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Quantifying the role of deep carbon fluxes on the geological carbon budgets of orogenic belts

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The Himalayan orogeny has been long thought to be a driver of Cenozoic cooling due to its capacity to sequester atmospheric CO_2 by silicate weathering and organic burial, which significantly exceeds the CO_2 release by other weathering processes such as sulfuric acid-induced carbonate weathering and rock organic matter oxidation. However, the impact of deep carbon fluxes, viz. mantle sources such as magmatic volatilization or crustal sources such as metamorphic decarbonation, oxidation of sedimentary organic matter, and aqueous carbonate dissolution on the carbon cycle, is poorly constrained. In this study, we quantified the CO_2 fluxes released from geothermal springs to the atmosphere through fault zones. A Rayleigh fractionation-based model that utilizes the geothermal discharge and the temperature, dissolved inorganic carbon (DIC) concentrations, and $\delta^{13}C$ composition of DIC ($\delta^{13}C_{DIC}$) in hot spring waters and $\delta^{13}C$ of degassed CO_2 ($\delta^{13}C_{CO2}$) was used to quantify the CO_2 degassed from hot springs. This direct CO_2 flux was combined with diffuse soil CO_2 flux estimates to arrive at deep CO_2 flux estimates for the entire orogen. We show that the Himalayan-Tibetan orogen can release an order of magnitude of 10^{11} mol C yr^{-1}, which is comparable to major geological carbon sources such as continental rifts, volcanoes, and mid-oceanic ridge as well as the CO_2 drawdown due to silicate weathering in the orogen (~3.4 x 10^{11} mol C yr^{-1}), thereby significantly counteracting the latter. Furthermore, a $CO_2/^3He$ – $\delta^{13}C_{CO2}$ mixing model in geothermal gases was used to separate crustal and mantle contributions. On the other hand, ionic concentrations in hot springs determined the proportion of the crustal contributions derived from carbonate dissolution, with the rest being metamorphic. Our analysis reveals that metamorphism is the primary source of the degassed CO_2 (65%), followed by aqueous carbonate dissolution (28%) and the mantle (7%). We conclude that this additional flux of CO_2 will more than halve the orogen's carbon sink and potentially turn it into a net carbon source. Thus, on million-year timescales, deep carbon releases will offset the impact of the carbon sink created by weathering processes and mute the orogeny's role in regulating long-term climate change.