CALCULATING THE AMOUNT OF DISSOLVED GARNET

The method assumes a starting map with raw pixel values and (free) NIH Image software:

(a) From several spot measurements, it is useful (although not required) to transform the raw Mn intensity map into an $X_{\text{mg}}$ map. Note that background corrections for garnets are so similar that even a few points will allow accurate conversion. Determine the lowest $X_{\text{mg}}$ by outlining the lowest Mn region and measuring.

(b) Cut out the core by drawing a closed contour along the minimum $X_{\text{mg}}$ and filling the interior.

(c) Using thresholding, delineate (white out) the rim area of increased Mn. Using the wand tool, outline the edge of the garnet and measure the area and mean concentration. This gives a background measurement of core plus low Mn-inclusions in the rim region.

(d) Using thresholding, black out the rim area and remeasure the same area delineated in (c). This gives the total area and mean concentration of the entire garnet.

(e) For simplicity, we assume that the lowest $X_{\text{mg}}$ value once extended to the edge of the garnet. The area of dissolved garnet is then calculated via the equation:

$$A_{\text{rim, original}} = \frac{[A(d) \times C(d) - A(c) \times C(c)]}{X_{\text{mg, (lowest)}}}$$

where $A$ and $C$ are area and mean concentration, and (c) and (d) refer to the measurements in steps (c) and (d). Alternatively, the amount of dissolved rim can be determined from the current rim volume times the excess Mn (mean $X_{\text{mg}}$ - minimum $X_{\text{mg}}$) divided by the minimum $X_{\text{mg}}$. Note that in these first-order calculations, the lowest measured $X_{\text{mg}}$ is used as a proxy for the mean $X_{\text{mg}}$ of the dissolved rim. Depending on one’s preferences, this estimate can be refined iteratively by constructing a model $X_{\text{mg}}$ profile for the original garnet (e.g., with steadily decreasing $X_{\text{mg}}$ towards the rim), estimating a new mean $X_{\text{mg}}$ for that profile, and using that as the lowest $X_{\text{mg}}$ in the calculation. The new estimate of the amount of dissolved garnet can then be used to infer a new Mn profile and mean $X_{\text{mg}}$, etc.

(f) For simplicity, we assume that the measured $X_{\text{mg}}$ and $X_{\text{mg}}$ at the “trough” are constant over the part of the garnet that dissolved, so these contents are multiplied by the volume of garnet dissolved to yield the amounts of Fe and Mg fluxed into the matrix via garnet dissolution. Alternatively one could assume $X_{\text{mg}}$ and $X_{\text{mg}}$ profiles for the dissolved rim. Finally, the fluxes of Fe and Mg caused by diffusional exchange with the matrix biotite must also be considered, although they are typically an order of magnitude less than the fluxes due to garnet dissolution. For Fe or Mg, we difference the assumed original concentration and the average Fe or Mg concentration of the diffusively affected rim. These Fe and Mg fluxes are then subtracted from the amount of Fe and Mg in the current biotite to yield the original biotite composition.

Note that *sensu stricto* this approach applies only for central-cut garnets, and assumes both that current area modes are directly proportional to volume percents, and that dissolution is uniformly radial. Non-central cuts (overrepresentation of the rim) and non-uniform dissolution (contribution of higher Mn garnet than at the Mn trough) will both tend to cause overestimation of the degree of dissolution. Also, this method uses area measurements for estimating amounts of garnet that have dissolved, which works best for small amounts of dissolution (<= 20%). For larger amounts and greater accuracy, area measurements can be converted to volumes, as we did with DH-58. Our approach is simplest when biotite is the only ferromagnesian mineral present, because biotite takes so little Mn. In instances where a new mineral is produced (e.g., retrograde chlorite), the Mn content of that mineral must be considered in the mass balance, as well as its Fe-Mg concentration and partitioning with other matrix minerals such as biotite.
Finally, this technique is a useful diagnostic tool and can be used to select for those samples that are not strongly influenced by dissolution.

