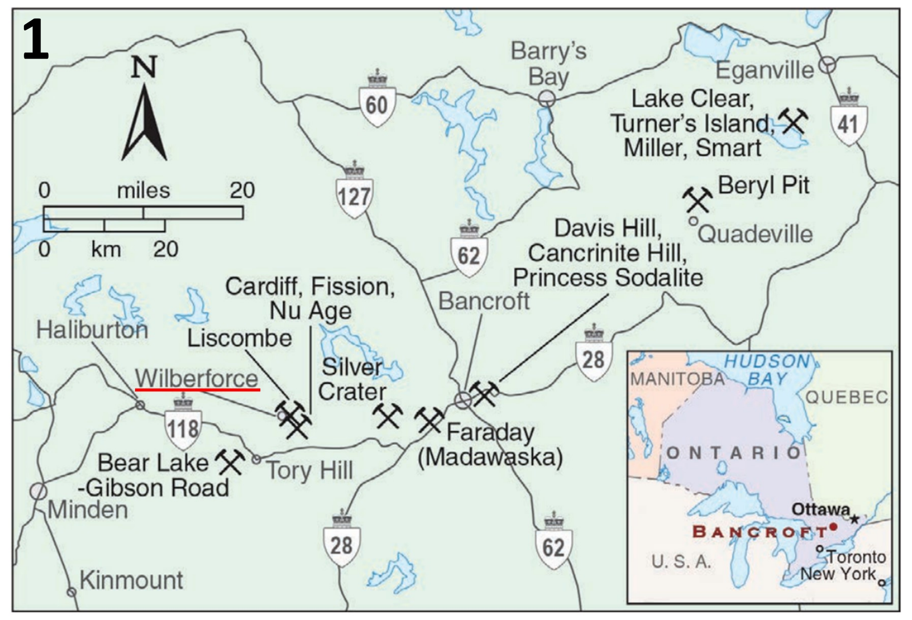
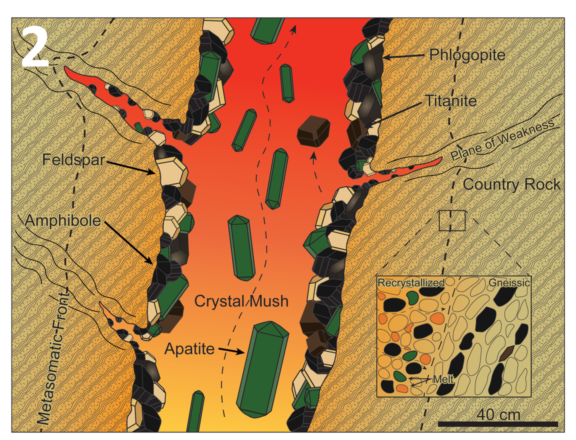
APATITE-HOSTED MELT INCLUSIONS FROM GRENVILLE CARBONATITIC VEIN DIKES AT THE SCHICKLER OCCURRENCE AND DWYER MINE, ONTARIO, CANADA

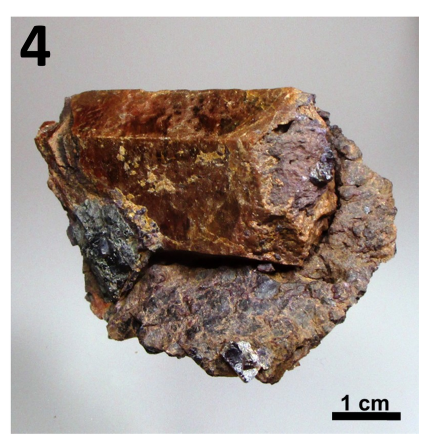
Stephanie E. Mounce[1] (mouncese@miamioh.edu), Christopher R. Emproto[2] (cemproto@umich.edu), and John F. Rakovan[1] (rakovajf@miamioh.edu)
[1]Miami University Department of Geology and Environmental Earth Science, Oxford, OH, 45056
[2]University of Michigan Department of Earth and Environmental Sciences, Ann Arbor, MI, 48109

