Linking *in situ* crystallisation and magma replenishment in the Rum Western Layered Intrusion, NW Scotland

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Introduction and Background

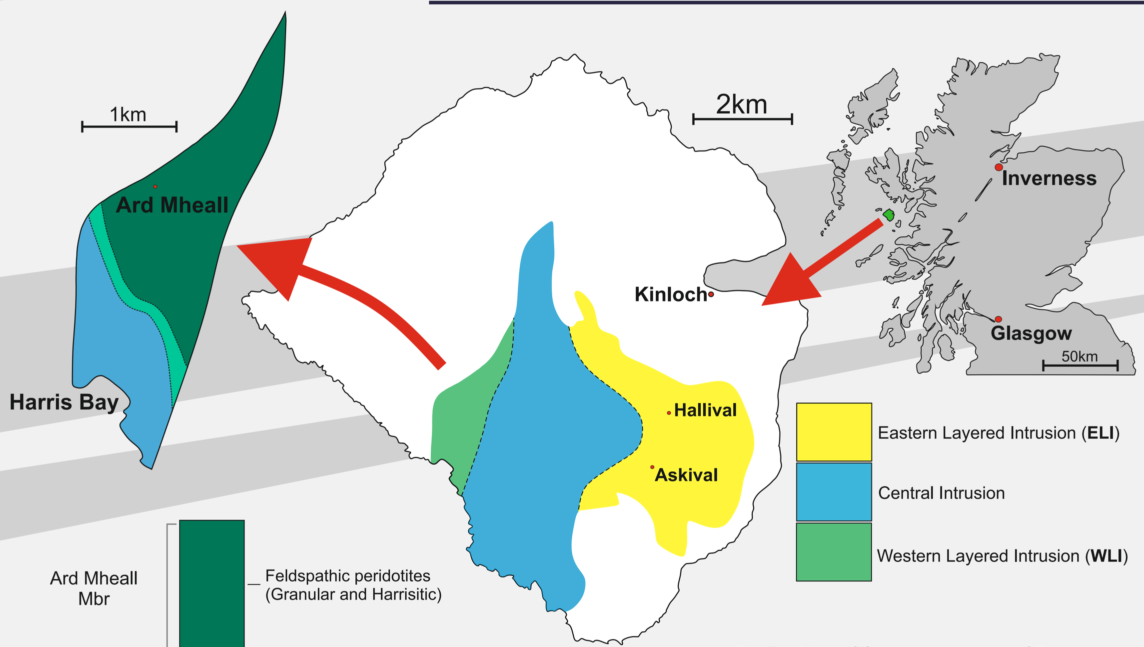


Fig 1 – Map of Scotland with Isle of Rum in green with magnified Rum Layered Suite and detail of the location and lithologies comprising the Western Layered Intrusion.

- The Rum Layered Suite (Fig. 1) represents a classic **open-system magma chamber**, active during the Palaeogene **(~60 Ma)** as a part of the North Atlantic Igneous Province[1].
- Chromitite seams are ubiquitous in the WLI, particularly in the **Ard Mheall Member**, where seams occur within **harrisites** (Figs. 3, 7), a significant example of ***in situ* crystallisation** in layered mafic intrusions.
- Chromitite seams have been linked to major **replenishment events** in the ELI, where fresh magma entered the chamber periodically[2].

Fig 2 – Small scale layering in Ard Mheall Member peridotites of the WLI. Cliff height ~6m

