PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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KECK GEOLOGY CONSORTIUM
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Keck Geology Consortium: Projects 2014-2015
Short Contributions— Tectonics of the Ruby Range, MT Project

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MONAZITE OCCURRENCE IN GARNET BEARING SCHIST AND GNEISS FROM THE RUBY RANGE, SOUTHWEST MONTANA

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INTRODUCTION

The ages of monazite compositional zones are established relative to garnet growth and consumption, melt related reactions, and fabric formation in a migmatitic schist from the Christensen Ranch Metamorphic suite (AM-9a) and a garnet bearing mylonitic leucogneiss from the Dillon Gneiss suite (AM-1b) in the Ruby Range of southwest Montana (Fig 1). Correlations are established based on well-known controls on compositional zoning and grain shape in monazite. For a particular bulk composition, monazite that grows in the presence of garnet is relatively depleted in yttrium compared to monazite that grows in the absence of garnet (Zhu and O'Nions, 1999). The zoning of thorium and uranium in monazite is typically controlled by melt producing reactions; monazite that grows in the presence of melt has an elevated Th/U ratio relative to monazite produced before melting and to monazite produced after melt has left the chemical system (Bea & Monterro, 1999). Euhedral monazite grains typically have a "football" shaped habit. Grains that are elongate may have either: 1) been deformed (pre-kinematic grains), 2) grown during deformation (syn-kinematic grains), or 3) grown constrained by surrounding minerals defining a fabric (late syn-kinematic to post-kinematic grains) (Williams et al., 2007).

METHODS

Rock samples were collected during the summer of 2014. At each location care was taken to collect un-weathered rock and to collect samples containing the greatest number of phases. Petrographic observations were made at the outcrop, using slabs,

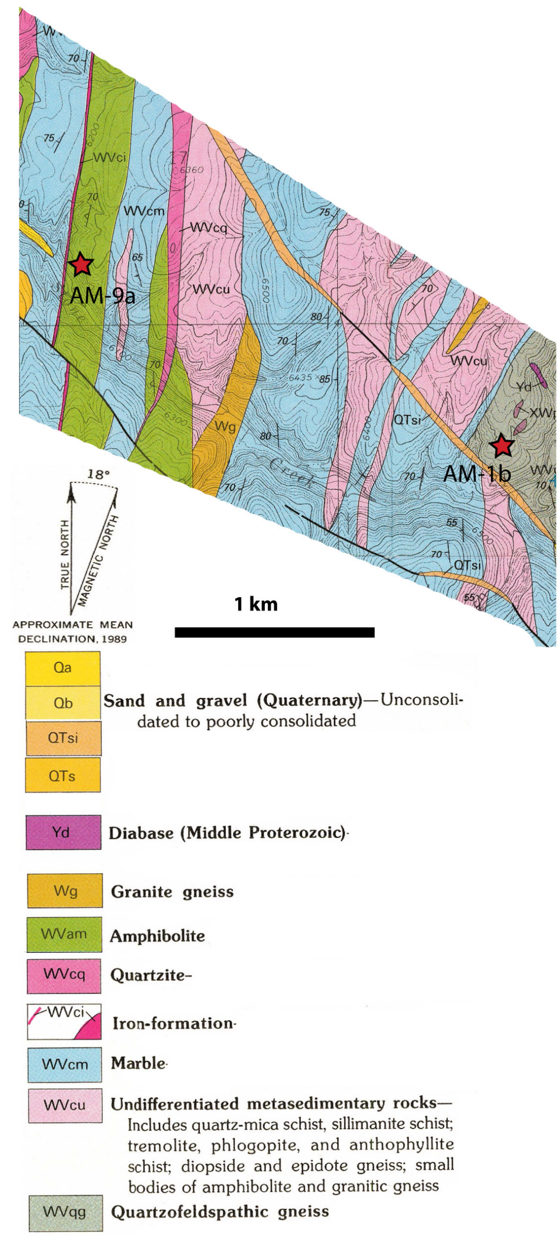

Figure 1. Map of sample locations. Geologic map is of area surrounding Stone Creek Road in the northern Ruby Range. Adapted from James (1990).

