-carbonaceous mineral phases is typical for soils that underwent different degrees of chemical weathering, comprising intermediate weathering products such as hydrobiotite (11.5 %, up to 24 %) (Coleman et al., 1963; Wilson, 1970; Meunier and Velde, 1979), as well as typical constituents of soils that have been deeply weathered under tropical humid conditions such as kaolinite (7.9 % up to 15.3 %), gibbsite (on average 21.7 %) and Ca, K, Al-rich Zeolite (6.7 %) (e.g. Weaver, 1975; Hughes, 1980; Ibrahim and Hall, 1996; Furian et al., 2002) (cf. Appendix Table A). When comparing minerals typical for residual soils such as kaolinite, gibbsite, and zeolite with feldspar and mica, both groups are anti-correlated (Table XRD) and exhibit distinct fluctuations throughout the core (cf. the albite *vs*. kaolinite ratio is depicted in Fig. 6). Relatively high abundances of weathering residuals like kaolinite are particularly present in the CWC-bearing interval between ca. 60 ~~to~~ and 200 cm and ~~(~~to a lesser extent~~d)~~ below 560 cm. This XRD-based data is also partly supported by the high-resolution ln(K/Al) record obtained via XRF scanning, which is particularly low during the interval 60–120 cm and below 530 cm (Fig. 6). Low ln(K/Al) ratios are ~~in~~ consistent~~line~~ with high kaolinite contents reflecting periods of strong K-removal from soils due to chemical weathering ~~under~~ during humid conditions in the hinterland. As the C_{org}/N_{total} ratio is also elevated during periods of low ln(K/Al) ratios and high kaolinite contents (Fig. 6), it can be inferred that high precipitation in the hinterland ~~fostered~~ enhanced chemical weathering ~~in combination with elevating~~and increased terrigenous organic matter transport to the continental slope. Stronger chemical weathering would have also enhanced the input of Fe to the continental slope (Govin et al., 2012) leading to fertilization of the surface waters, which ~~might~~ likely further~~have additionally~~ invigorated surface productivity and ~~thus~~ increased the food supply for CWC at Bowie Mound.

Table XRD: Correlation between terrigenous mineral phases in core M125-34-2. Positive correlations are marked in red (for r>0.4), negative correlations (for r<0.4) in blue.

	Quartz	Gibbsite	Kaolinite	Muscovite	Hydrobiotite	Microcline	Zeolite
Quartz							
Gibbsite	-0.07						
Kaolinite	-0.52	-0.09					
Muscovite	0.35	0.45	-0.31				
Hydrobiotite	-0.34	-0.62	0.55	-0.69			
Microcline	0.49	-0.26	-0.43	-0.15	-0.02		
Zeolite	-0.16	0.68	0.00	0.62	-0.43	-0.51	
Albite	0.65	-0.07	-0.76	0.47	-0.44	0.35	-0.07

To objectively evaluate the relative importance of terrestrial organic matter supply over changes in the hydraulic conditions ~~potentially~~ in influencing CWC proliferation at Bowie Mound we performed a discriminant analysis over n=34 samples using (i) ln(Alb/Kao) as a weathering proxy, (ii) $\overline{SS}$ for bottom current speed, (iii) $\delta^{13}C_{org}$, and (iv) C_{org}/N_{total} for organic matter provenance as predictors for the occurrences of CWC abundances above 7 % (reflecting representative CWC accumulations). Note that the $\delta^{13}C$ of benthic foraminifera had not been included due to the high scatter of the data. The restriction on those four parameters was also done to avoid unreliable results by over-prediction. The outcome of the discriminant analysis yields a correct classification of 76 % with highest skills in ln(Alb/Kao) (loading of -0.68) and C_{org}/N_{total} (+0.58), while loadings for $\overline{SS}$ (+0.06) and $\delta^{13}C_{org}$ (0.00) are insignificant (see Appendix Table B for details). This is consistent with peak CWC abundances during phases of strong hydrological activity, as evidenced by intensified chemical weathering (i.e. low ln(Alb/Kao) ratios), which enhanced the input of terrigenous organic matter (high C_{org}/N_{total}) to Bowie Mound and directly or indirectly (via surface water fertilization) stimulated CWC proliferation~~This is in line with peak CWC abundances synchronous to phases of a strong hydrological cycle as reflected by intensified chemical weathering (i.e. low ln(Alb/Kao) ratios) which triggered a strong input of terrigenous organic matter with a high C_{org}/N_{total} ratio to Bowie Mound directly or indirectly fueling CWC proliferation~~.

5.2 CWC at Bowie Mound in the paleoclimatological context

As discussed above, phases of enhanced CWC proliferation at Bowie Mound occurred in parallel to periods of increased terrigenous POC and/or DOC input ~~from land~~ due to enhanced run-off. ~~Within age model uncertainties~~T~~,~~ ~~t~~he most distinct CWC proliferation phases in fact took place during phases of anomalously ~~humid conditions in E Brazil~~strong monsoonal precipitation ~~associated~~ during~~with~~ the pronounced Heinrich Stadials (HS) 1 and~~,~~ ~~4, and~~ 6 as well as (within age model uncertainties) also during the shorter and less severe humid phases corresponding to HS 2–5 (Fig. 5F, G). The prominent growth phase during HS is ~~well~~ in agreement with published CWC occurrences along the south-eastern Brazilian Margin ~~during~~ from the same time frame ~~along the SE Brazilian Margin~~ (Mangini et al., 2010; Ruckelshausen, 2013) (Figs. 1, 5G), ~~corroborating~~ indicating that our results are representative for a larger geographic area. The slow overturning circulation during HS indicated by high $^{231}Pa/^{230}Th$ ratios (Fig. 5D; McManus et al., 2004; Böhm et al., 2015) ~~(Fig. 5 D) caused~~ resulted in enhanced precipitation over south-eastern and eastern Brazil (Waelbroeck et al., 2018) ~~as it led~~due to heat accumulation in the southern hemisphere and ~~thereby strengthening~~ intensification of the South Atlantic Convergence Zone (Fig. 1; Stríkis et al., 2015)~~ (Fig 1)~~. Humid phases during HS in otherwise dry eastern Brazil are documented by growth phases of speleothems and travertines (Fig. 5G), increased terrigenous ~~matter~~ input (core M125-95-3; Fig. 5F) (Campos et al., 2019), and a slight expansion of forest cover (Gu et al., 2018). It ~~might~~ is possible~~thus be argued~~ that the riverine suspension load from other rivers in eastern Brazil was advected southward by the BC and added to the enhanced ~~river~~ terrigenous load from rivers adjacent to Bowie Mound (mostly the Paraiba do Sul). Due to the baffling capacity of framework-building CWCs (Mienis et al., 2007; Huvenne et al., 2009; Titschack et al., 2015), the ~~Due to their baffling capacity, the~~ additional sedimentary input would have aided mound formation. This nutrient and organic-rich suspension potentially also enhanced marine surface productivity and thus directly and/or indirectly boosted food supply to the CWC. ~~-~~As freshwater admixture to the SMW and SACW may~~ight have~~ increased~~ caused a more pronounced~~ water column stratification and hence the~~increased~~ density contrast to the AAIW, the concentration of sediment and food particles at the nepheloid layer may~~might~~ also have been more ~~pronounced as well~~pronounced. The link between Monsoonal activity and CWC growth proposed here is in line with studies from the western Mediterranean Sea (Fentimen et al., 2020), the Gulf of Cadiz (Wienberg et al., 2010) and the tropical eastern Atlantic off Angola (Hanz et al., 2019) which all inferred that terrestrial input via dust or fluvial run-off can ultimately fuel CWC colonies.

Notably, HS occurred during phases of intermediate and low sea level, which facilitated the bypass of sediment across the shelf and thus allowed for an efficient supply of terrestrial organic matter~~OM~~ to Bowie Mound (Fig. 5A). As discussed in Raddatz et al. (2020), ~~a low sea level might have also forced water-mass boundaries to migrate downslope~~ during glacials, when sea level was ~~considerably lower by~~ up to 120 m lower than ~~today~~ present (Waelbroeck et al., 2002; Rohling et al., 2014), water-mass boundaries may have been forced to migrate downslope. Such a displacement of water-mass boundaries would have moved the SACW/AAIW interface and the corresponding nepheloid layer from its present position at ~500 m closer to the depth of Bowie Mound (~860 m), aiding the concentration and dispersal of food along the slope towards the CWC colonies. This suspected influence of sea level on the bottom-current dynamics ~~in~~ at the depth of Bowie Mound is in fact evident from a sortable silt record obtained from the~~on~~ off-mound site M125-50-3, which shows high (low) current speeds during low (high) sea level (Fig. 5B).

Hence, we argue that a dynamic hydraulic regime along with a pronounced nepheloid layer was required for CWC to flourish at Bowie Mound (Mienis et al., 2007). These prerequisite conditions were present throughout glacial periods, during which th~~Hence, it might be argued that for CWC to flourish at Bowie Mound a dynamic hydraulic regime was required with a pronounced nepheloid layer such as prevailing throughout glacial periods (Mienis et al., 2007). Th~~e development of wide-spread glacial unconformities and extensive drift bodies along~~at~~ the south-east Brazilian margin (Viana et al., 1998; Viana, 2001) are evidence for such intense bottom-current activity. This is notably different from the slope south of the Abrolhos Bank where reference core M125-50-3 is situated. Here, contouritic sediments and distinct hiatuses are largely absent in water depths affected by the AAIW and SACW, which testifies~~y~~ to ~~for~~ less dynamic hydrological conditions (Bahr et al., 2016), potentially responsible for ~~explaining~~ the lack of CWC mounds at this location. At the same time, $\overline{SS}$ and ln(Zr/Al) data from both~~neither~~ Bowie Mound core M125-34-2 (Fig. 4B) and~~nor~~ off-mound core~~site~~ M125-50-3 (Fig. 5B) indicate that bottom-current speed was~~has been~~ not anomalously high during HS relative to the glacial background level. Hence, the distinct, pulse-like CWC growth phases at Bowie Mound could have been ~~ultimately~~ initiated by enhanced nutrient and organic matter supply from land as evidenced by the high C_{org}/N ratio of the organic matter. Surface water fertilization by the increase in terrigenous organic matter may have also improved marine primary productivity and contributed to higher export production, further fueling CWC growth. ~~Due to ensuing fertilization of the surface waters, marine primary productivity might also have been enhanced and contributed to higher export production, additionally fueling CWC growth.~~ As discussed before, marine productivity ~~derived~~ caused by from upwelling on the shelf of Cabo Frio was apparently of minor importance. Based on planktic foraminiferal assemblages (Lessa et al., 2019), enhanced upwelling occurred between HS 3 and 4, at around 35 kys, when a small peak of CWC abundances occurs (Fig. 5G). However, during ~~at~~ all other instances of CWC occurrences, upwelling at Cabo Frio ~~appears~~ was relatively~~rather~~ low and likely did~~there is~~ not ~~evidence that it~~ reached as far north as Bowie Mound (Albuquerque et al., 2014, 2016).

We hence infer that CWC proliferation at Bowie Mound occurred simultaneously with an enhanced delivery of terrestrial organic matter towards the continental slope under glacial boundary conditions of low sea level and enhanced hydrodynamic activity along the slope. ~~As this temporal coincidence could point at~~This implies the direct utilization of terrestrial organic matter by the corals and thus~~, it~~ clearly stresses the necessity for future in-depth studies of the food preferences of *S. variabilis*.

Conclusions

Here we present a comprehensive multi-proxy study of a ~~cold-water coral (~~CWC~~)~~-bearing core retrieved off ~~SE~~ south-eastern Brazil with the aim to assess the relative importance of different environmental factors that supported and/or prohibited CWC proliferation and coral mound formation. We find that intervals of high CWC abundance~~s~~ are primarily related to millennial-scale high latitude cold events (Heinrich Stadials) that were characterized by major reconfigurations of ~~the~~ deep-ocean circulation and ~~an~~ enhanced ~~continental hydrological cycle~~monsoonal precipitation in eastern Brazil. The dominance of terrigenous- over marine-derived organic matter during phases of fast CWC proliferation indicate that strong run-off enhanced the input of nutrients and food to ~~the~~ coral mounds on the continental slope. Intensified hydrodynamic conditions at the water depth of Bowie Mound ~~on intermediate water level~~ during sea level lowstands thereby provided the necessary background conditions for an efficient dispersal of nutrient and food supply towards the upper and mid slope. Thus, thi~~i~~s study ~~thus~~ presents a prime example of the ~~high sensitivity of deep marine ecosystems to changes in the environmental conditions and points at a hitherto unrecognized~~ intimate coupling between continental hydroclimate and ecological changes in the deep ocean.

Appendices

Appendix Table A: Major non-carbonaceous mineral phases in core M125-34-2 derived from Rietveld analyses of X-ray diffractometry.

Depth (cm)	Quartz	Gibbsite	Kaolinite	Muscovite	Hydrobiotite	Microcline	Zeolite	Albite
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
5	8.5	20.2	5.7	5.6	7.8	7.0	6.7	7.2
15	8.0	19.1	7.8	5.5	16.1	4.6	6.7	10.0
30	6.9	18.7	6.5	2.1	10.1	6.3	4.2	12.1
40	7.6	20.3	7.7	3.4	17.1	9.3	3.8	10.5
55	10.4	18.4	8.7	4.0	14.1	3.7	5.0	11.3
75	4.6	20.0	15.3	4.8	20.2	2.1	6.5	4.2
95	4.3	17.6	12.0	4.4	21.7	4.8	5.9	3.8
100	4.8	16.4	12.6	5.6	24.0	3.2	6.2	4.6
120	9.7	15.5	10.3	4.4	18.2	6.2	4.7	8.9
135	8.3	24.5	9.9	9.4	12.9	4.3	6.7	7.2
145	7.1	24.1	9.0	5.1	17.4	3.3	7.1	9.6
155	7.8	25.9	10.2	11.5	7.8	4.6	7.9	8.6
170	7.6	22.3	9.0	6.1	17.6	4.0	7.1	9.8
185	9.2	25.1	7.4	11.5	6.0	6.2	7.4	8.9
200	10.2	21.3	6.2	6.2	12.5	7.9	6.6	12.2
235	9.2	20.6	5.4	13.3	10.7	3.6	7.4	12.0
245	9.5	22.6	6.5	13.2	5.7	5.8	6.8	12.4
265	8.1	22.8	6.5	9.9	9.8	6.4	7.4	12.7
275	9.2	23.5	7.5	12.9	6.9	5.4	7.0	11.3
290	9.6	21.6	4.0	10.7	9.7	6.9	6.3	13.0
315	10.4	21.9	6.3	12.8	7.1	5.0	6.7	11.1
330	9.3	19.8	4.0	11.4	8.7	5.1	6.4	16.3
345	7.7	19.7	8.3	11.9	10.2	4.9	7.1	11.9
360	6.9	19.4	5.5	9.0	10.0	5.8	6.3	14.3
380	8.3	23.1	4.5	13.7	5.2	3.2	7.2	14.5
400	7.0	21.2	6.2	7.6	12.9	6.8	6.5	10.1
435	7.9	23.1	8.3	12.6	6.2	3.1	6.8	11.8
450	7.8	23.1	7.0	12.0	7.4	3.8	7.4	11.7
470	8.3	18.6	6.4	11.8	14.6	4.6	7.5	13.2
485	6.3	27.4	12.2	12.3	5.5	2.8	8.5	5.8
505	5.5	23.7	9.5	12.5	6.2	2.8	7.7	9.9
525	5.7	24.6	7.4	10.2	11.2	3.6	8.0	10.1
545	4.4	23.1	8.4	4.4	10.3	3.0	7.4	6.0
560	6.5	26.3	5.3	6.8	8.1	3.8	7.1	7.8

570	5.8	22.0	7.3	6.0	10.5	3.5	6.4	7.0
580	5.3	23.0	8.1	5.8	12.9	2.8	7.3	6.5

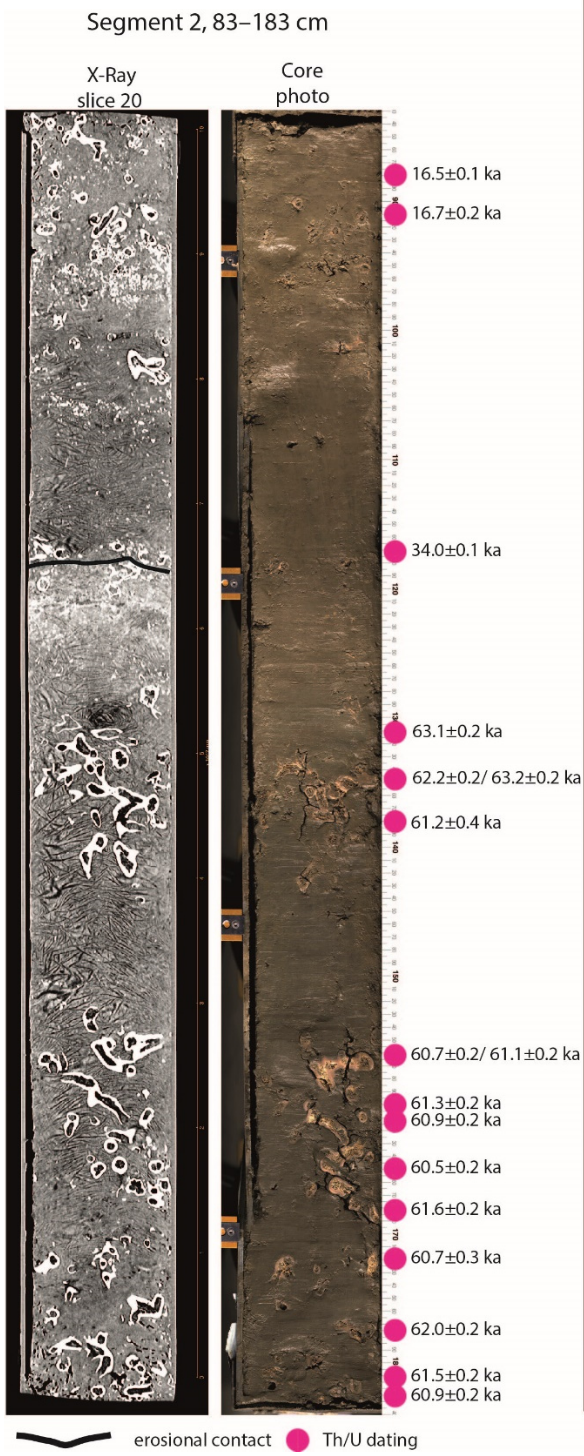
APPENDIX Table B. Result of discriminant analysis performed on detrended and normalized proxies obtained on core M125-34-2. Samples were divided into classes with CWC contents >7% (labelled "1") and <7% ("0"). Classes derived from discriminant analysis are displayed in the last column, with wrongly assigned ~~calls~~ classes marked in red.

