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SUMMARY

DETERMINANTS ON HOLOCENE FORAMINIFERAL ASSEMBLAGE SHIFTS OFFSHORE CAPE BLANC, NW AFRICA

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Summary

Offshore Cape Blanc, NW Africa, is one of the most productive areas on Earth due to the ocean currents, upwelling system, and a major dust influx from the Sahara Desert (Hagen, 2001; Mittelstaedt, 1983). Sahara is considered the main contributor of aeolian dust on our Globe (Huneeus et al., 2011; Jickells et al., 2005), thus having a major impact in shaping ocean productivity. By delivering nutrients and trace elements such as iron (Fe) and phosphorus (P) to the ocean (Kolber et al., 1994) they act as a fertilizer for the ocean, enhancing the biological carbon pump through the so-called ballasting process (Guerreiro et al., 2024). Modern observational and experimental data revealed that the input of dissolved Fe is a productivity trigger for phytoplankton blooms (Boyd, 2002; Coale et al., 1996).

In the North Atlantic, two major ocean productivity components could be determined: a net primary production at the ocean surface (controlled by photosynthetic organisms), and an export production (particulate organic matter sinking to the ocean floor) (Berger et al., 1989). Recent studies proved that an iron-rich dust influx can boost primary productivity up to 30% (Weis et al., 2024). However, still little is known about Fe-fertilization and dust impact on the benthic communities or how the phytoplankton productivity boost is translated to the ocean floor, and later exported into the sediment.

Consequently, offshore NW Africa is an ideal location to investigate the impact of ocean productivity and biogeochemistry. Furthermore, Cape Blanc is considered a classical site for benthic foraminiferal (BF) research, since it was here first observed and described the BF assemblage's vertical distribution in the sediments, and a linkage identified between the BF zonation, geochemical processes, and bacterial communities (Jorissen et al., 1998).

However, previously published studies are based only on larger benthic foraminifera fractions (>150 µm and >250 µm, respectively) collected along one transect (Lutze and Coulbourn, 1984). Therefore, the relative abundance of the smaller, phytodetritus-related taxa (e.g., *Alabaminella*, *Epistominella*) was likely underestimated. To fill this gap, we conducted a high-resolution study of the BF assemblages >63 µm and their determinants in this complex and intricate region. Here, we combine stable isotope analyses ($\delta^{13}C$ and $\delta^{18}C$) with benthic and planktonic foraminiferal assemblage data along two transects, spanning depths from the continental shelf (~100 m) to the abyssal plain (~3500 m). By analyzing the horizontal

and vertical distribution of foraminifera and stable isotope changes, we aim to identify the drivers of surface productivity and the organic matter flux effects on the benthic ecosystem dynamics and influence carbon cycling at different depths.

Chapter 1. Determinants on benthic foraminiferal shifts offshore Cape Blanc, NW Africa

The coastal area of Cape Blanc, situated offshore NW Africa, represents a complex oceanographic environment characterized by strong currents, upwelling, and significant dust influx from the Sahara. These conditions profoundly influence the distribution and dynamics of benthic foraminiferal assemblages, organisms used as environmental indicators. This study analyzes the structure of benthic foraminiferal assemblages (>63 μm) collected along two transects, spanning from the continental shelf (~100 m) to the abyssal plain (~3500 m), highlighting the relationship between their distribution, oxygen parameters (BWO and PWO), and food availability.

Spatial Distribution of Benthic Foraminifera

Benthic foraminiferal assemblages in the study area display a distinct zonation based on depth and geomorphology. On the outer shelf and upper bathyal zone (111–495 m), the Cassidulina laevigata-dominated assemblage reflects elevated oxygenation, with abundance decreasing with depth (Fig. 1). The proportion of oxic species increases from ~26% to >54%, while suboxic and dysoxic species decline. This trend aligns with a slight increase in bottom-water oxygen (BWO) and pore-water oxygen (PWO).

At mid-depths (844–2339 m), the Bolivina-Cassidulina assemblage on the northern transect displays heterogeneity and patchiness. The relative abundance of hyaline taxa decreases from ~92% to 57%, favoring porcelaneous and agglutinated forms. Despite significant increases in BWO and PWO, suboxic species dominate (~50%→73%), suggesting that food availability and interspecific competition play a larger role than oxygenation.

On the southern transect, within the same bathyal zone (780–1624 m), the *Bulimina aculeata* assemblage is more homogeneous, influenced by a canyon and south-north currents. The proportion of oxic species remains stable (~20–28.6%), while suboxic species increase (~39%→58%), despite BWO and PWO trends mirroring those of the northern transect. These differences underscore the impact of geomorphology on ocean circulation and nutrient fluxes.

In abyssal zones (2939–3405 m), two distinct assemblages reflect adaptations to high-oxygen environments and phytodetritus deposits. The *Eggerella-Alabaminella* assemblage (2939 m), dominated by agglutinated taxa (~36%), is associated with maximum oxygenation (BWO: 4.86 ml/l). In contrast, the Epistominella exigua assemblage (3405 m), dominated by suboxic species (~67–72%), colonizes phytodetritus-rich sediments despite high oxygen levels. This suggests adaptation to organic-rich microhabitats may compensate for oxygenation conditions.