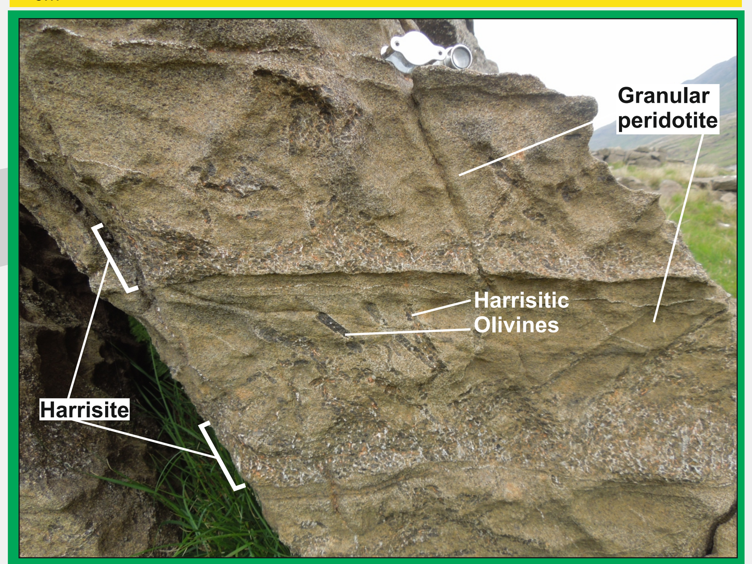


Fig 3 – Small scale layering in harrisitic peridotites. Note sharp based harrisites with irregular upper boundaries with successive granular peridotites.

In situ Chromitite Seam Petrogenesis

- Many previous models of chromitite seam petrogenesis have invoked **interaction of basaltic and more evolved magmas/cumulate**, two examples include:-
  - **Hybridization of two magmas**, one basaltic, one more evolved, such as in the Muskox Intrusion[3]
  - **Assimilation of troctolitic cumulate** by basaltic magma in the ELI[2]
- In both cases the resultant hybrid liquid is capable of crystallising abundant Cr-spinel.

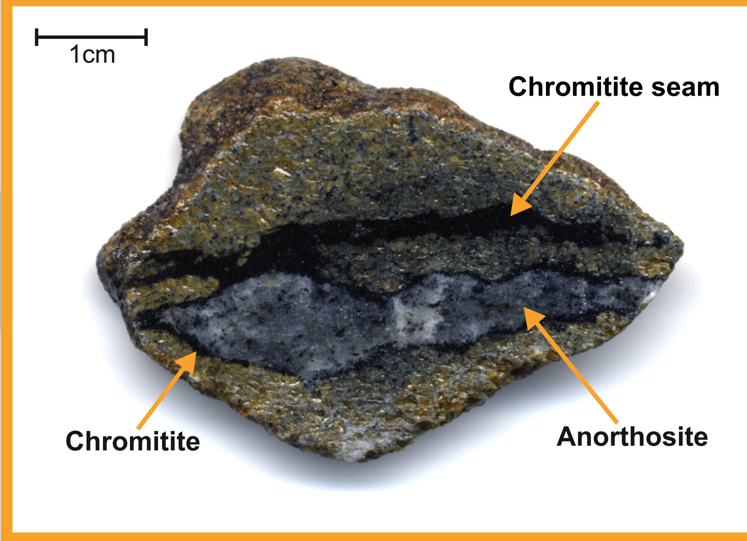


Fig 5 – Hand-specimen of peridotite with a lens of anorthosite surrounded by chromitite from the Unit 7-8 boundary of the ELI. A chromitite seam also occurs above the anorthosite lens. From O'Driscoll et al., 2010.