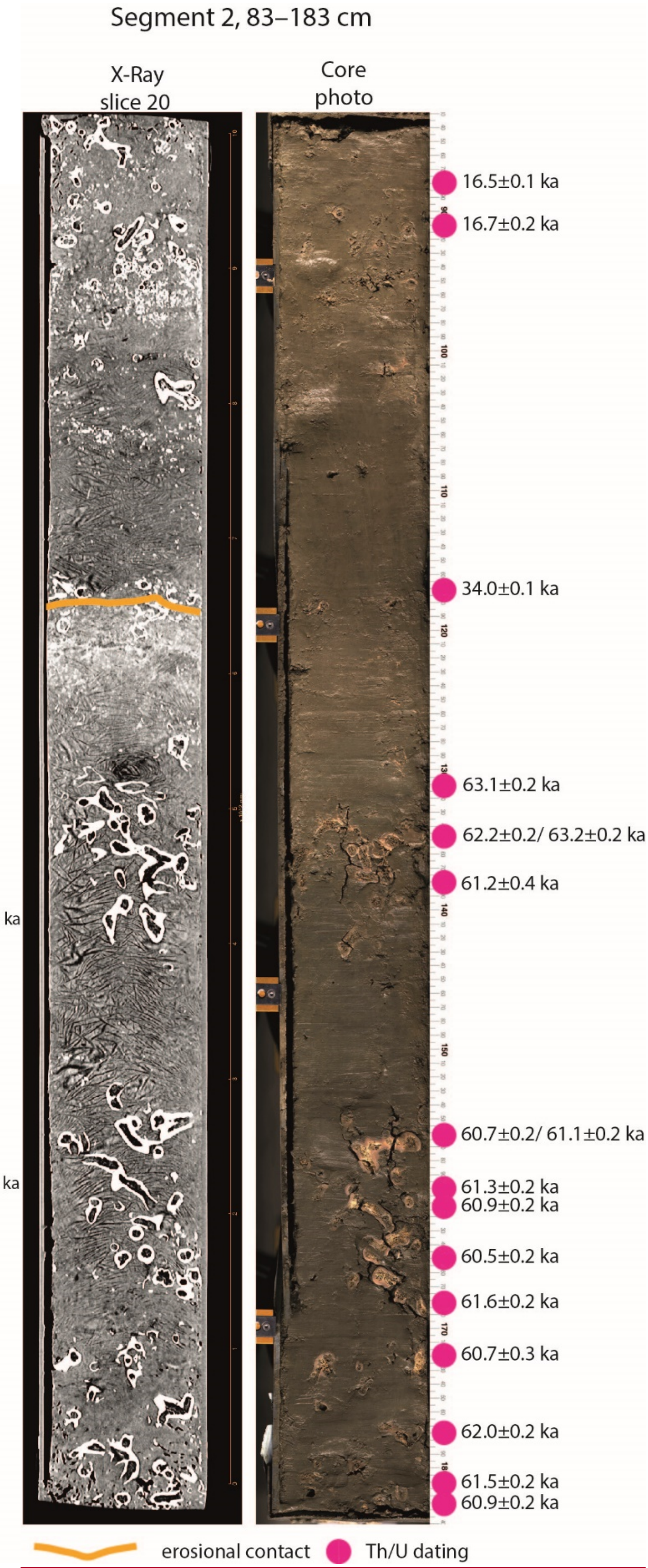
depth (cm)	ln(Alb/Kao)	$\overline{SS}$ (µm)	$\delta^{13}C_{org}$ (‰ PDB)	C_{org}/N	CWC > 7%	inferred class
5	0.01	0.71	0.58	2.03	1	1
15	0.03	-0.61	0.11	0.04	0	0
30	0.64	1.73	0.67	0.20	0	0
40	0.13	1.94	-0.39	0.35	0	0
55	0.06	0.84	-0.95	-0.33	0	0
75	-2.49	0.15	-1.17	0.77	1	1
95	-2.23	0.86	-1.24	0.33	1	1
100	-2.01	0.81	-1.10	0.54	1	1
120	-0.61	1.16	-1.25	0.00	0	1
135	-0.89	-1.07	-0.37	-0.55	1	0
145	-0.26	-1.61	-1.16	0.35	0	0
155	-0.65	-1.30	-1.28	-0.54	1	0
170	-0.22	0.54	-0.91	-0.03	1	0
185	-0.08	-0.85	-0.18	-0.38	1	0
200	0.72	0.53	-0.26	0.06	0	0
235	0.92	0.40	-0.08	-0.60	0	0
245	0.67	0.88	0.95	-0.26	0	0
265	0.72	0.04	-0.49	-0.88	0	0
275	0.29	1.00	-0.71	-0.30	0	0
290	1.53	1.17	-0.09	-1.06	0	0
315	0.55	0.40	1.65	-0.68	0	0
330	1.91	-0.27	0.24	0.25	0	0
345	0.21	-0.72	-0.06	0.86	0	0
400	0.42	0.12	1.12	-0.80	0	0
435	0.20	-0.87	-0.22	-0.88	0	0
450	0.46	0.41	-1.10	-0.59	0	0
470	0.80	-1.26	0.86	-1.13	0	0
485	-1.56	-1.98	0.28	0.42	0	1
505	-0.30	-2.22	-0.04	-0.91	0	0
525	0.13	-2.01	-0.30	-0.13	0	0
545	-0.90	-1.44	1.77	1.21	0	1
560	0.24	0.11	1.03	0.13	1	0
570	-0.43	-0.85	3.52	3.12	1	1
580	-0.72	0.82	1.40	3.17	1	1


Segment 1, 0–83 cm
X-Ray slice 20
Core photo
13.7±0.1 ka
14.3±0.1 ka
16.5±0.1 ka
erosional contact
Th/U dating


Segment 1, 0–83 cm
X-Ray slice 20
Core photo
13.7±0.1 ka
14.3±0.1 ka
16.5±0.1 ka
erosional contact
Th/U dating

Appendix Figure A: CT image (left) and photography (right) of segment 0-83 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U datings with calibrated ages are indicated by magenta dots.



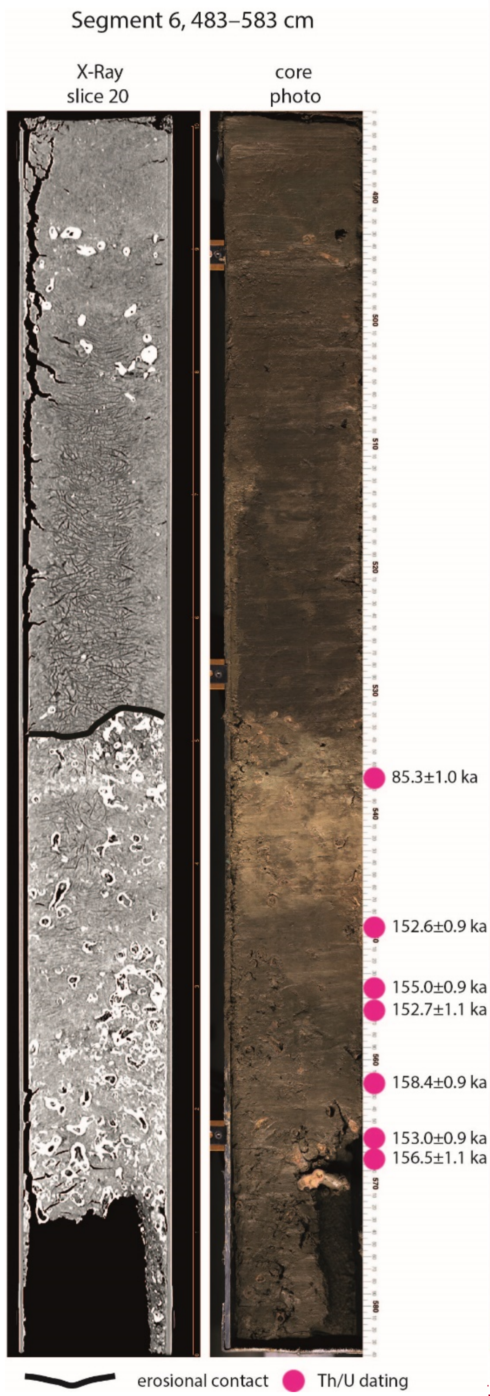


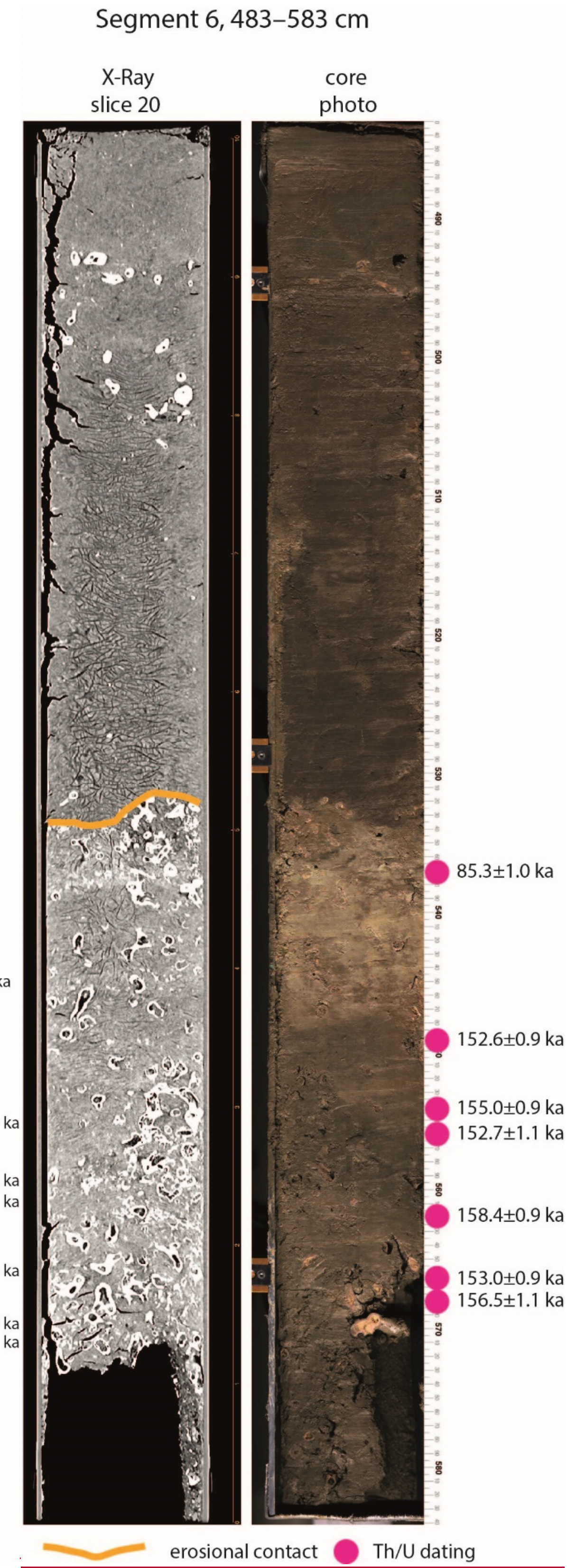
Appendix Figure B: CT image (left) and photography (right) of segment 83-183 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U datings with calibrated ages are indicated by magenta dots.

Appendix Figure C: CT image (left) and photography (right) of segment 183-283 cm of core M125-34-2. Position of Th/U dating with calibrated age is indicated by a magenta dot.

Appendix Figure D: CT image (left) and photography (right) of segment 283-383 cm of core M125-34-2.

Appendix Figure E: CT image (left) and photography (right) of segment 383-483 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U dating with calibrated age is indicated by a magenta dot.





Appendix Figure F: CT image (left) and photography (right) of segment 383-483 cm of core M125-34-2. Erosional contacts are marked by thick black lines, positions of Th/U datings with calibrated age are indicated by magenta dots**.**

Data availability

All data presented in this study will be made available in the Pangaea data base (www.pangaea.de).

Author contribution

AB and JR designed the study. AB, MD, JT, GA, DN, AK, and JR were involved in sampling and data generation. All authors contributed to data interpretation and manuscript writing.

Competing Interests

The authors declare that they have no conflict of interest.

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Monsoonal forcing ~~controlled~~ of cold-~~-~~water coral growth off south-eastern Brazil during the past 160 kyrs

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Abstract. Cold-water corals (CWC) constitute important deep-water ecosystems that are ~~increasingly~~ under increasing environmental pressure due to ocean acidification and global warming. The sensitivity of these deep-water ecosystems to environmental change is demonstrated by abundant paleo-records drilled through CWC mounds that reveal ~~a~~ characteristic alterations between rapid formation and dormant or erosive phases. Previous studies have identified several central parameters for driving or inhibiting CWC growth ~~parameters~~ such as food supply, oxygenation, and the carbon saturation state of bottom water ~~as central for driving or inhibiting CWC growth~~, yet there ~~is~~ are still ~~a~~ large uncertaintiesy about the relative importance of the different environmental parameters. To advance this debate we have performed a multi-proxy study on a sediment core retrieved from the 25 m high Bowie Mound, located at 866 m water depth on the continental slope off south-eastern Brazil, a structure built up mainly by the CWC *Solenosmilia variabilis*. Our results indicate a multi-factorial control on CWC growth ~~and mound formation~~ at Bowie Mound during the past ~160 kyrs, which reveals distinct formation pulses during northern high latitude glacial ~~high northern latitude~~ cold events (Heinrich Stadials, HS) largely associated with anomalously strong monsoonal rainfall ~~continental wet periods~~ over the continent. The ensuing enhanced run-off elevated the terrigenous nutrient and organic matter supply to the continental margin, and ~~might~~ likely have boosted marine productivity. The dispersal of food particles towards the CWC colonies during HS was facilitated by the highly dynamic hydraulic conditions along the continental slope that prevailed throughout glacial periods. These conditions caused the emplacement of a pronounced nepheloid layer above Bowie Mound thereby aiding the concentration and along-slope dispersal of organic matter. Our study thus ~~demonstrates a yet unrecognized~~emphasizes the impact of continental climate variability on a highly vulnerable deep-marine ecosystem.

1 Introduction

Cold-water corals (CWC) are hotspots of biodiversity in the deep-sea (Roberts and Cairns, 2014), important constituents of the deep water carbon cycle (Lindberg and Mienert, 2005; Titschack et al., 2009; White et al., 2012; Cathalot et al., 2015; Titschack et al., 2015, 2016), and potent bio-engineers due to their sediment baffling capacity that allows for enormous sediment accumulation rates of up to 1500 cm/kyr during maximum CWC mound formation phases (Titschack et al., 2015; Wienberg and Titschack, 2017, Wienberg et al., 2018). Yet the ~~fate~~ impact of global climate change on CWC reefs and the associated ecosystems under ~~global climate change~~ is poorly constrained, because the factors driving or inhibiting their ~~formation~~ occurrence ~~as well as~~and the potential thresholds in their resilience to environmental change are still under debate (Hebbeln et al., 2019; Raddatz and Rüggeberg, 2019). Geological records reveal that coral mounds typically exhibit distinct phases of formation, often intercalated by intermittent~~d~~ periods of non-deposition and/or potentially erosion, ~~pointing at~~indicating a high sensitivity of CWCs to changing boundary conditions (e.g., Rüggeberg et al., 2005; Kano et al., 2007; Frank et al., 2011; Raddatz et al., 2014, 2016; Wienberg and Titschack, 2017; Wienberg et al., 2018).

