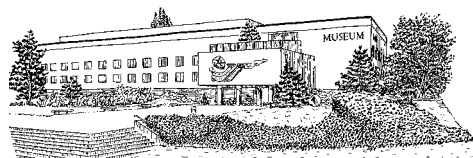


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Biological and environmental effects of Late Cretaceous benthic foraminiferal stage isotope compositions

Oliver FRIEDRICH^{1,2}

Key words

Stable isotopes, Cretaceous, benthic foraminifera, Maastrichtian, microhabitat.

Expanded Abstract

Stable isotope ratios of $d^{18}O$ and $d^{13}C$ measured on the calcite of foraminiferal tests are widely used as proxies to reconstruct the paleoceanographic conditions of the Cretaceous and the Cenozoic. In particular oxygen isotope ratios are one of the most important proxies to estimate paleotemperatures of marine sediments for the last 100 Ma (e.g., HUBER *et al.*, 2002; LEA, 2003). Most of these applications, however, have been restricted to the Cenozoic since the availability of pristine benthic foraminiferal tests and knowledge of the ecological requirements of different species are generally limited for older time periods. Furthermore, the complexity of factors influencing the stable isotope composition of benthic foraminiferal tests (carbonate growth out of thermodynamic equilibrium, vital effects, pore water $d^{13}C$ gradients, and age and origin of the respective water mass; e.g., WEFER & BERGER, 1991, MACKENSEN & BICKERT, 1999) demonstrates the necessity of studies on living specimens from ecosystems with well-known environmental parameters. For the fossil record, however, comparable information is still missing, since environmental studies on stable isotopes demand excellent preservation of foraminiferal tests. Nevertheless, stable isotope studies are commonly used to reconstruct the paleoceanographic and paleoclimatic evolution also for the Cretaceous. But until now, little information exists on the potential influence of microhabitat and vital effects on the stable isotope signal of Cretaceous benthic foraminifera.

For this reason, different species of Late Cretaceous benthic foraminifera from ODP (Ocean Drilling Program) Hole 690C were investigated based on the pristine preservation of foraminiferal calcite (e.g., BARRERA & HUBER, 1990). Hole 690C was drilled during ODP Leg

113 in a water depth of 2914 m on the southwestern flank of Maud Rise in the eastern Weddell Sea, southern South Atlantic. Studied sediments are composed of calcareous chinks and oozes representing the uppermost Campanian and Maastrichtian (Shipboard Scientific Party, 1990).

In total, nine samples that are decided to represent the best preserved benthic foraminiferal shells were selected for stable isotope analyses. These samples are located within a time interval with very stable environmental conditions to avoid an overprint of the original interspecific isotope signatures by strong environmental changes and isotope excursions. Sediment was disintegrated in distilled water and washed over a 63 μm mesh. Between 2 and 13 individuals of the biggest size-fraction possible were measured for stable isotopes, to make sure that the isotopic signatures of adult specimens were investigated. Stable isotopes were measured with a Finnigan MAT 251 mass spectrometer at the Leibniz-Labor (Kiel), coupled on-line to the Carbo-Kiel device I (external precision better than 0.07‰ and 0.04‰ for oxygen and carbon, respectively).

The total range of carbon and oxygen isotope values is between -2.66‰ to 1.60‰ and -0.04‰ to 1.10‰, respectively (Figs 1, 2). In total, a separation of the benthic foraminiferal species into two groups is shown by their $d^{18}O$ signal, whereas single species show specific $d^{18}O$ ranges with very similar mean values and low standard variations (<0.15‰; Fig. 2). The $d^{13}C$ values show a higher scattering than the $d^{18}O$ values. For a more detailed description of the stable isotope variations of single species see FRIEDRICH *et al.* (2006).

Since the average living depth of benthic foraminifera and therefore the microhabitat has an important effect on the stable isotopic composition of the tests, the separation of the investigated species into epifaunal and infaunal species was performed using literature data (Table 1). While the living depth of Recent benthic foraminifera can

¹ Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, 30655 Hannover, Germany

² Present address: Geosciences Research Division, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA, 92093-0244, USA, email: ofriedrich@ucsd.edu