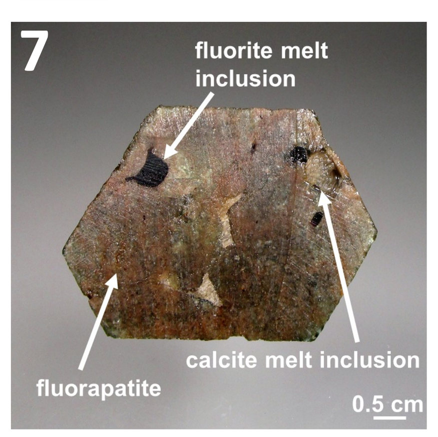
Introduction

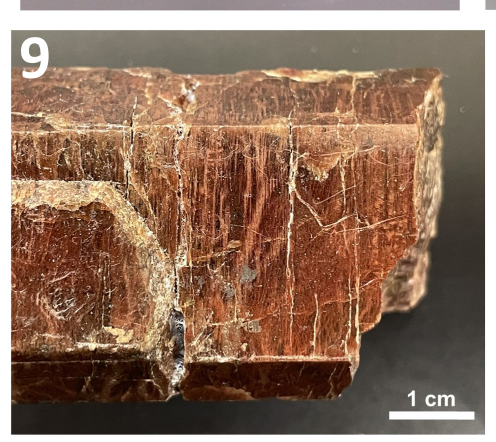
The Schickler Occurrence and Dwyer Mine are two vein dike localities situated near Wilberforce, Ontario, Canada (**1**) within the Central Metasedimentary Belt of the Grenville Province. Vein dikes are narrow bodies of crystallized carbonatitic magma which intruded into surrounding silicate country rock, resulting in partial dissolution-reprecipitation of the host rock. The main body of a vein dike consists mostly of calcite and apatite (**2 & 3**). Silicate minerals reflective of the mineralogy of the country rock comprise the coarsely-crystallized margins of the structure (**2**). The Schickler Occurrence and Dwyer Mine are unique in that the cores of these vein dikes host coarsely-crystallized, segregated bands of calcite and fluorite, in addition to the presence of apatite (**3**). Vein dikes in the Wilberforce area also show textures indicative of flow (**3 & 5**). Melt inclusions in the form of distinct globules of calcite and fluorite have been identified within fluorapatite crystals from both the Schickler Occurrence and Dwyer Mine (**6 & 7**). These globules are interpreted to have crystallized from trapped melt based on their external morphology, internal mineralogy, and texture. We have chemically characterized these melt inclusions and their internal mineral assemblages in order to better understand these unusual carbonatitic deposits. Apatite crystals from the Schickler Occurrence are distinctly reddish-brown in color (**4, 8 & 9**) with minimal green (**8**), while those from the Dwyer Mine are more green (**10**). Bands of hematite mineralization exist within Schickler apatite crystals (**9**). We hypothesize that these deposits represent the first example of a fluorite-dominant melt known to exist in nature, and we seek to elucidate the possible immiscible separation of carbonate and halide melts at these localities.

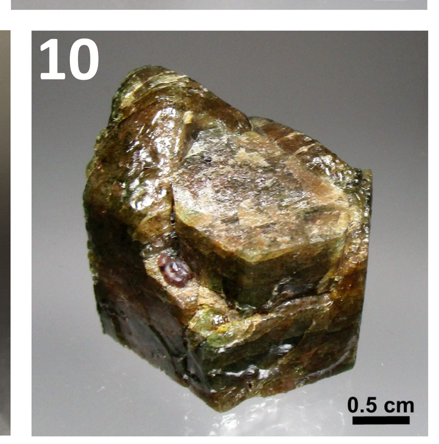












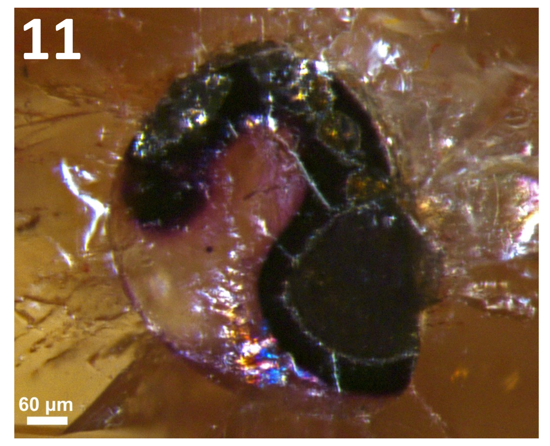
(**1**) Wilberforce area of Ontario, Canada underlined in red (McDougall, 2019). (**2**) Vein dike diagram by Chris Emproto. (**3**) Segregated bands of calcite and fluorite in the Schickler vein dike core. (**4**) Apatite on fluorite from Schickler. (**5**) Flow texture within calcite –fluorite matrix around apatite from the Richardson (Fission) Mine. (**6**) Example of separated calcite and fluorite melt inclusions within apatite crystals from the Wilberforce area. (**7**) Fluorite and calcite melt inclusions within Dwyer Mine apatite. (**8**) Large Schickler apatite with green and reddish brown coloration. (**9**) Schickler apatite with hematite banding, same as **8**. (**10**) Green Dwyer Mine apatite crystal, same sample as **7**.