The most common framework-forming CWC comprise of ~~preferences of *S. variabilis*, the dominant framework-building CWC discussed in this study, are still pending. Changes the species~~ *Lophelia pertusa* (recently assigned to the genus *Desmophyllum* by Addamo et ~~l~~al., 2016), *Macropora oculata*, *Solenosmilia variabilis*, *Bathelia candida*, and *Enallopsammia profunda* (e.g., Mangini et al., 2010; Frank et al., 2011; Muñoz et al., 2012; Hebbeln et al., 2014; Raddatz et al., 2020). Field and laboratory studies of *L. pertusa*, the most intensively investigated species, suggest that scleractinian CWC are non-specialists regarding food sources, which ~~may~~ range from particulate to dissolved organic carbon (POC and~~to~~ DOC, respectively) (Kiriakoulakis et al., 2005; Duineveld et al., 2007; Gori et al., 2014; van Oevelen et al., 2016), algae, bacteria, and zooplankton (Gori et al., 2014; Mueller et al., 2014~~; Wienberg and Titschack, 2017~~). However, we note that similar studies on the feeding preferences of *S. variabilis*, the dominant framework-building CWC at the herein investigated Bowie Mound (Raddatz et al. 2020) are still missing. Additionally, changes in the properties and spatial configuration of ambient intermediate- or deep-water masses may also strongly impact CWC through changes in the dissolved oxygen concentration and the seawater parameters pH, alkalinity and carbonate-ion concentration. ~~Note, however, that similar studies in the feeding in the properties and spatial configuration of ambient intermediate- or deep-water masses might have a strong impact on CWC as they alter the dissolved oxygen concentration and also the seawater parameters pH, alkalinity and carbonate-ion concentration.~~ All these parameters affect the capacity of CWC to build their aragonitic framework (e.g., Form and Riebesell, 2012; Maier et al., 2012; Lunden et al., 2014; Hennige et al., 2015; Büscher et al., 2017; Auscavitch et al. 2020). Spatial fluctuations of intermediate- to deep-water masses further influence the depth and strength of pycnoclines, which are thought to play an important role ~~for~~ in the concentration and dispersal of nutrients and food utilized by CWC (Frederiksen et al., 1992; Duineveld et al., 2007; Mienis et al., 2007; Rüggeberg et al., 2016). Aside ~~of~~ from processes directly affecting the water-mass properties bathing CWC, several studies also point ~~at~~ to the importance of sea surface productivity in providing food to the deep ocean ~~importance of surface productivity in providing food that is transported to the deep ocean~~ (Davies et al., 2009; Soetaert et al., 2016). However, despite the proximity of CWC mounds situated on the continental slope to adjacent continents, the role of terrestrial nutrient and POC input is still a matter of debate (Wienberg et al., 2010; Hanz et al., 2019; Fentimen et al., 2020).~~The role of adjacent continents via~~

~~the input of terrestrial nutrients and POC is still a matter of debate considering the proximity of CWC situated on the continental slope to land.~~

To systematically test the relative importance of the diverse factors potentially influencing CWC growth and mound formation, we investigated the response of CWC at Bowie Mound, a coral-bearing mound in the Campos Basin on the continental slope offshore south-eastern ~~SE~~ Brazil (Bahr et al., 2016; Raddatz et al., 2020) to changes in paleoenvironmental conditions. The presence of CWC-bearing mounds off Brazil ~~were~~ was first reported by Viana et al. (1998) and Sumida et al. (2004) along the continental slope at intermediate water depths between 500 to 1000 m, bathed by ~~within the~~ Antarctic Intermediate Water (AAIW). At Bowie Mound, the dominating species is *S. variabilis*, which is ~~adopted~~ adapted to colder (as low as 3-4°C; Fallon et al., 2014; Flögel et al., 2014; Gammon et al., 2018) and less aragonite saturated waters than ~~mounds formed by~~ *L. pertusa* (Thresher et al., 2011; Flögel et al., 2014; Bostock et al., 2015; Gammon et al., 2018).

The selected location at Bowie Mound is ideally suited to ~~test~~ assess~~for~~ a variety of external factors ~~potentially~~ capable of driving CWC growth dynamics as it is situated at the interface of distinctly different water masses (cf. Section 2) and is strongly influenced by terrigenous input from land and the broad shelf off Cabo Frio, which experiences ~~with~~ intense seasonal upwelling. This setting allows us to test the relative importance of different factors that are potentially crucial for the CWC growth at Bowie Mound, in particular (i) intermediate water-mass variability ~~and~~ via its impact on nutrient (e.g., Fe, P, N) concentration, food availability, and local hydrodynamics ~~as well as~~and (ii) variations in nutrients ~~-~~and organic matter fluxes derived from upwelling and terrestrial input in the context of global climatic changes. Our unique set of multi-proxy data combined with Th/U-dated CWC demonstrates ~~for the first time demonstrates~~ that an invigorated continental hydroclimate played a ~~so~~ thus far underestimated role in triggering CWC growth at the south-eastern ~~SE~~ Brazilian margin – a scenario that is likely affecting CWC-mounds worldwide.

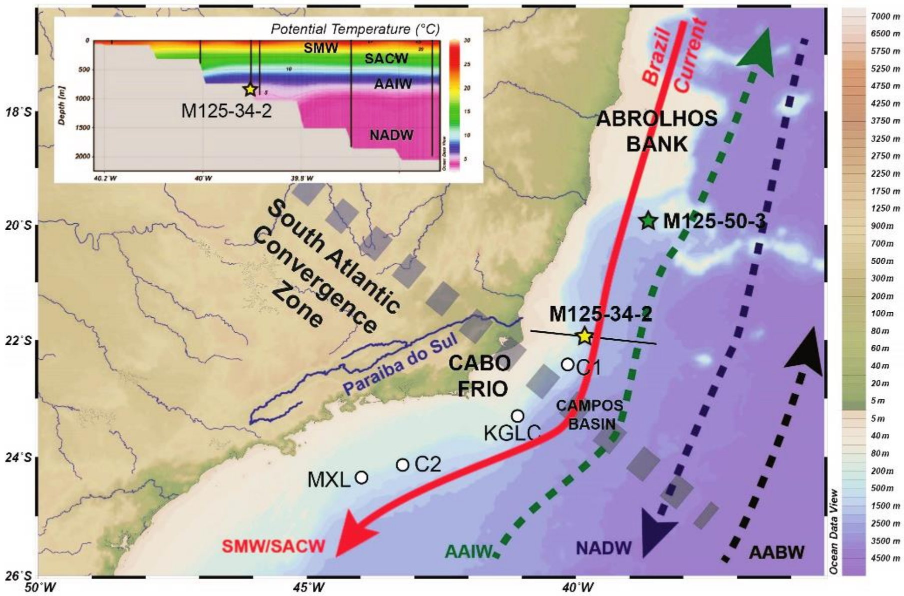
2 Hydrological, climatological and geological setting

The (sub)surface circulation in the western Tropical South Atlantic at the Campos Basin off southeast Brazil is dominated by the southward flowing, warm Brazil Current (BC; Fig. 1). The BC forms the western portion of the anticyclonic subtropical gyre (Stramma and England, 1999), which is characterized by high evaporation rates that ~~lead to the formation of~~ produced the Salinity Maximum Water (SMW, 24ºC, σ_θ ~ 25.2) ~~occupying~~ in the upper 200 m of the water column. The interaction of the BC with the coastal hydrographic system promotes subsurface upwelling of South Atlantic Central Water (SACW) on the shelf edge and on the shelf (Roughan and Middleton, 2002; Aguiar et al., 2014). Upwelling is particularly strong during austral spring and summer when northeasterly winds generating upward Ekman pumping on the mid shelf (Castelao and Barth, 2006; Castelao, 2012), which fuels productivity due to the subsurface encroachment of nutrient-rich SACW. ~~Below the SMW, the~~The SACW is found from below the SMW up to ~~until~~ 500 m water depth and is~~,~~ characterized by decreasing temperatures and salinities (20ºC, 36.0 psu to 5ºC, 34.3 psu; Fig. 1) (Raddatz et al., 2020) owing to its formation in the southwest Atlantic and the South Indian Ocean (Sverdrup et al., 1942; Stramma and England, 1999). The ~~The SACW is underlain by the Antarctic Intermediate Water (~~AAIW (~~;~~ 34.3 PSU, ~4°C; Fig. 1) lies below the SACT and above ~~(Fig. 1).~~ North Atlantic Deep Water (NADW) which is present~~is found~~ below 1100 m water depth and has~~with~~ higher oxygen concentrations and salinities compared to AAIW (Mémery et al., 2000). Below ~2500 m the Antarctic Bottom Water (AABW) constitutes the deepest and most dense water mass in this region (Stramma and England, 1999) ~~in this region~~.

The interaction between the north- or southward-directed flow of the different water masses with the morphology of the slope at Campos Basin ~~causes the formation of~~froms strong geostrophic currents (Viana and Faugères, 1998; Viana et al., 1998; Viana, 2001). These currents are responsible for enhanced sediment focusing leading to the formation of drift bodies, while internal waves at the boundary between different water masses create wide-spread erosional surfaces (Viana et al., 1998, 2001).

Bowie Mound itself has a total elevation of 25 m and is situated ~~s~~ within a field of mound-like structures, which are ~~at~~ presently barren of living framework-forming CWC ~~colonies~~ (Bahr et al., 2016). Located ~~With~~ at~~a water depth of~~ 866 m water depth, it lies within the core of the AAIW. Hence, it can be expected that changes in the nutrient and organic matter inventory of the AAIW (Poggemann et al., 2017) and/or displacement of the intermediate water mass may have had a direct impact on the hydrodynamic conditions at Bowie Mound.

The Campos Basin receives freshwater and sediment input primarily from the Paraíba do Sul River, which delivers between 180 to 4400 $m^3 s^{-1}$ water (Carvalho et al., 2002) and 30 t yr^{-1} of sediment ~~load~~ (Jennerjahn et al., 2010) to the study area. Most precipitation in the hinterland of the Paraíba do Sul River occurs during austral summer, when strong atmospheric convection forms the South Atlantic Convergence Zone, an elongated band of heavy precipitation that reaches from central Amazonia into the tropical South Atlantic (Carvalho et al., 2004; Marengo et al., 2012) (Fig. 1).



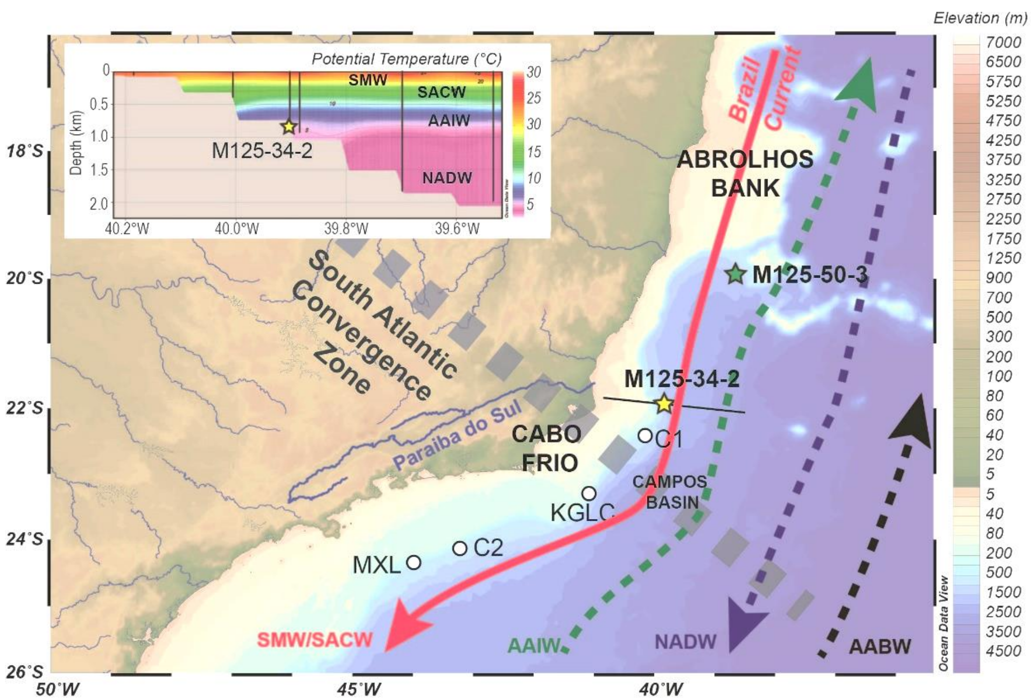


Fig. 1 Location of core M125-34-2 (yellow star) on Bowie Mound, reference core M125-50-3 (green star) and other CWC records published in Mangini et al. (2010) and Ruckelshausen (2013) (white dots). Major surface (red line), intermediate (green) and deep-water circulation features (blue) and water masses are indicated as well as the approximate location of the South Atlantic Convergence Zone (stippled line) as the main atmospheric feature. Inset shows a hydrographic section crossing the location of Bowie Mound core M125-34-2 with potential temperatures as measured via CTD (black lines) during R/V METEOR Expedition M125 (Bahr et al., 2016; Raddatz et al., 2020); the location of the hydrographic section is indicated by a black line in the map. Figure modified after Raddatz et al. (2020). AABW – Antarctic Bottom Water, AAIW – Antarctic Intermediate Water, NADW – North Atlantic Deep Water, SACW – South Atlantic Central Water, SMW – Salinity Maximum Water.

3 Material and Methods

3.1 Material

Gravity core M125-34-2 was retrieved during R/V METEOR cruise M125 from the top of the 25 m high Bowie Mound in 866 m water depth at 21°56.957'S and 39°53.117'W (exact positioning was secured by the Ultra-Short-Baseline system POSIDONIA; Fig. 1;~~,~~ Bahr et al., ~~2017~~2016). The core was cut into 1 m segments onboard and stored unopened at -20°C. After CT-scanning, the core was opened in the frozen state (for details on the CT-scanning cf. Skornitzke et al., 2019; Raddatz et al., 2020). Discrete samples for X-ray d~~D~~iffractometry (XRD), grain-size analyses, C and N content, and stable carbon and oxygen isotope analyses of foraminifera and organic matter were taken from the sediment matrix avoiding the sampling of coral fragments. X-ray ~~F~~fluorescence (XRF) scanning was performed on the archive halves~~ve~~, while avoiding coral segments when defining the sampling path of the detector.

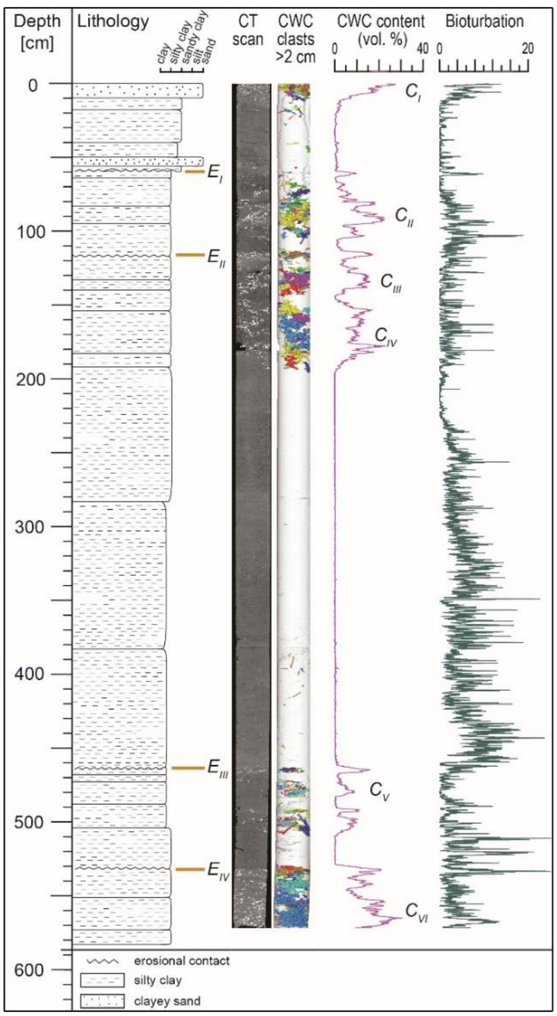


Fig. 2. Lithological log of Core M125-34-2 (21°56.957'S, 39°53.117'W, 866 m water depth) including CT-scanning image and CWC clasts >2 cm, CWC content and bioturbation index. Erosional surfaces E_I–E_{IV} are indicated as well as CWC-bearing intervals C_I–C_{VI} after Raddatz et al. (2020).

~~The~~ C~~c~~ore M125-34-2 (Fig. 2) consists of moderately to strongly bioturbated olive grey to dark grey, silty clayey sand with ~~an~~ alterati~~o~~ng ~~of~~ coral-bearing and coral-free zones (Raddatz et al., 2020). The sediments are rich in micro- and macrofossils including pteropods, bivalves as well as benthic and planktonic foraminifers. Six intervals (C_I–C_{VI}) ~~with~~ of particularly high coral contents of up to 31 vol.% were identified within the core ~~located between~~at 0–13 cm, 80–

105 cm, 131.5–138 cm, 157–190 cm, 479.5–480.5 cm, and 549.5–568 cm (Fig. 2; Raddatz et al., 2020) (Fig. 2). Coral-bearing intervals are characterized by the presence of *S. variabilis* and to a minor degree *M. oculata* as the major macrofossils (clast length >2 cm). Visual inspection and CT imaging (Appendix Figures A-F) reveal four prominent erosive surfaces (E_I–E_{IV}) with abundant coral fragments and shell debris at 58 cm, 117 cm, 465 cm, and 532 cm (Fig. 2).

For To constraining the chronostratigraphy of core M125-34-2 and to assess the intermediate-water variability, adjacent core M125-50-3 (19°56.957'S; 38°35.979'W; 904 m water depth; Fig. 1) was sampled in at 10 cm intervals for $\delta^{18}O$ analyses. Core M125-50-3 is barren of CWC and consists of bioturbated, greenish-grey hemipelagic mud with darker and lighter intervals. Two sandy, foraminifera-rich layers at 1226 and 1230 cm might point at to periods of condensed sedimentation, otherwise no unconformities or erosive surfaces could be identified.

3.2 Quantitative interpretation analysis of CT-scanning data

Prior to opening, the sediment core sections were scanned with a SOMATOM Definition Flash computer tomograph at the Clinic of Diagnostic and Interventional Radiology (DIR) of Heidelberg University Hospital, Heidelberg, Germany, with 140 kVp tube potential and 570 mAs tube current – time product with a pitch of 0.4 (for details see Skornitzke et al., 2019). The raw data with a resolution of 0.5 mm in z-orientation and 0.3 mm in xy-orientation was reconstructed iteratively (ADMIRE, Siemens Healthineers) using a sharp kernel (I70 h level 3) to an isotropic voxel size of 0.35 mm. Further data processing was carried out with the ZIB edition of the Amira software (Stalling et al. 2005; http://amira.zib.de). Within Amira, the core sections were virtually reunited and the core liner and marginal coring artefacts were removed (~2 mm of the core rim). Furthermore, coral clasts were segmented and separated with the ContourTreeSegmentation module (threshold: 1400; persistence value: 1150) and, quantified. M and macrofossils >2 cm were visualized as surfaces in 3D following the methodology of Titschack et al. (2015). As an index for bioturbation, we determined the standard deviation of the matrix sediment X-Ray attenuation within each XY-oriented CT slice. The matrix sediment was segmented by selecting the data volume surrounding the corals, removing areas with values <500 HU (considered to represent air and water) and reducing the remaining segmented volume by three voxels to avoid marginal artefacts in the Xx-Rray attenuation caused for example by the resolution depending averaging effect.