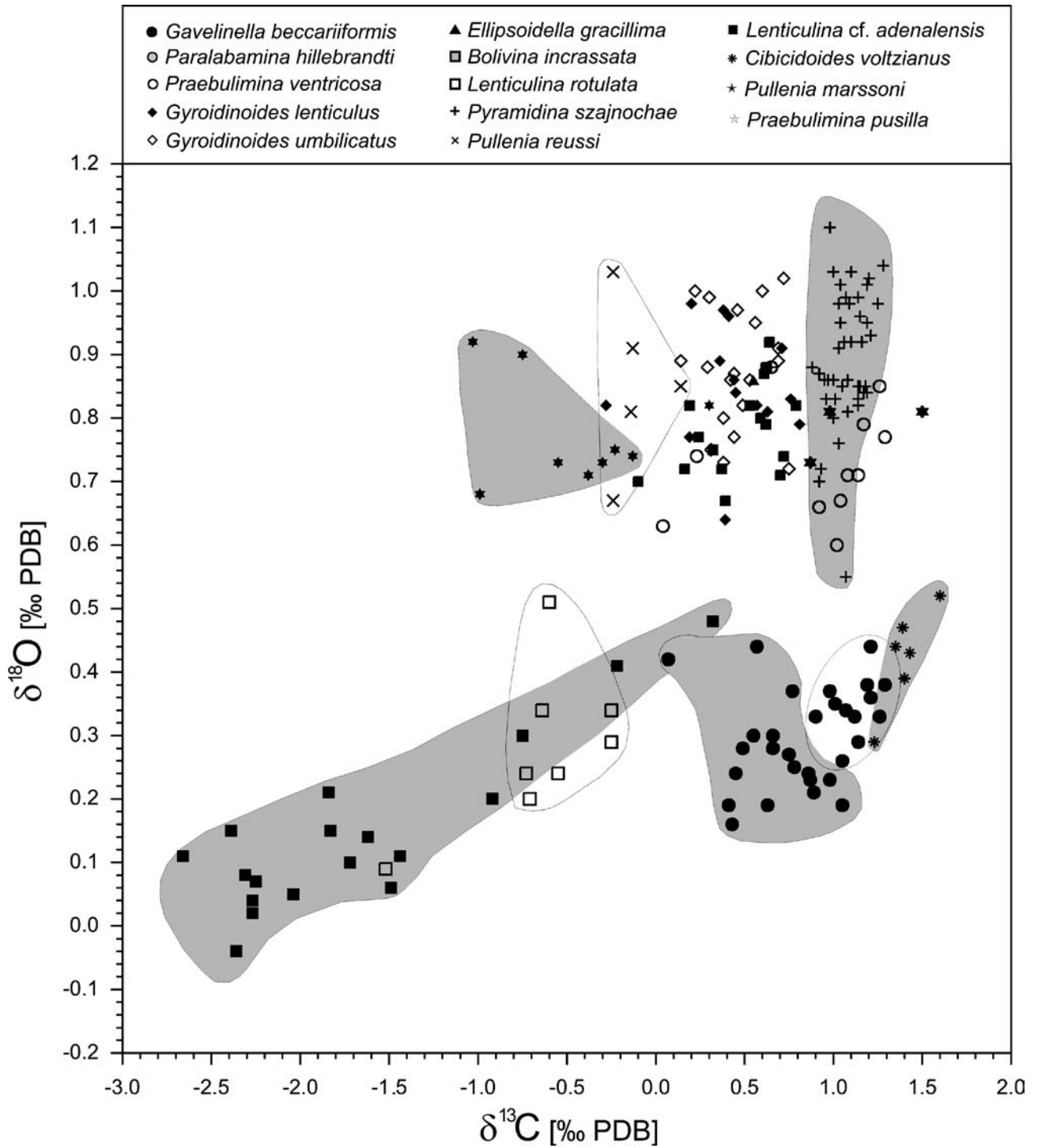


Fig. 1: Stable oxygen and carbon isotope values of the measured benthic foraminiferal taxa of ODP Hole 690C. Isotope data variance of some species are marked by grey fields. From FRIEDRICH *et al.* (2006).

