The composition and origin of sulfides in peridotitic xenoliths from Ruddon's Point (Fife, Scotland)

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1. Introduction

Permian mafic volcanic rocks occurring in southern terrains of Scotland (United Kingdom; Fig. 1a) are rich in peridotitic xenoliths. Sulfide abundances in these xenoliths provide insight into the metal migration through the Subcontinental Lithospheric Mantle (SCLM) beneath this area. Peridotites from the Ruddon's Point (Fife, Midland Valley Terrane) xenolith suite form four textural groups: **(1)** porphyroclastic and **(2)** protogranular lherzolites, **(3)** equigranular wehrlites and **(4)** lherzolites transitional between protogranular and equigranular peridotites (Fig. 1b). The SCLM beneath southern Scotland was affected by reaction with an alkaline melt resulting in clinopyroxene crystallization (wehrlitization) and decrease of Fo in olivine from groups **(1, 2)** through group **(3)** to **(4)** (Fig. 1c; Matusiak-Małek et al., 2022).

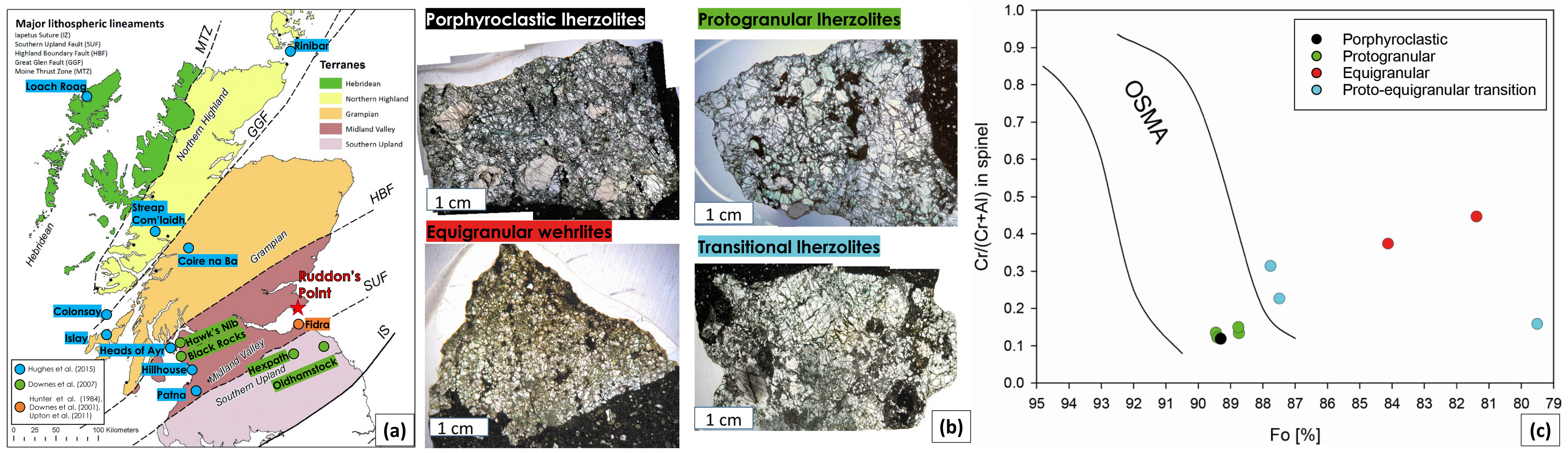

Fig 1. (a) Terrane map of Scotland, highlighting Ruddon's Point xenolith locality (red star) and previous studies of xenoliths from Scotland (Hughes et al., 2015, modified), **(b)** Thick sections of major lithologies occuring in Ruddon's Point xenolithic suite, **(c)** the #Cr vs Fo in olivine diagram of porphyroclastic and protogranular lherzolites, equigranular wehrlites and transitional lherzolites from Ruddon's Point xenolith suite. *Notes:* OSMA – Olivine-Spinel Mantle Array

2. Sulfide petrography

The sulfides occurring in the peridotites form oval, elongated or irregular grains (Fig. 2a) enclosed (predominantly occuring in protogranular lherzolites) in pyroxenes and olivine, or interstitial (dominating in the rest of lithologies) between these phases. The abundance of sulfides increases from the transitional lherzolites, through equigranular and porphyroclastic to protogranular lherzolites (Fig. 2b). Sulfide minerals present in all textural groups are pentlandite (**Pn**; $[Ni,Fe]_9S_8$) and chalcopyrite (**Ccp**; $CuFeS_2$). Ccp occurs on the edges or forms perpendicular exsolutions in Pn-grains (Fig. 2a). Pyrrhotite (**Po**; $Fe_{1-x}S$) occurs scarcely, but protogranular and transitional lherzolites contain minor amounts. Porphyroclastic lherzolites occasionally contain millerite (**Mlr**; NiS) and covellite (**Cv**; CuS) (Fig. 2a). The sulfides from the equigranular and protogranular peridotites are more enriched in Cu-, and depleted in Ni-phases in comparison to sulfides from the porphyroclastic and transitional peridotites (Fig. 2c).