3.3 X-Ray fluorescence (XRF) scanning

XRF core scanning was performed on the archive halvesve of the split split core. All segments of core M125-34-2 were scanned at the Heidelberg University, using an Avaatech 4th generation(GEN4) XRF Core Scanner. XRF core scanner data were collected every 1.0 cm down-core with a 1.2 cm cross-core slit size. The split core surface was cleaned and covered with a 4 micron µm thin SPEXCerti Prep Ultralene1 foil to avoid contamination of the XRF measurement unit. Core intervals with very abundant corals had towere be skipped to avoid damage ofing the foil covering the detector through sharp and rigid edges of coral fragments. Data waser e collected in two separate runs using generator settings of 10 and 30 kV and currents of 0.2 and 1.0 mA, respectively. Sampling time was set to 20 seconds per measurement. To counteract artifacts derived from variations in sediment porosity, water content and surface roughness, element counts were normalized by dividing the value of the component (C) by the sum of the counts for each depth (Bahr et al., 2014).

3.4 X-Ray diffractometry (XRD)

About 9 g of wet material was dried in an oven at 40°C and subsequently milled in a ball mill (Pulverisette, FRITSCH), with 300 cycles per sec for 3 minutes to obtain a powder with a grain size of 1-3 ~~micrometres~~µm. The XRD measurements were ~~done~~ carried out at ~~the Heidelberg University~~the~~,~~ ~~Department~~ Institute of Earth Sciences~~of Geosciences~~, Heidelberg University, using a Bruker, D8 ADVANCE Eco diffractometer (40 kV, 25mA) with a Cu Kα diode. The samples were measured in rotating, circular, synthetic sample holders. An angular range of 2θ from 5° to 70° was measured with a step size of 0.02 increments (3338 steps per sample) for 1 sec per step. Peak positions and intensity of data were~~as~~ analyzed with Diffract Suite EVA (Bruker Software). The Rietveld refinement program DIFFRAC.TOPAS (Bruker Software) was used to perform quantitative phase analysis~~For quantitative phase analysis the Rietveld refinement program DIFFRAC.TOPAS (Bruker Software) was used~~.

3.5 Grain-size analysis (Sortable Silt, $\overline{SS}$)

The preparation of the samples for the $\overline{SS}$ analyses followed Bianchi et al. (2001) and Stuut et al. (2002). Wet samples with a weight between 0.3 and 1 g were dried over night at 40 °C. Macroscopically visible coral fragments were removed. After weighting the dry samples, 10 ml of 30 % H_2O_2 were added to each sample to dissolve the organic material under sub-boiling conditions on a heating plate until the reaction ceased. To remove carbonates, 5 ml HCl (10 %) were added to each sample under sub-boiling conditions for at least 10 minutes until the end of the reaction. Samples were washed through standard sieves (63 µm mesh size) to remove the sand and coarser fraction. The fraction >63 µm was dried at 40°C and weigh~~t~~ed. The material <63 µm was transferred into 1 L beakers and~~,~~ filled ~~until capacity~~to the top with demineralized water. After a settling period of at least 8 hours (h), the supernatant water was decanted, and the sample transferred into a 200 mL beaker, topped with demineralized water and settled for 8 h. After decanting supernatant water, the sampled were~~as~~ transferred into ~~a~~ 50 mL plastic beakers and~~,~~ put into an ultrasonic bath to disintegrate aggregated sediment particles. Afterwards, 35 ml Na-Pyrophosphate was~~ere~~ added to prevent particles from forming new aggregates and 2 ml isopropyl alcohol ~~to keep~~minimize the formation of air bubbles in the liquid ~~to a minimum~~. Samples were measured with a Laser Particle Sizer (LPS) ANALYSETTE 22 by FRITSCH™ at the Institute of Earth Sciences, Heidelberg University, in wet dispersion covering the range 0.08-2000 µm with 99 size classes. ~~For analysis~~T ~~of t~~he raw data was analyzed with the software MaScontrol (FRITSCH™) ~~was~~ by~~used~~ applying a Fraunhofer model. Results are derived from a total of five analytical runs ~~à~~ with 100 scans per sample. Up to seven replicate samples were performed for each depth to minimize the natural variability of the samples. While there is~~The high number of replicates resulted from a~~ relatively large inter-sample variability that is likely caused by the high amount of mica flakes present in the sediment distorting the laser beam, w~~. W~~e nevertheless consider the results retrieved via the ANALYSETTE 22 as reliable (for an in-depth discussion see Jonkers et al., 2009).

3.6 Carbon and nitrogen content

Sediment samples were homogenized with a mortar and pestle and then weighted (0.5 mg for each analyses). The total organic carbon (TOC) and inorganic carbon (TIC, together TC) content was analyzed with a LECO RC-412 (Institute of Geoscience, Goethe University Frankfurt). The reproducibility of the replicate analyses was < ~~±~~ 0.1 %. The total nitrogen (TN) content was analysed with a LECO TruSpec Macro (Institute of Geoscience, Goethe University Frankfurt).

3.7 Stable oxygen and carbon analysis

3.7.1 Stable isotope analysis of foraminiferal calcite

For stable isotope analyses of core M125-34-2, samples were taken at 5–10 cm intervals, wet-sieved (>63 µm) and then dried ~~afterwards~~. For each sample 1–3 tests of *Uvigerina* spp. (*U. peregrina* and *U. proboscidea*) or *Planulina wuellerstorfi* were selected from the size fraction >125 µm, depending on availability. Stable carbon and oxygen isotope ratios were measured on a Thermo Fischer MAT 253 Plus IRMS gas isotope ratio mass spectrometer with coupled Kiel IV automated carbonate preparation device at the Institute of Earth Sciences, Heidelberg University. The instrument was calibrated using the in-house standard (Solnhofen limestone), ~~itself~~ which is calibrated against the IAEA-603. V~~; v~~alues are reported versus the VPDB (Vienna Peedee Belemnite) standard. Standard deviations derived from repeated measurements of the internal standard are ±0.06 ‰ for stable oxygen isotopes (~~-~~$\delta^{18}O$) and ±0.03 % for stable carbon isotopes ($\delta^{13}C$).
The ~13 m long core M125-50-3 was sampled ~~each~~ every ~10 cm for benthic foraminiferal isotope ~~studies~~analysis. The samples were freeze-dried and washed through a >63 µm sieve to separate the coarse ~~fraction from~~and ~~the~~ fine fractions. Specimens of the benthic genera *Uvigerina* spp. were hand-picked from the size fraction 315–400 µm. ~~Stable oxygen (~~$\delta^{18}O$~~) isotope~~ analyses were performed on a ThermoScientific MAT 253 mass spectrometer with an automated Kiel IV Carbonate Preparation Device at GEOMAR. The isotope values are calibrated versus the NBS19 (National Bureau of Standards) carbonate standard and the in-house "Standard Bremen" (Solnhofen limestone). Isotope values presented in the delta-notation are reported in permil (‰) relative to the VPDB scale. The analytic error is ±0.06 ‰ for $\delta^{18}O$ and ±0.03 ‰ for $\delta^{13}C$.

3.7.2 Stable isotope analysis of organic matter

Previously homogenized samples were decarbonized with 10 % HCl to remove all inorganic carbon. Afterwards, the samples were centrifuged and washed several times with deionized water in order to remove residual HCl. The samples were then dried in an oven at 50 °C. Subsequent analyses of the carbon isotopic composition of organic carbon ($\delta^{13}C_{org}$) was performed by a Flash Elemental Analyzer 1112, connected to the continuous flow inlet system of a MAT 253 gas source mass spectrometer (Institute of Geosciences, Goethe University Frankfurt). Samples and standards both reproduced within ±0.2‰ and are reported relative to the VPDB standard.

3.7 Statistical analysis

Correlation coefficients and associated p-values were calculated using the Monte-Carlo-based SurrogateCorr function implemented in the "astrochron" package in R (Meyers, 2014) with 1000 iterations. This method has been particularly developed to assess the correlation of parameters sampled on different down-core resolutions (e.g. XRF scanning data *vs*. discrete grain size measurements;~~) (~~ Meyers, 2014).

Discriminant analysis was performed with the program PAST (v3.15) (Hammer et al., 2001). Prior to analysis, the data was detrended and normalized to the mean and standard deviation.

4. Age model refinement

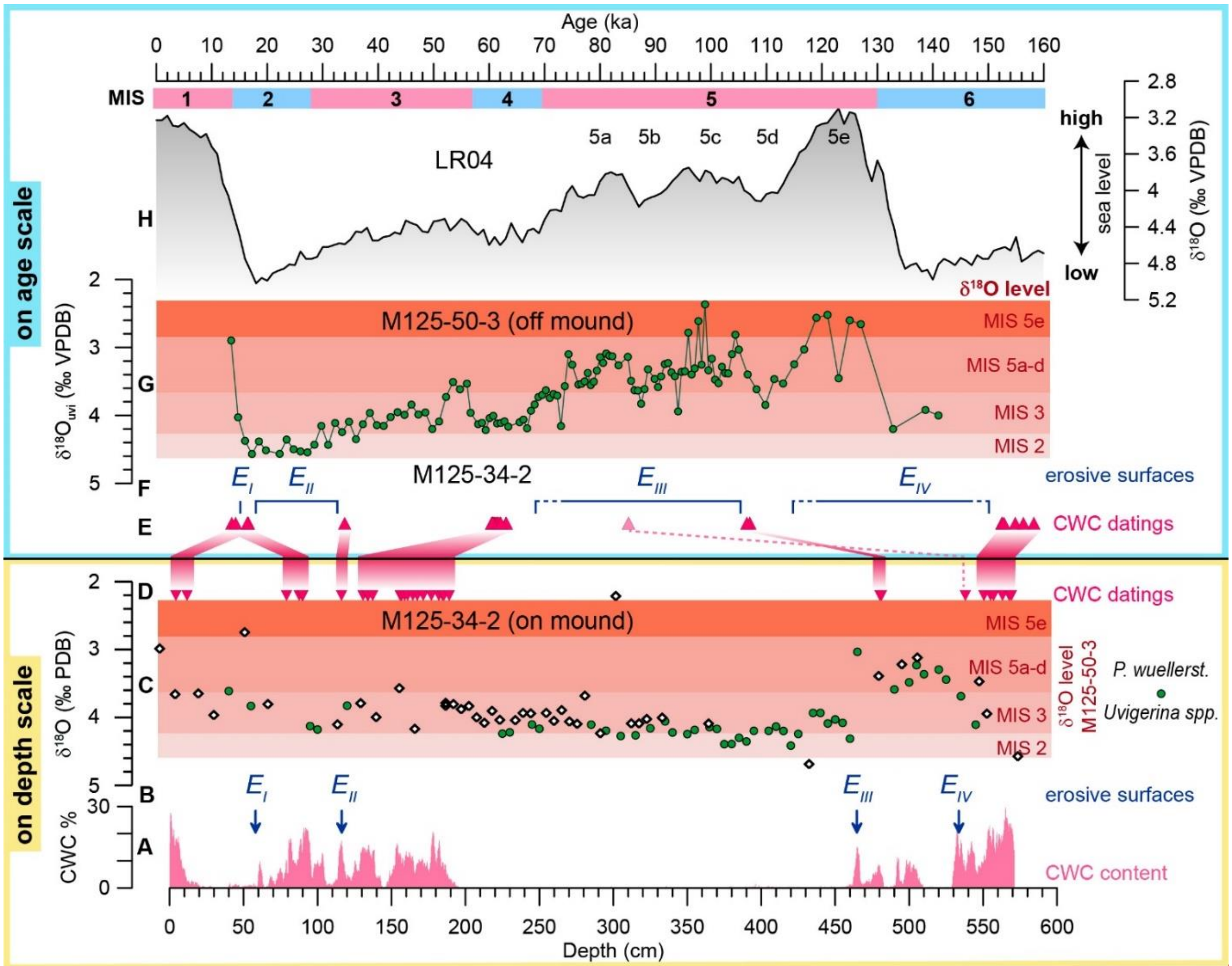
The age model of core M125-34-2 used in this study represents a refined version of the stratigraphy published in Raddatz et al. (2020), which is based on ^{230}Th/U dates of CWCs. The six coral-bearing intervals, as described in Section 3.1, exhibited a mean accumulation rate of 30 cm kyr^{-1} with an overall range from 2 cm kyr^{-1} (C_V) to 80 cm kyr^{-1} (C_{III}) (Raddatz et al., 2020).

To better constrain the age of CWC-barren intervals and evaluate the chronostratigraphic duration of potential hiatuses, we compared the $\delta^{18}O$ record of c~~C~~ore M125-34-2 with the benthic isotope record of adjacent c~~C~~ore M125-50-3. The clear glacial-interglacial pattern of $\delta^{18}O_{Uvi}$ in ~~Core~~ core M125-50-3 allows ~~to construct~~for the construction of a robust age model for this site by tuning its benthic isotope record to the LR04 benthic stack (Lisiecki and Raymo, 2005) and ~~,~~ indicates~~ing~~ that it extends~~reaches down~~ to ~135 ka (Fig. 3). Its stratigraphic range is thus only slightly shorter than the one of M125-34-2 (158 ka based on Th/U dates) and is therefore suitable as an off-mound reference site. As both cores are situated in similar water depths and are thus bathed by the same water mass (today the AAIW, see Section 2), we expect the respective $\delta^{18}O$ values ~~not only~~ to not only follow a common glacial/interglacial pattern but also to be comparable in their absolute values, allowing for~~to~~ further constraining the chronostratigraphy of M125-34-2.

As neither shallow infaunal *Uvigerina* spp. and epibenthic *P. wuellerstorfi* were consistently present throughout core M125-34-2, we generated a spliced record of both species. For the $\delta^{18}O$ splice we corrected values of *P. wuellerstorfi* by adding the correction factor of +0.47 ‰ according to Marchitto et al. (2014). The resulting ~~ant~~ combined $\delta^{18}O$ record of M125-34-2 exhibits a considerable scatter ~~in lithological Unit 1~~from the top to erosive horizon E_I including relatively depleted ~~$\delta^{18}O_{cib}$~~ $\delta^{18}O_{Plan}$ values as low as 2.5 ‰ (Fig. 3), which puts this ~~unit~~ interval into a transitional phase between glacial and interglacial $\delta^{18}O$ levels. Neither $\delta^{18}O$ values nor absolute dating supports the preservation of Holocene deposits at the top of the gravity core. A deglacial age for the deposition of this interval ~~Unit 1~~ is further corroborated by Th/U dates of 13.7 to 14.3 ka, respectively. Samples from between E_I and E_{II} ~~Unit 2 has~~show slightly heavier $\delta^{18}O$ values ~~than Unit 2~~ and Th/U dates clustering around 16.5 ka, which indicates a post-LGM deposition. The existing Th/U dates suggest that the hiatus represented by the erosive unconformity ~~between Units 1 and~~E_I~~-2~~ is most likely shorter than 2 kyr. ~~Unit 3~~The section between E_{II} and E_{III} on the other hand has relatively uniform $\delta^{18}O$ values ~~that cluster~~ around 4.3 ‰ ($\delta^{18}O_{Uvi}$) and 3.4 ‰ ($\delta^{18}O_{Plan}$~~cib~~), respectively, which matches M125-50-3 $\delta^{18}O_{Uvi}$ values during MIS 4~~2~~ to 2~~4~~. ~~The age of the top of Unit 3 is relatively well defined by~~A Th/U date~~s~~ at the top of this section at 117 cm reveals an age of 34 ka, while CWC ages from slightly deeper in the core (between 131-190 cm) fall within the range of 60–63 ka (MIS 4).~~ and older while its base lacks any absolute dating.~~ As ~~values of~~ $\delta^{18}O_{Uvi}$ ~~o~~values between E_{II} and E_{III} ~~f Unit 3~~ are ~~more~~ less depleted than ~~MIS 2 values but less than~~ MIS 5 samples of reference site M125-50-3, we infer that ~~lithological Unit 3~~those sediments were ~~was~~ most likely deposited during ~~MIS 3 and potentially~~ MIS 4 ~~but~~ and did not reach into MIS 5. Hence, i~~I~~t hence appears that ~~MIS 2~~ deposits of MIS 2 and large parts of MIS 3 are not present in core M125-34-2, either due to non-deposition or subsequent erosion (note the prominent erosive surface between Units 2 and 3E_{II}). This age assignment would also imply that the extended CWC-free portion of Unit 3 from 200 to 465 cm has beenwas deposited within a short period of approximately 8 kyr during MIS 4 (62.20 ka as the oldest Th/U dates and ~70 ka as the MIS 4/5 boundary). This would yield a sedimentation rate of 33 cm kyr^{-1} (Fig. 3A), which is typical for contouritic sediments as common at the south-eastern Brazilian margin (Viana et al., 1998; Hernández-Molina et al., 2014; Rebesco et al., 2014). The following interval between E_{III} and E_{IV} Unit 4 has relativelydistinctively more depleted $\delta^{18}O_{Uuvi}$ values that fall into values in the range of MIS 5a–d values in reference core M125-50-3, but less depleted as those of MIS 5e.. Th/U dates of ~107 ka forof CWC at the top of Unit 4below E_{III} support a deposition duringof this Unit in MIS 5d and further indicate a prolonged interval of non-deposition or erosion leading to the absence of MIS 5a-c in core M125-34-2. As $\delta^{18}O$ values below E_{IV} of Unit 5 are again on glacial levels, this unit section can be assigned to MIS 6 which is in line with Th/U dates of 152.6–158.4 ka. Hence the penultimate interglacial MIS 5e is likely not recovered and falls into the hiatus between Units 4 and 5represented by E_{IV}.

