

Origin of poikilitic garnet in a leucogranite dike

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1. What is the problem?

Garnet is not uncommon in granitoid rocks, but its origin is contentious.

What mechanisms have been proposed?

In a review, Clarke (1981) listed the following mechanisms:

- Derivation as a refractory restite phase from the zone of partial melting.
- Derivation as refractory xenocrysts from porphyroblasts in high-level pelitic country rocks.
- Generation in the marginal facies of a granite body as a result of reaction between magma and pelitic xenoliths rich in Al and Mn relative to the melt.
- Reaction between early-formed phases and silicate melt, for example: $Liq + Bt \rightarrow Grt + Ms$ or $Liq + Als + Bt \rightarrow Grt$.
- Nucleation directly from the silicate melt, especially in aplites and pegmatites, as late-stage differentiation increases the Mn / (Mn + Fe²⁺ + Mg) ratio sufficiently to stabilise spessartine-rich garnet.

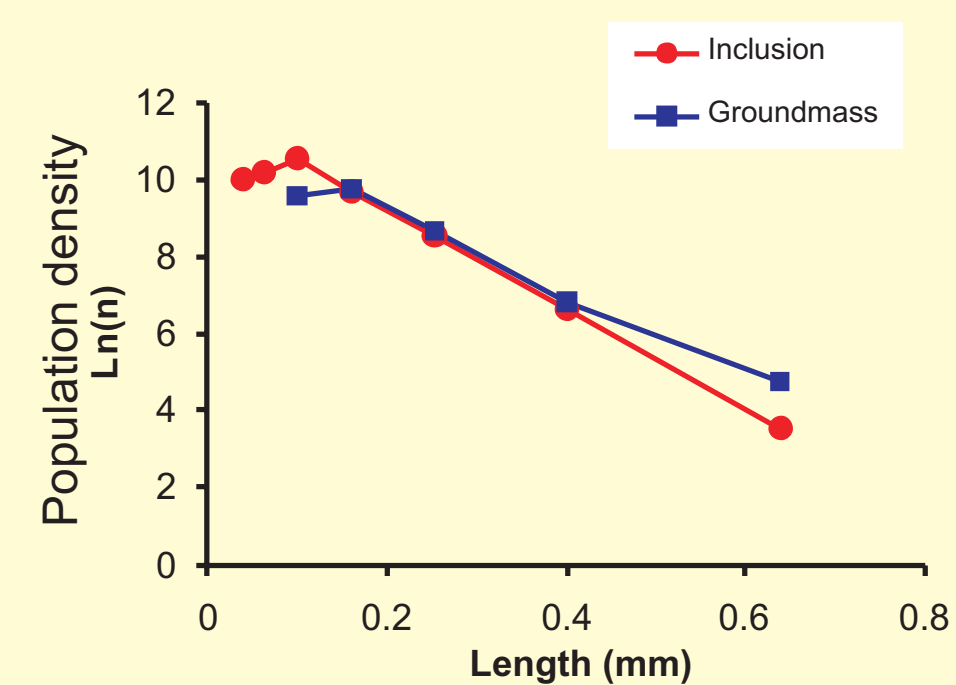
Essentially, 4 principal scenarios...

1. Xenocrysts.
2. Garnet crystals grown by solid-state replacement.
3. Garnet formed by reaction between solid or early-formed phases and granitoid melt.
4. Garnet crystallized directly from the granitoid melt.

3. Quartz size & shape data

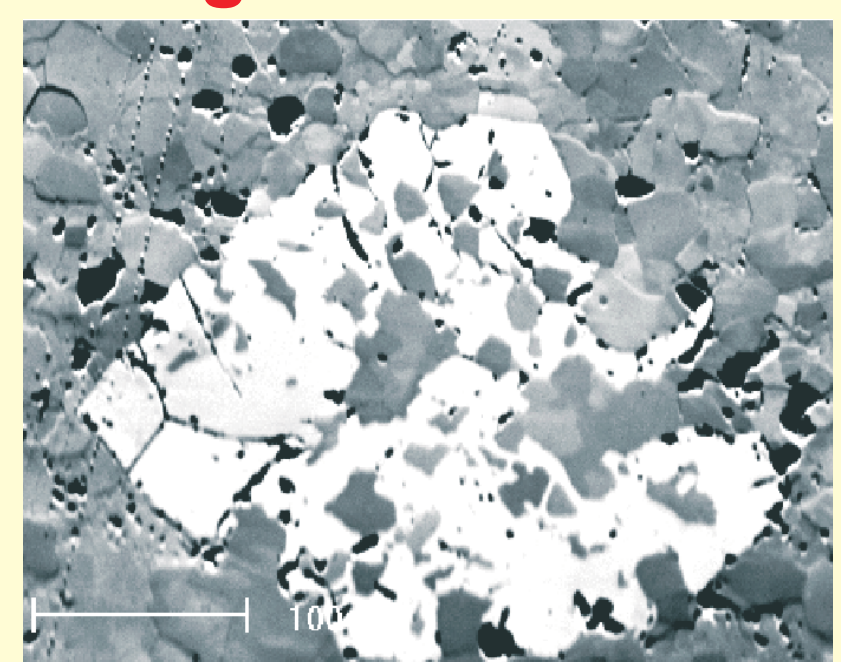
Quartz crystal size distributions (CSDs) and shapes were measured in the groundmass and in garnet inclusions to investigate relative timing of garnet growth.