on a petrographic microscope, using 400 dpi scans of thin sections, using billets stained by sodium cobaltinitrate to distinguish feldspars, and using the full thin section mapping feature of the Aztec software suite connected to the scanning electron microscope with a backscatter electron detector at Amherst College. Once general petrography had been conducted, thin sections of each sample were taken to the Ultrachron Lab at the University of Massachusetts, Amherst, where they were carbon coated, full thin section electron microprobe (Cameca SX50) maps were made (30 micron pixels, 25 milliseconds dwell per pixel) and individual EMPA monazite grain maps were made (0.5 micron pixels, 80-100 milliseconds dwell per pixel). For both types of mapping the charge difference between the cathode and anode was 15kv. The intensity of the current hitting the sample was 300 nanoamps for full section mapping and 200 nanoamps for grain mapping.

CHRISTENSEN RANCH MIGMATITIC SCHIST

Results

The study sample was collected from a migmatitic schist in the Christensen Ranch Metamorphic suite, whose mineral assemblage is consistent with a pelitic protolith: 34% quartz, 24% feldspar (plagioclase with very limited alkali feldspar), 18% biotite, 10% garnet, 4% sillimanite, considerable tourmaline and apatite, as well as trace rutile, ilmenite, retrograde chlorite and muscovite, zircon, monazite, and extremely limited xenotime. The schist has three end-member domains. Most of the rock is made up of a matrix of quartz, feldspar, fine-grained biotite, and tourmaline. Layers of leucosome made up of quartz and sillimanite are up to 1 cm thick and 20 cm long and make up approximately 20% of the rock volume. Layers of coarse biotite, and limited feldspar, quartz, and sillimanite make up less than 10% of the rock volume.

Garnet cores are inclusion rich and garnet rims have limited inclusions. Garnet core inclusions are dominantly quartz, plagioclase, and opaques and in one case sillimanite. Garnet rim inclusions are ilmenite and opaques. Garnet core inclusions are finer grained than the matrix and are oriented differently from rim inclusions, both of which are typically oriented differently from the fabric in the surrounding matrix. Garnets are fractured in a consistent direction that is parallel to the inclusion trails of some garnet cores.

The overwhelming majority of monazite grains occur in the matrix in one of the two types of biotite bearing layers (Fig. 2). Some grains occur as inclusions in garnet, but very few occur within the leucosome.

In the study sample, 15 grains included in garnet cores, garnet rims, sillimanite, biotite, quartz, and plagioclase were mapped (Fig 2). Grains mapped are in biotite bearing layers as well as in the leucosome. The uranium maps of grains m9 and m15 are difficult to interpret because those grains are included in biotite, whose potassium peak interferes with the uranium peak. The yttrium map of one euhedral grain (m8) preserves four discrete zones of differing Y concentration (Fig. 3). From core to rim, these zones are low Y (henceforth Y1), high Y (Y2), medium Y (Y3), and a partial very high Y rim (Y4). Two grains (m7, m8) preserve from core to rim, low Y, high Y, and medium Y zones. Two other grains preserve partial very high Y rims. The remaining grains preserve either two or no discrete Y compositional zones.

Discussion

The most parsimonious explanation of Y zoning is that many grains (m1, m5, m7, m8, m9, m11, m13, and m15) preserve the same four yttrium domains in order: low (Y1), high (Y2), medium (Y3), ultra-high (Y4) (Fig. 2, Fig. 3). It is possible that some correlations across domains are incorrect and that there are actually more than 4 domains preserved in these grains, but there is no basis on which to distinguish greater than four domains given the available information. Obtaining spot ages within observed Y domains can test, within instrument precision, all Y domain correspondences.

