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Linking East Asian Dust Flux to Surface Ocean Carbonate Chemistry in the Kuroshio-Oyashio Extension: A 23-kyr Record of Clay Mineralogy and Boron Isotopes

SUNHWA BANG[1], YOON JI[1], HYO-IM KIM[1], YOUNGSOOK HUH[2] AND JUNG OK KANG[3]

[1]Gyeongsang National University
[2]Seoul National University
[3]Korea University

The Kuroshio-Oyashio Extension (KOE) is a dynamic transition zone where the Kuroshio and Oyashio currents converge, linking surface ocean circulation, Asian dust transport, and marine carbonate chemistry. Here we present the first record of deglacial pH fluctuations in the KOE, reconstructed from boron isotopes ($\delta^{11}B$) measured in three planktic foraminiferal species from sediment core NPGM/P 1302-1B (32° 16′ N, 158° 13′ E, 2514 m water depth) spanning the last 23 kyr. Clay mineralogy records from oriented fine-fraction (<2 μm) samples of the same core reveal compositions closely resembling those of the Ulleung Basin and Asian desert sediments in a ternary diagram and crossplots in clay composition, consistent with a dust transport pathway driven by the westerly wind belt. The $\delta^{11}B$ records reveal a pronounced vertical pH gradient: surface-dwelling species (*G. bulloides, N. pachyderma*; 0–50 m) record a alkaline environment in late LGM (22.3-19.0 ka; ~pH 8.2), whereas lower thermocline species (*T. sacculifer*: 75-125 m) indicate acidification(~pH 8.0), a significant decoupling absent in other periods. This interval coincides with high illite content exceeding 70%, related to Asian dust compositions. We interpret this decoupled pH change as evidence for intensified iron fertilization driven by high dust flux in early warming conditions, which enhanced primary productivity at the surface, drawing down dissolved CO_2 and creating an alkaline environment. This hypothesis is corroborated by an exceptionally high foraminiferal flux (~$6x10^7$ shells cm^{-2} kyr^{-1}), coeval peaks in biogenic opal and organic carbon, and maximum linear sedimentation rates (~30 cm/kyr). Conversely, decomposition of organics and carbonate dissolution in the lower thermocline accumulated respired CO_2, driving subsurface acidification, consistent with the dissolved foraminiferal shell factor (F) during this interval. Through careful comparison of key regional references and multi-proxy records, we establish that late LGM dust fertilization during deglaciation created a biological pump and played a significant role in the ocean-atmosphere carbon cycle.