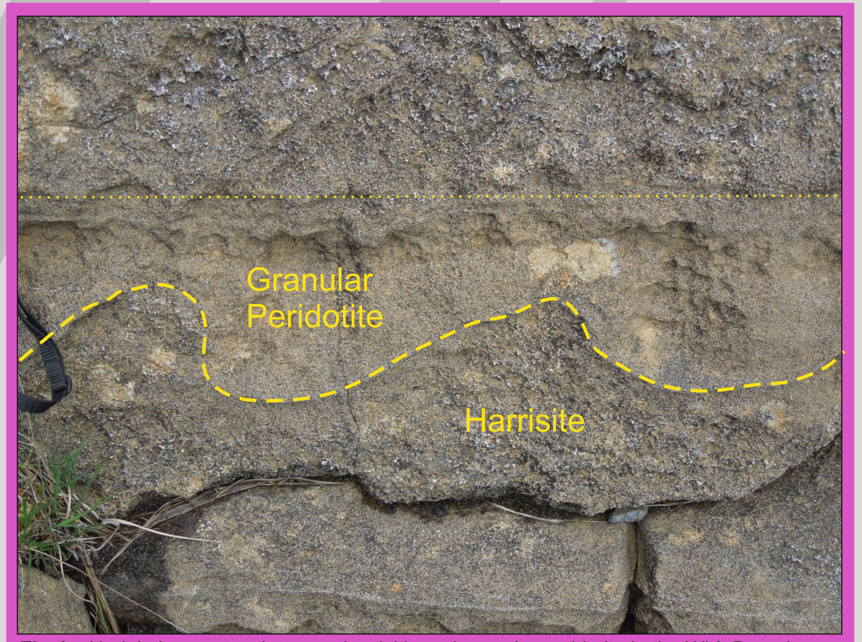


Fig 4 – Undulating contact between harrisitic and granular peridotite in the WLI. Boundary suggestive of mechanical/chemical removal of harrisitic cumulate by successive processes. Chromitite seam present at the boundary (dashed line). Upper dotted line represents sharp boundary of successive harrisite.

Evidence for *in situ* crystallisation:

- Chromitite seams present in the ELI can occur along pronounced undulations on anorthosite layers, including on overhangs.
- It can also occur **surrounding reworked anorthosite** as in Fig 5, whereby crystal settling could not have produced chromitite layers on the underside of the clast.
- Irregularities in chromitite seams from the upward and downward movement of liquid are common in the ELI.

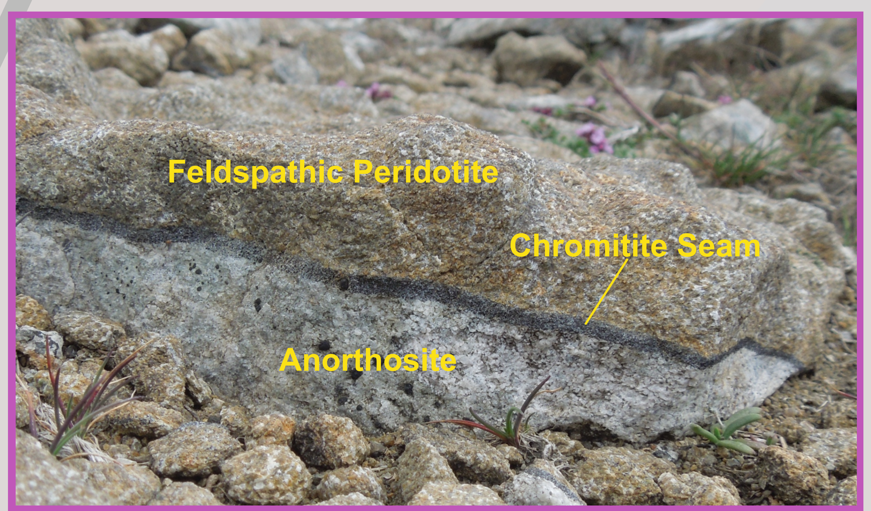


Fig 6 – 2mm thick chromitite seam at the Unit 10-11 boundary in the ELI. Anorthosite beneath chromitite seam representing assimilated troctolitic cumulate[2].

Fig 7 – Highly irregular, ~1cm thick chromitite seam in harrisite (WLI). Note the bend with consistent thickness in the seam, suggesting *in situ* crystallisation opposed to gravity settling.