Reliability of Oxygen Indices (BFOI and EBFOI)

The Benthic Foraminiferal Oxygen Index (BFOI) and Enhanced BFOI (EBFOI), used to estimate historical oxygen levels, were tested under Cape Blanc's complex conditions. Results show weak correlations between these indices and measured BWO/PWO levels. Suboxic species moderately correlate with BWO, and dysoxic species with PWO, but secondary factors (competition, upwelling, dust) reduce accuracy. For example, oxic species are affected by competition, while suboxic species thrive in well-oxygenated environments if sufficient food is available.

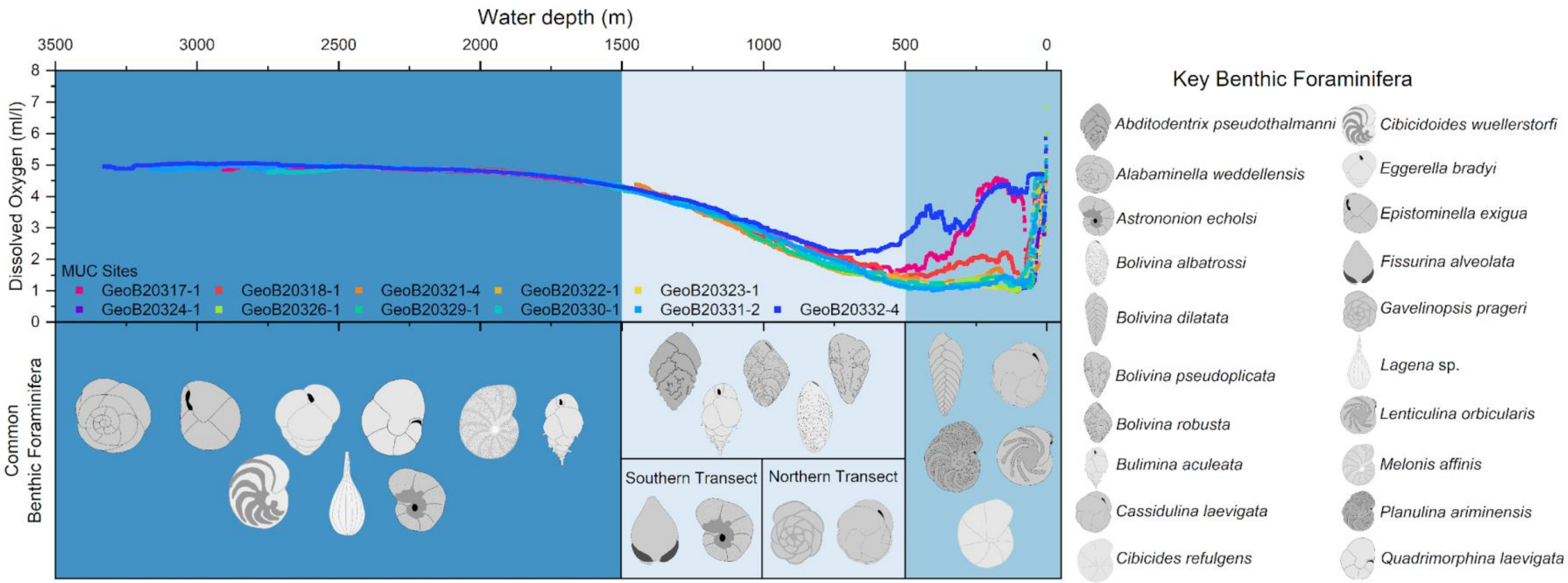

Figure 1. Benthic foraminiferal zonation offshore Cape Blanc, NW Africa. Dissolved Oxygen (ml/l) data was measured during the MSM48 ADOMIS cruise (Zonneveld et al., 2017).

Chapter 2. Uncovering Stable Isotope Variability and Foraminiferal Shifts Offshore Cape Blanc, NW Africa

Benthic Foraminiferal Zonation

The study of benthic foraminiferal assemblages offshore Cape Blanc revealed distinct zonation patterns controlled by depth, nutrient availability, and oxygen levels. In shallow coastal waters, *Cassidulina laevigata* dominates, thriving in warm, nutrient-rich, and oxygenated environments. Other infaunal species like *Bolivina dilatata* and *Bolivina robusta* are linked to high organic flux zones. At moderate depths (~500 m), *Planulina ariminensi*s and *Cibicides refulgens* prevail, reflecting adaptations to suspended particle feeding strategies.

In mid-to-lower bathyal zones (500–1500 m), oxygen-depleted conditions (OMZ) favor species like *Abditodentrix pseudothalmanni* and *Bulimina aculeata*, known for thriving in low-oxygen, high-productivity settings. Southern transect samples show distinct distributions (e.g., *Fissurina alveolata*), influenced by geomorphology and currents.

