REACTIVE LATE-STAGE MICROSTRUCTURES IN THE SEPT ILES LAYERED INTRUSION, QUEBEC, CANADA

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GATES Cambridge

Introduction:

- There is minimal research on the evolution of late-stage interstitial liquid within the crystal mushy layer that forms during crystallization of layered intrusions.
- Recent work has indicated that microstructural evidence can assist in determining processes during the evolution of the interstitial liquid (Holness *et al.,* 2007; 2011; Stripp, 2009).
- Symplectites are reactive microstructures that are commonly found in metamorphic rocks, mainly attributed to isochemical metamorphic reactions. However, they have been documented in many layered intrusions and may be a ubiquitous feature of them.
- Certain reactive symplectites of the Skaergaard intrusion were said to have formed by separation of immiscible Si-rich and Fe-rich liquids during evolution of the residual liquid (Holness *et al.,* 2011).
- This research focuses on symplectites of the Sept Iles intrusion, a 564 Ma ferrobasaltic intrusion located in Quebec, Canada.

AIM: Classify the symplectites of the Sept Iles intrusion, develop an understanding of their formation and test the hypothesis that they require separation of immiscible liquids to form.

Methods:

All procedures undertaken at the Department of Earth Sciences, University of Cambridge

- Petrography: Nikon Eclipse E600 POL petrographic microscope
- Scanning Electron Microscopy: JEOL 820 SEM
- Microprobe Analyses: Cameca SX-100 electron microprobe, 15kV accelerating voltage, 10nA beam current, 1μm beam size
- Cathodoluminescence: in-house cold-cathode instrument designed by Dr. Tony Dickson
- Thermometry: Hornblende-plagioclase thermometry (Holland and Blundy, 1994), Cpx-Opx thermometry (Andersen *et al.,* 1993), and Ti-in-biotite thermometry (Henry *et al.,* 2005)

Geology of the Sept Iles:

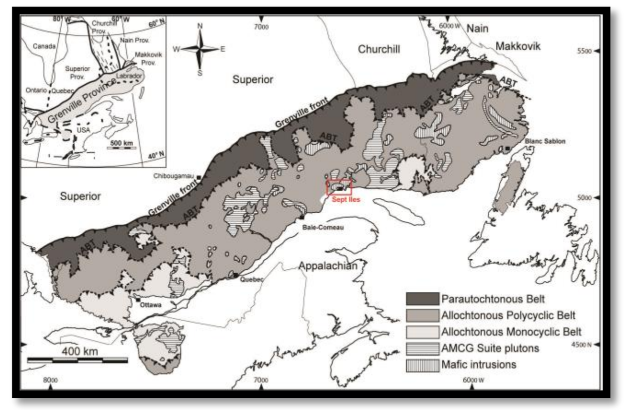

Fig. 1. Geologic map of the Grenville Province, showing the location of the Sept Iles intrusion (within red box). Modified by Charlier *et al.* (2010), after Rivers *et al.,* 1989; Davison, 1995; Corriveau *et al.,* 2007.

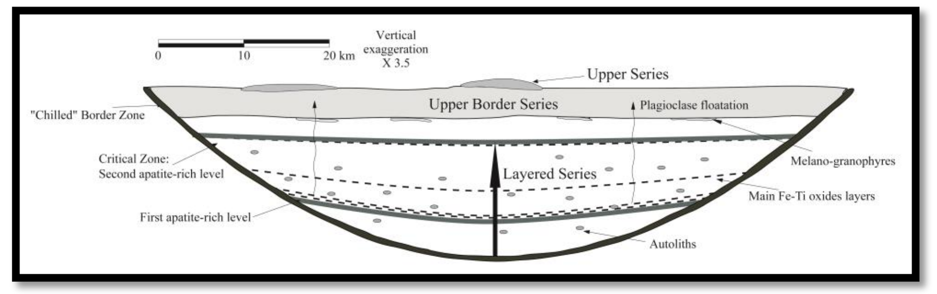

Fig. 2. Schematic cross-section of the Sept Iles, showing the major subdivisions of rock units. Modified from Higgins (2005).