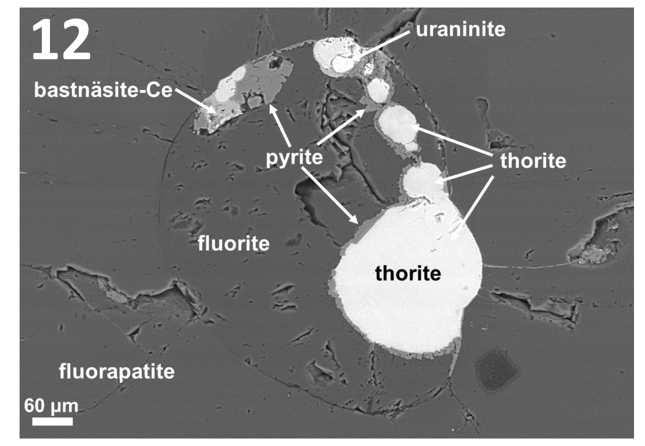
Materials and Methods

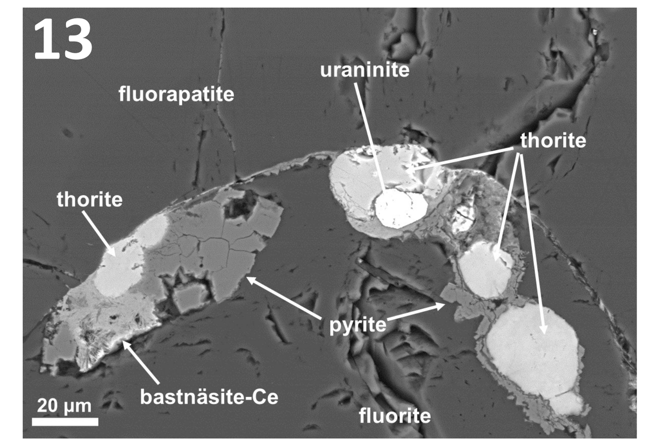
Samples of banded calcite-fluorite vein dike core material along with crystals of apatite and other prominent minerals were collected at the Schickler Occurrence in Ontario, while material from the Dwyer Mine was acquired from other sources. Apatite crystals from both localities were embedded within ~3 cm mounts of epoxy resin, and were subsequently polished from 600 grit through to colloidal silica. Polished mounts were carbon coated and taken to the Zeiss SUPRA 35VP scanning electron microscope (SEM) in the Center for Advanced Microscopy and Imaging (CAMI) at Miami University, for investigation using x-ray energy dispersive spectroscopy (XEDS) and backscattered electron (BSE) imaging.