Petrography

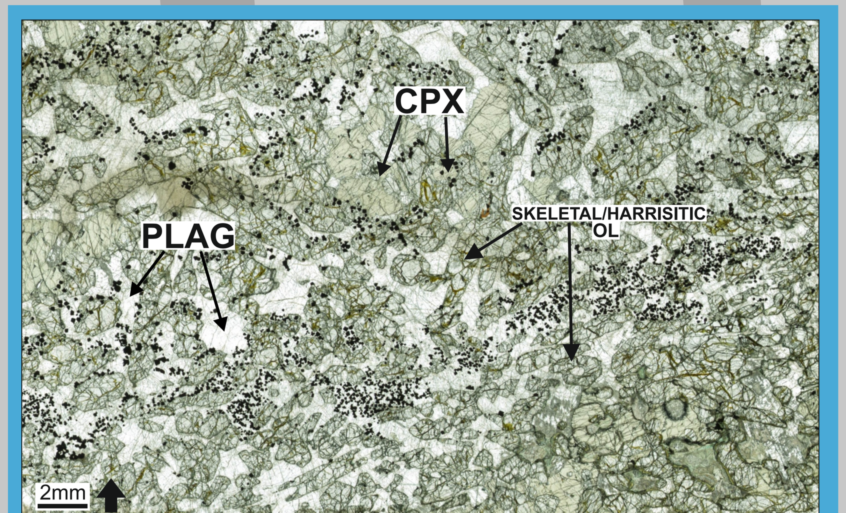


Fig 8 – Chromitite seam in harrisitic peridotite. Upward increase in intercumulus material from the seam, with possible increase in olivine crystal size. Note the relative abundance of intercumulus material compared with granular peridotites (Fig. 9).

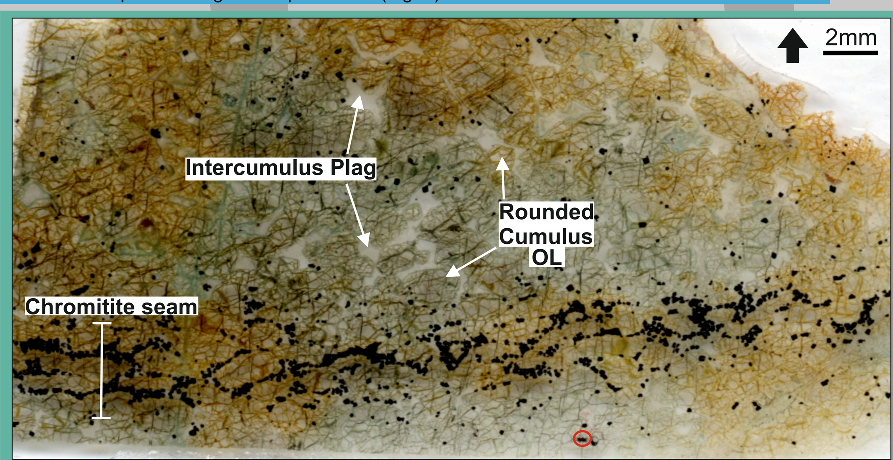


Fig 9 – Thin section scan of chromitite seam in granular peridotite. Upward increase in grain size in olivine crystals from the seam. There is also a complementary increase in the % of intercumulus plagioclase above the seam. Particularly large sulphide circled in red (SEM image Fig 15A).

Ard Mheall Peridotites:

- Mineralogy is dominated by cumulus **ol + Cr-sp**, and subordinate intercumulus **plag ± cpx**.
- Olivine habit is variable (Figs. 9, 12A), and **Harrisitic olivines are common** (Fig. 8).
- Secondary alteration is prevalent, with **amphibole**, **biotite**, and **chlorite** as common hydrous minerals (Fig. 11).
- Intercumulus cpx is less abundant than in the ELI.

Ard Mheall Chromitite Seams:

- Chromitite seams typically present in **chain-like**, diffuse textures, **1–10 mm** thick.
- Cr-spinel crystals occur abundantly in olivine embayments.
- Cr-spinel crystals are markedly euhedral in shape.
- Textural variations such as **foliation** of olivine crystals can develop **close to chromitite seams** (Fig. 12).