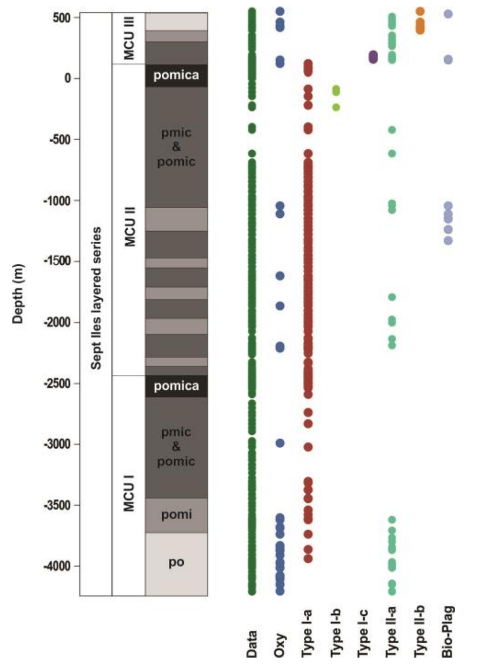

Fig. 3. Schematic section of the Sept Iles Layered Series, showing megacyclic units, cumulus assemblages, and stratigraphic position of all types of symplectites. (Modified from Namur *et al.,* 2012).

Abstract:

Ferrobasaltic layered intrusions form some of the largest magma chambers on earth and also host to the world's richest reserves of PGEs, Fe, Cr, Ti and V. Despite significant research on the liquid line of descent of the bulk magma of such intrusions during igneous differentiation, minimal research has been conducted on the evolution of the interstitial liquid within the crystal mushy layer. Holness et al. (2011) conducted a microstructural study of the Skaergaard Intrusion of East Greenland and indicated that microstructural evidence, along with other natural and experimental evidence, can help tease apart the late-stage magmatic history of the interstitial liquid in layered intrusions. This study showed that symplectites, "vermicular intergrowths" of two or more minerals that form from the breakdown of unstable phases, may have formed from phase separation of two immiscible liquids within the crystal mush. Here we present data from the Sept Iles intrusion in Quebec, where optical microscopy, scanning electron microscopy, cathodoluminescence and electron microprobe analyses were used to test the hypothesis that symplectites in layered intrusions require separation of immiscible liquids to form. All symplectites analysed contain highly anorthitic plagioclase compared to the replaced primocryst, with intergrowths of a mafic phase. Previous pressure constraints give pressures of 1-2kbar, and three types of thermometry indicate that the various symplectites of the Sept Iles formed at temperatures from ~700-1000°C. Such high anorthite content at these temperatures must be a consequence of a late-stage, super-solidus process. Liquid immiscibility within the crystal mush may therefore have produced the symplectites of the Sept Iles. However, hydrous partial melting of incompletely solidified rock could also produce such microstructures, particularly the hydrous ones. As symplectites may be a ubiquitous feature of layered intrusions, further work can provide information on late-stage processes operating during the crystallization of layered mafic intrusions.

Classification of Symplectite Microstructures:

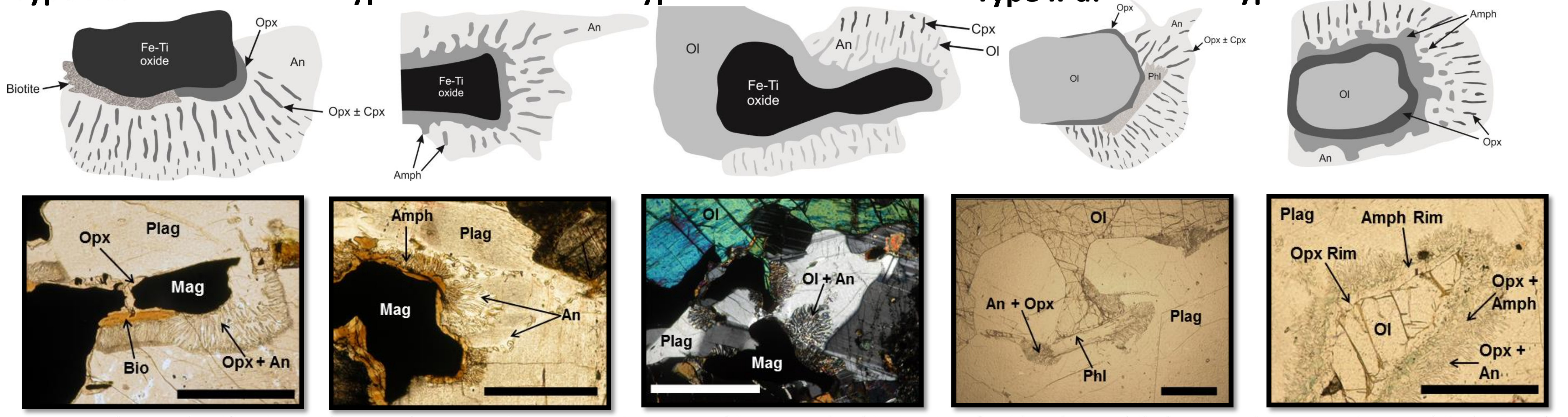

Fig. 4. Symplectite classification in the Sept Iles Layered Series. **I-a:** Opx + anorthite, rooted to biotite rim of oxide. **I-b:** amphibole + anorthite, rooted to amphibole rim of oxide. **I-c:** Olivine ± Cpx + anorthite, rooted to olivine rim of oxide. **II-a:** Opx + anorthite, rooted to Opx rim of olivine. **II-b:** Amphibole + Opx + anorthite, rooted to amph/Opx rims of olivine. Opx = orthopyroxene, Cpx = clinopyroxene, An = anorthite, Bio = biotite, Plag = plagioclase, Mag = magnetite, Amph = amphibole, Phl = phlogopite, Ol = olivine. Scale bar = 1mm.

Compositional Data:

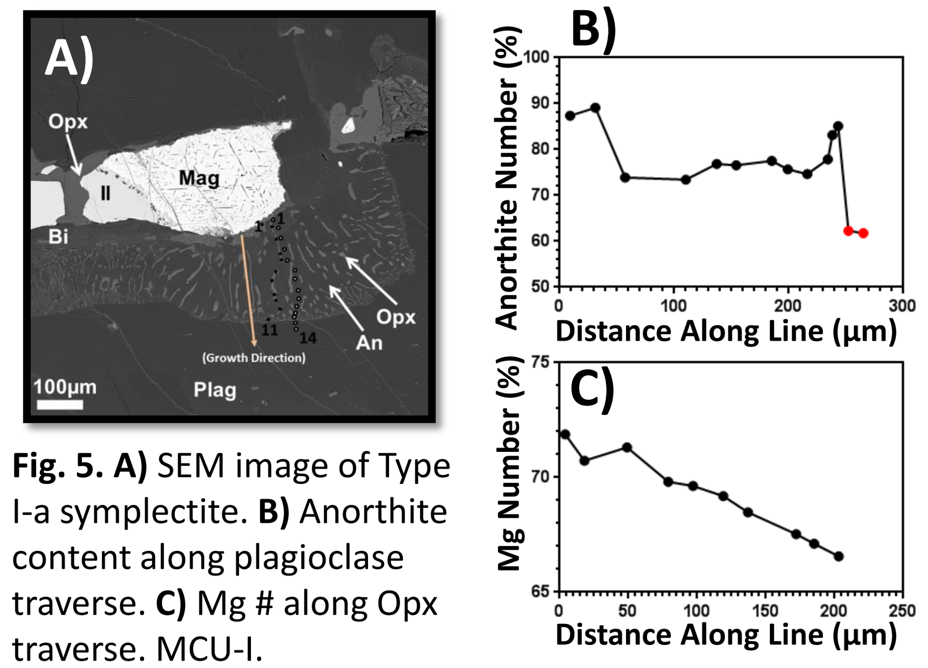

Fig. 5. A) SEM image of Type I-a symplectite. **B)** Anorthite content along plagioclase traverse. **C)** Mg # along Opx traverse. MCU-I.

