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

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PETROGRAPHY AND MINERALOGY OF ULTRAMAFIC PODS IN THE RUBY RANGE WITH SPECIAL ATTENTION TO IDENTIFYING ACCESSORY MINERAL PHASES, INCLUDING ZIRCON

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AARON CAVOSIE, Curtin University Australia, University of Puerto Rico-Mayaguez

GEOLOGIC SETTING

The Ruby Range is an uplifted exposure of Archean to Early Proterozoic rocks in southwestern Montana. The Ruby Range and the adjacent ranges such as the Tobacco Root Mountains are part of the larger Montana Metasedimentary subdivision within the Wyoming province, which also includes the Beartooth–Bighorn Magmatic terrane and the Wyoming Greenstone province (Mogk et al., 1992). These ranges represent deep Laramide uplifts in southwestern Montana that have exposed the basement of the Wyoming province. Past studies have identified a previous orogenic event in the Montana

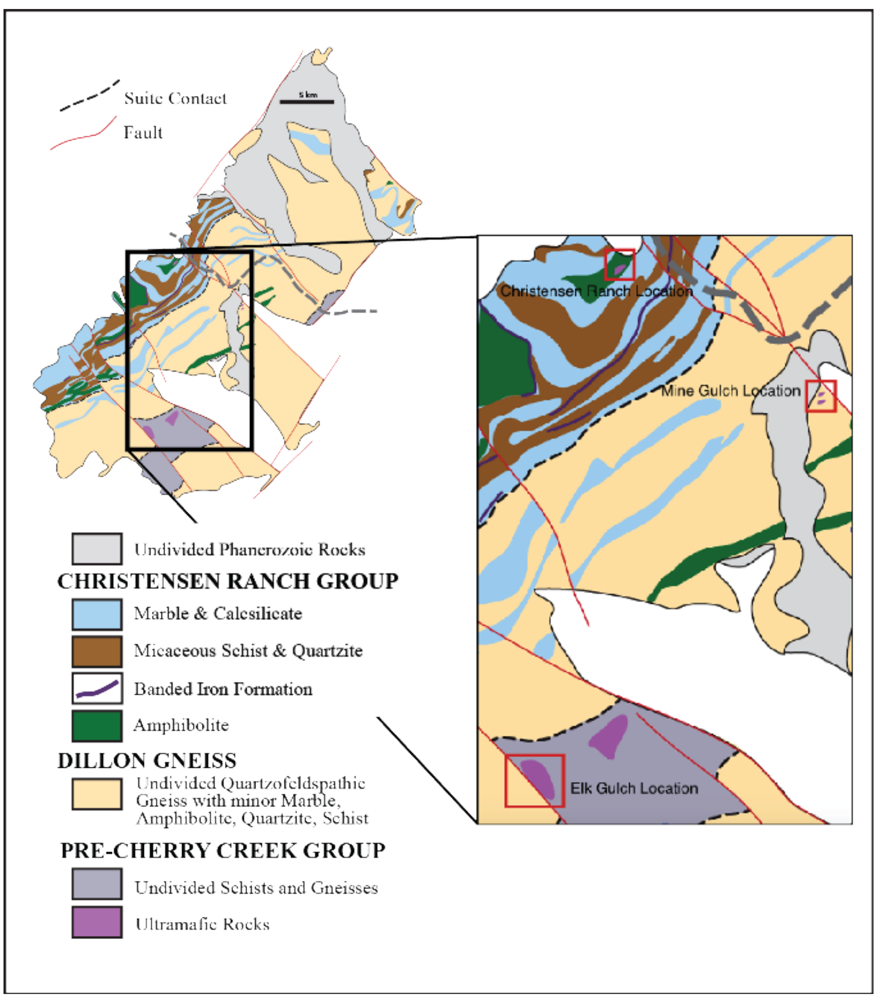

Figure 1. Schematic geologic map of the Ruby Range. Geology taken from Ruppel and others (1993). Enlarged area shows the study locations of this project.

Metasedimentary terrane timed at ≈1.78 Ga in what is known as the Big Sky orogeny (Brady et al., 2004). The Precambrian rocks of the Ruby Range are divided into three principal groups: The Christensen Ranch suite, the Pre-Cherry Creek suite and the Dillon Gneiss (Fig. 1) (James, 2004). Podiform ultramafic rock bodies of varying sizes are found in all of the rock groups of the Ruby Range.

INTRODUCTION

This study focuses on the various exposures of ultramafic rock found disseminated through all of the three rock suites in the Ruby Range. The goals of the project are to provide careful petrographic analysis of the ultramafic rocks, identify the accessory minerals present and provide textural analysis of zircon grains to determine the timing of zircon growth relative to metamorphism. This will help constrain the character and origin of the ultramafic rocks prior to metamorphism, and also inform further geochronology and geochemistry studies of zircons. Several origins of the meta-ultramafic rocks in the Ruby Range and the Tobacco Root Mountains have been proposed. Johnson and others (2004), have compiled the different hypotheses for the origin of the Tobacco Roots Mountains meta-ultramafic rocks:

- Forcibly emplaced hydrous peridotitic magmas.
- Alpine-type ultramafic intrusives.
- Cumulates of a differentiating basaltic magma.
- A sliver of oceanic crust.
- Metamorphosed komatiite lavas or intrusions.

Based on mineral assemblages and geochemical data, Johnson and others (2004) concluded that the protolith of the Tobacco Root Mountains ultramafic rocks was an ultramafic cumulate rich in orthopyroxene, probably formed from a more silica rich basaltic magma. Desmarais (1981) has proposed that the ultramafic rocks of the Ruby Range were tectonically emplaced as serpentinized slivers of mantle prior to being metamorphosed, then reserpentinized to their current state. A more recent study by Alcock and others (2013), proposes that the ultramafic rocks of the Elk Gulch area of the southern Ruby Range were emplaced as high temperature magmas during metamorphism, based on metamorphic conditions in surrounding metapelites.