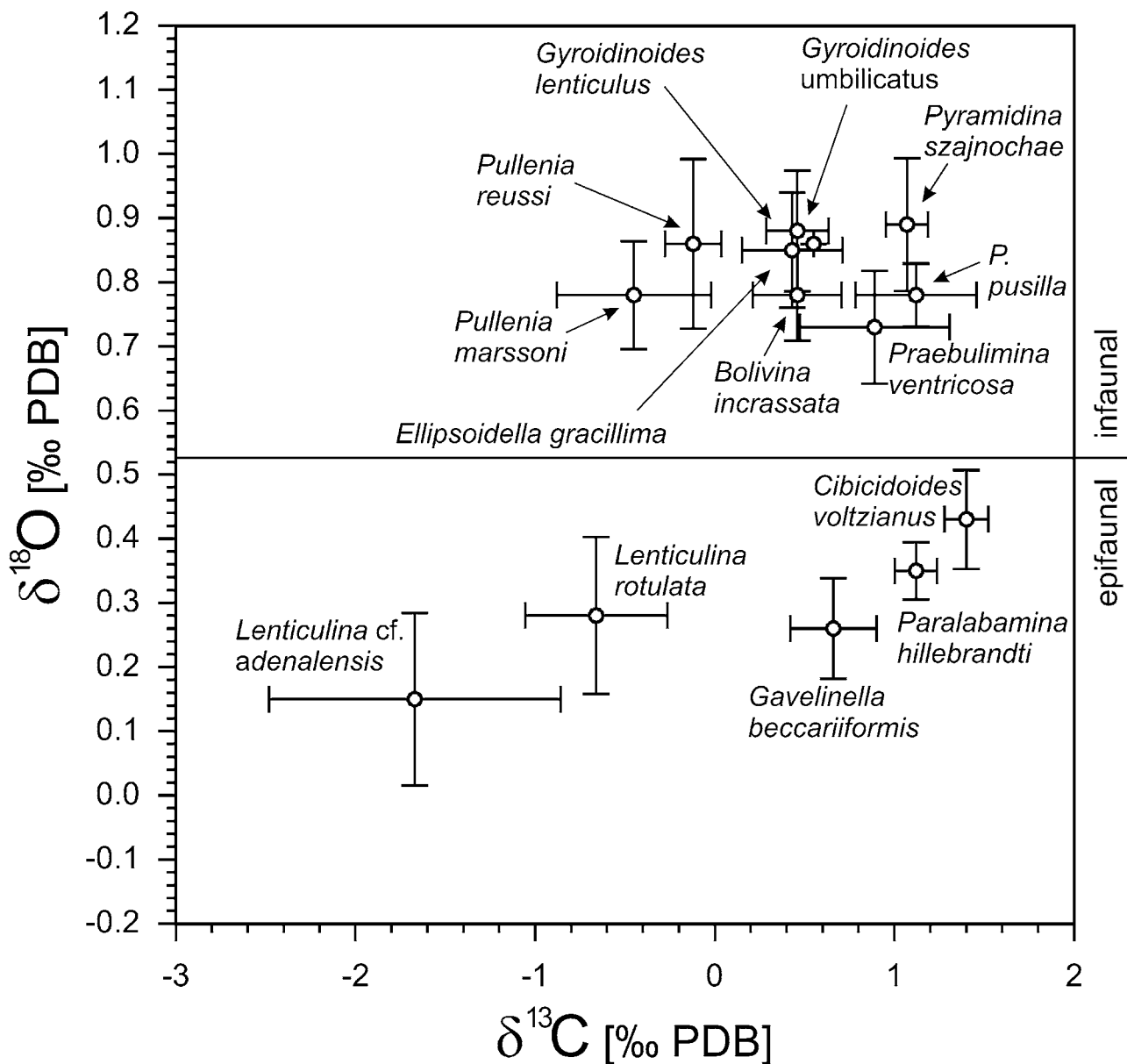


Fig. 2: Mean values of stable oxygen and carbon isotope data (open circles) of benthic foraminiferal taxa of ODP Hole 690C. Horizontal and vertical bars indicate 1 standard deviation. From FRIEDRICH *et al.* (2006).

be calculated from the down-core distribution (SCHMIEDL *et al.*, 2004), the living depth of fossil benthic foraminifera was inferred from their morphology and comparison with Recent species (e.g., CORLISS, 1985). This microhabitat of the different benthic foraminiferal species is suggested to be responsible for most of the variability observed in the $\delta^{13}\text{C}$ values of Recent infaunal taxa (e.g., RATHBURN *et al.*, 1996). Thereby, the most dominant influence on $\delta^{13}\text{C}$ values is proposed to be the $\delta^{13}\text{C}_{\text{DIC}}$ gradients in the pore water (McCORKLE *et al.*, 1997). In our data most infaunal species are characterized by similar or only slightly lower $\delta^{13}\text{C}$ values than those of epifaunal species (Figs 1, 2). FRIEDRICH *et al.* (2006) suggested that this

pattern might be explained by changing organic carbon fluxes or higher pore water gradients of pH and $[\text{CO}_3^{2-}]$. A constant offset to more negative values is only observed in *Pullenia marssoni* and *Pullenia reussi*, suggesting a deeper infaunal habitat for these species when compared to the others. In all samples the stable carbon isotope data of *Pyramidina szajnochae* and praebuliminids are among the highest values, maybe explained by a weaker vital effect shifting their $\delta^{13}\text{C}$ signal closer to isotopic equilibrium or by the fact that these species have a different microhabitat than previously supposed. Further exceptions from the proposed microhabitat preferences are suggested by *Gyroidinoides lenticulus* and *Gyroidinoides*