Quartz Grain CSDs



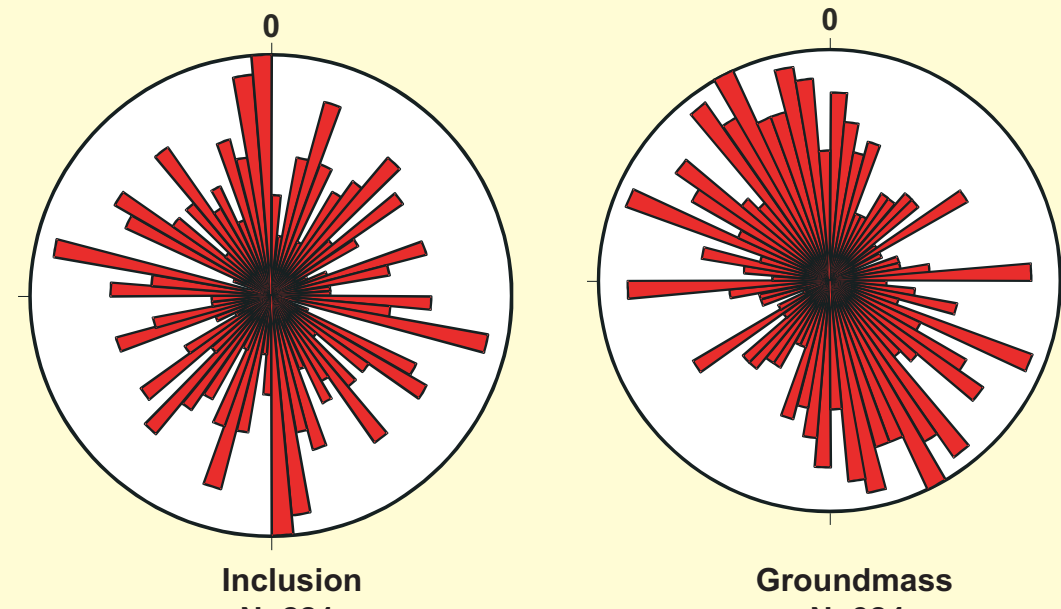
- CSD analysis reveals that groundmass and inclusion quartz have similar size/population slopes, but inclusion quartzes extend to finer sizes.
- No evidence for garnet attempting to include >1mm xenocrystic quartz
- Finer grain sizes in inclusions are not a simple function of sequential entrapment during quartz growth

OC image of Qtz inclusions



Note that there is no simple relation between size (or shape) of Qtz crystals and distance from the core.

Quartz Grain SPOs



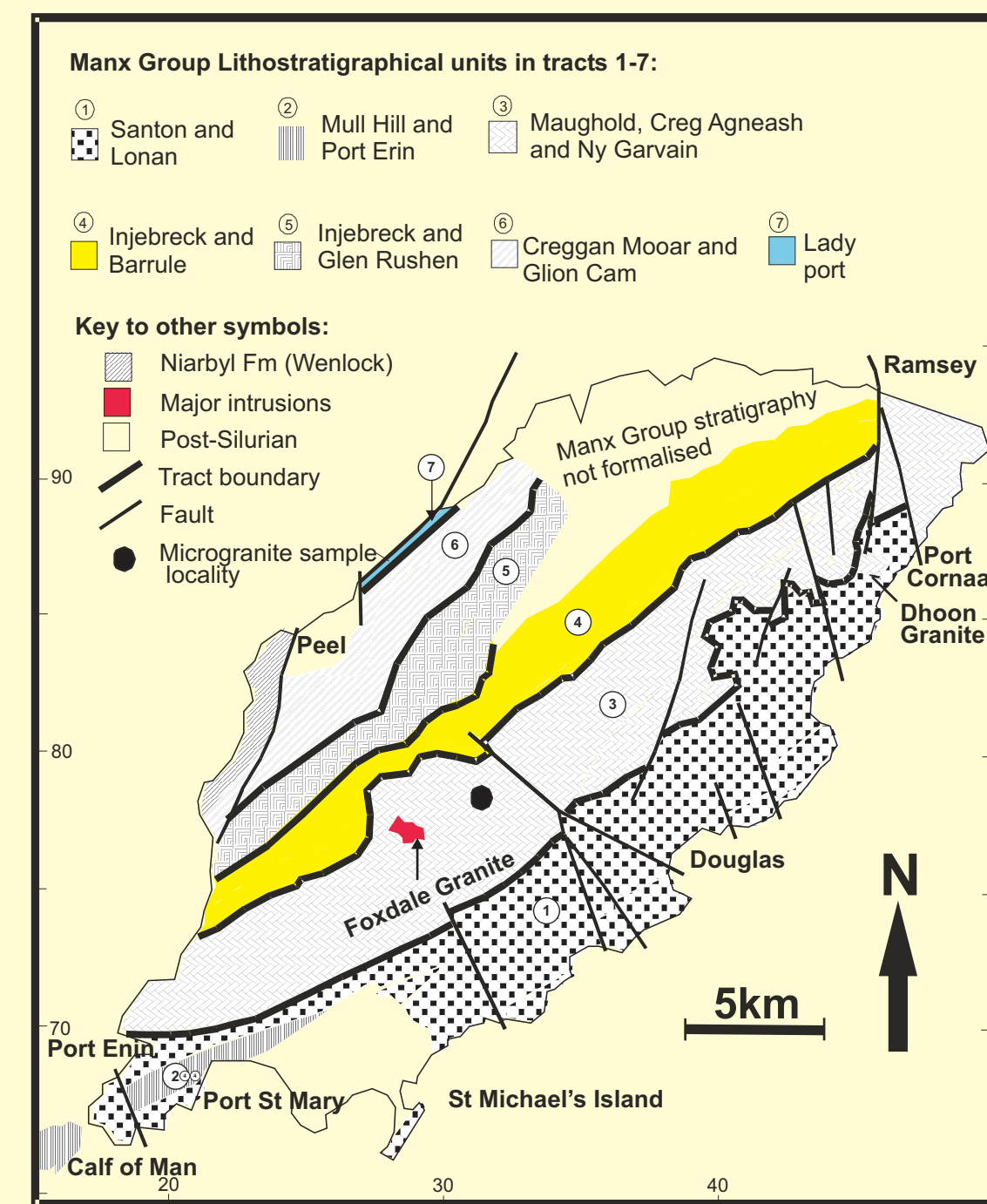
- Groundmass quartzes show a distinct SPO, whereas inclusion quartzes do not.
- SPO function of flow during emplacement or subsequent deformation?

