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EARTHCODES: an open-source program to easily design, test and compare geochemical models against large multivariate datasets

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Decades of extensive sampling and analytical work gave rise to rich multivariate geochemical datasets for thousands of oceanic basalts. Radiogenic isotopes in particular hold compositional and chronological information on mantle history and heterogeneity.

Recent work shows geochemical inversions based on processes (e.g. melting, depletion, mixing, hybridization, recycling) can extract far more information from multivariate radiogenic isotope data than the classic “mantle endmembers” paradigm and enable direct comparisons with geophysical observations and models, breaking a longstanding barrier to inter-disciplinary research. In Hawai‘i, peridotite depletion quantified from isotope data brings an explanation for recent bursts of plume activity observed by geophysics [1]. Globally, new models of plume and ridge mantle source compositions informed by geochemical data successfully output metrics that independently validate geodynamical models of mantle convection [2].

Comprehensive, processes-based geochemical modelling thus have the potential to transform deep Earth research at a time where emphasis is shifting away from data generation. These methods however require programming skills, are time-consuming to implement, and lead to model-dependent results.

I developed EARTHCODES, a freely available, open-source Python-based script that successfully resolves these issues. Users can rapidly build and customize complex geochemical models by assembling modules that perform calculations related to individual processes. Modules are assembled in chronological order, building multiple geochemical reservoirs that are easily merged within a fully flexible model architecture. Models can then be run (e.g. with a laptop), translating large multivariate datasets into quantified model variables at the sample scale. This geochemical inversion is done through a Monte Carlo routine (optionally using Markov Chains), enabling a thorough assessment of model sensitivity and uncertainty. Model customization and results treatment can entirely be done using spreadsheets, with only simple commands in Python. Multiple distinct models can easily be designed, run, and compared, directly addressing the problem of model dependency [2]. In a logic of open-science, the Python code can also be modified, for instance to write new processes modules.

I will discuss processes-based geochemical research and present examples of how EARTHCODES can be used to investigate magmatic systems.

[1] Béguelin et al. (2025). AGU Advances, 6(2).

[2] Béguelin et al. (2025). G-Cubed 26(8).