Table 1: Proposed microhabitat of the investigated benthic foraminiferal species. For references see Friedrich *et al.* (2006).

Species	Proposed living depth
<i>Bolivina incrassata</i>	infaunal
<i>Cibicidoides veltziana</i>	epifaunal
<i>Gavelinella beccariiiformis</i>	epifaunal
<i>Gyroidinoides lenticulus</i>	epifaunal
<i>Gyroidinoides umbilicatus</i>	epifaunal
<i>Ellipsoidella gracillima</i>	infaunal
<i>Lenticulina cf. adenalensis</i>	epifaunal
<i>Lenticulina rotulata</i>	epifaunal
<i>Paralabamina hillebrandti</i>	epifaunal
<i>Praeulimina pusilla</i>	infaunal
<i>Praeulimina ventricosa</i>	infaunal
<i>Pullenia marssoni</i>	infaunal
<i>Pullenia reussi</i>	infaunal
<i>Pyramidina szajnochae</i>	infaunal

umbilicatus (Figs 1, 2). These taxa have been proposed to be epifaunal. In our dataset, however, these two species show clearly the same isotope signature as the infaunal species, suggesting an infaunal microhabitat. A striking feature of this data set is also the strong depletion of ^{13}C in lenticulinids. A similar depletion in lenticulinid d^{13}C values was also shown for other Cretaceous data (e.g., FISHER & ARTHUR, 2002) and may be attributed to a deep infaunal microhabitat, strong vital effects, or different feeding stratigraphy when compared to other species. Since lenticulinids are common taxa of Cretaceous low-oxygen environments (e.g., FRIEDRICH *et al.*, 2005), it could be also suggested that these species had certain adaptations, including a tolerance of dysoxia.

One of the most significant features of the data set is the clear separation of epifaunal and infaunal species based on their d^{18}O values (epifaunal species show a depletion of $\sim 0.6\text{‰}$; Figs 1, 2). Some of the observed d^{18}O differences between epifaunal and infaunal species could be related to microhabitat-specific metabolic rates, as proposed by some authors based on studies on living benthic foraminifera. Deep infaunal species have lower metabolic rates and life cycles longer than 2 years, favouring calcite precipitation closer to equilibrium (see discussion in SCHMIEDL *et al.*, 2004), whereas epifaunal species adapted to seasonal organic matter flux show strong depletion in d^{18}O . These metabolic effects are also proposed to be an explanation for the generally absence or only small d^{13}C depletion of infaunal species (FRIEDRICH *et al.*, 2006). Another possible reason for the d^{18}O increase of infaunal species could be the pore

water gradients in pH and $[\text{CO}_3^{2-}]$. A significant effect of seawater carbonate concentration on the d^{13}C and d^{18}O values of Recent planktic foraminifera was described by SPERO *et al.* (1997). These authors showed that increasing $[\text{CO}_3^{2-}]$ led to a decrease in both d^{13}C and d^{18}O values of the foraminiferal tests. Based on a higher atmospheric pCO_2 during the Late Cretaceous, however, surface water pH and $[\text{CO}_3^{2-}]$ concentrations were likely considerably lower during this time (ZEEBE, 2001). Thus, applying the $[\text{CO}_3^{2-}]$ effect of SPERO *et al.* (1997), a general increase in the order of 0.6‰ for d^{18}O and up to 1.5‰ for d^{13}C can be expected for the Cretaceous relative to the modern surface ocean (0.2‰ for oxygen, 0.5‰ for carbon; SCHMIEDL *et al.*, 2004). Therefore, a $[\text{CO}_3^{2-}]$ effect may contribute to the observed trend in the oxygen isotope composition of Cretaceous benthic foraminifera with higher values of infaunal species compared with epifaunal ones. This effect could also explain why d^{13}C depletions of infaunal vs. epifaunal species are lower than compared with modern assemblages. The potential of a $[\text{CO}_3^{2-}]$ effect on bottom and pore waters during the Late Cretaceous, however, is speculative due to the unknown seawater carbonate chemistry of the Cretaceous deep ocean.