In summary, deposition at Bowie Mound site M125-34-2 appears to be concentrated during glacial intervals of intermediate ice volume and reduced during interglacial periodsIn summary, deposition at Bowie Mound core M125-34-2 appears to be focused on glacial intervals of intermediate ice volume, such as MIS 3, contrary to the reduced presence in interglacial deposits.

The erosive horizons present in core M125-34-2 caused by winnowing due to strong current activity and internal waves provide evidence for extreme variability in the hydrological regime at the south-eastern Brazilian Margin (Viana and Faugères, 1998; Viana et al., 1998; Viana, 2001), produced by winnowing due to strong current activity and internal waves. While winnowing has the capacity to remove the sediment matrix leading to lag deposits, it is rather unlikely that it would also remove coral fragments. Hence, it is feasible to assume that the dated intervals of CWC presence represent the complete sequence of CWC presence at this part of Bowie Mound.



on age scale
on depth scale
Age (ka)
MIS
LR04
5a
5b
5c
5d
5e
high
low
sea level
δ18O (‰ VPDB)
δ18O level
M125-50-3 (off mound)
MIS 5e
MIS 5a-d
MIS 3
MIS 2
δ18Ouvi (‰ VPDB)
M125-34-2
erosive surfaces
CWC datings
M125-34-2 (on mound)
δ18O (‰ PDB)
δ18O level M125-50-3
P. wuellerst.
Uvigerina spp.
CWC %
CWC content
Depth (cm)

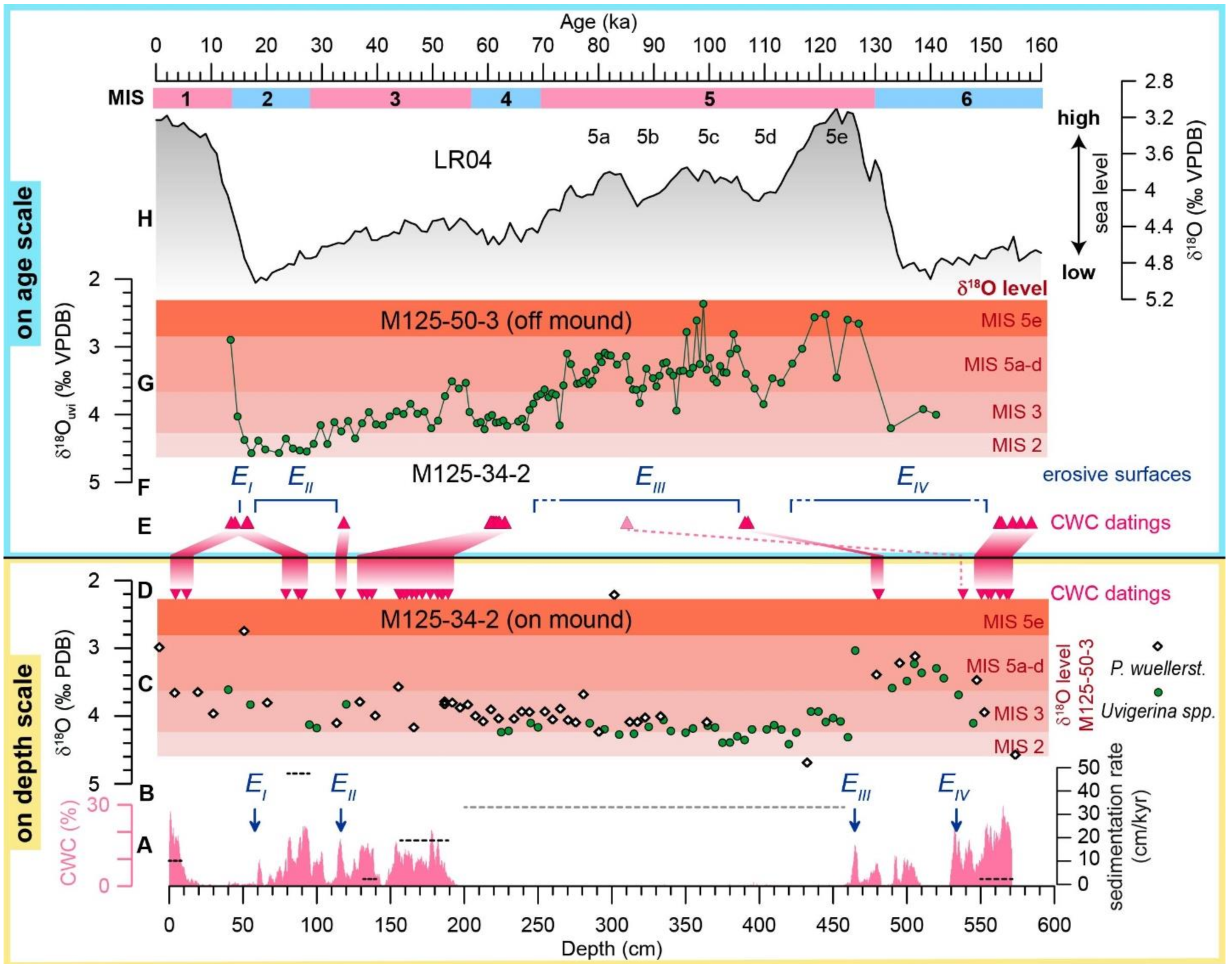


Fig. 3 Refined age model of c~~C~~ore M125-34-2 from Bowie Mound. Lower panel displays data from M125-34-2 on depth scale, comprising (A) CWC abundances (%; magenta) based on CT-scanning and accumulation rates for both, the Th/U-dated CWC bearing intervals (black dashed lines; cf. Raddatz et al., 2019) and the CWC-barren interval between 200–465 cm (grey dashed line);~~;~~ (B) blue arrows denote erosive horizons (hiatuses)~~; (B) erosive horizons~~ E_I–E_{IV} (cf. Fig. 2); (C) benthic $\delta^{18}O$ data from *Uvigerina* spp. (green dots) and *P. wuellerstorfi* (white diamonds; elevated by +0.47 to adjust for the interspecies offset to *Uvigerina* spp. after~~(~~ Marchitto et al., 2014~~)~~); red horizontal shadings indicate reference $\delta^{18}O$ levels for the respective Marine Isotope Stages (MIS) taken from off-mound core M125-50-3 (see panel G); (D) red triangles mark Th/U datings. The upper panel displays data in the time domain, with (E) Th/U dates of M125-34-2; (F) the inferred duration of hiatuses reflected by erosive horizons E_I–E_{IV} of core M125-34-2; (G) the $\delta^{18}O$ record on *Uvigerina* spp. on off-mound core M125-50-3 with red horizontal shadings illustrating the $\delta^{18}O$ level during different isotope stages as used in panel (C); (H) the LR04 benthic stack (Lisiecki and Raymo, 2005) as an approximation for eustatic sea-level changes; Marine Isotope Stages (MIS) are indicated by pink and blue bars signifying relatively warm and cold periods, respectively.

5. Results and Discussion

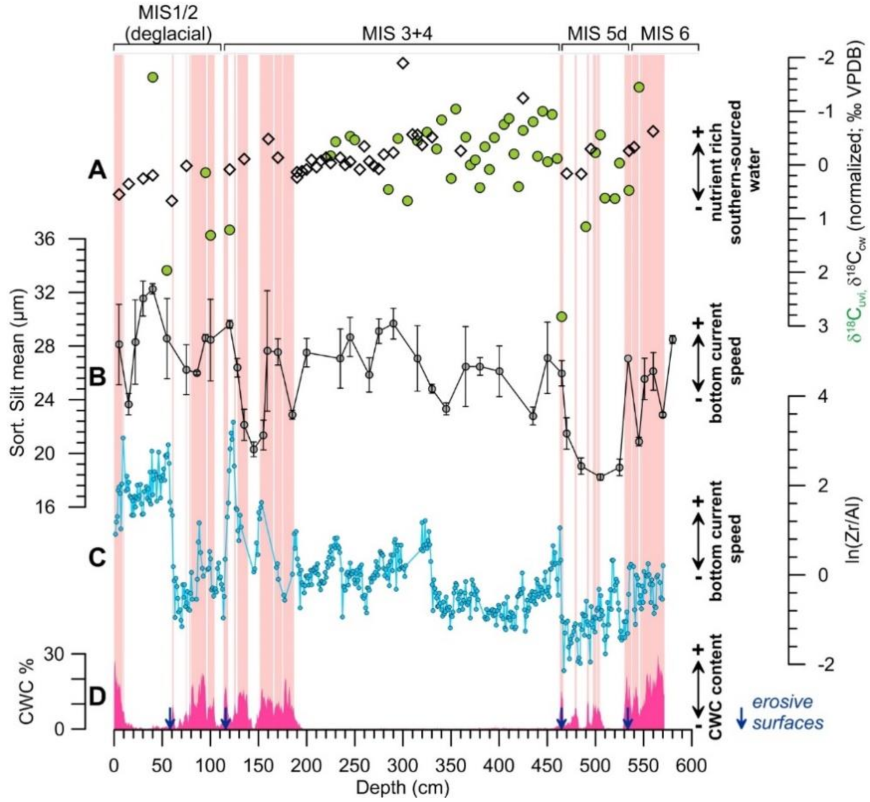
In the following we discuss if and how changes in environmental parameters might have enhanced or prohibited CWC growth at Bowie Mound, focusing on the role of intermediate water-mass variability and varying terrigenous sediment supply. We argue that the most dominant environmental factor for triggering CWC growth was elevated river run-off during -periods of strong monsoonal rainfall in the coastal hinterland, which provided nutrients and organic matter that enhanced the food supply of CWC colonies.

5.1 Drivers and inhibitors of CWC growth at Bowie Mound

5.1.1 Intermediate water mass properties and hydraulic dynamics

Intermediate water-~~-~~mass properties ~~might~~ may have played a crucial role for the development of Bowie Mound. First, Bowie Mound lies within the ~~nutrient-rich~~ AAIW, which ~~might~~ probably~~have~~ boosted CWC growth at the East Brazilian slope. Secondly, nutrients and POC typically concentrate within nepheloid layers at water mass boundaries and provide a prolific food source for CWCs (Mienis et al., 2007; Dullo et al., 2008; Raddatz et al., 2014; Rüggeberg et al., 2016; Magill et al., 2018). In the case of Bowie Mound, it is possible ~~might thus be suspected~~ that enhanced production (Pahnke and Zahn, 2005; Pahnke et al., 2008) and/or nutrient-enrichment ~~(i.e~~(e.g.~~,~~ increasing phosphate and nitrate concentration) of the AAIW (Poggemann et al., 2017) during phases of weak Atlantic Meridional Overturning Circulation (AMOC) could have triggered its episodic formation phases. A more prominent AAIW ~~might have further~~likely also strengthened internal waves hitting the slope at the AAIW/SACW boundary in the Campos Basin (Viana et al., 1998; Viana, 2001) and thus fueled the nepheloid layer by enhanced resuspension.

Here, we use the benthic $\delta^{13}C$ obtained on M125-34-2 as an indicator of the relative contribution of~~ nutrient-rich (hence,~~ ^{13}C depleted~~)~~ southern-sourced intermediate water masses (Kroopnick, 1985; Curry and Oppo, 2005). As we had to use different species (shallow infaunal *Uvigerina* spp. and epibenthic ~~C~~*P*. *wuellerstorfi*), we combined both records. To adjust for intra-species offsets, we followed the approach of Kaboth et al. (2017) and normalized the $\delta^{13}C$ values of each species to the respective mean and standard deviation. The resulting~~ant~~ normalized data exhibits a considerable scatter in the *Uvigerina* spp. record due to the pooling of different species, and hence only allows for a discussion of major shifts in the isotopic composition. However, ~~, although exhibiting a considerable scatter,~~the $\delta^{13}C$ data of *Uvigerina* spp. and *P. wuellerstorfi* do not provide compelling evidence for distinctly depleted values during phases of CWC growth compared to CWC-barren intervals (Fig. 4). ~~Albeit~~ Although ~~the~~ $\delta^{13}C_{Uvi}$~~ of *Uvigerina* spp.~~ might be influenced by isotopic variations of dissolved inorganic carbon of pore-water (Zahn et al., 1986) and inter-species offsets (Rathburn et al. 1996; Theodor et al., 2016), we nevertheless consider it as appropriate ~~to~~ for reconstructing ~~profound~~ major changes in the bottom-water signature. Even when only considering ~~the~~ $\delta^{13}C_{Plan}$~~ values obtained on epibenthic *C. wuellerstorfi*~~, there are no apparent systematic difference between CWC-bearing and CWC-barren intervals~~ becomes apparent~~. The continuous, monospecific~~ *Uvigerina* spp.~~ $\delta^{13}C_{Uvi}$ record obtained on off-mound core M125-50-3 ~~also~~ likewise lacks negative excursions during times of CWC growth at Bowie Mound (Fig. 5C). Hence, it appears that changes in the nutrient or organic matter content of the AAIW as observed during the last deglaciation (Poggemann et al., 2017) did not significantly affect CWC growth.



MIS1/2
(deglacial)
MIS 3+4
MIS 5d
MIS 6
A
B
C
D
nutrient rich southern-sourced water
bottom current speed
bottom current speed
CWC content
erosive surfaces
Sort. Silt mean (µm)
CWC %
δ18C_uvi, δ18C_cw (normalized; ‰ VPDB)
ln(Zr/Al)
Depth (cm)

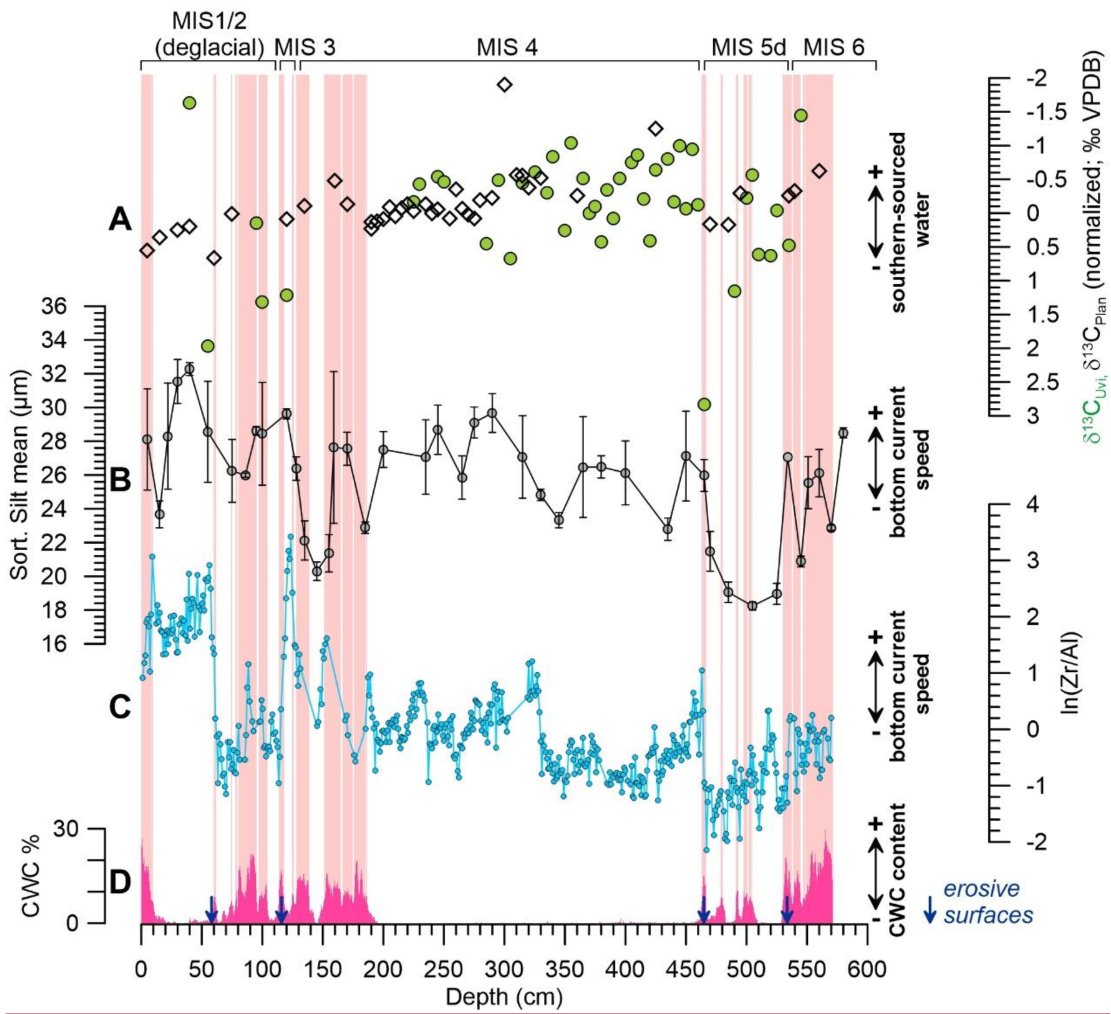
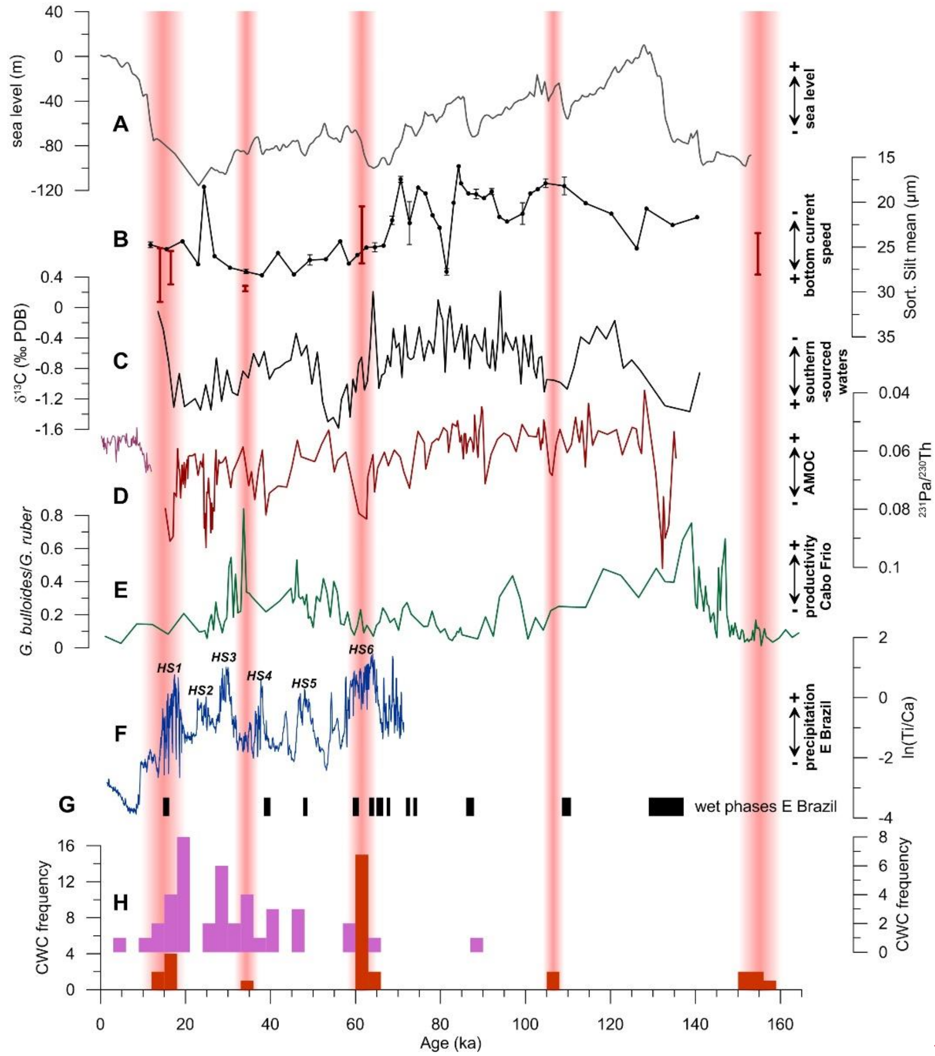