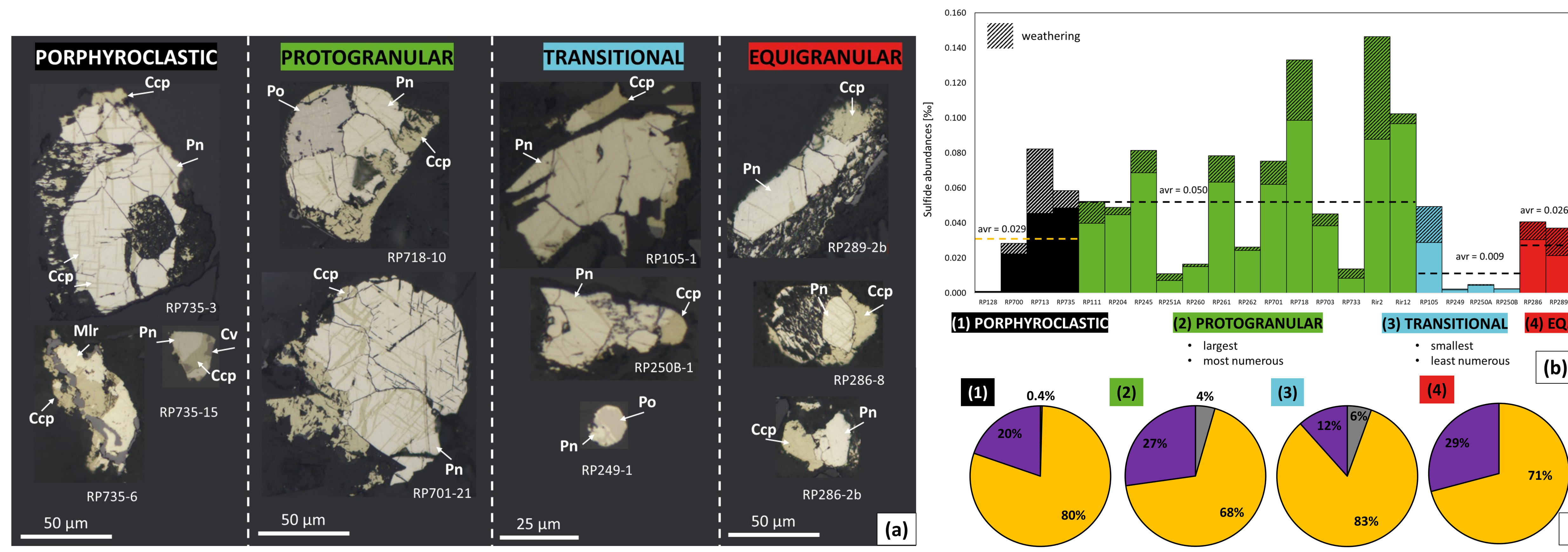

Fig. 2 (a) Microphotographs of sulfide grains, reflected light, **(b)** sulfide abundances, with marked weathering (shaded areas) and mean for every lithology (dashed lines), **(c)** the averaged proportion of major sulfide phases represented by pentlandite, chalcopyrite and pyrrhotite in porphyroclastic, protogranular, equigranular and transitional peridotites from Ruddon's Point xenolith suite.

3. Sulfide chemistry

The range of Cu/(Cu+Fe) values is equivalent across all textural types (Fig. 3a), whereas Ni/(Ni+Fe) in pentlandite is equal only in transitional and equigranular peridotites in contrast to porphyroclastic and protogranular ones (Fig. 3b). The concentration of major and trace elements were analysed *in situ* for sulfide grains from protogranular and transitional lherzolites. These showed differences in abundances of Ni and Cu (Fig. 3c), Co and Zn (Fig. 3d), total PGE (Fig. 3e) and $(Re/Os)_N$ values (Fig. 3f).