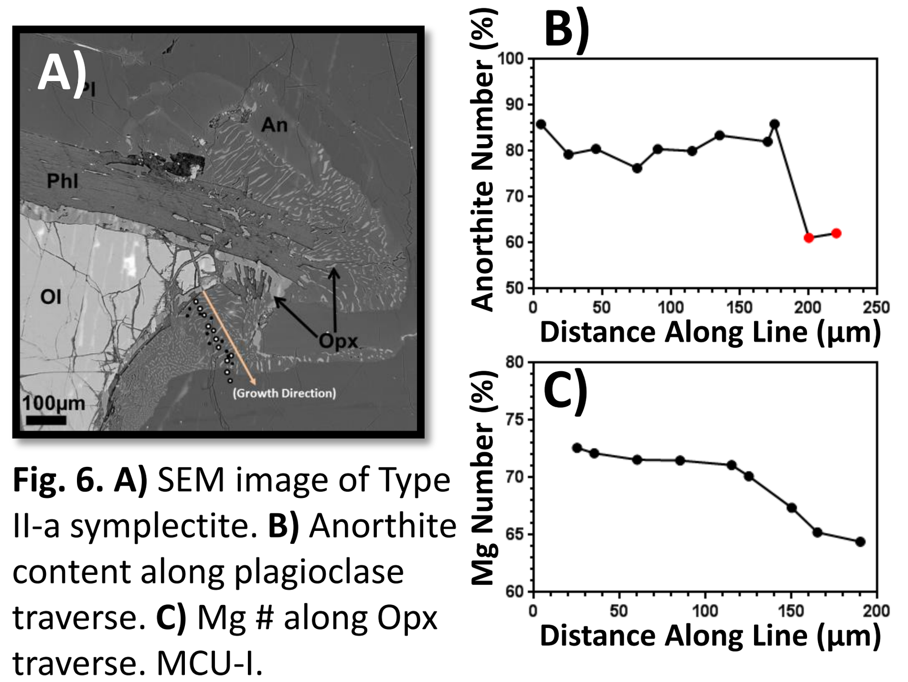

Fig. 6. A) SEM image of Type II-a symplectite. **B)** Anorthite content along plagioclase traverse. **C)** Mg # along Opx traverse. MCU-I.

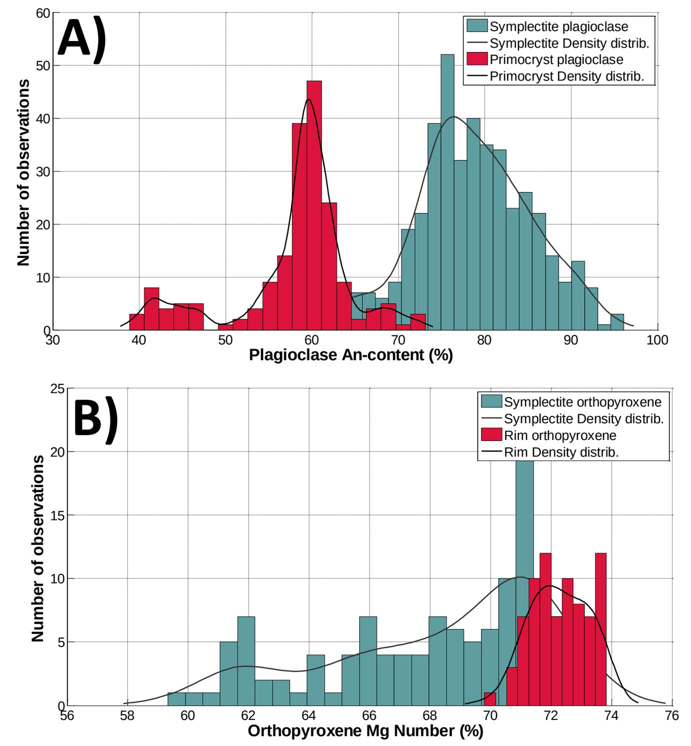

Fig. 7. Compositional Variation for **A)** Plagioclase and **B)** Orthopyroxene in the Sept Iles.