**MEASUREMENTS AND CALCULATIONS FOR SAMPLE DH-58.**

Total area of thin section = 490 mm².

Grt mode = 7.35% [determined from the areas of all garnets (36 mm²), divided by the area of the thin section]

Bt mode = 27±2% (determined from digital optical images = ~0.00532 mol biotite/cm³).

Bt Fe/(Fe + Mg) (matrix) = 1.222 mol ptu/(1.222+1.088 mol ptu) = 0.529

X_{ps} at Mn trough = 0.02

X_{Ahn} at Fe/(Fe + Mg) trough: 0.60

X_{tg} at Fe/(Fe + Mg) trough: 0.11

Present area of analyzed Grt: 8.7 mm² (=135766 pixels*64 μm²/pixel)

Present volume of Grt: 19.3 mm³ (assuming spherical geometry)

Present radius of Grt: 1.66 mm (assuming spherical geometry)

Area of Grt rim with increased Mn: 46030 pixels * 64 μm² = 2.95 mm².

Volume of Grt rim with increased Mn: 8.9 mm³ (assuming spherical geometry, ≈3 volume percent for the rock based on similar profiles in other garnets).

Average X_{ps} between trough and edge: 0.0584 (i.e., 0.0384 excess relative to the Mn trough)

Volume of dissolved Grt: 8.9 mm³ x 0.0384/0.02 = 17.1 mm³ (or ~6 volume %)

Original volume of Grt: ~36.4 mm³

Original area of Grt: ~13.3 mm².

Original radius of Grt: ~2.06 mm.

Grt Fe concentration: 0.60 x 0.0261 = 0.015660 mol/cm³ Grt (60% Almandine)

Grt Mg concentration: 0.11 x 0.0261 = 0.002871 mol/cm³ Grt (11% Pyrope)

Bt Fe concentration: 1.222 x 0.0197/3 = 0.008024 mol/cm³ Bt (1.222 moles ptu)

Bt Mg concentration: 1.088 x 0.0197/3 = 0.007145 mol/cm³ Bt (1.088 moles ptu)

Bt Fe (moles, final) = 0.008024 x 0.27 = 0.002166 mol/cm³ of rock

Bt Mg (moles, final) = 0.007145 x 0.27 = 0.001929 mol/cm³ of rock

Grt Fe (moles, added by dissolution) = 0.015660 x 0.06 = 0.000940 mol/cm³ of rock

Grt Mg (moles, added by dissolution) = 0.002871 x 0.06 = 0.000172 mol/cm³ of rock

Grt Fe (moles, added by diffusion) = 0.03 x 0.02610 x 0.04 x 3 = 0.000094 mol/cm³ of rock.

(Maximum amount is 0.08 mole percent; minimum is 0; 0.04 = value used; 0.03 = mode).

Grt Mg (moles, added by diffusion) = negligible.

Bt Fe(moles, original) = 0.002166 - 0.000940 - 0.000172 - 0.000094 = 0.001132 mol/cm³ of rock

Bt Mg(moles, original) = 0.001929 - 0.000172 - 0.000094 = 0.001757 mol/cm³ of rock

Bt Fe/(Fe + Mg) (original) = 0.390

Bt mode (original) = (0.001132 + 0.001757)/(0.002166 + 0.001929) x 27% = 19%

Note that on a volume basis, the molar concentrations for garnet and biotite are:

Fe in Almandine: 0.0260 mol/cm³

Mg in Pyrope: 0.0265 mol/cm³

Fe in Annite: 0.0194 mol/cm³

Mg in Phlogopite: 0.0200 mol/cm³

So for typical garnets and biotites, the molar concentrations are approximately:

Garnet: 0.0261 mol (cub. site)/cm³

Biotite: 0.0197 mol (oct. site)/cm³