- Garnet growth is after groundmass quartz growth, but before the development of Qtz SPO and undulose extinction.

2. Geological setting, petrography & chemistry

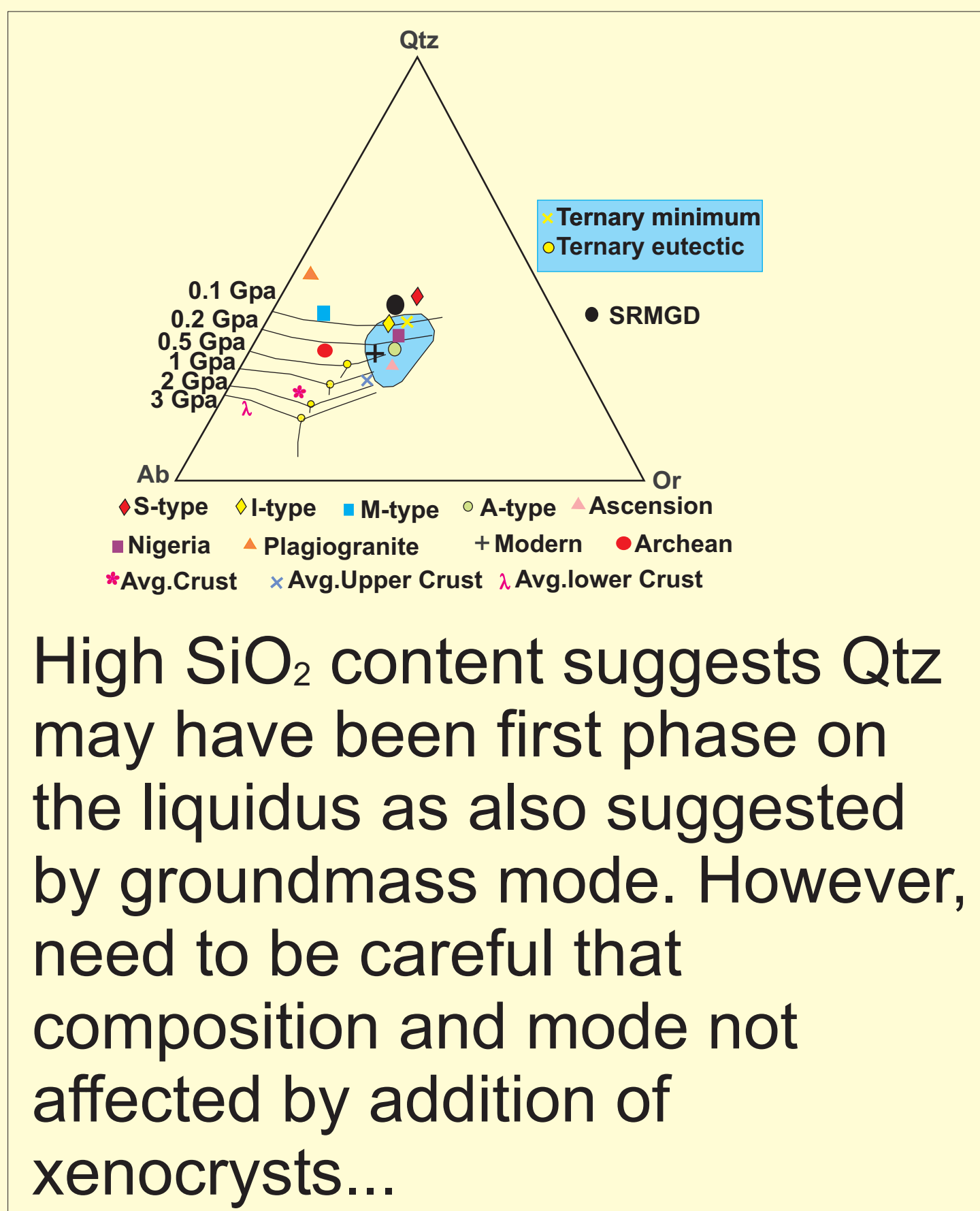
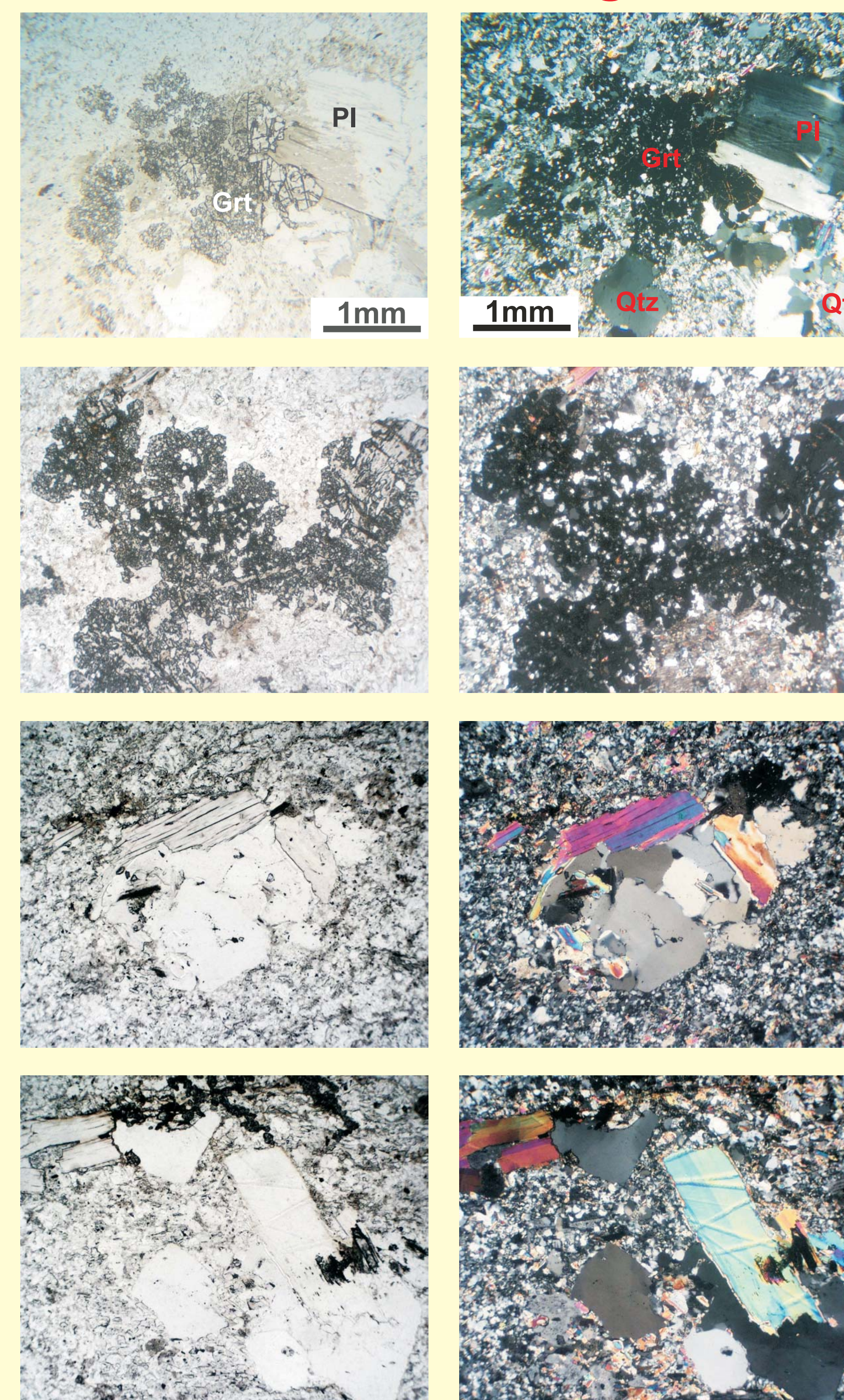
The sample studied comes from a Caledonian 1-10 metre wide peraluminous leucogranite dike at St. Ruuan on the Isle of Man. It is characterised by three main textural components:

1. an equigranular sub-100 m groundmass with a poorly defined shape fabric;
2. xenocrysts and aggregates of coarse, >1mm, Qtz, Pl, Ksp and Ms;
3. garnet grains typically showing faceted margins and tending to occur in >1mm clumps or clusters. The garnets are strongly poikilitic with included grains being almost exclusively quartz, but inclusion free where in contact with xenocrystic plagioclase.



- Xenocrystic phases show undulose extinction, as does quartz in the groundmass. Quartz inclusions in garnet do not show undulose extinction.
- Garnet appears to partly replace plagioclase.
- Quartz inclusions look similar size to matrix quartz grains.

PPL & XPL Images



High SiO₂ content suggests Qtz may have been first phase on the liquidus as also suggested by groundmass mode. However, need to be careful that composition and mode not affected by addition of xenocrysts...