Discussion:

- Hornblende-plagioclase thermometry on amphibole-bearing symplectites gives an average temperature of 899°C. QUILF Cpx-Opx thermometry gives an average temperature of 821°C.
- High enough temperatures that symplectites likely formed in the super-solidus regime.

Q: Did the anhydrous symplectites form from silicate liquid immiscibility within the crystal mush?

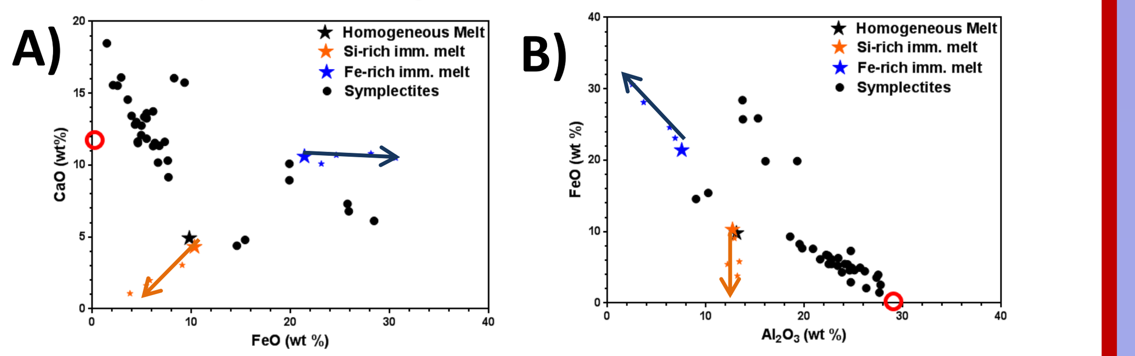

Fig. 8. A) CaO vs. FeO and **B)** FeO vs. Al_2O_3 for bulk symplectite compositions, Si-rich and Fe-rich immiscible melt compositions, and homogeneous melt compositions (Charlier and Grove, 2012).

Q: Did the hydrous symplectites form from hydrous partial melting reactions?

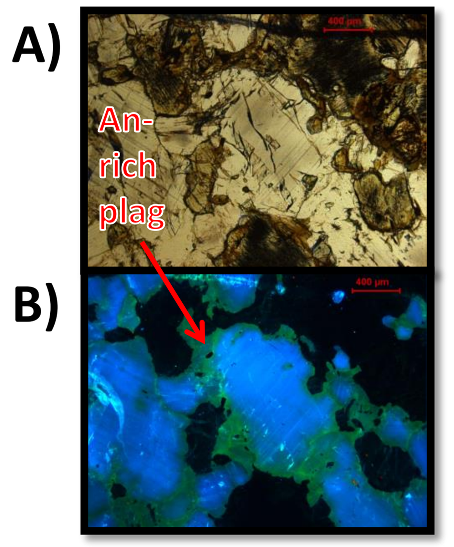

Fig. 9. A) PPL and **B)** colour CL images from a segment of the Oman ophiolite, showing hydrous partial melting. Koepke *et al.,* (in press).

