Mantle-to-crust scale chemical fractionation and sulphide saturation of the Paleoproterozoic komatiites of the Central Lapland Greenstone Belt, Finland – implications for geochemical exploration

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In the Central Lapland Greenstone Belt (CLGB) komatiites are present along a >250 km long SE-NW zone across the northern Finland (Fig. 1). The CLGB komatiites formed at ca. 2.05 Ga mostly as underwater eruptions on a sedimentary basin, which is known to have contained abundant sulphurous black shales and evaporites [1]. This association with sulphurous sedimentary rocks makes the CLGB komatiites promising targets for Cu-Ni-PGE sulphide deposits. Indeed, these sedimentary rocks supplied sulphur to the Kevitsa and Sakatti Cu-Ni(-PGE) sulphide deposits (Fig. 1), which formed during the same magmatic event as the CLGB komatiites [1,2]. To understand the petrogenesis of the CLGB komatiites from their mantle source to their crustal sink, we conducted computational thermodynamic simulations to constrain the chemical fractionation and sulphide saturation state without the effects of assimilation. These simulations guide identification of chemical anomalies related to assimilation and sulphide saturation in the CLGB komatiites and related intrusive rocks.

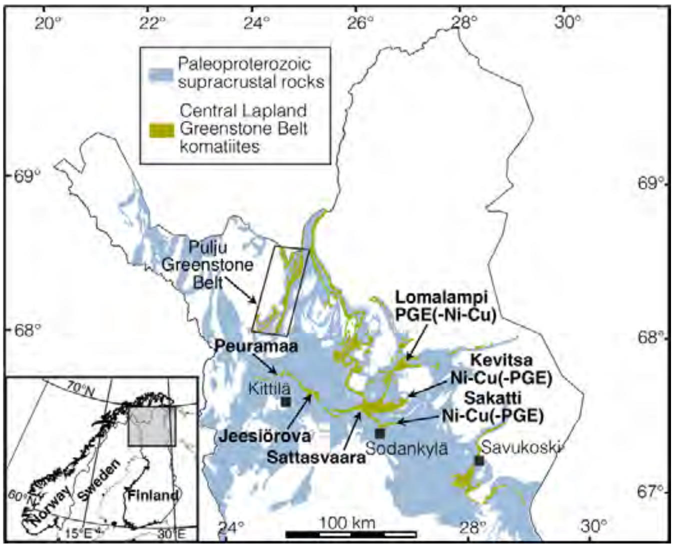

Figure 14. Geological map showing the distribution of the Central Lapland Greenstone Belt komatiites.

We defined the parental melt of the CLGB komatiites using a chilled margin of a komatiitic dyke from Kevitsa, which represents quenched olivine-saturated melt [3]. We added olivine to the chilled margin composition to reversely fractionate it to be in equilibrium with the most primitive olivine (Fo_{92}) in Sakatti [1]. Using this method, we constrained major element oxides, Ni, Cu, and rare earth elements (REE) for the komatiitic (MgO = 20.6 wt.%) parental melt. Assuming adiabatic propagation through the lithosphere, the parental melt should be compositionally identical to the primary mantle melt and allows constraining the mantle melting conditions. We used REEBOX PRO [4] to define Ti and REE contents as well as temperature of the adiabatically melting mantle source. Several mantle sources and mantle potential temperatures were tested. Consistent with the previous studies related to the mantle source of the CLGB komatiites [3,5,6], we found that pyrolite mantle-source with depleted MORB -type REE contents is suitable. The best fit of Ti, REE, and temperature was reached with the mantle potential temperature of 1575 °C and with degree of melting at 15–20 %. The mantle potential temperature determines that melting starts at ca. 5 GPa and the required degree of melting is reached at ca. 3 GPa (equivalent to ca. 100 km depth). Major element oxide composition of the parental melt (assumed here as identical to the primary mantle melt as noted above) is well compatible with literature data from mantle melting experiments with pyrolite mantle source [7]. We calculated the sulphur content at sulphide saturation (SCSS) for the primary mantle melt using the parental melt composition (major element oxides, Ni, and Cu) and the final pressure-temperature conditions in the mantle using the parameterization of Smythe et al. [8]. This constrains the maximum sulphur content of the primary mantle melt to 1172 ppm. With the typical range of sulphur content for a depleted mantle source of 150–200 ppm [9] and with the degree of mantle melting at 15–20%, the initial sulphur content of the CLGB komatiites is estimated to be 750–1172 ppm.