Composition

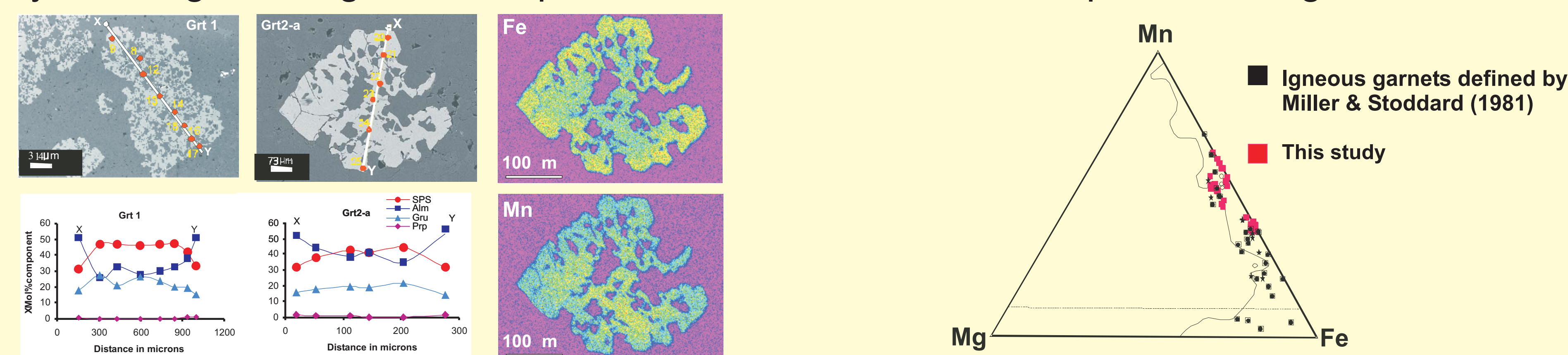
| | |
|--------------------------------|--------|
| SiO ₂ | 74.63 |
| TiO ₂ | 0.04 |
| Al ₂ O ₃ | 14.96 |
| Fe ₂ O ₃ | 0.51 |
| MgO | 0.03 |
| MnO | 0.04 |
| CaO | 0.67 |
| Na ₂ O | 5.41 |
| K ₂ O | 3.62 |
| P ₂ O ₅ | 0.05 |
| LOI* | 0.48 |
| Total | 100.44 |
| A/CNK | = 1.54 |

Groundmass Mineral Mode

| | |
|------|--------|
| Qtz | = 37% |
| Pl | = 28% |
| Ksp | = 25.5 |
| Ms | = 6% |
| Bt | = 1% |
| Grt | = 1.5% |
| Acc. | = 1% |

4. Garnet chemistry

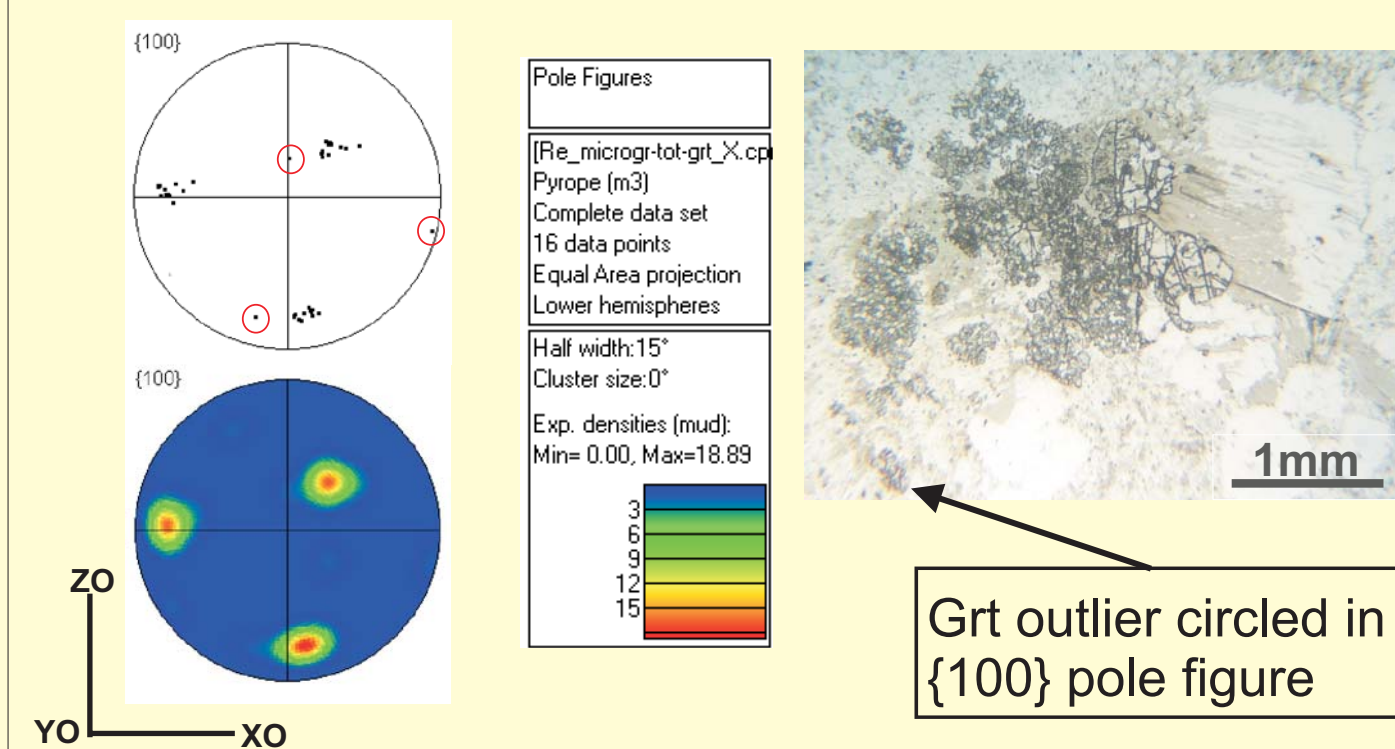
Garnet shows zoning profiles with high Mn (Sps) between 40-50 mol% in cores and significant Ca-contents (Grs) between 12-25 mol%. Fe-content (Alm) is antipathetic with Sps. Mg-content (Prp) is very low. In general, garnet compositions are similar to those reported from granites.