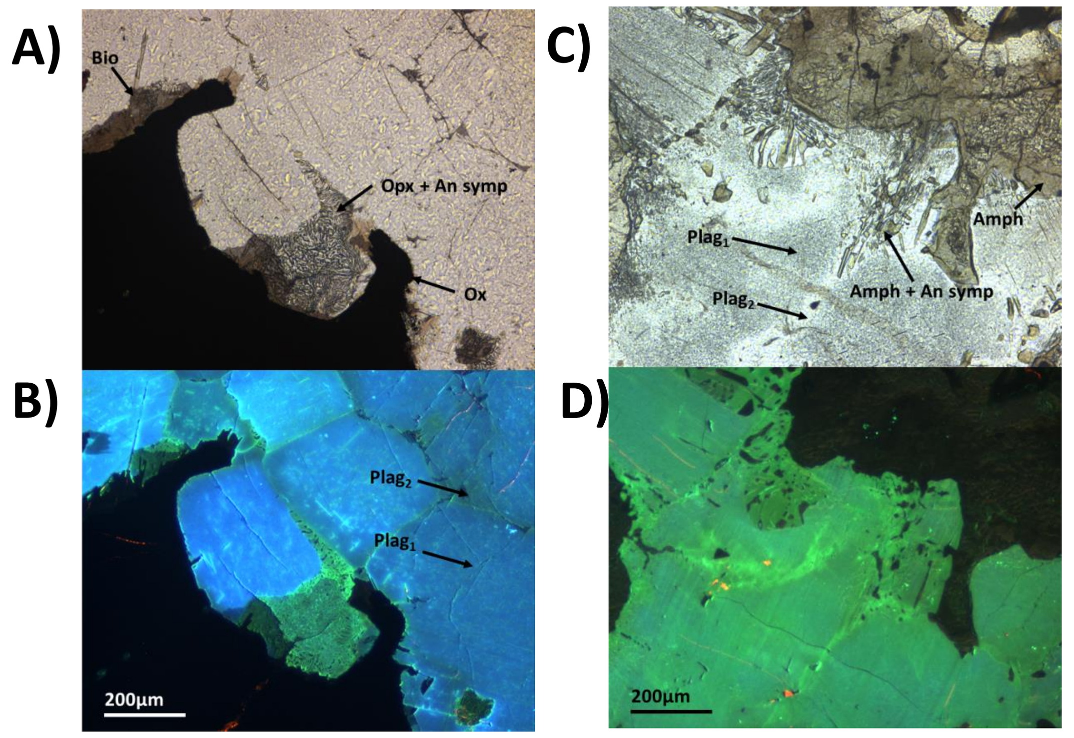

Fig. 10. A) PPL and **B)** colour CL images from a Type I-a symplectite in MCU-II. **C)** PPL and **D)** colour CL images from a Type I-b symplectite in MCU-III. Note how MCU-III has considerably more anorthitic plagioclase than MCU-II.

Conclusions:

- Seven different types of symplectites were identified (5 primary types shown in this poster).
- Anhydrous symplectites are similar to Skaergaard symplectites (Holness *et al.,* 2011), and may be formed by separation of Si- and Fe-rich liquids within the crystal mush.
- Hydrous Type I and II symplectites may have formed by hydrous partial melting reactions, e.g. Koepke *et al.,* (in press).
- Any theory except for the immiscibility theory needs to explain the source of water, which would involve future isotope work.
- Other future work should involve documenting and analysing symplectites in other mafic layered intrusions.
- Regardless of specific process, a fluid must have been present along grain boundaries in the super-solidus regime (Fig. 11).

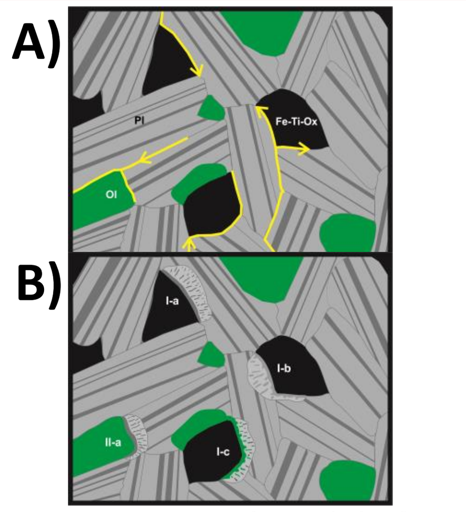

Fig. 11. General model of symplectite formation. **A)** During and **B)** after fluid influx

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