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# Quantifying Carbonate Weathering and $CO_2$ Outgassing in Orogenic Regions of Southwestern Taiwan: Insights from Triple Sr Isotopes and a Machine Learning Approach

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In the orogenic regions of southwestern Taiwan, river water chemistry revealed that carbonate weathering is the dominant process—accounting for 50–80% of total weathering—with sulfuric acid driving 50–67% of the carbonate dissolution. A strong correlation between increased river discharge and sulfuric acid-induced carbonate weathering indicates that during wetter periods, the heightened runoff carries minerals such as pyrite, which in turn boosts sulfuric acid production and enhances carbonate dissolution. Moreover, higher river discharge not only accelerates carbonate dissolution but also triggers secondary carbonate precipitation, significantly increasing $CO_2$ outgassing from carbonate-rich rivers. Although stable isotope fractionation has been widely applied to quantify post-weathering reactions and to measure metal removal via secondary carbonates, distinguishing between signals from lithological mixing and those from fractionation remains challenging. To address this issue, we applied triple Sr isotopes ($^{87}Sr/^{86}Sr$ and $\delta^{88/86}Sr$) to determine the "unfractionated" $\delta^{88/86}Sr$ signature of the water, allowing us to accurately quantify the fractionation driven by carbonate precipitation. Our findings indicate that a median of 48% of the Sr and 69% of the initially weathered Ca is incorporated into carbonates. This process is closely linked to elevated bicarbonate ($HCO_3^-$) concentrations, driven by intensified carbonate weathering during periods of high discharge. Lastly, our machine learning model shows that $CO_2$ outgassing from precipitation in these rivers is nearly double the long-term $CO_2$ emission flux, underscoring its significant impact on the terrestrial carbon cycle in orogenic regions.