This Y zoning in monazites implies two episodes of garnet growth and breakdown. Garnet growth occurred before or during the growth of the low Y domain (Y1); garnet consumption occurred during the growth of the high Y domain (Y2); garnet growth occurred before or during the growth of the medium Y domain (Y3); garnet consumption occurred during the growth of the very high Y domain (Y4) (Fig 4).

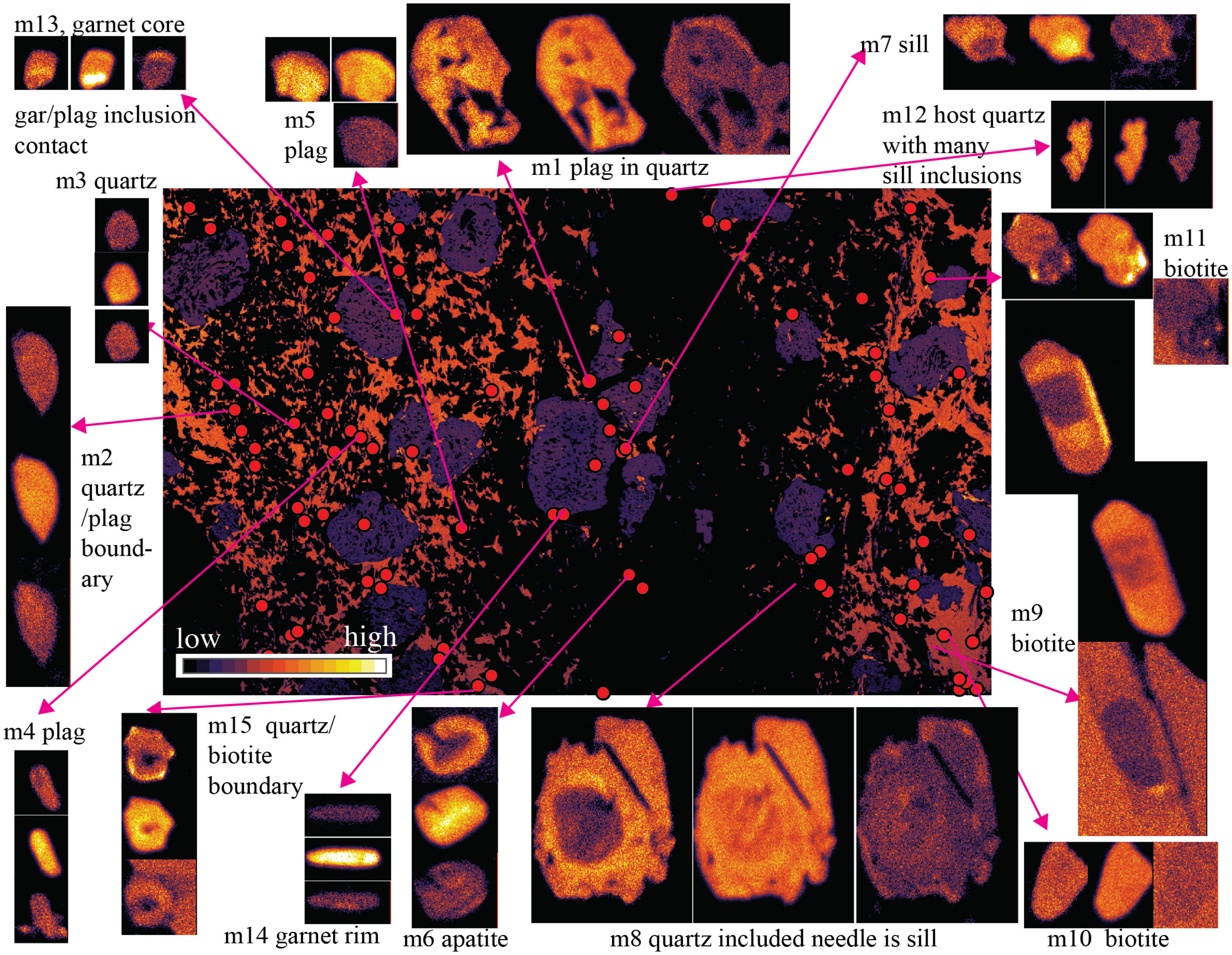

Figure 2. Christensen Ranch migmatitic metapelite (AM-9a). Mg thin section map and monazite grain maps. Color scale applies to all element maps. In Mg map, orange = biotite, purple = garnet. Red dots are locations of 86 brightest Ce hotspots. Grain maps are arranged right to left, top to bottom: Y, Th, U. Mineral in which grain is included is listed after the grain name (m#). Orientation of the thin section is the same as the orientation of the grains.