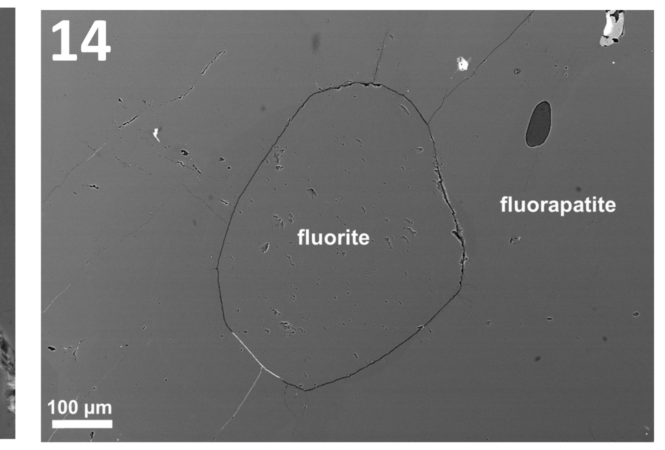
Results and Discussion

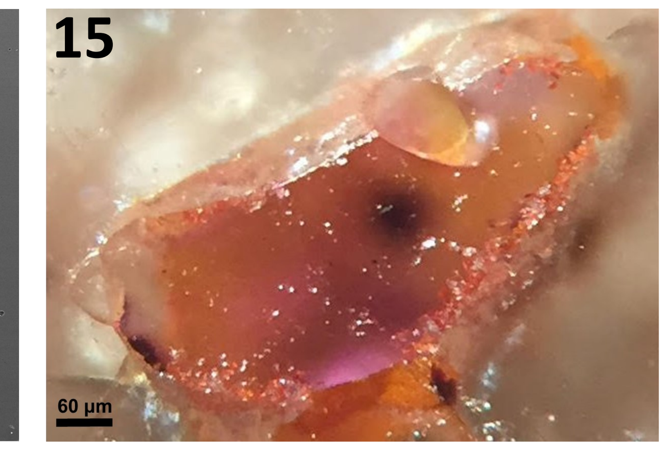
Melt Inclusions

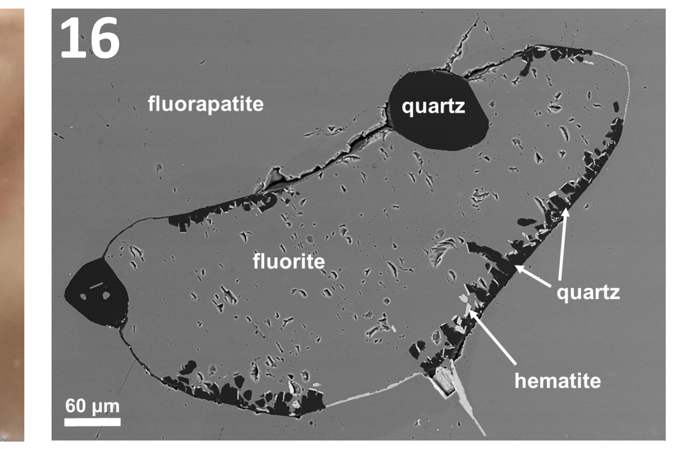


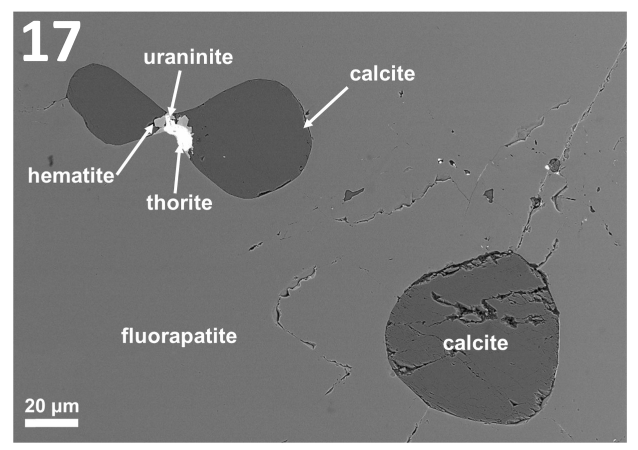


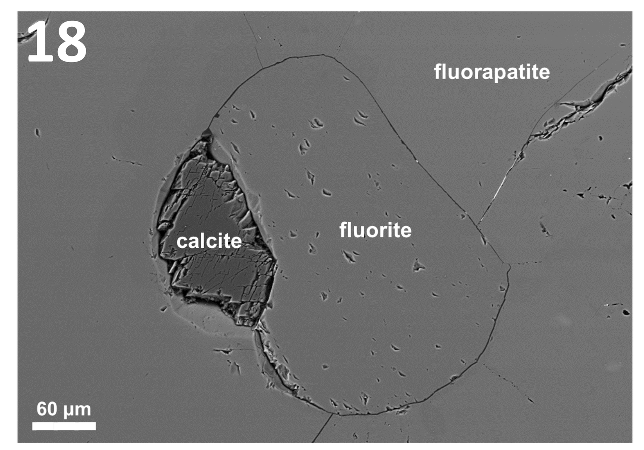


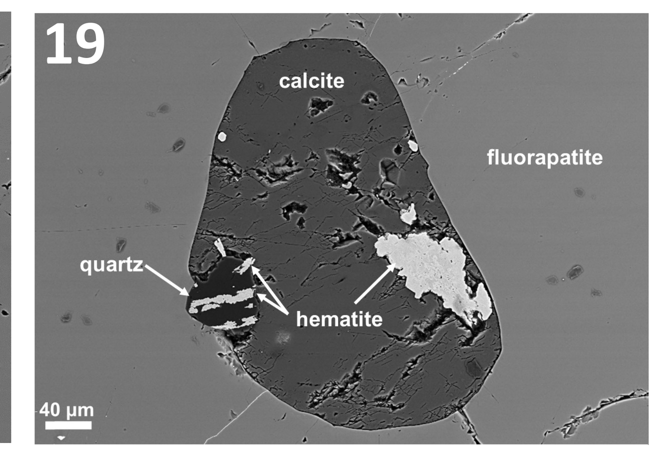


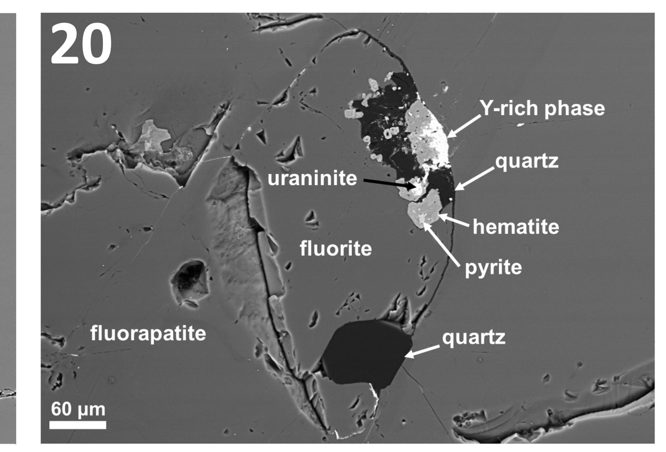








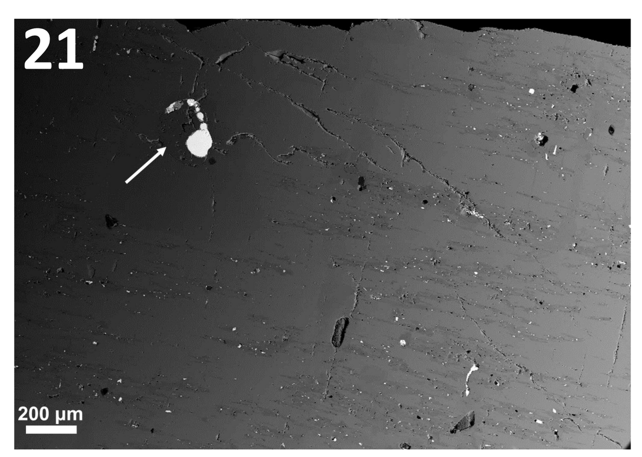


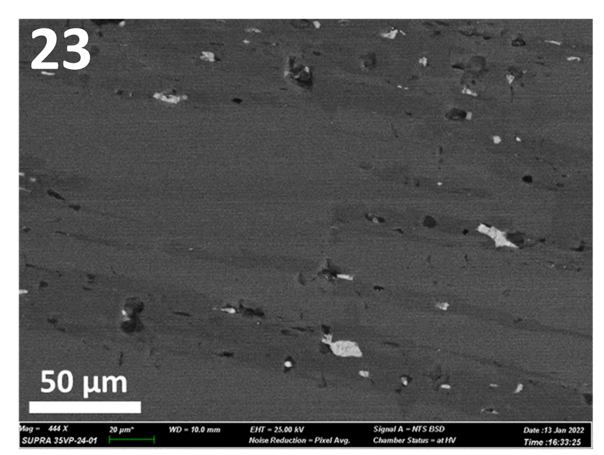


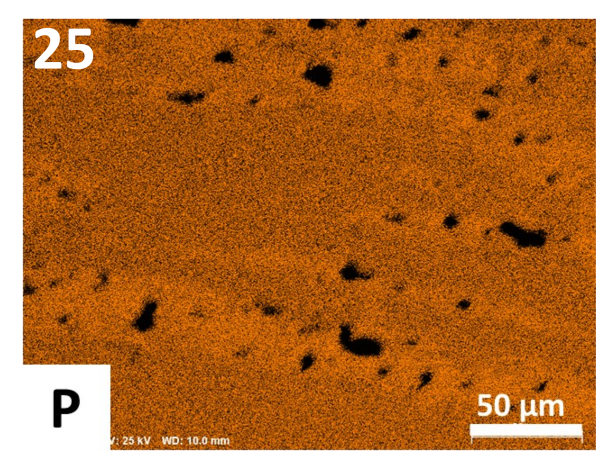
12-14, 16-20 SEM-BSE images of both monomineralic and polyphase calcite and fluorite melt inclusions from the Schickler Occurrence (**12 & 13**) and Dwyer Mine (**16-20**). **14** Example of a monomineralic fluorite melt inclusion from the Dwyer Mine. **17** Example of a monomineralic calcite melt inclusion from the Dwyer Mine. Greyscale value in BSE imaging corresponds to the mean atomic weight of the phases being imaged. Melt inclusions are labeled with their