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Lower continental crust sulphides from the Ivrea-Verbano Zone (ICDP-DIVE project 5071): textures, trace-element chemistry and mobility

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The mobility of sulphur and chalcophile metals through the lithosphere remains poorly constrained, yet it is likely to have a significant impact on metal budgets and the localisation of ore systems that underpin the supply strategic commodities for the energy transition.

Increasing evidence suggests that sulphur and chalcophile metals can be redistributed via multiple, potentially overlapping processes, including sulphide melt migration, fluid-mediated transport, partial melting, and deformation-assisted remobilisation. These mechanisms operate across a wide range of pressure-temperature conditions and may decouple metal transport from large-volume magmatic fluxes, producing complex metal redistribution patterns within the lithosphere.

In this framework, deep mafic-ultramafic cumulates in lower crustal zones act as major reservoirs and transfer hubs where sulphide melts can sequester a large fraction of the metal budget, while being episodically mobilised within melt-bearing cumulate frameworks, enabling upward transfer to upper-crustal levels (i.e. Holwell et al. 2022). A complementary mechanism for enriching and moving sulphur and copper is provided by devolatilization and wall-rock assimilation. Fluids can already effectively mobilise sulphur and copper under subsolidus conditions, enhancing mobilisation that may have already accompanied partial melting and produce Cu-rich sulphide droplets that can attach to fluid bubbles (i.e. Blanks et al. 2020) or carbonate melt droplets (i.e. Cherdantseva et al. 2024) which can be transported buoyantly within silicate melt (i.e. Virtanen et al. 2021). Deformation potentially introduces an additional mechanism of redistribution, which is highly relevant for interpreting sulphide signatures in deep crustal rocks, and metamorphism commonly overprints ore systems, creating favourable conditions for further mobilization of critical metals (i.e. Cugerone and Cenkci 2025).

Newly acquired continuous drill core from the Ivrea-Verbano Zone provides an exceptional opportunity to investigate these processes in a well-constrained lower-crustal setting. The core samples mafic and ultramafic lithologies across documented igneous, metamorphic, and structural domains, allowing sulphide occurrence, texture, and chemistry to be examined in their primary context, while also distinguishing deep-crustal magmatic processes from later deformation- or fluid-assisted remobilisation.

Borehole 5071_1_A is dominated by gabbroic lithologies, with intercalations of granulite-facies metasediments and pyroxenites, as well as intrusive gabbro-norites. We combine (i) XRF elemental mapping on the flat split core surfaces to track core-scale variations and identify sulphide-rich intervals and their structural/lithological controls, with (ii) SEM-EDS analyses to characterise sulphide mineralogy and (iii) LA-ICP-MS trace-element analyses of the major sulphide phases to constrain phase-dependent trace-element budgets and variations among various host lithologies as well as different textures. The sulphide assemblage is dominated by Fe-Ni-Cu sulphides (pyrrhotite-pentlandite-chalcopyrite), occurring both as disseminated interstitial grains and as foliation- and fracture-related networks associated with localised deformation and late-stage fluid pathways. Across these textural populations, trace-element systematics display different variations consistent with sulphide-silicate equilibration as well as later stage remobilisation.

By linking centimetre-scale elemental maps from continuous core to micro-analytical sulphide fingerprints, the ICDP-DIVE record allows us to advance the exploration and resource assessment for critical raw materials in complex crustal systems.

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