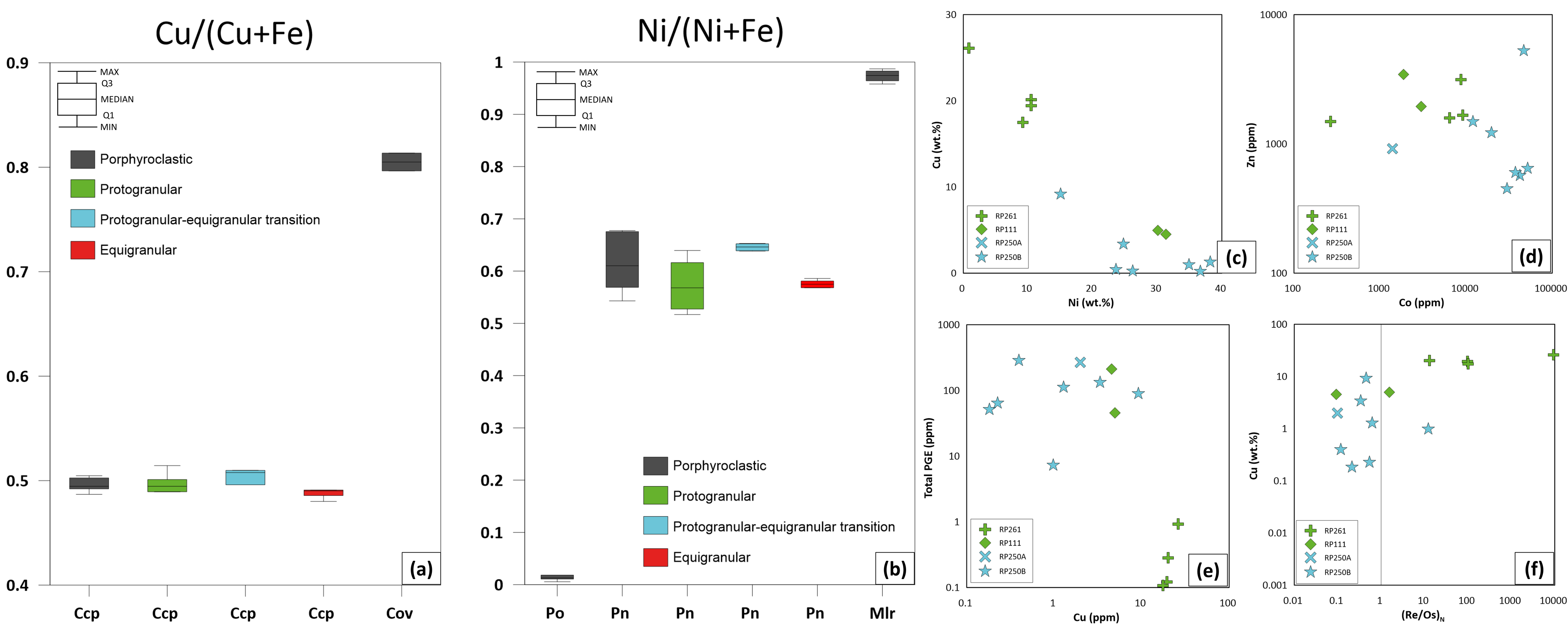

Fig 3. The distribution of **(a)** Cu/(Cu+Fe) in chalcopyrite (**Ccp**) and covellite (**Cov**) and of **(b)** Ni/(Ni+Fe) in pentlandite (**Pn**) and millerite (**Mlr**) in sulfide grains between porphyroclastic, protogranular, equigranular and transitional peridotites. The concentrations of **(c)** Ni vs Cu, **(d)** Co vs Zn, **(e)** Cu vs total PGE and **(f)** $(Re/Os)_N$ vs Cu in bulk sulfide grains from protogranular and transitional peridotites. The plot **(c)** is presented in linear scale, whereas the plots **(d–f)** are in logarythmic scale. The Re/Os ratio is normalized to Primitive Mantle (McDonough and Sun, 1995).

4. Conclusions

- Sulfides from more primitive protogranular lherzolites have features characteristic for melt-metasomatism (highest abundances, Cu-Zn enrichment, $(Re/Os)_N$ mostly above 1) in contrast to sulfide from melt-metasomatized transitional peridotites (much lower abundances, Cu-Zn depletion, $(Re/Os)_N$ mostly below 1), which could be interpreted as residual sulfides after partial melting (e.g., Alard et al., 2000; Lorand and Alard, 2001; Saunders et al., 2015; Hughes et al., 2017; Patkó et al., 2021).
- Therefore, the evolution of sulfides is contrary to the evolution recorded in silicate and oxide mineral chemistry. Sulfides in the protogranular lherzolites appear to have a metasomatic origin, whereas sulfides in the transitional transitional lherzolites appear to be restitic.
- The presence of millerite and covellite in sulfides from porphyroclastic lherzolites indicates hydrothermal, post-volcanic activity, affecting the xenoliths after the exhumation to the surface by basaltic lavas (Warner, 2013).

5. Acknowledgements

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