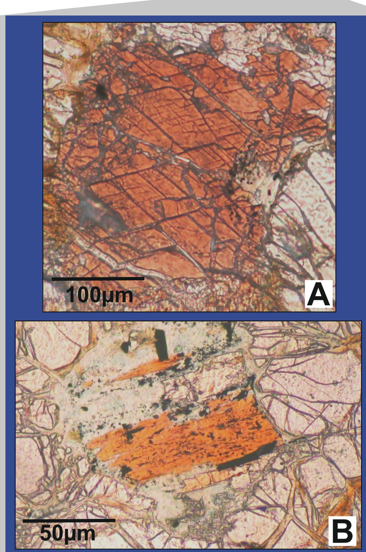


Fig 11 – Hydrous alteration in Ard Mheall peridotites; A) Red-brown amphibole, B) Biotite + Chlorite.

- Textural and mineralogical variations above and below seams are common in the Ard Mheall peridotites:-
  - **Change in grain size of olivine above the seam**; often an increase in grain size (see Fig 8, 9)
  - **Increase in intercumulus material** above the seam; predominately plag, but also clinopyroxene (see Fig. 8, 9).

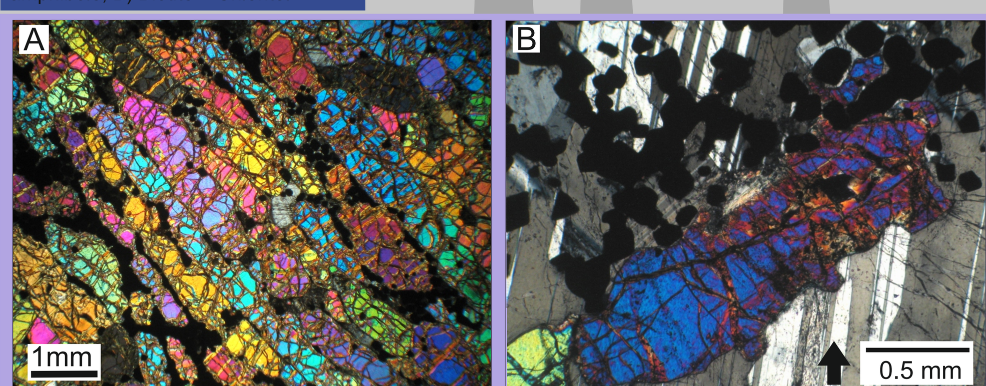


Fig 12 – Petrographic features of chromitite seams in the Ard Mheall peridotites; A) Strong foliation of elongate olivine crystals at diffuse chromitite seam (black), B) Chromitite seam cross cutting olivine crystal in harrisite.