5. Garnet & quartz crystal orientations

Electron backscatter diffraction was used to determine crystallographic orientations in garnet and in both groundmass and inclusion quartzes.

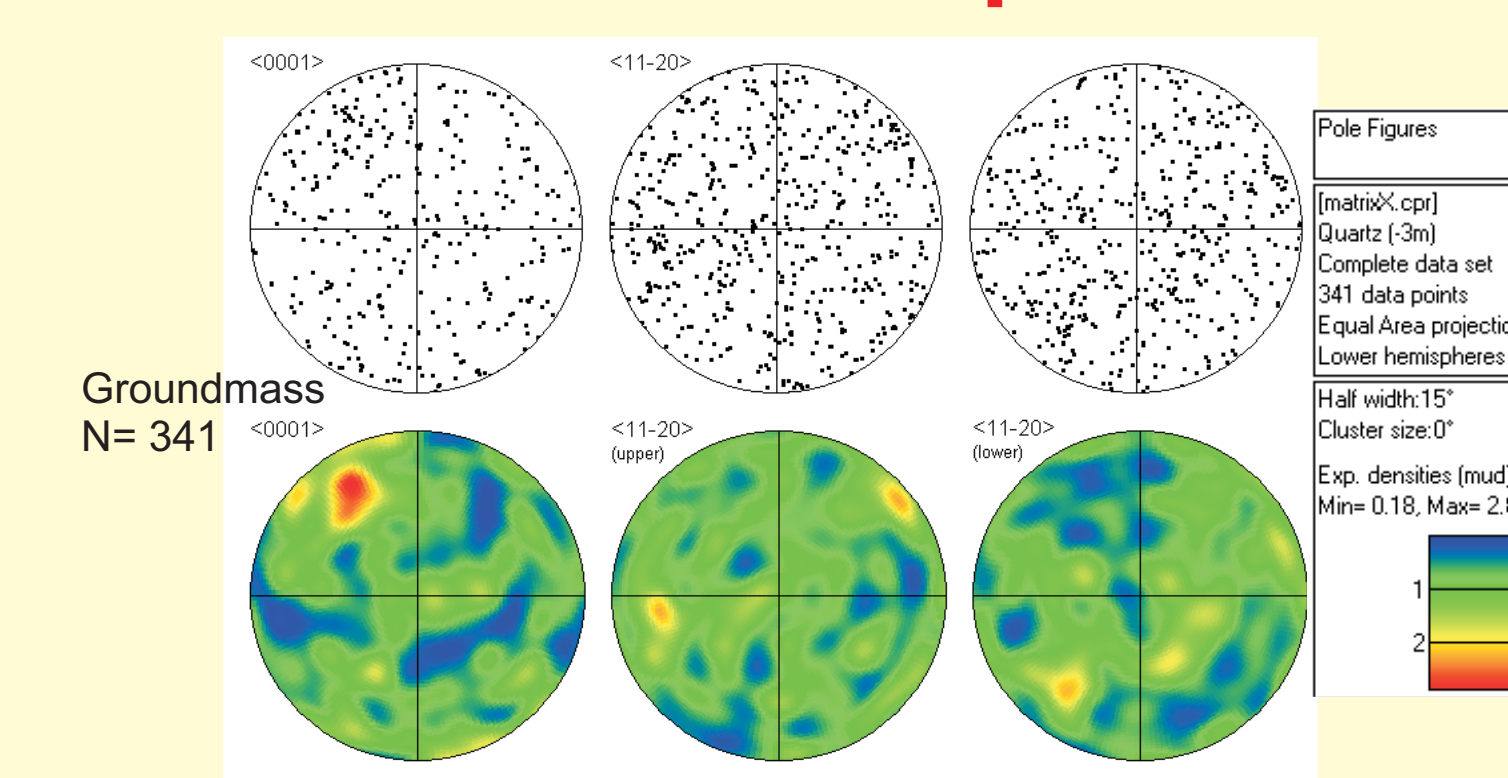
Crystal orientations of 15 clumped garnets



The clumped garnets have similar crystal orientation...