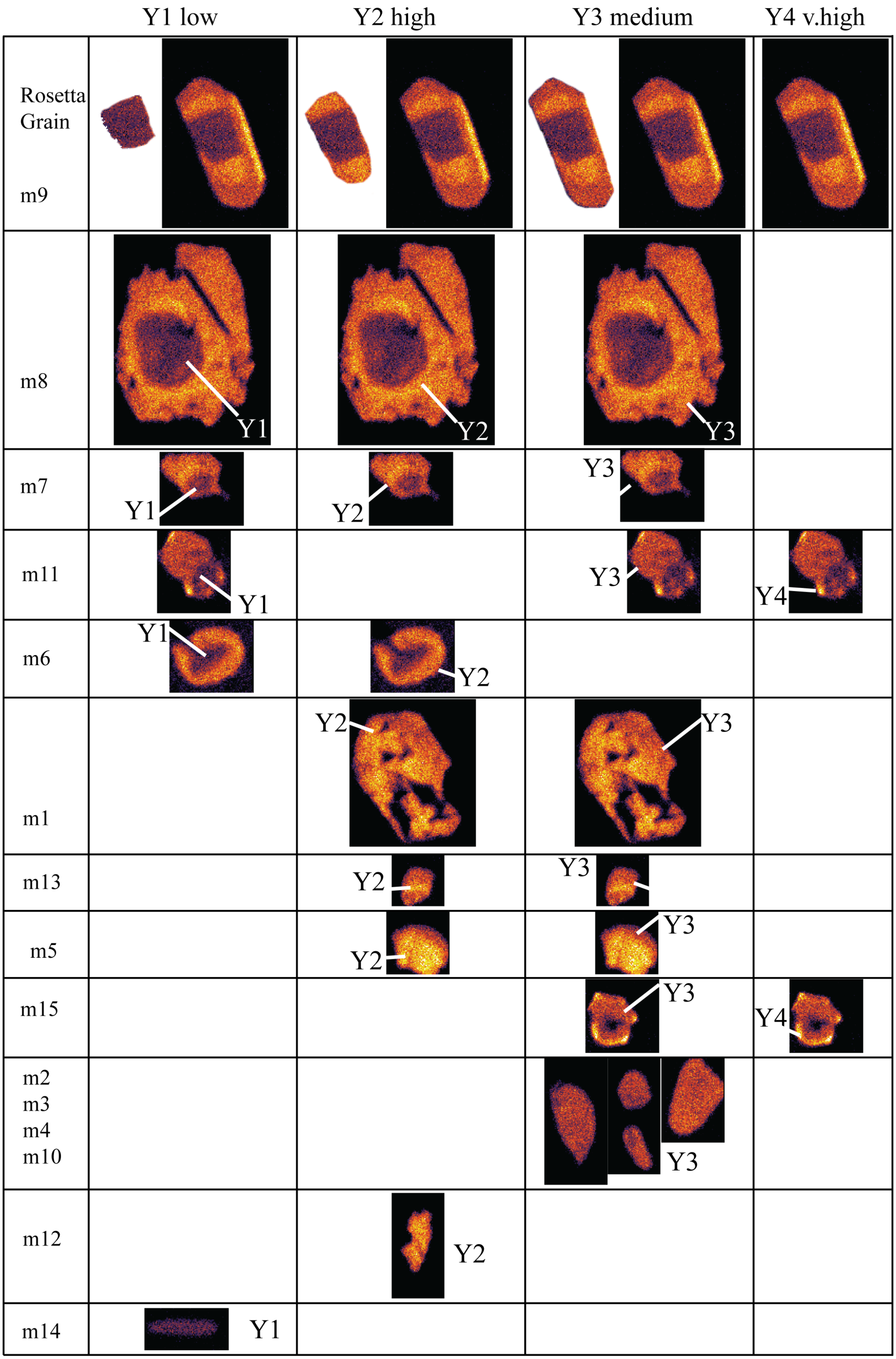

Figure 3. Table of Y domain correspondences (AM-9a).