corresponding mineralogy, identified through the use of EDS. **12 & 13** are the same fluorite melt inclusion from the Schickler Occurrence. **15** Light microscopy image of the fluorite melt inclusion shown in **16**; boundary relationships suggest possible mixed trapping of solid quartz crystals and fluorite melt. Orange coloration in **15** is due to hematite. **11** Light microscopy image of the same fluorite melt inclusion shown in **12 & 13**; note globular morphology of daughter phases within the melt inclusion. Darkening of fluorite around thorite in **11** is due to the radioactivity of thorite. **18** Globular inclusion showing distinct separation of calcite and fluorite components in a melt inclusion.

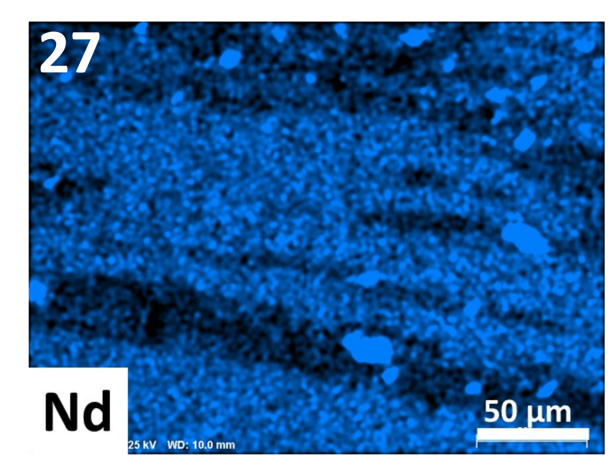
Melt inclusions observed within Schickler Occurrence and Dwyer Mine apatite crystals range in size from 10 µm to over 1 cm in diameter. Both monomineralic and polyphase fluorite-dominant and calcite-dominant melt inclusions exist at these localities (**11-20**). While fluorite and calcite may be present together within the same melt inclusion, they are distinctly separated from each other rather than intermixed (**18**). Polyphase calcite and fluorite-dominant melt inclusions often host combinations of pyrite, hematite, thorite, uraninite, quartz, REE carbonates including bastnäsite-Ce, Y-rich phases, and other REE phases (**11-20**). The identities of all of these minerals are based on chemistry alone and some are tentative until structural data can be obtained. Boundary relationships and morphology of phases within and in contact with melt inclusions suggests possible mixed trapping of molten and solid phases (Ex: **16**). Globular minerals within melt inclusions or following curvilinear melt inclusion boundaries are interpreted as daughter phases crystallized from trapped melt (Ex: **12**).