Based on these observations the epifaunal species of this study (*Gavelinella beccariiiformis*, *Paralabamina hillebrandti*, and *Cibicidoides veltzianus*) are likely the best representatives for a bottom-water signal and may be further applied to the reconstruction of deep-water circulation and temperature changes during the Late Cretaceous. Furthermore, the ecology of Cretaceous benthic foraminifera was commonly assessed by their morphology and comparison with Recent equivalents (e.g., CORLISS, 1985). Our results demonstrate that stable isotope analyses of pristine tests can also be used as an independent tool to reconstruct the microhabitat for fossil taxa. Such an accurate knowledge of microhabitat preferences of fossil species is absolutely crucial for any comprehensive paleoceanographic interpretation of faunal and isotopic data.

The high number of specimens and different ontogenetic stages of *P. szajnochae* was further used to reveal potential ontogenetic effects on the stable isotope composition. A weak positive correlation exists between d^{13}C and test size ($r=0.32$), the linear correlation between d^{18}O and test size, however, revealed a much higher correlation coefficient ($r=0.85$, Fig. 3). This enrichment seems to be slightly stronger in the size classes below $550\ \mu\text{m}$ and weaker in the later growth stages. Although d^{13}C lacks a corresponding trend these data likely represent the presence of changes in metabolic rates during ontogenesis. Ontogenetic effects on the stable isotope composition of benthic foraminifera are reported so far only from two Recent species (SCHMIEDL *et al.*, 2004). Most other studies on deep-sea benthic foraminifera do not give evidence of a ^{13}C enrichment with test size. For *P. szajnochae* the

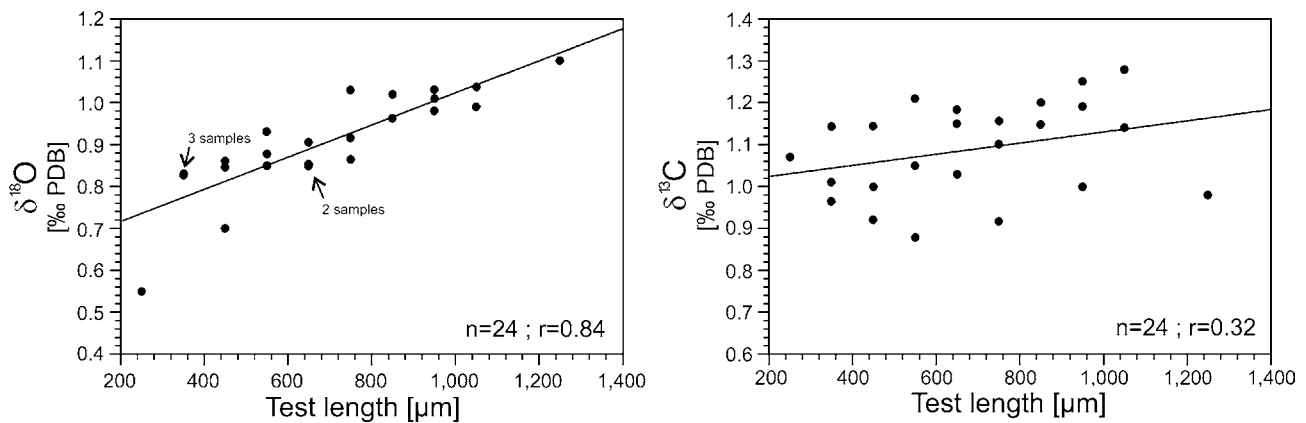


Fig. 3: Stable oxygen and carbon isotope values of *Pyramidina szajnochae* from sample 690C 20/4 33-34cm plotted against test size in 100 µm steps. From FRIEDRICH *et al.* (2006).

ontogenetic enrichment of $\delta^{18}\text{O}$ (0.55‰) is comparable to the Recent species (SCHMIEDL *et al.*, 2004). The $\delta^{13}\text{C}$ values of the latter ones, however, are enriched two- or three-fold when compared to $\delta^{18}\text{O}$. In contrast, the $\delta^{13}\text{C}$ values lack a significant ontogenetic enrichment. This observation implies that other yet unknown effects affect the carbon isotope values of *P. szajnochae*, obliterating ontogenetic enrichment. To clarify this observation, further studies on different size classes of Cretaceous deep-sea benthic foraminifera are needed.

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