Crystal Size Distribution (CSD) Analysis

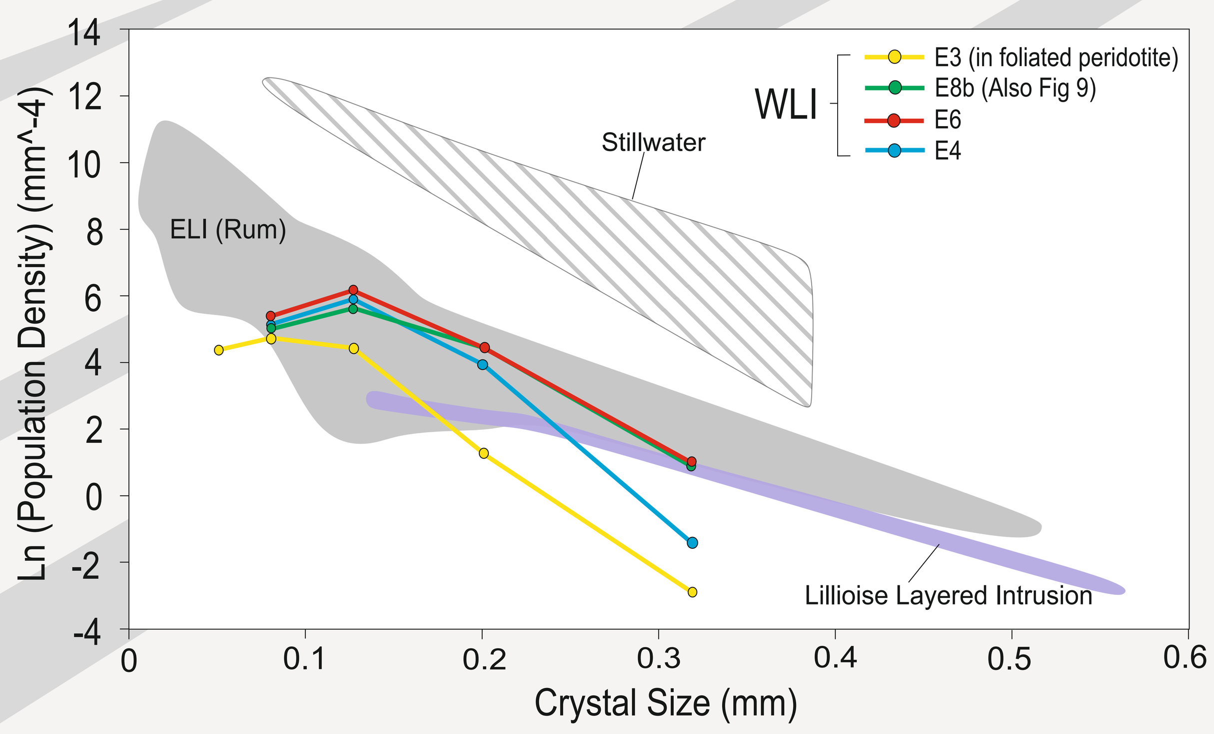


Fig 13 – Crystal size distribution graph (CSD) showing results of 4 chromitite seams from peridotites in the WLI (E3, E4, and E8b in Fig. 14). Comparative fields for chromitite seam CSD data shown for the ELI[2], Stillwater Complex[5], and Lilliose Layered Intrusion[4].

Results:

- E8b, E4 and E6 all exhibit (particularly E8b and E6), **similar CSD characteristics** (i.e., nucleation densities, crystal size ranges).
- Slope gradients for the large size fractions of the CSDs are also similar for the four seams: $-18\ mm^{-1}$ – $-29\ mm^{-1}$.
- With the exception of E3, the **WLI chromitite seams plot within the field for previously reported ELI CSDs**.
- **E3**, a particularly thin seam present in strongly foliated peridotite (Fig 14C), reveals a lower nucleation density.