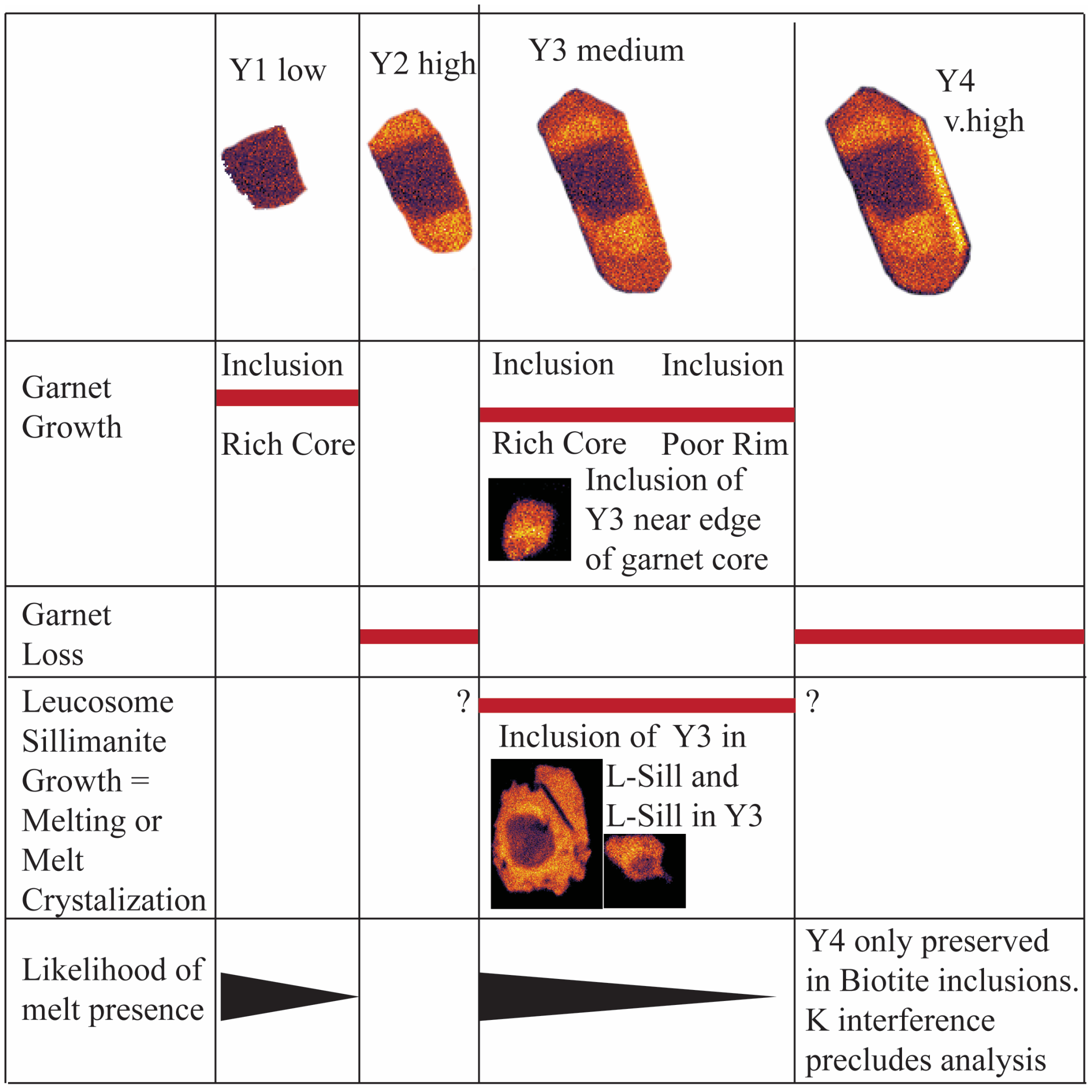

Figure 4. Interpretation of correlations between monazite growth domains and fabric formation in the Christensen Ranch Metamorphic suite migmatitic schist (AM-9a). Question marks indicate that it is unknown if the specified reaction extends into adjacent time period.

The inclusion of one grain (m13) in garnet informs the relative ages of Y domains and garnet zones. Grain m13 grew during one episode of garnet breakdown and the start of a second episode of garnet growth (Y2 and Y3). Because m13 is included near the outer edge of the plagioclase-quartz inclusion rich core of a garnet, the first episode of garnet breakdown preceded the formation of the core-rim boundary.

The Y zoning of two other grains (m6 and m11) can be relatively easily integrated with the four established Y domains. The two grains have a low Y domain partially surrounded by an outer medium Y domain. These may be correlated with Y1 and Y3. Since Y2 is a small domain in the grains that preserve it, it is possible that the two grains simply did not grow under Y2 conditions.

Many grains (m2, m3, m4, m10, and m14) do not have any yttrium zoning. One grain (m14) that occurs as a near-rim inclusion in garnet is entirely low Y. The other Y-homogenous grains are entirely medium Y, are all smaller than 40 microns in the longest direction, and are included in matrix minerals. It is likely that these grains only preserve domain Y3, and it is unlikely that they were homogenized during ongoing metamorphism (Cherniak et al., 2000; Gardes et al., 2006).

Thorium zoning in monazite can be useful in establishing the timing of melt production, crystallization, and loss. In some grains (m6, m7, and m14) thorium zoning is similar to Y zoning, such that Y1 is a high thorium domain. This suggests that Y1 grew in the presence of both garnet and melt. Yet in other grains (m8, m9, and m11) Y1 is not particularly high thorium. This difference can be explained by the distance of monazite grains from leucosome: Y1 grew at a time when melt was present, but only grains near the leucosome extracted thorium from the melt. In a few grains, (m5, m11, and m13) part of Y3 is high Thorium. Melt may have been present during the growth of Y3 as well.