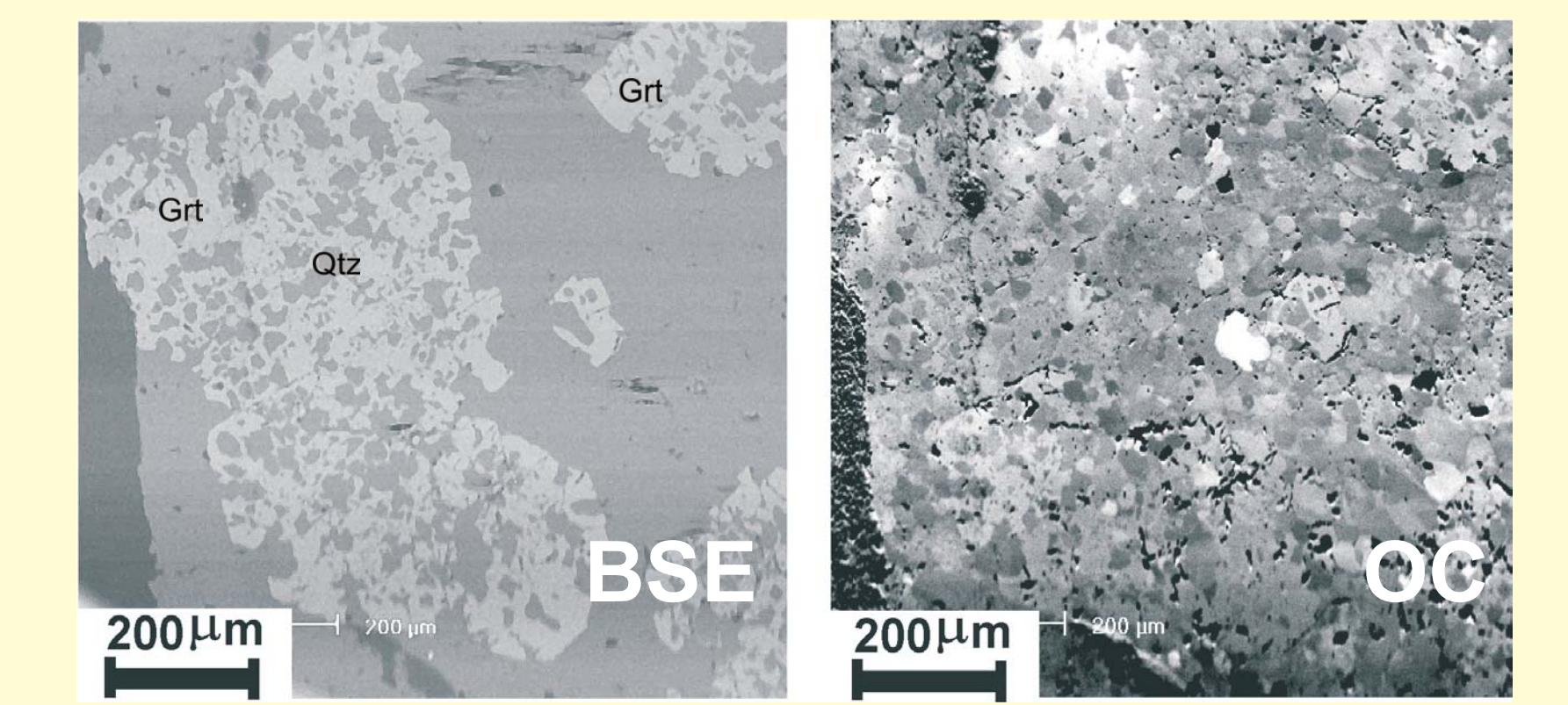
- Discrete glomerocrystic grains or connected as skeletal/dendritic growths?
- Small size of outliers favours discrete grains?

Groundmass quartz CPOs



Clumped or clustered garnets have similar crystallographic orientation, suggesting:

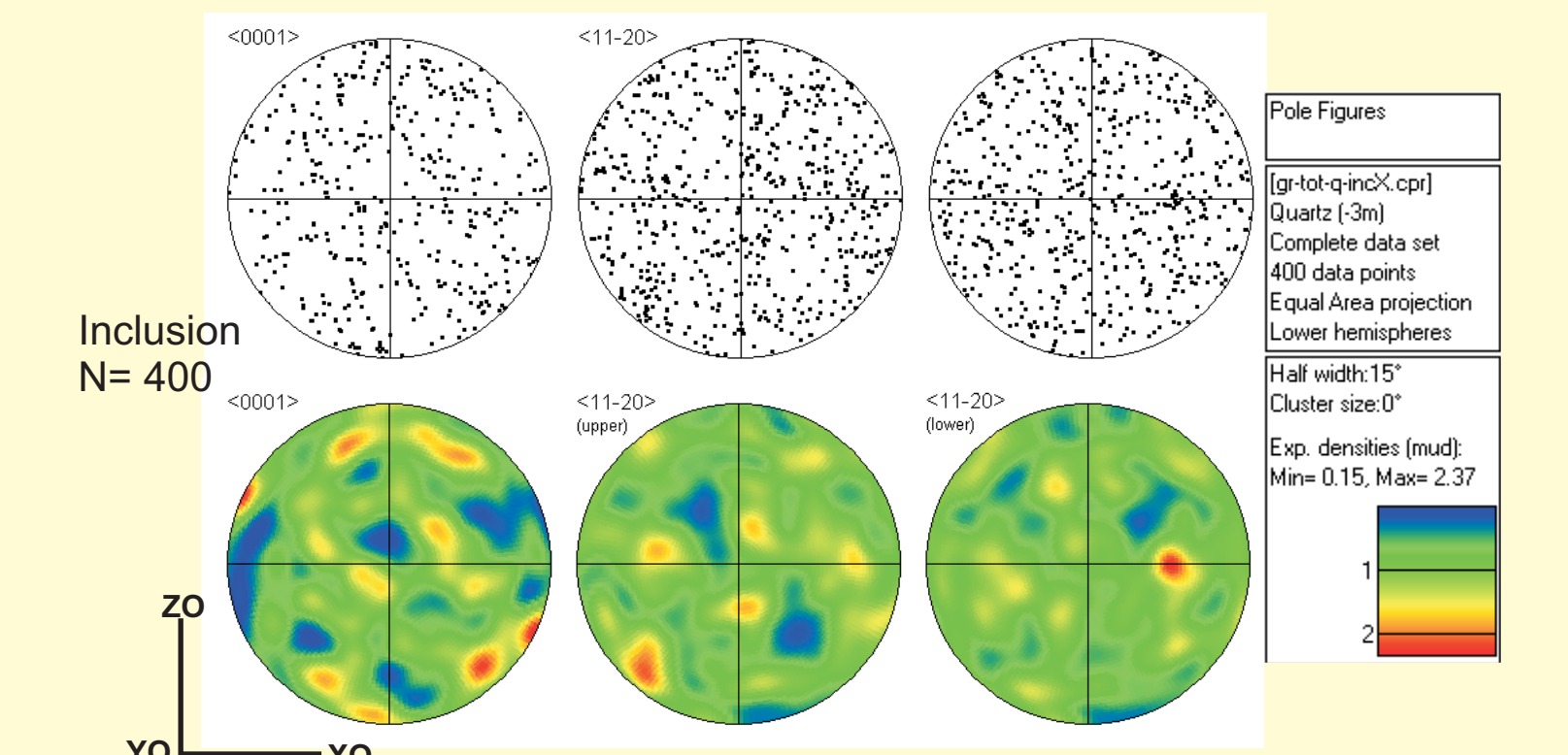
- they either "know" something about each other, or
- they are interconnected in 3D



Quartz crystallographic orientations were measured for 400 inclusions in the two labelled garnets above, and for 341 quartz grains in the surrounding groundmass. For both datasets the crystallographic preferred orientation (CPO) is uniform.

- The development of an SPO has not resulted in any significant CPO.
- The inclusion forming process has not resulted in any "selection" of grains on a crystallographic basis

Inclusion quartz CPOs



6. Discussion

Did garnet form as xenocrysts?

For

Xenocrysts of other phases are present

Against

Xenocryst grain sizes are much larger than those included in garnet. Faceted outlines - no evidence of reaction with melt. Similar quartz inclusion and groundmass grain sizes and shapes. garnet appears to cut across xenocryst outlines.

Did garnet grow by solid-state replacement?

For

Poikilitic texture.

Qtz inclusion sizes similar to Qtz in groundmass.

Absence of feldspar and muscovite inclusions.

If the clustered garnets are skeletal.

Against

If the garnets are not clustered but are discrete grains.

Qtz inclusion SPO different to groundmass SPO.

Did garnet grow by reaction between melt & Bt?

For

(the reactions: $Liq + Bt \rightarrow Grt + Ms$ or $Liq + Als + Bt \rightarrow Grt$)

Absence of biotite.

Absence of aluminium silicate.

Against

No evidence of biotite or aluminium silicate having been present.

No evidence of muscovite intergrown with garnet.

Did garnet grow from the granitoid melt?

For

Subhedral and euhedral grain shapes.

Poikilitic texture.

Similar chemical composition to published "granite garnets", high MnO contents and normal zoning.

If garnet clusters are discrete grains, possibility of glomerocrystic aggregation?

Against

Absence of feldspar and muscovite inclusions.

Glomerocrysts - poikilitic texture suggests granite largely crystallised

making movement of garnets through melt difficult?

7. Conclusions

Decision Time - melt or solid state - or both?

Putnis (2002, Min Mag):

"The precondition for a dissolution-precipitation reaction is merely that a solid phase or phase assemblage is out of equilibrium with a fluid phase, and that re-equilibration may be achieved by the crystallisation of a "different" solid phase. This difference may be chemical or textural, and the fluid may be a simple aqueous solution, a melt or anything in between."

Both solid and liquid?

- Perhaps the Mn-rich garnet crystallises from a final stage granitoid melt/fluid, but rather than produce lots of small spatially separate crystals it has made a few large ones.
- This will have involved dissolution (PI+Kfs+Ms) and precipitation (Grt), supported by the "clean" Grt in contact with groundmass and xenocrystic PI, and favouring a skeletal geometry.
- If the garnet is skeletal, might it have grown along end-stage melt/fluid