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Reconstructing Expansion of the Eastern Arabian Sea Oxygen Minimum Zone During Late Quaternary: Using Multiproxy Record

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The Arabian Sea, situated in the northwestern Indian Ocean, is a climatically sensitive and oceanographically dynamic basin. Its circulation and productivity are strongly controlled by the Indian monsoon system, which drives seasonal reversal wind. These processes sustain high marine productivity and contribute to the formation of one of the most intense oxygen minimum zones (OMZs) in the global ocean. The basin plays a significant role in regional carbon cycling, nutrient regeneration, and air–sea interactions. Owing to its strong response to monsoon variability, the Arabian Sea provides an important natural archive for understanding past climate–ocean linkages and changes in biogeochemical cycle. To understand how this system behaved in the past, we investigated a high-resolution sediment core from the eastern Arabian Sea. By combining geochemical and micropaleontological proxies, we reconstructed past changes in ocean oxygenation and productivity during Late Quaternary. During MIS 3, higher $\delta^{15}N$ values together with increased Mo/Al, U/Al, and U/Th ratios indicate stronger denitrification and the development of oxygen-poor bottom waters. These geochemical records are supported by a clear rise in low-oxygen tolerant benthic foraminifera such as *Uvigerina*, *Bolivina*, *Bulimina*, and *Fursenkoina*, reflecting persistent dysoxic to suboxic conditions. At the same time, elevated TOC, TN, Cd/Al, Ni/Al, Zn/Al and more negative $\delta^{13}C_{org}$ values suggest enhanced organic matter export to the seafloor and nutrient availability, most likely driven by intensified southwest monsoon upwelling. TOC/TN ratios below 8 and $\delta^{13}C_{org}$ values between −20‰ and −22‰ confirm that the organic matter was predominantly marine in origin. Changes in surface dwelling planktonic foraminifera further indicate reduced surface stratification and stronger vertical mixing, which would have helped nutrient supply to surface waters as confirmed by the increased Cd/Al, Ni/Al, and Zn/Al ratio. Benthic abundance and diversity were notably higher during this interval, consistent with elevated productivity under oxygen-limited conditions. Together, these results demonstrate that strengthened monsoon forcing during MIS 3 led to enhanced productivity and hence a significant expansion of the OMZ, reaching depths of ~1850 m. This study highlights the close coupling between monsoon variability and OMZ dynamics, offering valuable insight into how these systems may respond to future climate change.

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Abstract

The Arabian Sea, situated in the northwestern Indian Ocean, is a climatically sensitive and oceanographically dynamic basin. Its circulation and productivity are strongly controlled by the Indian monsoon system, which drives seasonal reversal wind. These processes sustain high marine productivity and contribute to the formation of one of the most intense oxygen minimum zones (OMZs) in the global ocean. The basin plays a significant role in regional carbon cycling, nutrient regeneration, and air–sea interactions. Owing to its strong response to monsoon variability, the Arabian Sea provides an important natural archive for understanding past climate–ocean linkages and changes in biogeochemical cycle. To understand how this system behaved in the past, we investigated a high-resolution sediment core from the eastern Arabian Sea. By combining geochemical and micropaleontological proxies, we reconstructed past changes in ocean oxygenation and productivity during Late Quaternary. During MIS 3, higher $\delta^{15}N$ values together with increased Mo/Al, U/Al, and U/Th ratios indicate stronger denitrification and the development of oxygen-poor bottom waters. These geochemical records are supported by a clear rise in low-oxygen tolerant benthic foraminifera such as *Uvigerina*, *Bolivina*, *Bulimina*, and *Fursenkoina*, reflecting persistent dysoxic to suboxic conditions. At the same time, elevated TOC, TN, Cd/Al, Ni/Al, Zn/Al and more negative $\delta^{13}C_{org}$ values suggest enhanced organic matter export to the seafloor and nutrient availability, most likely driven by intensified southwest monsoon upwelling. TOC/TN ratios below 8 and $\delta^{13}C_{org}$ values between −20‰ and −22‰ confirm that the organic matter was predominantly marine in origin. Changes in surface dwelling planktonic foraminifera further indicate reduced surface stratification and stronger vertical mixing, which would have helped nutrient supply to surface waters as confirmed by the increased Cd/Al, Ni/Al, and Zn/Al ratio. Benthic abundance and diversity were notably higher during this interval, consistent with elevated productivity under oxygen-limited conditions. Together, these results demonstrate that strengthened monsoon forcing during MIS 3 led to enhanced productivity and hence a significant expansion of the OMZ, reaching depths of ~1850 m. This study highlights the close coupling between monsoon variability and OMZ dynamics, offering valuable insight into how these systems may respond to future climate change.

Keywords: Arabian Sea, Oxygen Minimum Zone, Foraminifera