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Data-driven inversion of melting processes during subduction initiation of the Oman ophiolite: Constraints from Independent Component Analysis (ICA) & Open-System Melting (OSM) optimization

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The Oman Ophiolite exposes a section of oceanic crust and upper mantle peridotite formed during subduction-initiation in a fore-arc similar to the Izu-Bonin-Mariana arc system. Its mantle peridotites record mantle processes associated with subduction initiation (partial melting, melt/fluid-rock interaction, and metasomatism).

We analyze whole-rock trace elements for 194 peridotites (lherzolite, harzburgite and dunite) from the Fizh [2, 3] and Wadi Tayin (this study) massifs. We conducted Independent Component Analysis (ICA) on these samples to understand the compositional systematics and optimization of Open-System Melting (OSM) model [1] to each sample to constrain the melting processes and their evolution.

ICA decomposes the compositions into four ICs interpreted with geological and petrological constraints [4]: IC1, partial melting beneath a spreading ridge; IC2, slab-fluid-fluxed melting during subduction-initiation; IC3, Sr & Ba enrichment during serpentinization; and IC4, mantle metasomatism by slab-derived fluids. These components explain most of the trace element variance of peridotite compositions.

We then fit an OSM model to each sample by numerical optimization. Best-fit OSM estimation indicates melting degrees in the garnet and spinel stability fields, critical melt fraction, influx composition, and influx rate. Best-fit parameters indicate 0-11% melting in the garnet field followed by 3.5-29% in the spinel field, with critical melt fraction 0-0.18. Two influx endmembers are required: Type I is consistent with extracted melts compositions during partial melting with a little slab-fluid contribution, whereas Type II has a slab-melt-like composition in high temperature with high LREE/HREE ratio. Observed compositions are reproduced by 0-11% melt/fluid-rock reaction between inferred influx melts and residual peridotite.

ICA and OSM model highlight that the studied peridotites record two distinctive melting processes. Stage 1 shows spreading ridge stage with 0-23% melting, 0-0.08 critical melt fraction and little reaction with Type I influx. Stage 2 shows subduction proceeding stage with 7-29% melting, 0.01-0.18 critical melt fraction and more reaction with Type II influx. ICA & OSM approach is a valid computational tool to quantify how igneous processes evolve in subduction-initiation.

[1] Ozawa (2001), *JGR*, 106(B7). [2] Takazawa *et al*. (2003), *G-Cubed*, 4(2). [3] Kanke & Takazawa (2014), *GSLSP*, 392(1). [4] Miki *et al*. (2025), *G-Cubed*, 26(3).