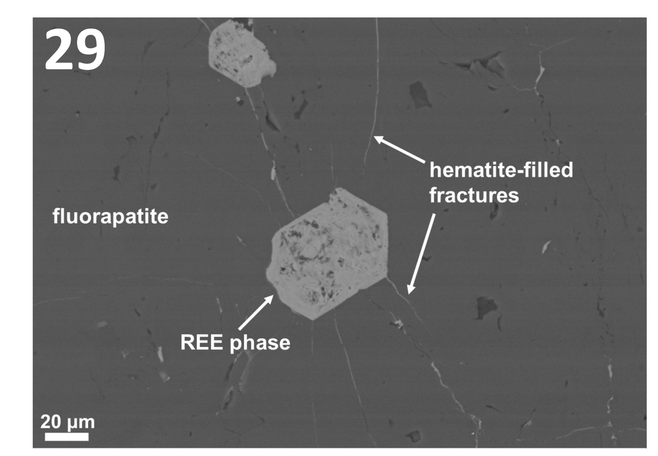
Regenerative Mineral Replacement (RMR)

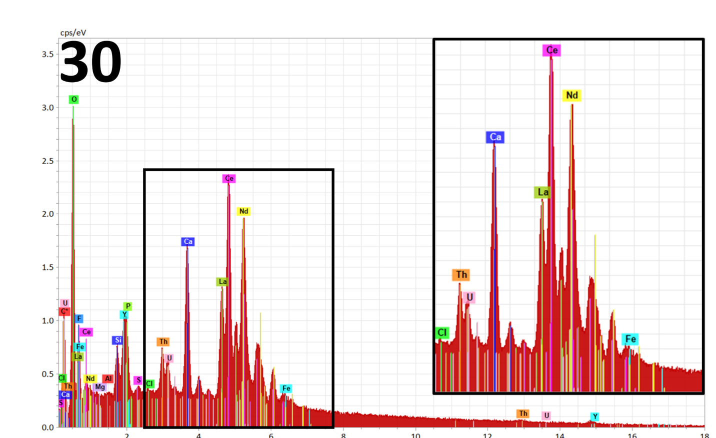


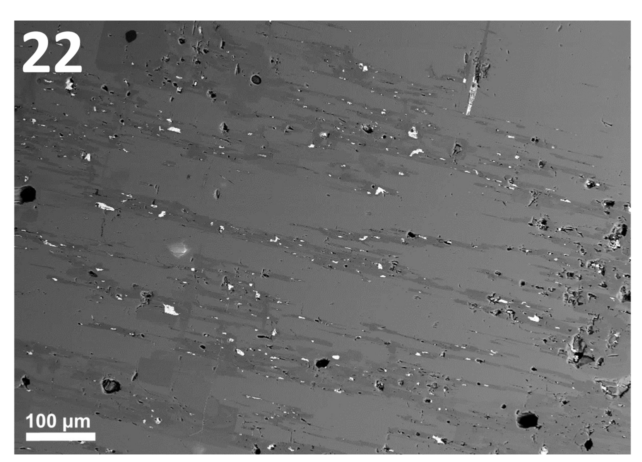


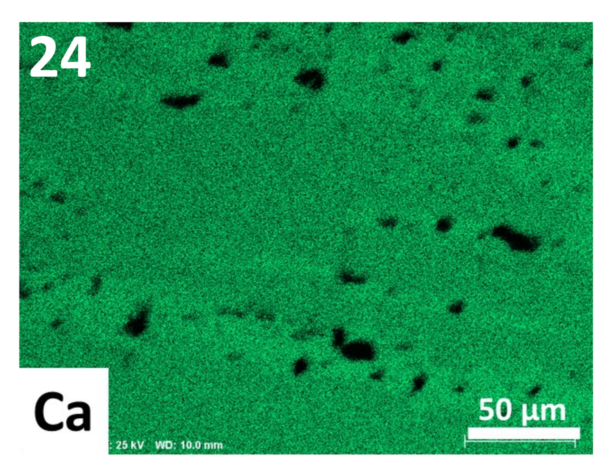


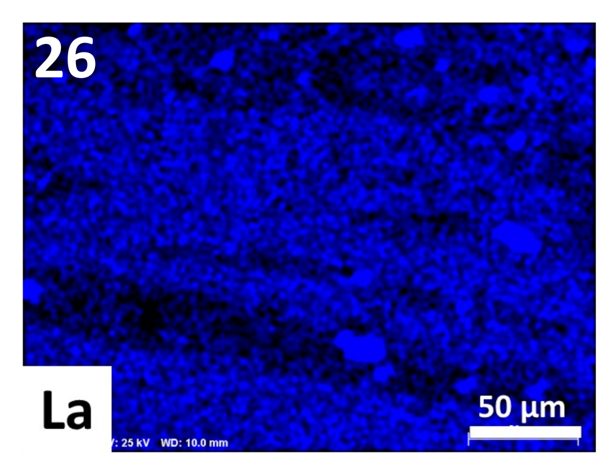


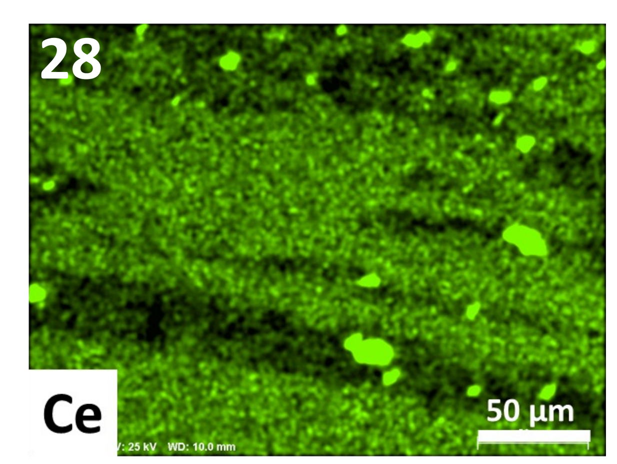












21 & 22, 29 SEM-BSE images of micro-mineral inclusions within apatite from the Schickler Occurrence. Greyscale value corresponds to mean atomic weight of the mineral phases being imaged. **21** and **22** Areas within a Schickler Occurrence apatite crystal showing apparent lamellae of differing BSE intensity. Note enrichment of micro-inclusions within darker BSE intensity lamellae. **21** Larger field of view including the fluorite melt inclusion from **11-13** (arrow) in relation to apatite lamellae present in the sample. **23-28** SEM-BSE images (**23**) and EDS elemental distribution images (**24-28**) EDS map of lamellae within a Schickler Occurrence apatite crystal. **29** is a SEM-BSE image of one of the typical micro-inclusions found within inclusion-rich lamellae of Schickler apatites. An example EDS spectrum from these typical inclusions is shown in **30**, including a magnified inset.

Apatite crystals, especially those from the Schickler Occurrence, host a profusion of micro-mineral inclusions in addition to fluorite and calcite melt inclusions. These micro-inclusions are segregated into lamellae of low BSE intensity, with inclusion-free lamellae of higher BSE intensity in between (**21-23**). Apatite crystals from the Dwyer Mine do not exhibit the same abundance of micro-inclusions. Micro-inclusion mineral assemblage includes those minerals found as daughters within melt inclusions, as well as additional mineral phases not identified within melt inclusions (all identified through EDS analysis). EDS mapping indicates an apparent greater concentration of calcium and phosphorus within the inclusion-rich lamellae (**24 & 