Fig. 4 Proxies of intermediate water mass variability *vs*. phases of mound formation obtained on ~~Core~~ core M125-34-2. (A) normalized $\delta^{13}C$ of *Uvigerina* spp. (green dots) and *P. wuellerstorfi* (white diamonds) as a proxy for bottom water-~~-~~mass origin~~ and nutrient level~~, (B) mean sortable silt ($\overline{SS}$) reflecting bottom current speed, (C) XRF-derived sedimentary ln(Zr/Al) ratio which are dependent~~s~~ on bottom current speed (Bahr et al., 2014) and advection of fine-grained material from the nepheloid layer, and (D) CWC abundances based on CT-scanning. Phases of CWC proliferation appear to require background state of high hydrodynamics conditions (elevated ln(Zr/Al) and $\overline{SS}$) but do not show an influence of deep-water mass variability ($\delta^{13}C$). ~~-~~Light red shadings denote intervals with coral contents >7 % used for discriminant analysis; blue arrows indicate erosive unconformities.



sea level (m)
A
sea level
B
bottom current speed
Sort. Silt mean (µm)
δ13C (‰ PDB)
C
southern -sourced waters
D
AMOC
231Pa/230Th
G. bulloides/G. ruber
E
productivity Cabo Frio
HS1
HS2
HS3
HS4
HS5
HS6
F
precipitation E Brazil
ln(Ti/Ca)
G
wet phases E Brazil
CWC frequency
H
CWC frequency
Age (ka)

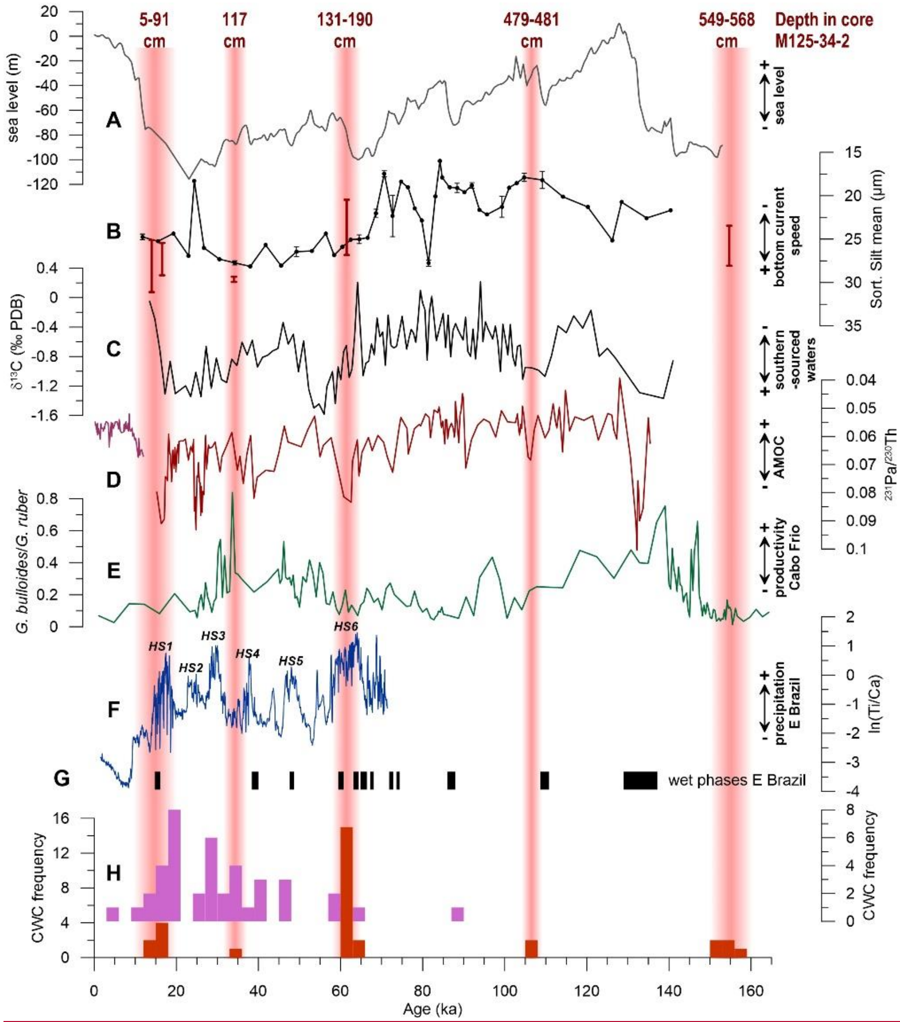
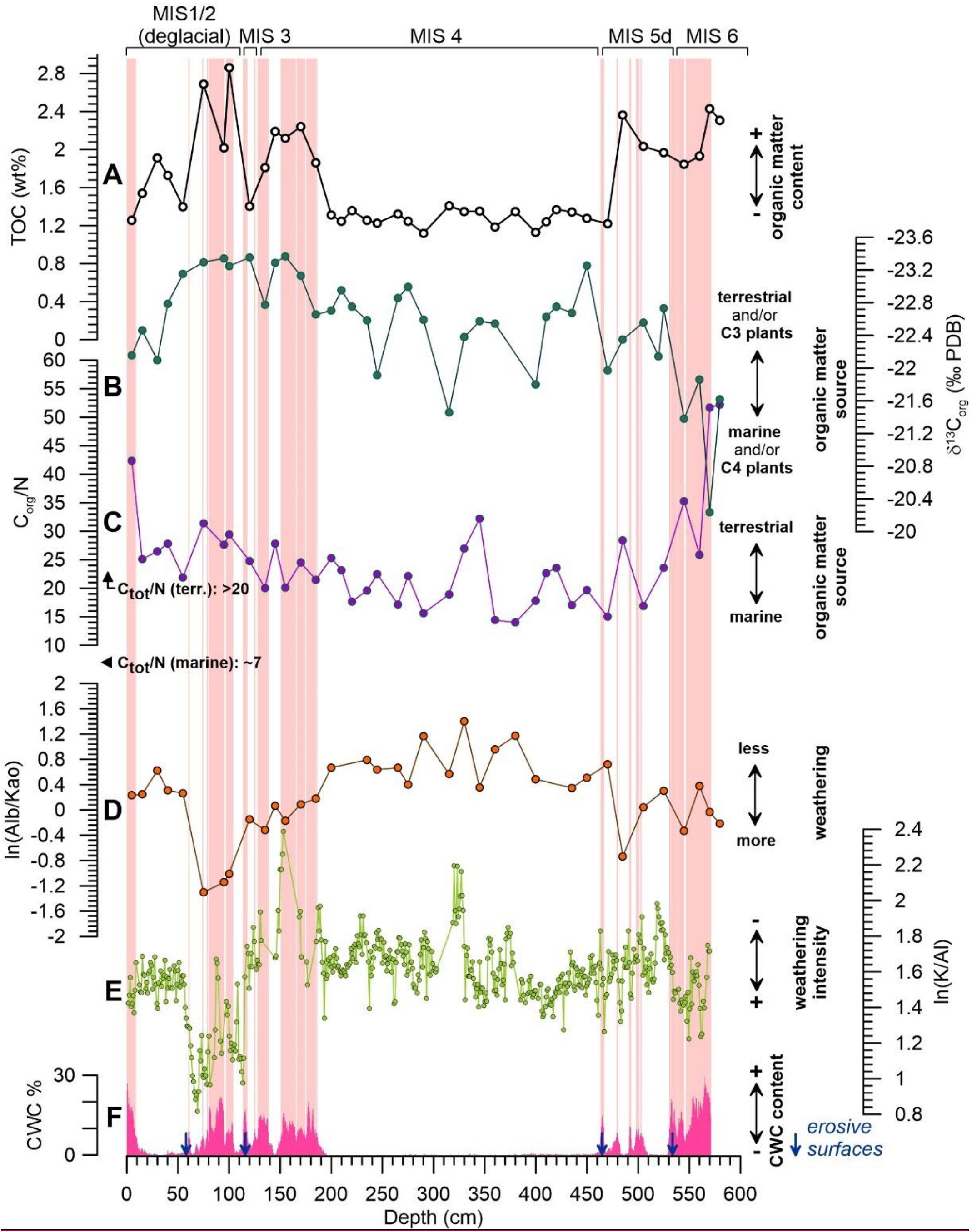


Fig. 5 Frequency of CWC occurrences in the time domain at Bowie Mound core M125-34-2 and adjacent cores from the south-eastern ~~SE~~ Brazilian Margin in the paleoclimatic context. (A) global sea level (Grant et al., 2012); (B) mean sortable silt in off-mound core M125-50-3, range of sortable silt values of CWC-bearing intervals in core M125-34-2 are indicated by red ~~error~~ bars; (C) benthic $\delta^{13}C$ of *Uvigerina* spp. in off-mound core M125-50-3 reflecting the portion of ~~nutrient-rich~~ southern-sourced waters (AAIW) at the south-eastern ~~SE~~ Brazilian Margin; (D) variability of ~~deep~~ Atlantic Meridional Overturning Circulation~~oceanic overturning circulation~~ (AMOC; dark red line: Böhm et al., 2015; purple: Lippold et al., 2019); (E) upwelling intensity at Cabo Frio reflected by the ratio between upwelling-related planktonic foraminifer *Globigerinoides bulloides* and oligotrophic *Globigerinoides ruber*; (F) ln(~~–~~Ti/Ca) ratio reflecting terrigenous input to the ~~E~~ eastern Brazilian margin off the Sao Francisco River (core M125-95-3; Campos et al., 2019); (G) growth periods of travertine and speleothems in E Brazil during anomalous wet periods, indicated by black bars (Wang et al., 2004); (H) frequency of CWC Th/U dates per 3 kyrs bins at Bowie Mound (core M125-34-2; red bars) and in cores at the south-eastern ~~SE~~ Brazilian Margin (violet) (Mangini et al., 2010; Ruckelshausen, 2013) (Fig. 1). Note the good match between CWC occurrences and enhanced monsoonal activity on the continent (correlation between ln(Ti/Ca) and CWC frequency: $r = 0.56$, $p = 0.02$; computed using the SurrogateCor function of the R-package "astrochron"; Meyers, 2014). Red bars indicate periods of enhanced CWC growth at Bowie Mound, with the respective depths in core M125-34-2 annotated.

While nutrient and/or food delivery by the AAIW seems~~ed~~ to have~~d~~ had an insignificant effect on CWC growth at Bowie Mound, changes in the hydrodynamics regime ~~altering~~ affecting the depth and strength of the nepheloid layer might have ~~influenced mound formation~~had an impact of CWC proliferation. Hydrodynamic conditions at core M125-34-2 can be reconstructed by using the variation in $\overline{SS}$, a well-established proxy for bottom current speed reflected by the mean grain size of the 10-63 µm fraction (McCave et al., 1995), and the sedimentary ln(Zr/Al) ratio (Fig. 4). The latter proxy follows the rationale that heavy minerals accumulate relative to aluminosilicates ~~during~~ when the high bottom current flow speed is high (e.g., Turnewitsch et al., 2004; Bahr et al., 2014; Miramontes et al., 2019). The significant correlation (r=~~+~~0.49; p<0.05) of both proxies ~~may~~ therefore predominantly reflects the hydraulic regime at Bowie Mound, despite certain intervals where both parameters deviate (e.g. between 60 and –115 cm with high $\overline{SS}$ and low ln(Zr/Al) values), which might be due to small-scale hydraulic effects created by the CWC branches themselves (Mienis et al., 2019). Based on both hydrodynamic proxies, CWC at Bowie Mound tend to accumulate ~~in~~ during intervals with elevated flow speed. Phases of low flow speed are accompanied by low CWC abundances (e.g., ~~between~~ at 140–150 cm and 465–550 cm), in line with the notion that active bottom currents play a significant role in distributing nutrients and food towards CWC colonies (e.g., Thiem et al., 2006; Dorschel et al., 2007; Davies et al., 2009; Raddatz et al., 2011). High current speeds will also increase sediment ~~and POC~~ supply, thereby ~~providing food and at the same time~~ increasing~~e~~ accumulation rates due to the baffling capacity of CWC. Our data, however, suggest that a relatively high flow speed does not necessarily lead to CWC growth as demonstrated by the extended CWC-free section between 200 and –460 cm, where ln(Zr/Al) and $\overline{SS}$ ~~fluctuates on a relatively~~reach high levels ~~as well as between~~and at 15–60 cm where no CWC are preserved despite high TOC accumulation. Hence, the absence of CWC~~-bearing intervals~~ despite persistently high bottom current speeds during most of the glacial intervals MIS 3 and 4 indicate that ~~additional~~ environmental drivers other than intermediate water-~~-~~mass variability must have played an important~~active~~ role for triggering~~for~~ CWC proliferation ~~growth at~~ on the Brazilian Margin.

5.1.2 Terrestrial and marine organic matter supply

Having a sufficient food supply to Bowie Mound is a ~~The~~ prerequisite for enhanced CWC growth~~ is sufficient food supply to Bowie Mound~~. To assess the potential impact of enhanced POC and/or DOC supply as an incentive for enhanced CWC growth we compared TOC measurements to CWC abundances (Fig. 6). It appears that CWC abundance is ~~s are~~ highest during~~in~~ intervals of~~with~~ elevated organic matter~~OM presence~~ content, while the long CWC-barren interval between 200 and 460 cm is characterized by relatively low TOC contents, thus~~which~~ stressing the~~es its~~ importance of TOC as a prerequisite for mound aggregation. While statistically significant, the down-core pattern of CWC abundances and TOC (r = 0.55; p < 0.05) also indicates that this correlation is not straight forward; an example is the coral-free, high-TOC interval between 15 and– 60 cm ~~with high TOC contents that is barren of corals~~ (Fig. 6). However, a~~A~~s suggested ~~argued also~~ in the previous section, there are~~have been~~ multiple factors necessary for~~to~~ stimulating~~e~~ coral growth at Bowie Mound.