In many grains, (m1, m5, m6, m7, m8, m13, and m14) some of the rim has elevated uranium content. In all but one (m14) this high U rim occurs within the Y3 zone of the grain. In m14, the high U rim is part of Y1.

Timing the growth of sillimanite found in leucosome layers can be constrained by inclusion relationships. The inclusion of a monazite grain with Y3 (m7) in a leucosome sillimanite implies that some leucosome sillimanite continued to grow after Y3 monazite growth had begun. The inclusion of a leucosome sillimanite in Y3 (m8) means that some leucosome sillimanite grew before Y3 had begun to form. These two constrains imply that leucosome sillimanite formed at least partly during Y3. This in turn suggests that either melting or melt precipitation occurred during Y3. Textural observations provide no timing constraints on the growth of sillimanite found outside of the leucosome.

DILLON GNEISS MYLONITIC GARNET LEUCOGNEISS

Results

The study sample was collected from a mylonitic garnet leucogneiss with foliated and lineated quartz ribbons (Fig 5.). The rock has no distinct compositional bands. The rock is made up of 64% alkali feldspar, 28% quartz, 5% garnet, 2% An33 plagioclase, and also includes trace muscovite. Alkali feldspar occurs as matrix grains and as augen; matrix grains occur as both microcline and perthite but augen occur exclusively as perthite. This assemblage is consistent with an alkali feldspar granite protolith.

Quartz occurs in ribbons that range from 0.2 to 1 mm high (typically 1 grain) and from 2 mm up to 12 cm long (many grains) (Fig. 5). There are neither undulose extinction nor subgrains in at least 90% of quartz ribbons. The orientations of subgrains and undulose extinction where present are not systematic.

