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Research Advisor: John B. Brady

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INVESTIGATING THE TIMING OF MELT-PRODUCING HIGH GRADE METAMORPHISM IN THE RUBY RANGE, SOUTHWESTERN MONTANA THROUGH ZIRCON U-PB GEOCHRONOLOGY

MARIAH ARMENTA, University of Arizona
Research Advisor: George Gehrels

INTRODUCTION

The Montana Metasedimentary terrane of southwestern Montana is one of three regions that comprise the Wyoming province (Mogk et al., 1992; Mueller et al., 1993). The Ruby Range, a basement-cored Laramide uplift exposing the Montana Metasedimentary terrane, is located to the east of Dillon, Montana. The Pre-Cherry Creek suite, Dillon Gneiss, and Christensen Ranch metasedimentary suite are three northeast-southwest trending Precambrian lithotectonic units that comprise the Precambrian basement of the Ruby Range (James, 1990). Past studies suggest that two regional metamorphic events affected this terrane at ~2.45 Ga and ~1.78 Ga (Cheney et al., 2004; Erslev and Sutter, 1990; James and Hedge, 1980; Jones, 2008; Mueller et al., 2004; Roberts et al., 2002). The Big Sky orogeny is the name given to the Proterozoic regional thermotectonic event constrained to be between 1.78 and 1.72 Ga (Cheney et al., 2004; Mueller et al., 2004; Brady et al., 2004). Previous zircon geochronology studies indicate a mean $^{207}Pb/^{206}Pb$ age of ~1.76 Ga for the Big Sky orogeny in the Ruby Range (Alcock and Muller, 2012). Over the last few decades, relatively few zircon U-Pb ages have been obtained in the Ruby Range, which provides the motivation for this study.

The objective of this project is to determine the timing of peak metamorphism as represented by partial melt in metamorphic rocks and by leucocratic meta-igneous rocks using Laser Ablation-Multicollector-Inductively Coupled Plasma-Mass Spectrometry (LA-ICPMS) for zircon U-Pb geochronology. This study presents $^{207}Pb/^{206}Pb$ ages from five samples collected from the Pre-Cherry Creek, Dillon Gneiss, and Christensen Ranch metasedimentary suites. Samples collected and analyzed were neosome and mylonitic garnet leucogneiss. Placing constraints on the timing of crystallization and metamorphism in the Ruby Range will provide an enhanced understanding of the relationship between the three lithotectonic suites and their histories. Furthermore, this study will provide a more detailed description and understanding of the geological history of the Ruby Range and its role in the tectonic evolution of the Wyoming province.

METHODS

For the purpose of this study, five samples were analyzed for U-Pb geochronology. Analyzed samples include a neosome from an amphibolite (14-MA-03) from the Pre-Cherry Creek suite. From the Dillon Gneiss, neosome from a metapelite (14-MA-06) and mylonitic garnet leucogneiss (14-MA-11) were collected. In the Christensen Ranch metasedimentary suite, neosome from a metapelite (14-MA-12) and a second mylonitic garnet leucogneiss (14-MA-15) were obtained. Zircons were separated using traditional separation techniques (Gehrels et al., 2008). Zircons that were the most clear in color and the largest in size were selected from each sample. Also, zircons chosen from each sample best represent the zircons that were extracted from the sample. Approximately fifty zircons were chosen from four of the five samples; the fifth sample (14-MA-12) had a poor yield resulting in only four zircons obtained. Backscattered electron (BSE) and cathodoluminescence (CL) images were acquired from the Scanning Electron Microscope (SEM) lab at the Arizona LaserChron Center. BSE imaging of the zircons was essential for locating potential spots for laser ablation. For these samples, CL imaging was helpful because it shows the variety of internal structures present in the grains. Analyses were acquired using Laser Ablation-Multicollector-Inductively Coupled Plasma-Mass Spectrometry (LA-ICPMS) at the Arizona LaserChron Center located at the University of Arizona in Tucson, Arizona. From the five samples, a total of 457 new U-Pb analyses were obtained. On average, 111 spots were analyzed from each sample, with the exception of sample 14-MA-12. On average (with the exception of sample 14-MA-12) about 2-4 spots per zircon grain were analyzed. More spots were analyzed on large zircon grains with multiple zones. BSE and CL images were used to select representative spots for each distinct zone where present.