MIS1/2 (deglacial)
MIS 3
MIS 4
MIS 5d
MIS 6
TOC (wt%)
A
organic matter content
B
terrestrial and/or C3 plants
marine and/or C4 plants
organic matter source
δ13Corg (‰ PDB)
Corg/N
C
Ctot/N (terr.): >20
Ctot/N (marine): ~7
terrestrial
marine
organic matter source
ln(Alb/Kao)
D
less
more
weathering
E
weathering intensity
ln(K/Al)
CWC %
F
CWC content
erosive surfaces
Depth (cm)

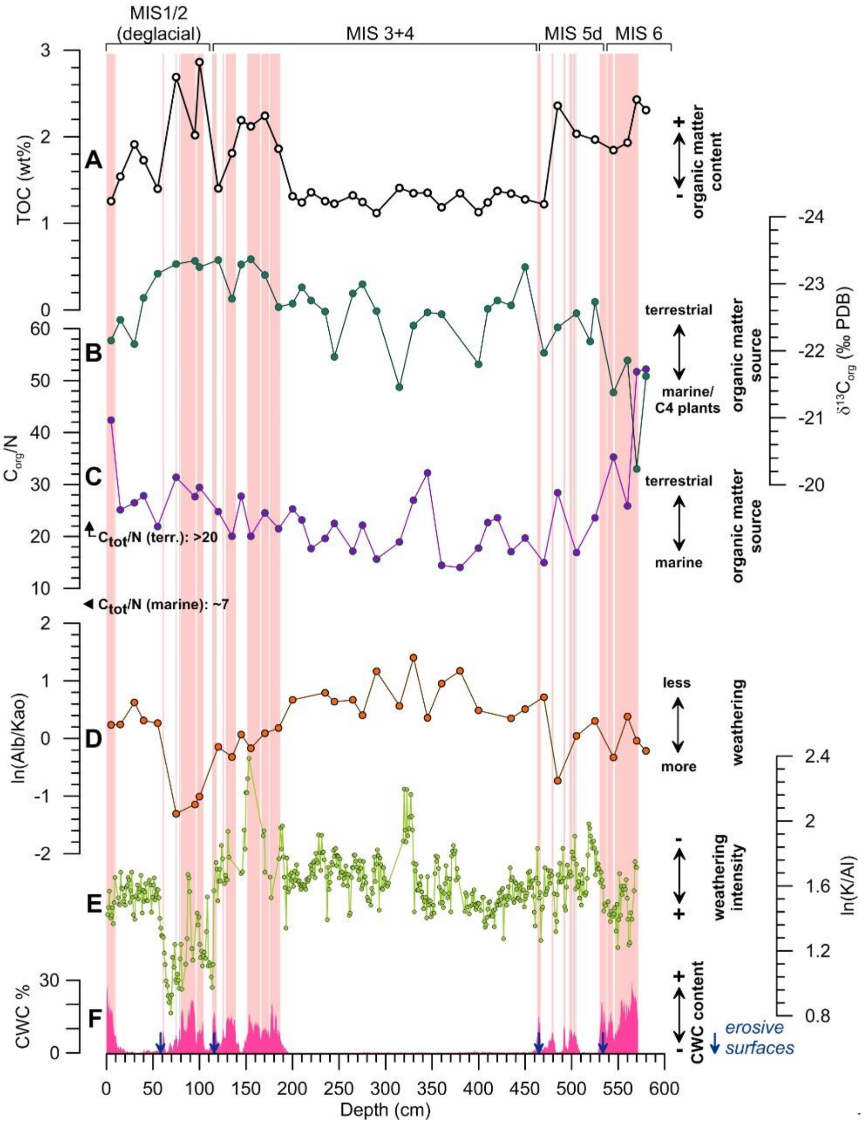


Fig. 6 Organic-matter accumulation and origin at Bowie Mound core M125-34-2 in context with continental hydroclimate and CWC occurrences. (A) Total organic carbon (TOC, white dots) reflecting organic-matter accumulation; (B) and (C) $\delta^{13}C$ and C_{org}/N_{tot} ratio of organic matter as measures for terrestrial *vs.* marine organic matter input, respectively. Marine and terrestrial endmembers are indicated (Holtvoeth et al., 2003); (D) and (E) XRD-derived ln(Albite/Kaolinite) and XRF-derived ln(K/Al) ratios, respectively, as indicators of the weathering intensity in the hinterland, reflecting the strength of the continental hydrological cycle; and (F) CWC abundances based on CT-scanning. Note that high CWC abundances fall into intervals of high TOC and increased weathering due to an intensified continental hydrological cycle. Light red shadings denote intervals with coral contents >7 % used for discriminant analysis; blue arrows indicate erosive unconformities.

To investigate the origin of the organic matter within the sediment matrix we analyzed its C_{org}/N_{total} ratio and stable carbon isotopic composition ($\delta^{13}C_{org}$). Marine organic matter has lower C_{org}/N_{total} ratios (~6.6) compared to terrestrial organic matter (>20) (Holtvoeth et al., 2003). Organic matter in core M125-34-2 exhibits C_{org}/N_{total} ratios of 14 to 52

(Fig. 6), indicating that land-derived material ~~has been~~was ~~an significant~~a dominant source of organic matter throughout the record. Intervals ~~with~~ of high CWC abundances are ~~thereby~~ characterized by elevated C_{org}/N_{total} ratios, namely at the top and at the base of the core with ratios >40~~, pointing at~~indicating an overwhelming contribution of terrigenous matter. Notably, in line with the upwelling center off Cabo Frio being confined to the shelf without reaching northward to the slope where Bowie Mound is situated (Albuquerque et al., 2014, 2016), upwelling derived organic matter with typical marine C_{org}/N_{total} ratios below 6.5 (Albuquerque et al., 2014) apparently played a subordinate role. ~~Notably, organic matter derived from upwelling on the shelf off Cabo Frio apparently plays a subordinate role as this predominantly marine organic material has low C_{org}/N_{total} ratios typically below 6.5 (Albuquerque et al., 2014) in line with the upwelling center being confined to the shelf without reaching northward to the slope where Bowie Mound is situated (Albuquerque et al., 2014, 2016).~~ A significant terrigenous admixture of terrestrial organic matter is also indicated by the relatively low $\delta^{13}C_{org}$ (-23.2 to -20.2 ‰) as terrigenous organic material has a more depleted signature (-27 ‰) compared to typical marine $\delta^{13}C_{org}$ values (-19 ‰) (Holtvoeth et al., 2003). In this regard, ~~low~~ high $\delta^{13}C_{org}$ values during CWC-bearing intervals in the upper 50 cm and below 549.5 cm ~~might~~ can be interpreted as periods of enhanced marine productivity, which ~~is in contradiction to~~ contradicts contemporaneous~~parallel~~ C_{org}/N_{total} ratios of as high as 52. This conflicting evidence might be resolved by interpreting the high $\delta^{13}C_{org}$ values as ~~representing~~ being influenced by enhanced input of POC from C4 plants (typically grasses), which are characterized by an endmember of ca. -12 ‰ (Holtvoeth et al., 2003). Palynological evidence ~~in~~ indeed~~fact~~ point to the establishment of grassland biomes in the catchment of the Paraiba do Sul during the last glacial ~~caused~~ as a result of~~by~~ generally drier conditions (Behling et al., 2002). This is in accordance with the presumed deposition of the intervals 0–50 cm and 549.5–568 cm during the last deglaciation and MIS 6, respectively (Fig. 5).

5.1.3 Influence of the continental hydrological cycle

A major source of terrigenous material and thus a potent organic-matter source for the Brazilian Margin are rivers draining the densely vegetated hinterland, especially the Paraiba do Sul (Fig. 1). To investigate if enhanced riverine input due to more humid conditions in the hinterland ~~contributed to enhanced~~increased terrestrial organic-matter supply to Bowie Mound, we studied the mineralogical and geochemical composition of the terrigenous fraction of the sediment. Changes in the water availability in the hinterland should impact the degree of weathering and thus leave an imprint in the mineralogical composition of the terrigenous sediments. The composition of the non-carbonaceous mineral phases is typical for soils that underwent different degrees of chemical weathering, comprising intermediate weathering products such as hydrobiotite (11.5 %, up to 24 %) (Coleman et al., 1963; Wilson, 1970; Meunier and Velde, 1979), as well as typical constituents of soils that have been deeply weathered under tropical humid conditions such as kaolinite (7.9 % up to 15.3 %), gibbsite (on average 21.7 %) and Ca, K, Al-rich Zeolite (6.7 %) (e.g. Weaver, 1975; Hughes, 1980; Ibrahim and Hall, 1996; Furian et al., 2002) (cf. Appendix Table A). When comparing minerals typical for residual soils such as kaolinite, gibbsite, and zeolite with feldspar and mica, both groups are anti-correlated (Table XRD) and exhibit distinct fluctuations throughout the core (cf. the albite *vs*. kaolinite ratio is depicted in Fig. 6). Relatively high abundances of weathering residuals like kaolinite are particularly present in the CWC-bearing interval between ca. 60 ~~to~~ and 200 cm and ~~(~~to a lesser exten~~d)~~t below 560 cm. This XRD-based data is also partly supported by the high-resolution ln(K/Al) record obtained via XRF scanning, which is particularly low during the interval 60–120 cm and below 530 cm (Fig. 6). Low ln(K/Al) ratios are ~~in~~ consistent~~line~~ with high kaolinite contents reflecting periods of strong K-removal from soils due to chemical weathering ~~under~~ during humid conditions in the hinterland. As the C_{org}/N_{total} ratio is also elevated during periods of low ln(K/Al) ratios and high kaolinite contents (Fig. 6), it can be inferred that high precipitation in the hinterland ~~fostered~~ enhanced chemical weathering ~~in combination with elevating~~and increased terrigenous organic matter transport to the continental slope. Stronger chemical weathering would have also enhanced the input of Fe to the continental slope (Govin et al., 2012) leading to fertilization of the surface waters, which ~~might~~ likely further~~have additionally~~ invigorated surface productivity and ~~thus~~ increased the food supply for CWC at Bowie Mound.

Table XRD: Correlation between terrigenous mineral phases in core M125-34-2. Positive correlations are marked in red (for r>0.4), negative correlations (for r<0.4) in blue.

	Quartz	Gibbsite	Kaolinite	Muscovite	Hydrobiotite	Microcline	Zeolite
Quartz							
Gibbsite	-0.07						
Kaolinite	-0.52	-0.09					
Muscovite	0.35	0.45	-0.31				
Hydrobiotite	-0.34	-0.62	0.55	-0.69			
Microcline	0.49	-0.26	-0.43	-0.15	-0.02		
Zeolite	-0.16	0.68	0.00	0.62	-0.43	-0.51	
Albite	0.65	-0.07	-0.76	0.47	-0.44	0.35	-0.07

To objectively evaluate the relative importance of terrestrial organic matter supply over changes in the hydraulic conditions ~~potentially~~ in influencing CWC proliferation at Bowie Mound we performed a discriminant analysis over n=34 samples using (i) ln(Alb/Kao) as a weathering proxy, (ii) $\overline{SS}$ for bottom current speed, (iii) $\delta^{13}C_{org}$, and (iv) C_{org}/N_{total} for organic matter provenance as predictors for the occurrences of CWC abundances above 7 % (reflecting representative CWC accumulations). Note that the $\delta^{13}C$ of benthic foraminifera had not been included due to the high scatter of the data. The restriction on those four parameters was also done to avoid unreliable results by over-prediction. The outcome of the discriminant analysis yields a correct classification of 76 % with highest skills in ln(Alb/Kao) (loading of -0.68) and C_{org}/N_{total} (+0.58), while loadings for $\overline{SS}$ (+0.06) and $\delta^{13}C_{org}$ (0.00) are insignificant (see Appendix Table B for details). This is consistent with peak CWC abundances during phases of strong hydrological activity, as evidenced by intensified chemical weathering (i.e. low ln(Alb/Kao) ratios), which enhanced the input of terrigenous organic matter (high C_{org}/N_{total}) to Bowie Mound and directly or indirectly (via surface water fertilization) stimulated CWC proliferation~~This is in line with peak CWC abundances synchronous to phases of a strong hydrological cycle as reflected by intensified chemical weathering (i.e. low ln(Alb/Kao) ratios) which triggered a strong input of terrigenous organic matter with a high C_{org}/N_{total} ratio to Bowie Mound directly or indirectly fueling CWC proliferation~~.

5.2 CWC at Bowie Mound in the paleoclimatological context

As discussed above, phases of enhanced CWC proliferation at Bowie Mound occurred in parallel to periods of increased terrigenous POC and/or DOC input ~~from land~~ due to enhanced run-off. ~~Within age model uncertainties~~T~~,~~ ~~t~~he most distinct CWC proliferation phases in fact took place during phases of anomalously ~~humid conditions in E Brazil~~strong monsoonal precipitation ~~associated~~ during~~with~~ the pronounced Heinrich Stadials (HS) 1 and~~,~~ ~~4, and~~ 6 as well as (within age model uncertainties) also during the shorter and less severe humid phases corresponding to HS 2–5 (Fig. 5F, G). The prominent growth phase during HS is ~~well~~ in agreement with published CWC occurrences along the south-eastern Brazilian Margin ~~during~~ from the same time frame ~~along the SE Brazilian Margin~~ (Mangini et al., 2010; Ruckelshausen, 2013) (Figs. 1, 5G), ~~corroborating~~ indicating that our results are representative for a larger geographic area. The slow overturning circulation during HS indicated by high $^{231}Pa/^{230}Th$ ratios (Fig. 5D; McManus et al., 2004; Böhm et al., 2015) ~~(Fig. 5 D) caused~~ resulted in enhanced precipitation over south-eastern and eastern Brazil (Waelbroeck et al., 2018) ~~as it led~~due to heat accumulation in the southern hemisphere and ~~thereby strengthening~~ intensification of the South Atlantic Convergence Zone (Fig. 1; Stríkis et al., 2015)~~ (Fig 1)~~. Humid phases during HS in otherwise dry eastern Brazil are documented by growth phases of speleothems and travertines (Fig. 5G), increased terrigenous ~~matter~~ input (core M125-95-3; Fig. 5F) (Campos et al., 2019), and a slight expansion of forest cover (Gu et al., 2018). It ~~might~~ is possible~~thus be argued~~ that the riverine suspension load from other rivers in eastern Brazil was advected southward by the BC and added to the enhanced ~~river~~ terrigenous load from rivers adjacent to Bowie Mound (mostly the Paraiba do Sul). Due to the baffling capacity of framework-building CWCs (Mienis et al., 2007; Huvenne et al., 2009; Titschack et al., 2015), the ~~Due to their baffling capacity, the~~ additional sedimentary input would have aided mound formation. This nutrient and organic-rich suspension potentially also enhanced marine surface productivity and thus directly and/or indirectly boosted food supply to the CWC. ~~-~~As freshwater admixture to the SMW and SACW may~~ight have~~ increased ~~caused a more pronounced~~ water column stratification and hence the~~increased~~ density contrast to the AAIW, the concentration of sediment and food particles at the nepheloid layer may~~might~~ also have been more ~~pronounced as well~~pronounced. The link between Monsoonal activity and CWC growth proposed here is in line with studies from the western Mediterranean Sea (Fentimen et al., 2020), the Gulf of Cadiz (Wienberg et al., 2010) and the tropical eastern Atlantic off Angola (Hanz et al., 2019) which all inferred that terrestrial input via dust or fluvial run-off can ultimately fuel CWC colonies.

Notably, HS occurred during phases of intermediate and low sea level, which facilitated the bypass of sediment across the shelf and thus allowed for an efficient supply of terrestrial organic matter~~OM~~ to Bowie Mound (Fig. 5A). As discussed in Raddatz et al. (2020), ~~a low sea level might have also forced water-mass boundaries to migrate downslope~~ during glacials, when sea level was ~~considerably lower by~~ up to 120 m lower than ~~today~~ present (Waelbroeck et al., 2002; Rohling et al., 2014), water-mass boundaries may have been forced to migrate downslope. Such a displacement of water-mass boundaries would have moved the SACW/AAIW interface and the corresponding nepheloid layer from its present position at ~500 m closer to the depth of Bowie Mound (~860 m), aiding the concentration and dispersal of food along the slope towards the CWC colonies. This suspected influence of sea level on the bottom-current dynamics ~~in~~ at the depth of Bowie Mound is in fact evident from a sortable silt record obtained from the~~on~~ off-mound site M125-50-3, which shows high (low) current speeds during low (high) sea level (Fig. 5B).

Hence, we argue that a dynamic hydraulic regime along with a pronounced nepheloid layer was required for CWC to flourish at Bowie Mound (Mienis et al., 2007). These prerequisite conditions were present throughout glacial periods, during which th~~Hence, it might be argued that for CWC to flourish at Bowie Mound a dynamic hydraulic regime was required with a pronounced nepheloid layer such as prevailing throughout glacial periods (Mienis et al., 2007). Th~~e development of wide-spread glacial unconformities and extensive drift bodies along~~at~~ the south-east Brazilian margin (Viana et al., 1998; Viana, 2001) are evidence for such intense bottom-current activity. This is notably different from the slope south of the Abrolhos Bank where reference core M125-50-3 is situated. Here, contouritic sediments and distinct hiatuses are largely absent in water depths affected by the AAIW and SACW, which testifies~~y~~ to~~ for~~ less dynamic hydrological conditions (Bahr et al., 2016), potentially responsible for ~~explaining ~~the lack of CWC mounds at this location. At the same time, $\overline{SS}$ and ln(Zr/Al) data from both~~neither~~ Bowie Mound core M125-34-2 (Fig. 4B) and~~nor~~ off-mound core~~site~~ M125-50-3 (Fig. 5B) indicate that bottom-current speed was~~has been~~ not anomalously high during HS relative to the glacial background level. Hence, the distinct, pulse-like CWC growth phases at Bowie Mound could have been ~~ultimately ~~initiated by enhanced nutrient and organic matter supply from land as evidenced by the high C_{org}/N ratio of the organic matter. Surface water fertilization by the increase in terrigenous organic matter may have also improved marine primary productivity and contributed to higher export production, further fueling CWC growth. ~~Due to ensuing fertilization of the surface waters, marine primary productivity might also have been enhanced and contributed to higher export production, additionally fueling CWC growth. ~~As discussed before, marine productivity ~~derived ~~caused by from upwelling on the shelf of Cabo Frio was apparently of minor importance. Based on planktic foraminiferal assemblages (Lessa et al., 2019), enhanced upwelling occurred between HS 3 and 4, at around 35 kys, when a small peak of CWC abundances occurs (Fig. 5G). However, during~~ at~~ all other instances of CWC occurrences, upwelling at Cabo Frio ~~appears ~~was relatively~~rather~~ low and likely did~~there is~~ not~~ evidence that it~~ reached as far north as Bowie Mound (Albuquerque et al., 2014, 2016).