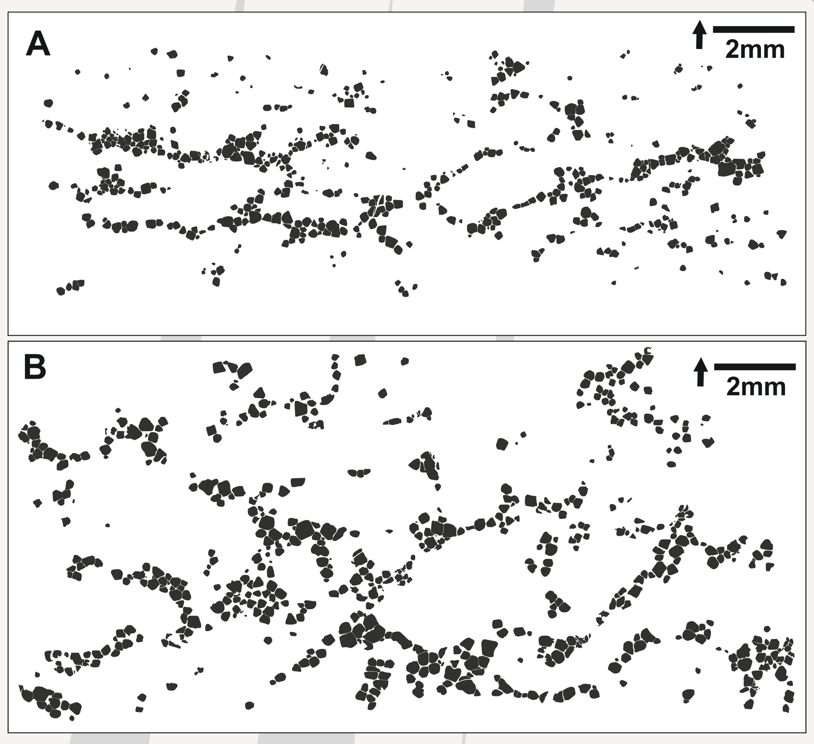
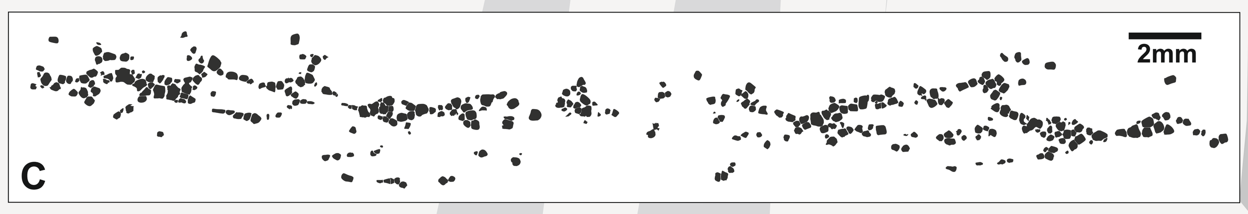


Fig 14 – (Above and Below) Texture maps of three chromitite seams used in CSD analysis. Note the diffusiveness of seams, and variation in thicknesses. A) E8b, B) E4, C) E3

Interpretation:

- The markedly **similar shapes of chromitite CSDs** from different WLI peridotites suggests that they formed via a similar process, albeit with varying volumes of Cr-spinel produced in different samples.
- This is in sharp contrast to the ELI chromitite CSDs, which extend to greater crystal size ranges, have shallower CSD slopes and significantly greater numbers of crystals in the small size ranges (Fig. 13).



Discussion/Conclusion

- Chromitite seams within harrisitic peridotites (Fig. 7) in the WLI suggest ***in situ* crystallisation for the seams**, similar to the ELI.
- However, the **absence of troctolitic cumulate in the WLI** suggests a differing catalyst for chromitite seam petrogenesis.

Some important preliminary conclusions are:

- **Mineralogical and textural variations above and below chromite seams** may suggest changing environments of crystallisation respectively:
  - **Differences in the volume of intercumulus material** (specifically plagioclase) on either side of a given seam
  - **Undulating contacts** suggestive of mechanical/chemical removal of underlying cumulates (Fig. 4).
- **The CSDs are quite 'simple'** compared to previously reported CSDs for chromitites associated with troctolite/anorthosite in the ELI.
- Might the WLI chromitites represent a 'window' to a first order chromitite seam forming process, in the absence of plagioclase-rich cumulate which may complicate the textures at the post-cumulus stage?

Sulphides

- Sulphide mineralisation is present in the WLI peridotites;
  - **Closely associated with Cr-spinel**, often attached to individual crystals.
  - **Chalcopyrite** is most abundant, with **native copper** occurring more rarely.
- Not as abundant as found in the ELI.
- Harrisitic peridotites contain higher % sulphide content than granular peridotites