To examine chemical fractionation of the CLGB komatiites in crustal conditions (25 MPa), we conducted closed-system fractional crystallization simulations using Magma Chamber Simulator [10]. For SCSS, we used the same parameterization [7] as with the mantle melting simulations. Using new and literature data [1,2,3,5,6,11,12,13,14], we compiled a comprehensive whole-rock (n = 299–403 depending on the element) and olivine (n = 917) chemistry database for the CLGB komatiites and spatiotemporally related rocks (from Kevitsa and Sakatti) to evaluate the simulation results. We find that closed-system fractional crystallization produces a good fit to the reference data for major element oxides and Ni (Fig. 2a). Importantly, simulated Ni contents in olivine are in good agreement with natural data (Fig. 2a) and could be used to identify Ni-depleted olivine to indicate those CLGB komatiites that experienced early sulphide saturation. Sulphur and Cu show highly incoherent behaviour in the reference data set and were likely affected by sulphide accumulation, degassing, and post-magmatic alteration. However, the simulation results are compatible with literature data for S (Fig. 2b) and Cu from chromite-hosted melt inclusions from the CLGB komatiites [6], which show relatively coherent behaviour compared to the whole-rock data. Depending on the initial S content (750–1172 ppm, see above), our SCSS simulations show that both Ni-rich (Ni/Cu = 1.9) and Cu-rich (Ni/Cu = 0.4) sulphide melt could have formed from the CLGB komatiite melt upon closed-system fractional crystallization (Fig. 2b). Moreover, the simulations indicate that the S content of CLGB komatiite melt was constantly close to SCSS starting from the liquidus (Fig. 2b). Accordingly, assimilation of sulphur-bearing country rocks has the potential to form relatively large sulphide accumulations within this region.

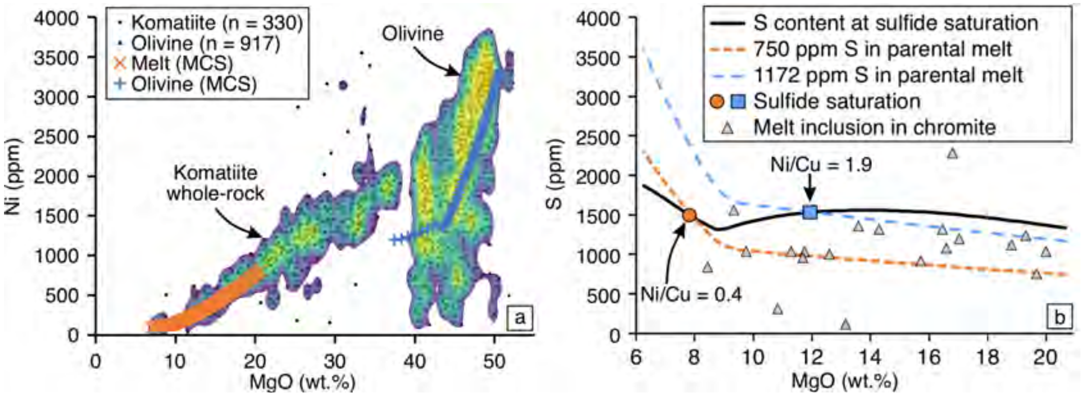

Figure 15. Closed-system fractional crystallization simulation results shown on a) MgO (wt.%) vs Ni (ppm) and b) MgO (wt.%) vs. S (ppm) diagrams. The data clouds in a) represent whole-rock and olivine data from the Central Lapland Greenstone Belt (CLGB) komatiites and related rocks (Kevitsa and Sakatti). Sulphur contents in b) are shown only for chromite-hosted melt inclusions from the CLGB komatiites.

References:

[1] Brownscombe W et al. (2015) Min Dep of Finland 211-252
[2] Luolavirta K et al. (2018) Lithos 296-299:37-53
[3] Puchtel I et al. (2020) Chem Geol 554:1-23
[4] Brown E and Lesher C (2016) Geochem Geophys Geosystems 17:3929-3968
[5] Hanski E et al. (2001) J Pet 42:855-876
[6] Hanski E and Kamenetsky V (2013) Chem Geol 343:25-37
[7] Walter M (1998) J Pet 39:29-60
[8] Smythe D et al. (2017) Am Min 102:795-803
[9] Lorand J-P and Luquet A (2016) Rev Mineral Geochem 81:441-488
[10] Bohrson W et al. (2014) J Pet 55:1685-1717
[11] Luolavirta K et al. (2018) Bull Geol Soc Finland 90:5-32
[12] Patten C et al. (2023) Min Dep 58:461-488
[13] Saverikko M (1985) Bull Geol Soc Finland 57:55-87
[14] Törmänen T et al. (2016) Min Dep 51:411-430