25**). REEs like La, Nd, and Ce are found to be dispersed throughout lamellae of higher BSE intensity, and concentrated within inclusion phases within lamellae of lower BSE intensity (**24-28**). **29** represents an example of a typical REE-bearing phase found within inclusion-rich lamellae (EDS spectrum in **30**). We interpret these lamellae within Schickler apatite crystals to be regenerative mineral replacement (RMR), in which a mineral undergoes dissolution and reprecipitation to replace itself as the same mineral. When undergoing dissolution-reprecipitation the apatite recrystallized as a more pure form, and the REEs that were within the apatite structure went into separate micro-inclusions.

Conclusions

Melt inclusions, banded calcite and fluorite vein dike cores, and flow textures at Wilberforce-area localities indicate a carbonate-halide melt that was or became heterogeneous and immiscible. These conclusions are supported by distinct separation of fluorite and calcite phases within melt inclusions and the vein dike core, variability in melt inclusion mineralogy, and the texture of daughter minerals within the melt inclusions. Spatial correlation of micro-inclusions with apatite lamellae of low BSE intensity in Schickler apatite crystals suggests partial apatite alteration via dissolution and reprecipitation through the process of regenerative mineral replacement involving late-stage hydrothermal fluids. These fluids were possibly sourced from the magma body during cooling. While some of the elemental constituents of micro-inclusion phases could be sourced from the alteration fluids, many were likely sourced from the apatite itself during the dissolution process. Lower abundance of micro-inclusions in Dwyer apatite suggests that those crystals did not experience the same degree of alteration as Schickler apatite.

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References

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