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Do oriented rutile needles and faceted/zoned inclusions in garnet require very high P-T to form?

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Oriented rutile needles in garnet commonly occur in high-temperature / high-pressure rocks such as high-pressure granulites, ultrahigh-pressure rocks, and mantle peridotite. Faceted inclusions of plagioclase and quartz in garnet are also indicators of high – and possibly very high – grade conditions. Both inclusion textures are spectacularly displayed in garnets in sillimanite-bearing gneiss of the North Cascade Range (USA) in rocks that record peak P-T conditions of 1 GPa and 725°C; i.e. at significantly lower pressure than most other occurrences of rutile needle-bearing garnets and at the low end of the temperature range relative to most other occurrences of faceted (negative crystal) inclusions.

The most dramatic example of faceted inclusions is in sillimanite gneiss containing ~1-2 mm garnets that contain kyanite inclusions and abundant negative crystals of plagioclase. Matrix plagioclase (Pl) is unzoned, but Pl inclusions in garnet are strongly zoned: anorthite content increases by up to 24 mol% from core to rim. Zoned inclusions are surrounded by depletion haloes in Ca and Mg in garnet, documenting inclusion-garnet reaction. Zoning in garnet is most pronounced near Pl inclusions with visible fractures that connect to the garnet rim/matrix. Reaction involving Grt and Pl must involve other phases, such as Qz and kyanite/sillimanite, indicating that inclusions were not completely armored. Inclusion faceting and Grt/Pl zoning indicate that Grt interiors experienced significant modification after entrapment of the inclusions.

Some quartz inclusions are slightly faceted to rounded and are surrounded by Ca-poor regions of garnet. A recent study that applied Qz-in-Grt barometry to isolated, rounded inclusions in these rocks determined lower P (~0.6-0.7 GPa) than previous conventional-barometry results at similar T. These lower-P results are inconsistent with the presence of Ky inclusions in Grt and may reflect the modification of Qz inclusions that is apparent in garnet zoning around Qz and Pl inclusions.

Possible explanations for these observations are that: (1) the estimated P and/or T conditions are significantly lower than the actual conditions and the gneiss therefore experienced previously-unrecognized high-P granulite and/or eclogite facies metamorphism, or (2) rutile needles and faceted inclusions in Grt can form during metamorphism at upper amphibolite facies conditions; in this case, possibly the nature of the P-T-t path and/or role of fluids were important. The first possibility has significant implications for the tectono-metamorphic evolution of the orogen and perhaps other continental arc-related orogens, and the second is important for understanding the metamorphic processes that produce these inclusion textures in garnet. Using element maps and

other methods for evaluating garnet and inclusion textures and compositions, we discuss these interpretations and implications.