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Machine Learning Insights into Primitive CO_2 and Cl Contents of MORB and OIB: Implications for Mantle Volatile Cycling

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The mantle serves as a crucial reservoir for deep-Earth volatiles, and mid-ocean ridge basalts (MORB) and ocean island basalts (OIB) provide critical windows into the cycling of carbon and chlorine in the mantle. However, during magma ascent, significant carbon loss results from degassing, while chlorine content often increases due to seawater contamination and assimilation, making it challenging to determine the primitive CO_2 and Cl concentrations. Previous studies commonly relied on assumed volatile-to-incompatible trace element (ITE) ratios to estimate the basalts' primitive volatile contents, particularly carbon. Nevertheless, growing evidence suggests that these ratios exhibit considerable variability, raising significant doubts about the reliability of the fixed volatile-to-ITE ratio method. In this study, we address this challenge by employing the machine learning technique. First, we rigorously curated two global MORB and OIB datasets: one for carbon (samples without significant degassing) and another for chlorine (samples without significant seawater alteration or assimilation). Subsequently, we developed separate machine learning models to predict primitive CO_2 and Cl contents based on their respective major and trace element compositions. These models were then applied to global MORB and OIB datasets. Our results reveal substantial variability in the primitive CO_2 and Cl contents, as well as CO_2/Nb and Cl/Nb ratios, further underscoring the heterogeneity of the mantle. Notably, enriched mantle (EM) endmembers exhibit higher CO_2/Nb and Cl/Nb ratios compared to depleted mantle and HIMU endmembers, challenging the conventional view that EM endmembers are often characterized by lower volatile-to-ITE ratios. Additionally, the enrichment of carbon and chlorine in the mantle is not solely associated with hotspots but is also influenced by factors such as the recycling of subducted crust. In conclusion, machine learning has opened new avenues for advancing our understanding of the distribution and dynamic processes of mantle volatiles.