Sulfur and Metal Fertilization of the Lower Continental Crust

Marco Fiorentini,[1] Marek Locmelis,[2] John Adam,[3] Tracy Rushmer,[3] Federica Zaccarini,[4] Giorgio Garuti,[4] Zoja Vukmanovic,[5] Stefano Caruso,[1] Marilena Moroni,[6] Steve Barnes,[7] Steve Reddy,[5] and Belinda Godel[7]

[1]CET/CCFS, University of Western Australia, Crawley, Australia
[2]NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States
[3]Macquarie University/CCFS, North Ryde, Australia
[4]Department of Applied Geosciences and Geophysics, University of Leoben, Austria
[5]Curtin University/CCFS, Perth, Australia
[6]Earth Science Department, Università degli Studi di Milano, Italy
[7]CSIRO Mineral Resources Flagship, Perth, WA, Australia

*E-mail, marco.fiorentini@uwa.edu.au

Early Permian pipe-like bodies of amphibole- and sulfide-rich peridotite were emplaced into the crust-mantle section of the Ivrea-Verbano zone of northwest Italy. In this study, we investigated one such body, the Valmaggia pipe, and we used an integrated approach to unravel the relationship between the microstructural features of the pipe, its 3-D mineralogical and mineralogical-chemical textural network, and its emplacement mechanism at the interface between the lithospheric mantle and the base of the continental crust. The outcomes from this work bear an insight on the capacity of hydrous mafic melts to transport sulfur and chalcophile metals from the mantle into the crust. We propose that the pipe rocks and their sulfide mineralization are cumulates that crystallized under lower crustal conditions (≤0.8 GPa) within feeder conduits for ascending basaltic magmas. The original cumulates were dunitic, but during cooling of the magmatic system these partially reacted with water-rich melts (at 1,000°–1,050°C) to produce abundant amphibole and (lesser) orthopyroxene, together with residual olivine. Plagioclase, mica, apatite, and spinel co-crystallized during this stage and/or precipitated during the final solidification of residual intercumulus liquid. The parent magmas of the pipes were probably alkaline and sodic (similar to alkali olivine basalt or basanite) and enriched in a broad range of incompatible elements. They display a signature that resembles that of high-Nb basalts, which are commonly associated with adakites in postcollisional settings worldwide. Results from EBSD analysis and 3-D X-ray tomographic studies on cumulate minerals from the Valmaggia pipe suggest that deformation of olivine, amphibole, and orthopyroxene occurred synchronously during emplacement of the magma. In terms of multiple sulfur isotope systematics, the mineralization associated with the pipes generally displays a mantle-like $\delta^{34}S$ signature (0 ± 2‰), with rare but notable lighter signatures ($\delta^{34}S$ = –4‰). The results from the 3-D X-ray tomographic study together with the grain and size analysis support the hypothesis that the parental magma to the Valmaggia pipe was sulfide saturated at the time of emplacement. In the initial stages of magma emplacement, fine sulfide blebs (made up of mainly pyrrhotite and minor amounts of chalcopyrite) were transported and subsequently incorporated into the early crystallizing olivine cumulates. Subsequently, larger blebs formed due to coalescence of the finer ones along the margins of the pipe, where shear flow and wall-rock interactions favored the accumulation of Ni-Cu-PGE sulfide mineralization. Sulfide transport and coalescence may have also been favored by the exsolution of CO_2-bearing vapor bubbles. Deep-seated magmatic mineral systems such as the ones exposed in the Ivrea zone provide fundamental insights into the nature of volatile and metal transfer from the lithospheric mantle into the base of the continental crust.