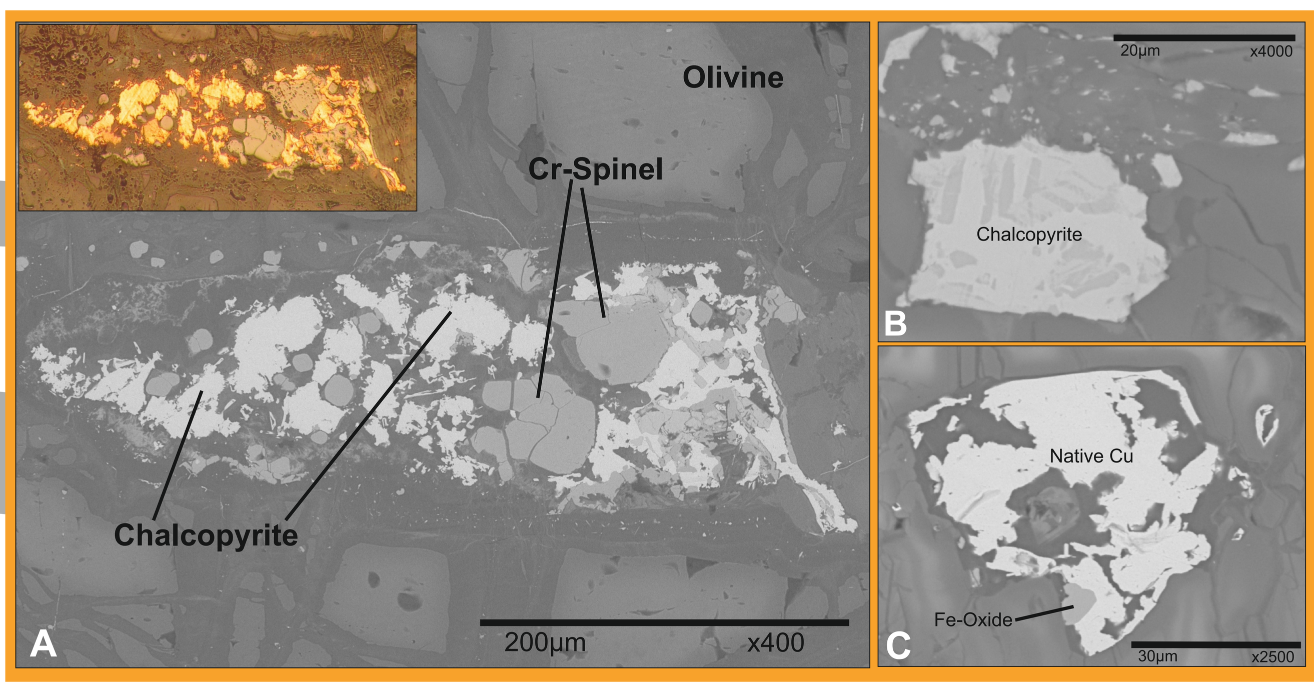


Fig 15 – (Right) Sulphide minerals of the WLI; A) BSE image and reflective light image of an unusually large sulphide mineral occurring with several small Cr-spinel grains Some replacement has occurred with Cr-deficient (largely Fe) spinel labelled (lighter than Cr-spinel). B) BSE image; Chalcopyrite with possible exolution in harrisitic peridotite C) BSE image; Native copper in granular peridotite.

PGE Enrichment:

- Metal sulphides found in the ELI are highly enriched in platinum-group elements, up to **2–3 ppm**[6].
- It is likely the sulphides in the **WLI are also enriched in the PGE.**
- By investigating the mechanisms of chromitite seam petrogenesis in the WLI, and compared to similar work in the ELI[6], it could further provide insight into sulphide mineralisation and **PGE enrichment in layered mafic-ultramafic intrusions.**

Current and Ongoing Work

We are evaluating **three potential scenarios** for chromitite seam development in the WLI:

- **Settling of Cr-spinel (±olivine) from a column of magma.**
- **Reaction of fresh magma (picritic) with feldspathic peridotite chamber floor.**
- **A reaction of magma and crystal mush due to infiltration metasomatism.**

References

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