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Geochemical Evidence for Widespread Off-Axis Hydrothermal Circulation: Tracking Diffusive Exchange in Sediment Porewater Chemistry

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Off-axis hydrothermal flow is a widespread but underrecognized process occurring within basaltic basement beneath deep-sea sediments. While high-temperature ridge-axis systems have been extensively characterized, the geochemical expression and quantitative contribution of off-axis systems to global ocean biogeochemical cycles remain poorly constrained. This study develops a geochemical framework for identifying off-axis hydrothermal influence using sediment porewater data from scientific ocean drilling programs. Five regions with confirmed off-axis circulation were examined through a literature review to establish reference geochemical patterns. Concentration differences between sediment and basalt layers drive porewater gradient reversals of Sr^{2+}, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and NH_4^+ near the sediment–basement interface, which serve as proxies for this circulation. To assess the broader occurrence of these proxies, the first-ever integrated sediment porewater dataset from IODP expeditions ("sed-PIE") was compiled by aggregating porewater data from all DSDP, ODP, and IODP expeditions. A web-scraping, AI-assisted Python script was developed to systematically screen both expedition reports and the new sed-PIE dataset for off-axis hydrothermal circulation proxies. This approach identified 37 new sites with geochemical signatures of off-axis flow, suggesting that this flow may be more widespread than previously documented. Because individual concentration profiles can be superimposed by diagenesis, or magmatic processes, $^{87}Sr/^{86}Sr$ isotope ratios were evaluated as a potentially more specific diagnostic tool. At IODP Site U1541, located on the western flank of the East Pacific Rise ~160 nmi from the spreading axis, porewater concentration profiles show some features suggestive of off-axis hydrothermal circulation. In contrast, strontium isotope ratios clearly exhibit curvature toward modern seawater values near the sediment–basement interface, consistent with diffusive exchange with basalt-derived fluids. These results suggest that while traditional tracers may provide limited evidence for off-axis circulation, Sr isotopes may serve as a more sensitive proxy for off-axis hydrothermal circulation, however, broader isotopic evaluation across additional sites is needed. The site identification in this study relies solely on geochemical and isotopic porewater profiles, so future integration with heat flow and other physical proxies will be essential for understanding subsurface hydrologic pathways and quantifying off-axis hydrothermal fluxes.