For the purposes of this study, $^{207}Pb/^{206}Pb$ ages are reported because $^{207}Pb/^{206}Pb$ ages are more accurate for systems with zircons greater than 1.2 Ga; Pb loss in older systems is common, and $^{207}Pb/^{206}Pb$ ages are less effected by Pb loss (Gehrels et al., 2008). Due to the complex metamorphic history of the Ruby Range it is essential to assess the U/Th ratios from zircon U-Pb analyses because it may be used to determine metamorphic zircon growth. Zircons with high U/Th ratios may be indicative of the presence of metamorphic fluids in a system during the crystallization of zircons (Harley et al., 2007; Hoskin and Schaltegger, 2003; Rubatto, 2002; Rubatto et al., 2001; Williams, 2001).

SAMPLE DESCRIPTIONS

Sample 14-MA-03

Garnetiferous neosome from part of a Pre-Cherry Creek amphibolite consists of garnet, plagioclase, biotite, and quartz. The neosome formed within the amphibolite. This sample was selected to constrain the timing of maximum metamorphic temperature in the Pre-Cherry Creek suite.

Sample 14-MA-11

Mylonitic garnet leucogneiss (MGL) in the Dillon Gneiss is dominated by potassium feldspar, plagioclase, quartz, and garnet. Foliation of elongated quartz grains and garnet-rich bands can be seen in hand sample and at the outcrop level. This sample was chosen to determine its intrusive age and to determine if all MGL in the Ruby Range is coeval.

Sample 14-MA-06

Neosome sampled from a metapelite located in the Dillon Gneiss is composed of quartz, potassium feldspar, plagioclase, sillimanite, garnet, biotite, and amphibole. The layers of paleosome are distinguishable from the neosome layers; sillimanite is not evenly distributed in the neosome layers. Neosome from this area in the Dillon Gneiss was selected to determine and constrain the timing of metamorphic events in this area of the Ruby Range.

Sample 14-MA-15

Mylonitic garnet leucogneiss (MGL) located in the Christensen Ranch metasedimentary suite is composed of garnet, quartz, and feldspar. Along strike, samples were collected from four different places. This sample was chosen to date the intrusive age of the mylonitic garnet leucogneiss and to constrain the maximum age of metamorphism.

Sample 14-MA-12

Structurally at the top of the Christensen Ranch metasedimentary suite, neosome from a metapelite is composed of quartz, feldspar, garnet, amphibole, and biotite. Some parts in the neosome contain larger quartz grains relative to other quartz grains in the sample; garnets are rusted and very few still have bright coloring. This sample was selected to constrain the timing of maximum temperature of metamorphism and to compare to other neosome samples from the Ruby Range.

RESULTS

There is evidence for Pb loss in each sample analyzed in the Ruby Range because ages are discordant with respect to concordia; upper intercepts lie between ~2.68- 2.39 Ga and lower intercepts between the Mesozoic and Cenozoic. A discordance filter was applied that removed analyses greater than 20% discordant and 5% reverse discordant (by comparison of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages). The following results and discussion are based on the retained analyses.

In the Pre-Cherry Creek suite along Cottonwood Creek Road, neosome from an amphibolite (sample 14-MA-03) was collected and analyzed. There are three distinct $^{207}Pb/^{206}Pb$ age peaks from this sample: 2.74 Ga, 2.4 Ga, and 1.76 Ga. There are a distinguishable number of high U/Th values at spots with ages between ~2.4 Ga and ~1.71 Ga; while the 2.7 Ga age group contains relatively low ratios of U/Th. Backscattered Electron (BSE) images of many of the zircons reveal cores that yield ~2.7 Ga ages, and metamorphic rims that yield ~2.4 Ga ages (Fig. 1). There is a mixture of high and low U/Th values around the 2.5 Ga age value.