At abyssal depths (>1500 m), oxygen-rich North Atlantic Deep Water (NADW) supports opportunistic phytodetritus-associated species like *Alabaminella weddellensis* and *Epistominella exigua*. These species exploit sporadic organic matter inputs, while *Astrononion echolsi* fills ecological niches during low productivity intervals.

Planktonic Foraminifera and Surface Productivity Drivers

Nearshore surface waters are dominated by upwelling indicators *Globigerina bulloides* and *Globigerinita glutinata*. Offshore, *Neogloboquadrina incompta* becomes predominant, linked to seasonal Saharan dust fertilization. Dust-driven productivity pulses, modulated by the Intertropical Convergence Zone (ITCZ), trigger short-lived phytoplankton blooms, reflected in $\delta^{13}C$ variability in *Globigerinoides ruber*.

Isotopic Signatures and Carbon Cycling

Epibenthic *Cibicidoides wuellerstorfi*'s $\delta^{13}C$ values near the coast align with efficient carbon export driven by upwelling. In contrast, abyssal $\delta^{13}C$ depletion reflects organic matter remineralization in the water column and NADW influence. The $\Delta\delta^{13}C$ gradient between *G. ruber* and *C. wuellerstorfi* increases with depth, highlighting stratification and episodic dust inputs disrupting vertical carbon transfer.

In OMZ depths (500–1500 m), the $\Delta\delta^{13}C$ between *C. wuellerstorfi* (epibenthic) and *Uvigerina peregrina* (endobenthic) rises due to intense organic matter remineralization. At abyssal depths, stable NADW conditions homogenize isotopic signatures, minimizing variability.

Hence, the coastal zones exhibit efficient carbon export, while abyssal regions are marked by remineralization and stratification (Fig. 2). Benthic foraminiferal assemblages and isotopic data underscore the sensitivity of marine ecosystems to regional oceanographic and climatic drivers, emphasizing the need for species-specific assessments in palaeoceanographic reconstructions.

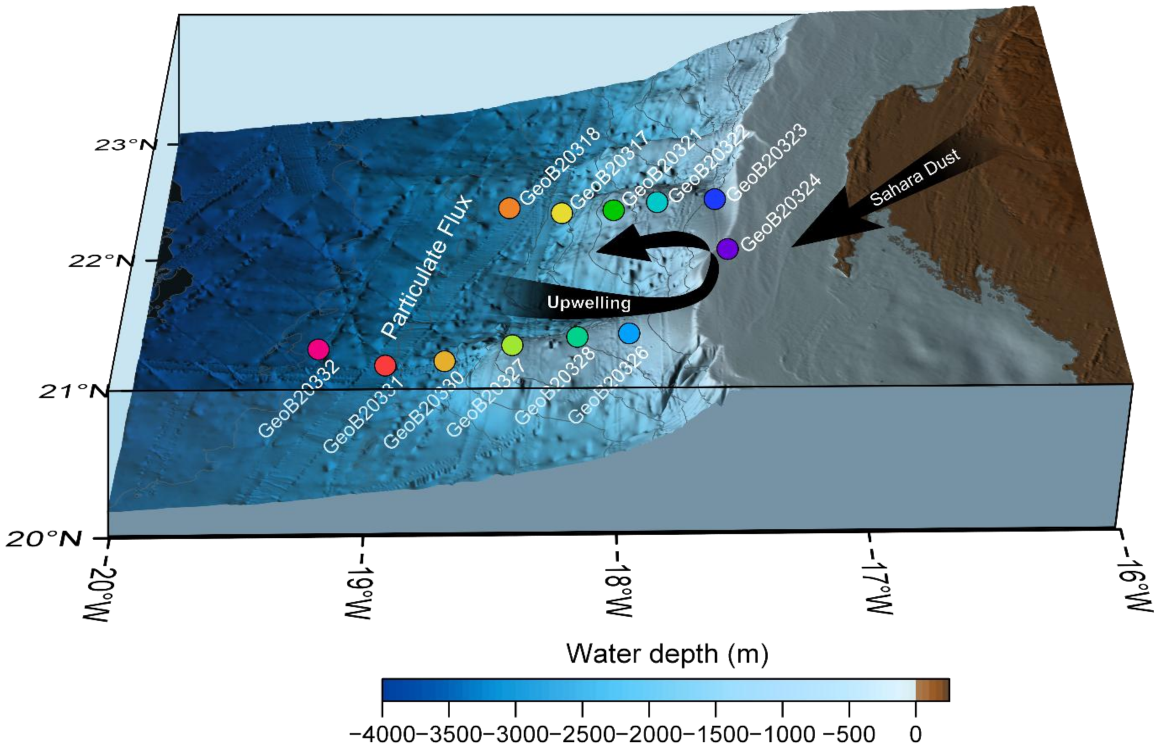

Figure 2. Determinants and drivers of the different productivity regimes offshore Cape Blanc, NW Africa.

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