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Mg isotopic insights into subducted mélanges and implications for the subduction zone carbon cycle

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Subduction zones are key gateways in the solid Earth carbon cycle, regulating the transfer of carbon between surface reservoirs and the deep mantle. Within these settings, fluid–rock interaction exerts a first-order control on element mobilization, mass transfer, and the formation of critical metal deposits, yet the nature and sequencing of multistage fluid–rock processes in subduction channels remain poorly constrained. We present bulk-rock major and trace element data together with Mg isotope compositions ($\delta^{26}Mg_{DSM-3}$) for a suite of subducted ophiolitic mélange rocks from Wadi Al Barramiyah in the Arabian–Nubian Shield, Eastern Desert of Egypt. The rocks include serpentinites, talc rocks, talc–dolomite rocks, tremolite-dominated schists, and marbles. Talc rocks show relatively low MgO contents and elevated $\delta^{26}Mg_{DSM-3}$ values (0.03–0.13‰) compared with serpentinites (≈ −0.18‰), consistent with the loss of isotopically light Mg during metasomatic replacement of antigorite by talc and the release of a light-Mg fluid. Tremolite-dominated schists and talc–dolomite rocks have higher CaO contents and lower $\delta^{26}Mg$ (−0.25‰ to −0.03‰ and −1.04‰ to −0.18‰, respectively) than both talc rocks and serpentinites. Combined with high CaO/Al_2O_3 and low Rb/Sr ratios, these signatures point to the infiltration of carbonate-rich, low-$\delta^{26}Mg$ fluids, consistent with extremely low $\delta^{26}Mg$ values (down to −2.38‰) measured in adjacent marbles. We infer that antigorite dehydration liberates substantial volumes of H_2O-rich fluid that enhances carbonate dissolution in marbles; subsequent carbonate metasomatism efficiently sequesters carbon from aqueous carbon-bearing fluids and converts silicate assemblages into carbonates. These results highlight the key role of mélange rocks in recording multistage fluid–rock interactions and carbon recycling in subduction zones, and provide new constraints on mantle Mg-isotopic heterogeneity and crust–mantle coupling associated with subduction.