A mylonitic garnet leucogneiss from the Dillon Gneiss unit (sample 14-MA-11) was collected and analyzed, and resulted in $^{207}Pb/^{206}Pb$ age populations of 2.71 Ga, 2.57 Ga, and 2.44 Ga. Zircons contain relatively high U/Th for the 2.7 Ga spots. In addition, there is a mixture of low and high U/Th for age spots of 2.7 to 2.5 Ga and high U/Th around the 2.4 Ga age spots. The BSE image (Fig. 2) of a few grains from sample 14-MA-11 shows the complexity and variety of the zircons. Neosome from a pelitic gneiss within the Dillon Gneiss unit (sample 14-MA-06) yielded a dominant $^{207}Pb/^{206}Pb$ age of 2.44 Ga. There is a mixture of low and high U/Th ratio values around the 2.4 Ga spot ages. There are low U/Th values for ages ~2.6 Ga to ~2.3 Ga. The BSE image displays many of these zircon grains that resulted with ~2.4 Ga ages with a few scattered ages betwen ~2.57 Ga and ~1.77 Ga (Fig. 3).

Along Stone Creek Road in the Christensen Ranch metasedimentary suite, two different rock samples were collected: mylonitic garnet leucogneiss and neosome from a metapelite. The mylonitic garnet leucogneiss (14-MA-15) generated three distinctive

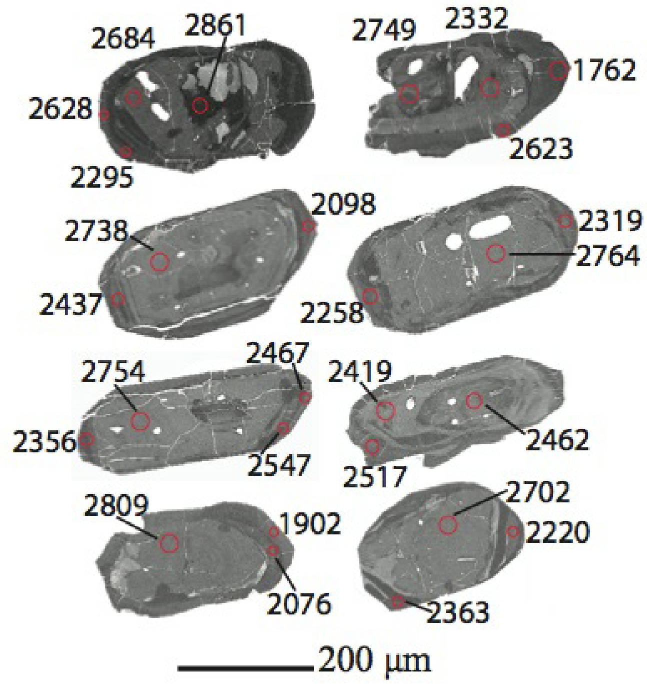

Figure 1. BSE image of a few representative grains from sample 14-MA-03, neosome from an amphibolite in the Pre-Cherry Creek suite, showing the complexity of the zircons. The cores from many of these grains yield ~2.7 Ga ages while many of the rim ages are ~2.45 Ga. Other minor age groups consist of ages ~2.68 Ga, ~2.32 Ga, ~2.25 Ga, and ~1.76 Ga.

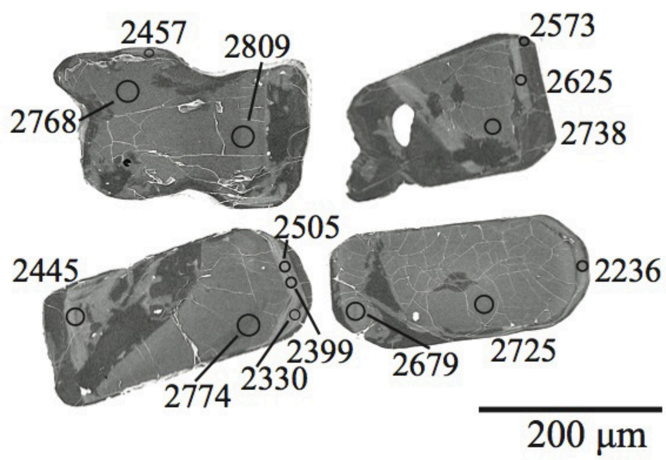

Figure 2. BSE image of a few representative grains from sample 14-MA-11, a mylonitic garnet leucogneiss in the Dillon Gneiss suite, showing the complexity and variety of the zircons. The cores from many of these grains give ~2.7 Ga ages; many of the rim ages are ~2.45 Ga; there is a smaller age population that consists of ages of ~ 2.56 Ga. The grain in the lower left corner has an age of 2.44 Ga and in this region of the zircon there is convoluted zoning.

