Metal migration and ore minerals across the crust-mantle transition zone (Oman DP ICDP holes CM1A, CM2B)

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Holes CM1A and CM2B of the International Continental Scientific Drilling Program (ICDP) Oman Drilling Project (OmanDP, https://www.omandrilling.ac.uk/) drilled through the Moho Transition Zone (MTZ). CM1A is composed of layered gabbro (0–160 meters below surface, mbs), dunite (160–310 mbs), and harzburgites (310–405 mbs), whereas CM2B contains dunite (20–120 mbs) and harzburgites (120–300 mbs). The drillholes provided an unprecedented opportunity to study the behavior of metals in the MTZ, where arriving primitive MORB melts extensively react with the mantle. Here, melts, typically enriched with sulfur and chalcophile elements, are supposed to enrich the mantle and lower crust with sulfides (Gonzalez-Jimenez et al., 2020 – Ore Geol. Rev.; Ciążela et al., 2018 - GCA).

Modal sulfide content increases downwards the gabbro sequence from ~0.004 vol.‰ to ~1.0 vol.‰ but decreases again from 0.8 vol.‰ to 0.01 vol.‰ in the lower part of the MTZ and in the harzburgite of the upper mantle. This is reflected in the S concentration increasing from 341 ± 17 ppm, 2sd to 832 ± 37 ppm, 2sd, in the gabbro section and decreasing downwards from the middle part of Moho into harzburgites from 475 ± 21, 2sd ppm to 63 ± 3 ppm, 2σ. The sulfides in olivine gabbro from MTZ are mostly (56–87% of all sulfides) pyrrhotite-pentlandite-chalcopyrite assemblages indicating the magmatic origin. Sulfides in layered gabbro sequence are consisted of similar magmatic assemblages (36-100%) with minor chalcopyrite, bornite, heazlewoodite, chalcocite, millerite, siegenite and sphalerite with secondary origin. In dunite and harzburgite sequences sulfides are exclusively hydrothermal.

Based on EMPA and LA-ICPMS measurements, Zn, Co and Cu seem to reach their maximum concentrations in magmatic sulfides from the MTZ. Although, no significant differences are observed between the Fe isotope signatures in magmatic pyrrhotites from the lower crust (~0.73 to ~0.24, 2sd [%] of δ56Fe) and the MTZ (~0.73 to ~0.53, [%] of δ56Fe), we found different δ56Fe for
pyrrhotite (-0.24‰) and chalcopyrite +0.36‰ within the same sulfide grain. The bulk signature of \( \delta^{56}\text{Fe} \) for this grain is -0.12‰ being in accordance with the mass balance calculated \( \delta^{56}\text{Fe} \) 0.025‰ ± 0.025‰ of the mantle (Craddock et al., 2013 – Earth Planet. Sci. Lett).

The enrichment in sulfides and selected metals (Zn, Co, Cu) towards the MTZ might result from melt-mantle reaction as we proposed previously for the slow-spread oceanic lithosphere based on the Kane Megamullion Ocean Core Complex (Ciążela et al., 2018 - GCA). In the CM1A/2B ultramafic rocks: dunites and harzburgites, most sulfides are, however, secondary, formed by the same secondary fluids which caused the pervasive serpentinization. To verify whether these sulfides replaced the primary magmatic sulfides or were brought from late-stage seawater-derived fluids, we plan to measure sulfur in whole-rocks and \textit{in situ} and more iron isotopes \textit{in situ}. Preliminary \( \delta^{56}\text{Fe} \) signature isotope data give us evidence for magmatic origin of the sulfides from upper part of the MTZ section.