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Chemical Geodynamics Insights from a Machine Learning Approach

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The isotopic heterogeneity of oceanic basalts is the surface expression of mantle heterogeneity. So far, inferences about the compositional evolution of Earth's mantle mostly derive from inspection of two-dimensional (2D) isotope ratio diagrams. But the simple 2D analysis may obscure the genuine or suggest spurious systematics of the underlying multi-dimensional radiogenic isotope data ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $^{176}Hf/^{177}Hf$, $^{208,207,206}Pb/^{204}Pb$). Here, we apply t-distributed stochastic neighbor embedding (t-SNE), a multi-variate statistical data analysis technique, to deduce the isotopic affinities of a global data set of mid ocean ridge (MORB) and ocean island basalts (OIB). The t-SNE results show that the apparent overlap of MORB-OIB data trends in 2-3D isotope ratios diagrams does not exist in multi-dimensional isotope data space, revealing that there is no discrete 'component' that is common to most MORB-OIB mantle sources on a global scale. Rather, MORB-OIB sample stochastically distributed small-scale isotopic heterogeneities. Yet, oceanic basalts with the same isotopic affinity, as identified by t-SNE, delineate several globally distributed regional domains. In the regional geodynamic context, the isotopic affinity of MORB and OIB is caused by the capture of actively upwelling mantle by adjacent ridges, and thus melting of mantle with similar origin in on, near, and off-ridge settings. Moreover, within a given isotopic domain, subsidiary upwellings rising from a common deep mantle root often feed OIB volcanism over large surface areas. Overall, the t-SNE results provide a novel, self-consistent framework for investigating the mantle's 'chemical geodynamics'.