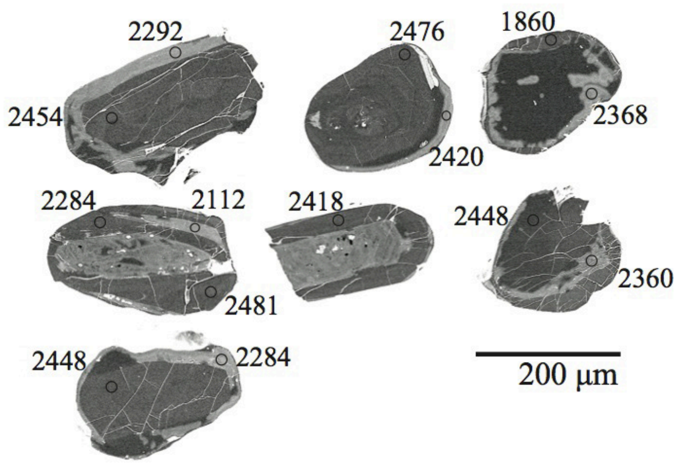

Figure 3. BSE image of a few representative grains from sample 14-MA-06, neosome from a pelitic gneiss in the Dillon Gneiss suite, showing the complexity and variety of the zircons. The ages from many of these grains are ~2.4 Ga with a few scattered ages betwen ~2.57 Ga and ~1.77 Ga.

$^{207}Pb/^{206}Pb$ ages: 2.71 Ga, 2.42 Ga, and 2.19 Ga; with the 2.71 Ga signature being most abundant. All three age groups record spots with high U/Th ratios. Neosome from the metapelite (sample 14-MA-12) yielded few zircons. The most distinct $^{207}Pb/^{206}Pb$ age for this sample was 2.41 Ga; there are high U/Th ratios for this age group. The CL images of zircons from this sample and sample 14-MA-15 show convoluted zoning (Fig. 4) (Hoskin and Black, 2000).

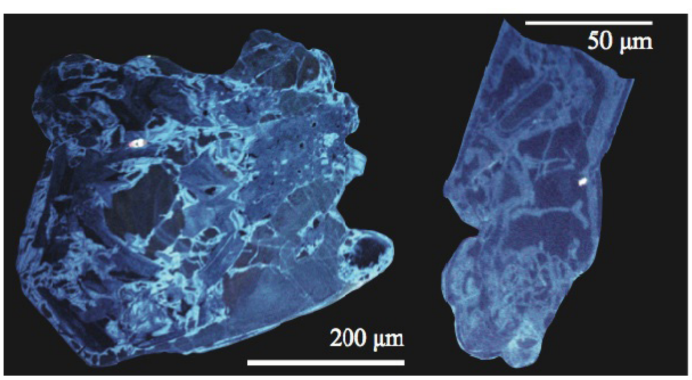

Figure 4. CL image of a zircon from 14-MA-15 (left, mylonitic garnet leucogneiss) and 14-MA-12 (right, neosome from a metapelite) from the Christensen Ranch suite show convoluted zoning which results from the presence of metamorphic fluids during zircon growth. Regions in the zircons with this metamorphic texture (convoluted zonation) yielded ages of ~2.4 Ga.

DISCUSSION

Zircon grains from all five analyzed samples from the Ruby Range experienced significant Pb loss during the Mesozoic- Cenozoic. Hot fluids, typically between 300-400 degrees C, present in a rock system result in Pb loss in zircons (Gehrels, 2014). One possible explanation is that there may have been a thermotectonic event between the Mesozoic and Cenozoic that introduced a significant amount of hot fluid and affected the zircons from all three suites in the Ruby Range. The results from this study are similar to a study that reported a significant amount of Pb loss during the Cenozoic (~48 Ma) from detrital zircons from the Bighorn Basin in Wyoming that may have resulted from a hydrothermal fluid event (May et al., 2013). Zircons from the Ruby Range and the Bighorn Basin experienced a significant amount of Pb loss indicating a possible wide regional event that introduced hydrothermal fluids into the separate systems.