In the thin section of sample AM-1b, there is a single large grain (400 micron diameter) of monazite and about a dozen smaller grains (up to 20 microns in diameter) of monazite. Of the dozen smaller grains several are partially altered to allanite and therefore cannot be dated. Three of the small grains and the single large grain were mapped. Figure 5 shows the Y and Th grain maps of one of the small grains, grain 1b-m3, which is elongate in the same direction as the fabric defined by quartz ribbons and is included in a grain of alkali feldspar (Fig. 5).

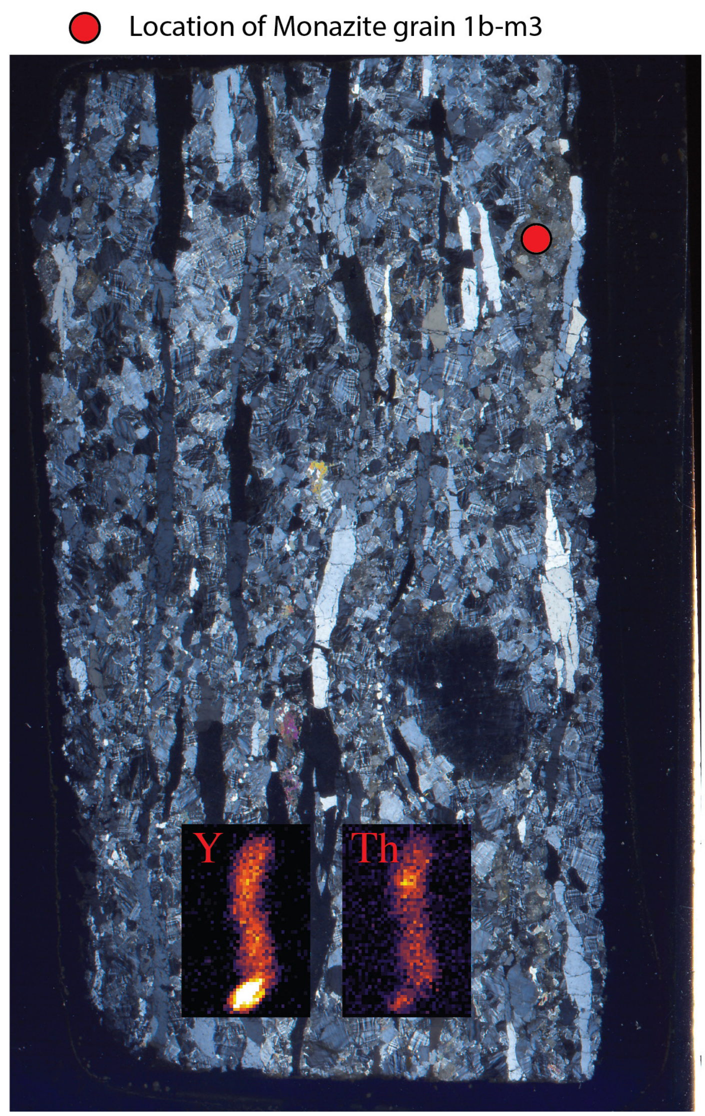

Figure 5. Dillon Gneiss mylonitic garnet leucogneiss (AM 1B). Cross-polarized thin section scan and monazite grain maps. Red dot shows location of grain. Left map is yttrium, right map is thorium.

Discussion

Grain 1b-m3 likely grew during deformation. Prekinematic growth and synkinematic deformation of the grain is unlikely because the rock appears to have deformed predominantly through the dynamic recrystallization of quartz into ribbons. Further, post-kinematic elongate monazite is typically a feature of rocks where monazite grows surrounded by foliated minerals (Williams et al., 2007). Grains of alkali feldspar in no particular orientation surround 1b-m3. An age obtained on this grain would therefore refer to a time at which deformation was occurring in the mylonitic garnet leucogneiss.

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