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The origin of clinopyroxene - titanomagnetite clustering during crystallisation of synthetic trachybasalt

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Crystal clustering impacts rheology and differentiation in magmatic systems, and also offers insights into nucleation processes. Electron backscatter diffraction (EBSD) is ideal for studying interactions between crystals at interfaces. Clinopyroxene (Cpx) – titanomagnetite (Timt) clusters formed in time series experiments on synthetic trachybasaltic melt were studied using EBSD to understand the cause of clustering. Experiments were performed at 400 MPa and the NNO +2 buffer, at both anhydrous and hydrous (2 wt.% H2O) conditions, by cooling from 1300 °C (superliquidus) to 1100 °C with a rate of 80°C/min and holding at the target temperature for 4 – 8 hours before isobaric quenching.

All experiments crystallize dendritic Cpx (Lmax = 50 – 60 µm) and isometric euhedral to hopper-shaped Timt (Lmax = 5 – 6 µm). Infrequent (~ 10 mm^{-2}) unmelted Cr-oxide crystals are surrounded by polycrystalline Cr-bearing Timt rims (Lmax Cr-oxide + rim = 20 µm). Cpx dendrite “rosettes” radiate from the polycrystalline rims, but many dendrites do not belong to rosettes, at least in 2D. Individual Timt crystals (Cr-free) are strongly associated with the sides and tips of Cpx dendrites. About 75% of Timt grains are in contact with Cpx in 2D. Cpx-Timt interfaces are irregular, and Timt is often attached only by thin necks. Timt grain centers are weakly clustered (R = 0.87 – 0.95, 1 = random).

Timt shows a strong crystallographic orientation relationship (COR) with Cpx, with 75 – 89% of Timt grains in contact with Cpx lying within 6° of a single fixed (“specific”) COR, OR1 = Cpx [010] // Timt <110>; Cpx (100) // Timt <111>; Cpx [001] // Timt <112>. The axes Cpx [010] // Timt <110> show the least dispersion (< 3°) from the ideal alignment. Relative to Cpx, individual Timt may be rotated up to 6° away from OR1, around an axis close to Cpx [010]. There are two peaks in this continuous distribution, corresponding to OR1 (above) and OR2 = Cpx [010] // Timt <110>; Cpx (-101) // Timt <111>; Cpx [101] // Timt <112>. The misorientation between OR1 and OR2 is 5.3°. OR1 and OR2 together represent 68 – 77% of Timt grains in contact with Cpx (tolerance angle 2.6°).

Cpx dendrite branches bend around Cpx [010]. The anhydrous sample with dwell time 4 hours shows continuous bending of up to ~15°, whereas the hydrous sample with dwell time 8 hours shows bending of up to only ~7° and subgrain boundaries (1 - 2°) separating undistorted domains, suggesting recovery of bent crystals during annealing. Initial Cpx nucleation likely occurred heterogeneously as rosettes on Cr-bearing Timt rims around Cr-oxide crystals. Multiple Timt grains touching different branches of the same bent Cpx crystal all maintain a close COR with the Cpx orientation immediately adjacent to the Cpx-Timt interface, indicating that Timt nucleated on (or attached to) dendrite branches during or after their growth.

In conclusion, EBSD is a powerful method for understanding crystallization and cluster formation. Future work will study the effect of annealing time, water content, and undercooling on Cpx – Timt cluster development.