BSE and CL imaging of the zircons from the Ruby Range document the presence of cores with multiple zoned thick overgrowths. Due to the complexity of the zircons from each sample, BSE and CL imaging was essential in determining which spots on the grains to ablate. For sample 14-MA-03, the CL image demonstrates very irregular textures for the zircons (Fig. 5).

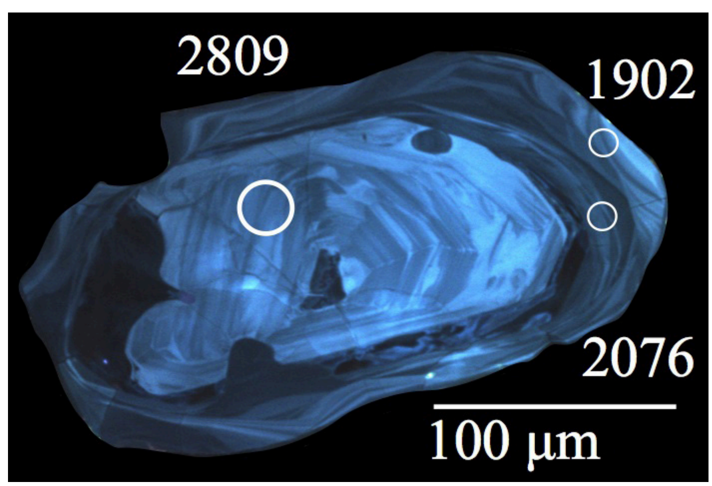

Figure 5. CL image of a zircon from sample 14-MA-03, neosome from an amphibolite in the Pre-Cherry Creek suite, with different zones present. Oscilatory zonation in the core suggests an igneous origin at 2.8 Ga and two rims of 2.07 Ga and 1.9 Ga (this being the most outer rim) suggesting metamorphic overgrowth at those times.

In the Ruby Range, the 2.7 Ga age has been recognized in all three suites. In CL imaging, the zones with this age display oscillatory zonation indicating igneous crystallization of the zircons in a crustal growth event of that age.

In all three suites in the Ruby Range there is a 2.45 Ga age signature present. However the U/Th ratios differ between each suite. The Pre-Cherry Creek suite (structurally the lowest suite), contains both low and high U/Th ratios for ~2.45 Ga. Both samples from the Dillon Gneiss (14-MA-11 and14-MA-06) contain a mixture of low and high U/Th values. In the Christensen Ranch (structually the highest suite) there is an abundance of high U/Th ratios present. One possible intrepretation: the structually lower suites experienced zircon growth from a juvenile intrusive rock source around 2.45 Ga.

Throughout the range the Pre-Cherry Creek, Dillon Gneiss, and Christensen Ranch metasedimentary suites experienced zircon growth during the 2.45 Ga metamorphic event. Many zircons that were affected by the ~2.45 Ga metamorphic event display convoluted zoning; indicative of metamorphic fluids that were present in the system during zircon growth (Gehrels, pers. comm.). Furthermore, this study supports the evidence for metamorphism at ~2450 Ma based on the analyses of zircons extracted from gneisses elsewhere in the range (Jones et al., 2004; Jones, 2008).

In the structurally highest suite, the Christensen Ranch metasedimentary suite, no ages younger than ~2.1 Ga were found. The Dillon Gneiss and Pre-Cherry Creek suites produced few ages of ~2.0 Ga with high U/Th ratios. This age is similar to the age of a metamorphosed mafic dike located in the Tobacco Root Mountains (Mueller et al., 2005). Of the three suites, neosome from an amphibolite (sample 14-MA-03) from the Pre-Cherry Creek suite along Cottonwood Creek Road contained the most zircons with ages ~ 1.76 Ga and high U/Th ratios. Zircon growth in this part of the range was most affected by metamorphism during the Big Sky orogeny (1.78 - 1.72 Ga). Overall, the three lithotectonic suites in the Ruby Range did not experience zircon growth from a juvenile intrusive rock source or partial melt during the Big Sky orogeny because there are no distinctive $^{207}Pb/^{206}Pb$ ages between 1.78 and 1.72 Ga with low U/Th ratios.

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