We hence infer that CWC proliferation at Bowie Mound occurred simultaneously with an enhanced delivery of terrestrial organic matter towards the continental slope under glacial boundary conditions of low sea level and enhanced hydrodynamic activity along the slope. ~~As this temporal coincidence could point at~~This implies the direct utilization of terrestrial organic matter by the corals and thus~~, it~~ clearly stresses the necessity for future in-depth studies of the food preferences of *S. variabilis*.

Conclusions

Here we present a comprehensive multi-proxy study of a ~~cold-water coral (~~CWC~~)~~-bearing core retrieved off ~~SE ~~south-eastern Brazil with the aim to assess the relative importance of different environmental factors that supported and/or prohibited CWC proliferation and coral mound formation. We find that intervals of high CWC abundance~~s~~ are primarily related to millennial-scale high latitude cold events (Heinrich Stadials) that were characterized by major reconfigurations of ~~the ~~deep-ocean circulation and ~~an ~~enhanced ~~continental hydrological cycle~~monsoonal precipitation in eastern Brazil. The dominance of terrigenous- over marine-derived organic matter during phases of fast CWC proliferation indicate that strong run-off enhanced the input of nutrients and food to ~~the ~~coral mounds on the continental slope. Intensified hydrodynamic conditions at the water depth of Bowie Mound ~~on intermediate water level ~~during sea level lowstands thereby provided the necessary background conditions for an efficient dispersal of nutrient and food supply towards the upper and mid slope. Thus, thiis study thus presents a prime example of the high sensitivity of deep marine ecosystems to changes in the environmental conditions and points at a hitherto unrecognized intimate coupling between continental hydroclimate and ecological changes in the deep ocean.

Appendices

Appendix Table A: Major non-carbonaceous mineral phases in core M125-34-2 derived from Rietveld analyses of X-ray diffractometry.

Depth (cm)	Quartz	Gibbsite	Kaolinite	Muscovite	Hydrobiotite	Microcline	Zeolite	Albite
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
5	8.5	20.2	5.7	5.6	7.8	7.0	6.7	7.2
15	8.0	19.1	7.8	5.5	16.1	4.6	6.7	10.0
30	6.9	18.7	6.5	2.1	10.1	6.3	4.2	12.1
40	7.6	20.3	7.7	3.4	17.1	9.3	3.8	10.5
55	10.4	18.4	8.7	4.0	14.1	3.7	5.0	11.3
75	4.6	20.0	15.3	4.8	20.2	2.1	6.5	4.2
95	4.3	17.6	12.0	4.4	21.7	4.8	5.9	3.8
100	4.8	16.4	12.6	5.6	24.0	3.2	6.2	4.6
120	9.7	15.5	10.3	4.4	18.2	6.2	4.7	8.9
135	8.3	24.5	9.9	9.4	12.9	4.3	6.7	7.2
145	7.1	24.1	9.0	5.1	17.4	3.3	7.1	9.6
155	7.8	25.9	10.2	11.5	7.8	4.6	7.9	8.6
170	7.6	22.3	9.0	6.1	17.6	4.0	7.1	9.8
185	9.2	25.1	7.4	11.5	6.0	6.2	7.4	8.9
200	10.2	21.3	6.2	6.2	12.5	7.9	6.6	12.2
235	9.2	20.6	5.4	13.3	10.7	3.6	7.4	12.0
245	9.5	22.6	6.5	13.2	5.7	5.8	6.8	12.4
265	8.1	22.8	6.5	9.9	9.8	6.4	7.4	12.7
275	9.2	23.5	7.5	12.9	6.9	5.4	7.0	11.3
290	9.6	21.6	4.0	10.7	9.7	6.9	6.3	13.0
315	10.4	21.9	6.3	12.8	7.1	5.0	6.7	11.1
330	9.3	19.8	4.0	11.4	8.7	5.1	6.4	16.3
345	7.7	19.7	8.3	11.9	10.2	4.9	7.1	11.9
360	6.9	19.4	5.5	9.0	10.0	5.8	6.3	14.3
380	8.3	23.1	4.5	13.7	5.2	3.2	7.2	14.5
400	7.0	21.2	6.2	7.6	12.9	6.8	6.5	10.1
435	7.9	23.1	8.3	12.6	6.2	3.1	6.8	11.8
450	7.8	23.1	7.0	12.0	7.4	3.8	7.4	11.7
470	8.3	18.6	6.4	11.8	14.6	4.6	7.5	13.2
485	6.3	27.4	12.2	12.3	5.5	2.8	8.5	5.8
505	5.5	23.7	9.5	12.5	6.2	2.8	7.7	9.9
525	5.7	24.6	7.4	10.2	11.2	3.6	8.0	10.1
545	4.4	23.1	8.4	4.4	10.3	3.0	7.4	6.0
560	6.5	26.3	5.3	6.8	8.1	3.8	7.1	7.8

570	5.8	22.0	7.3	6.0	10.5	3.5	6.4	7.0
580	5.3	23.0	8.1	5.8	12.9	2.8	7.3	6.5

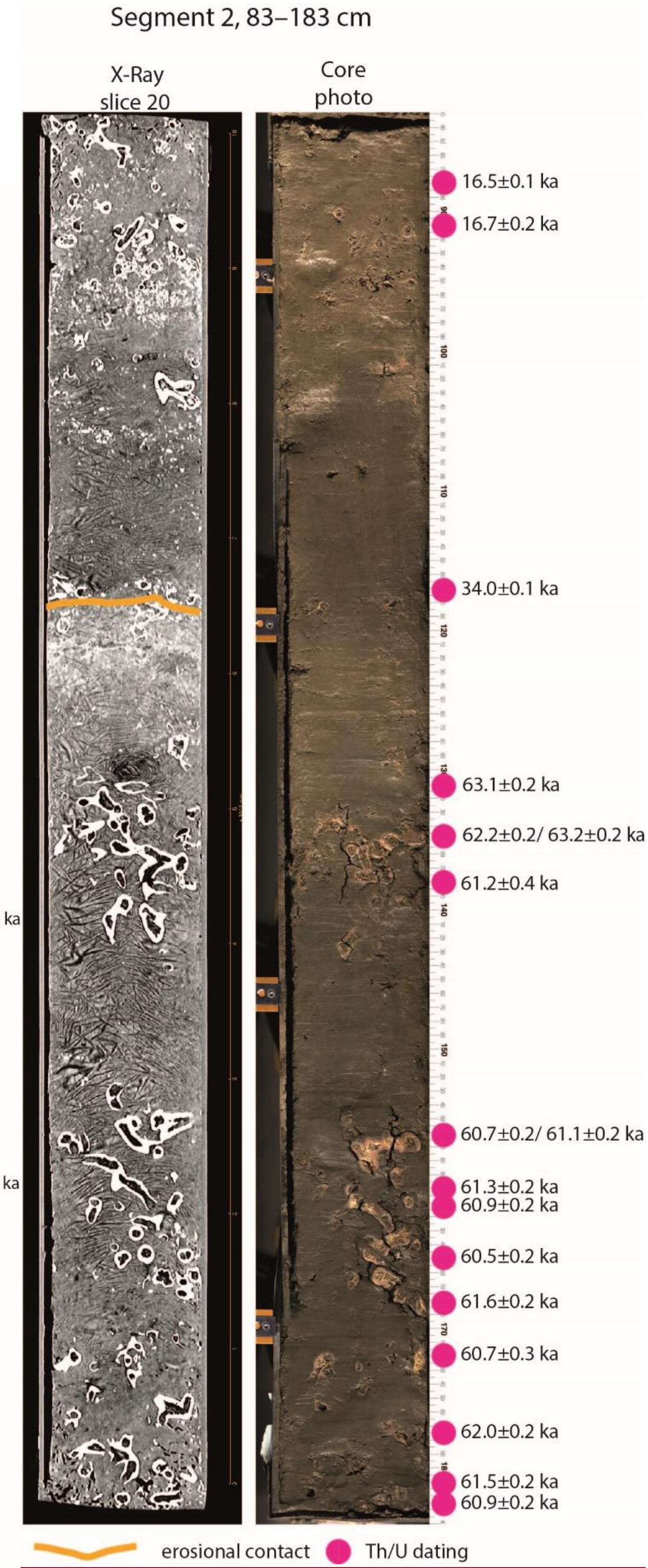
APPENDIX Table B. Result of discriminant analysis performed on detrended and normalized proxies obtained on core M125-34-2. Samples were divided into classes with CWC contents >7% (labelled "1") and <7% ("0"). Classes derived from discriminant analysis are displayed in the last column, with wrongly assigned ~~calls~~ classes marked in red.

depth (cm)	**ln(Alb/Kao)**	**$\overline{SS}$ (µm)**	**$\delta^{13}C_{org}$ (‰ PDB)**	**C_{org}/N**	**CWC > 7%**	**inferred class**
5	0.01	0.71	0.58	2.03	1	1
15	0.03	-0.61	0.11	0.04	0	0
30	0.64	1.73	0.67	0.20	0	0
40	0.13	1.94	-0.39	0.35	0	0
55	0.06	0.84	-0.95	-0.33	0	0
75	-2.49	0.15	-1.17	0.77	1	1
95	-2.23	0.86	-1.24	0.33	1	1
100	-2.01	0.81	-1.10	0.54	1	1
120	-0.61	1.16	-1.25	0.00	0	1
135	-0.89	-1.07	-0.37	-0.55	1	0
145	-0.26	-1.61	-1.16	0.35	0	0
155	-0.65	-1.30	-1.28	-0.54	1	0
170	-0.22	0.54	-0.91	-0.03	1	0
185	-0.08	-0.85	-0.18	-0.38	1	0
200	0.72	0.53	-0.26	0.06	0	0
235	0.92	0.40	-0.08	-0.60	0	0
245	0.67	0.88	0.95	-0.26	0	0
265	0.72	0.04	-0.49	-0.88	0	0
275	0.29	1.00	-0.71	-0.30	0	0
290	1.53	1.17	-0.09	-1.06	0	0
315	0.55	0.40	1.65	-0.68	0	0
330	1.91	-0.27	0.24	0.25	0	0
345	0.21	-0.72	-0.06	0.86	0	0
400	0.42	0.12	1.12	-0.80	0	0
435	0.20	-0.87	-0.22	-0.88	0	0
450	0.46	0.41	-1.10	-0.59	0	0
470	0.80	-1.26	0.86	-1.13	0	0
485	-1.56	-1.98	0.28	0.42	0	1
505	-0.30	-2.22	-0.04	-0.91	0	0
525	0.13	-2.01	-0.30	-0.13	0	0
545	-0.90	-1.44	1.77	1.21	0	1
560	0.24	0.11	1.03	0.13	1	0
570	-0.43	-0.85	3.52	3.12	1	1
580	-0.72	0.82	1.40	3.17	1	1


Segment 1, 0–83 cm
X-Ray slice 20
Core photo
13.7±0.1 ka
14.3±0.1 ka
16.5±0.1 ka
erosional contact
Th/U dating


Segment 1, 0–83 cm
X-Ray slice 20
Core photo
13.7±0.1 ka
14.3±0.1 ka
16.5±0.1 ka
erosional contact
Th/U dating

Appendix Figure A: CT image (left) and photography (right) of segment 0-83 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U datings with calibrated ages are indicated by magenta dots.

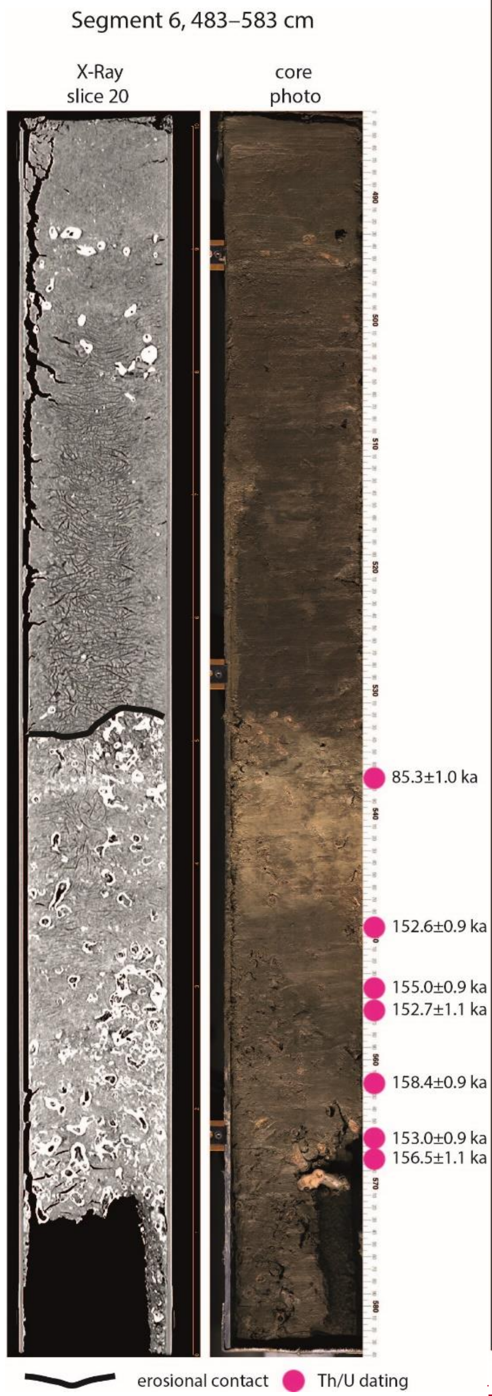


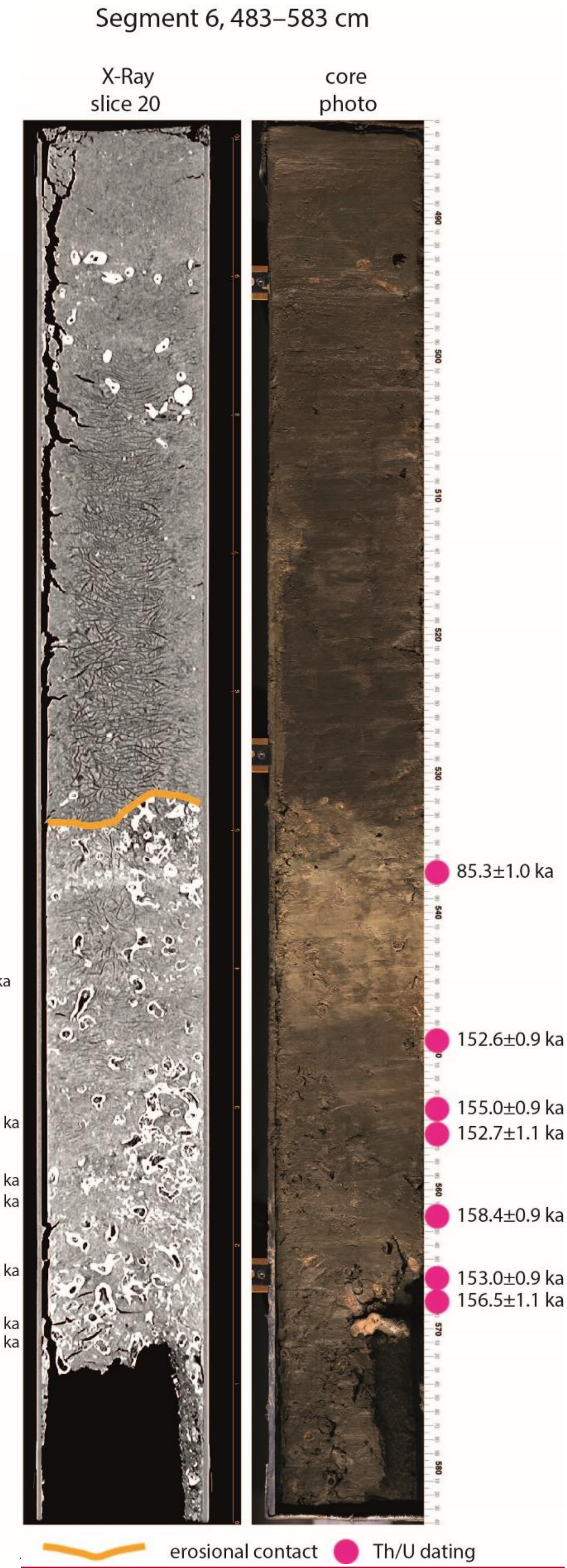
Appendix Figure B: CT image (left) and photography (right) of segment 83-183 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U datings with calibrated ages are indicated by magenta dots.

Appendix Figure C: CT image (left) and photography (right) of segment 183-283 cm of core M125-34-2. Position of Th/U dating with calibrated age is indicated by a magenta dot.

Appendix Figure D: CT image (left) and photography (right) of segment 283-383 cm of core M125-34-2.

Appendix Figure E: CT image (left) and photography (right) of segment 383-483 cm of core M125-34-2. Erosional contacts are marked by thick black lines, position of Th/U dating with calibrated age is indicated by a magenta dot.





Appendix Figure F: CT image (left) and photography (right) of segment 383-483 cm of core M125-34-2. Erosional contacts are marked by thick black lines, positions of Th/U datings with calibrated age are indicated by magenta dots**.**

Data availability

All data presented in this study will be made available in the Pangaea data base (www.pangaea.de).

Author contribution

AB and JR designed the study. AB, MD, JT, GA, DN, AK, and JR were involved in sampling and data generation. All authors contributed to data interpretation and manuscript writing.

Competing Interests

The authors declare that they have no conflict of interest.

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