METHODS

Samples were extracted from several of the ultramafic bodies within all three of the rock suites within the Ruby Range. Samples were taken from the edges and the center of the pods when possible. Foliation measurements were made where foliation was observed. Of these samples, 15 were made into thin sections at the University of Puerto Rico, Mayaguez. The samples were organized into 3 groups, according to geography, which corresponds to rock suites: The Elk Gulch (pre-Cherry Creek suite), Mine Gulch (Dillon Gneiss suite), and Christensen Ranch suites. (Fig. 1) Six additional polished sections were made commercially for Scanning Electron Microscope backscatter electron imaging, cathodoluminescence and Energy Dispersive Spectroscopy analyses. SEM images, cathodoluminescence and EDS analysis were collected at Hewlett Packard in Aguadilla, PR, and at the University of Montana by Julia Baldwin.

RESULTS

Field Observations

Ultramafic bodies of the Ruby Range are pod shaped and elongate parallel to the regional foliation; they range from small (1 to 10 m) to medium (>50 m) bodies, with the largest ultramafic exposure found in the Elk Gulch location. Most ultramafic bodies exhibit some form of foliation along the perimeter of

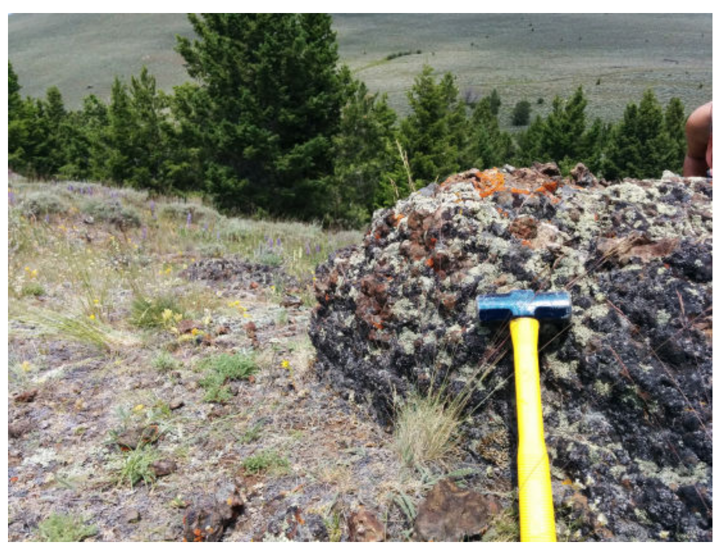

Figure 2. Elk Gulch ultramafic rock outcrop. Orthopyroxene megacrysts in excess of 5 cm are visible. Differential weathering of the rock creates the knobby aspect of the outcrop.

Sample & Location	Olivine	Orthopyroxene	Mg-Hornblende	Magnetite	Spinel	Talc	Apatite	Titanite	Ilmentite	Serpentine	Anthophyllite	Hydrothermal Minerals	Magnetite (Alteration)	Zircon
14-LR-1A (CR)	10%	60%	10%	X	X	X				10%	X		10%	
14-LR-1B (CR)	10%	60%	10%	X	X	X				15%	X		5%	
14-LR-2 (CR)	10%	60%	10%	X	X	X				15%	X		5%	
14-LR-4 (CR)	10%	60%	10%	X	X	X				10%	X		10%	X
14-LR-5 (CR)	10%	60%	10%	X	X	X				10%	X		5%	
14-LR-7A (EG)	15%	70%	15%	X	X	X				X	X		X	
14-LR-7B (EG)	10%	80%	10%	X	X					X	X		X	
14-LR-8A (MG)	5%	75%	20%	X	X		X	X	X	X	X	X	X	X
14-LR-8B (MG)	5%	75%	20%	X	X					X	X	X	X	
14-LR-9 (MG)	10%	75%	15%	X	X		X	X	X	X	X	X	X	X
14-LR-10A (MG)	10%	75%	10%	X	X					X	X	X	X	
14-LR-10B (MG)	10%	75%	10%	X	X					X	X	X	X	
14-LR-11 (CR)	10%	60%	10%	X	X	X				X	X		X	
14-LR-12 (CR)	10%	60%	10%	X	X	X				X	X		X	
14-JB-6 (CR)	10%	60%	10%	X	X	X				X	X		X	

Table 1. Mineralogy and modes of major minerals of analyzed samples from the three sample localities in the Ruby Range. %= Major minerals, X= minor and accessory phases, CR= Christensen Ranch (Christensen Ranch suite), EG= Elk Gulch (Pre-Cherry Creek suite), MG= Mine Gulch (Dillon Gneiss suite).

the pods, wrapping around the pods with weak or no foliation the interior. These qualities create a grain size and rock texture zonation that is visible in most pods (Fig. 2) similar to Desmarais' (1981) observations of texturally zoned podiform bodies with foliations on their exteriors.

Petrography

All of the ultramafic rocks of the Ruby Range in this study show a remarkably similar mineral assemblage of orthopyroxene, forsterite, and magnesio-hornblende (Table 1). Clinopyroxene was not found in any of the samples. Chromium rich spinel with minor magnetite are the main accessory phases. Alteration minerals include serpentine, talc, anthophyllite, and magnetite. Minor and trace minerals include titanite, ilmenite, apatite and zircon. The rocks from Mine Gulch also include appreciable hydrothermal minerals that include pentlandite, nickeline and what may be the REE- rich allanite-type mineral dissakisite (Hoshino et al., 2010).

Textures in the rocks include bladed anthophyllite and magnesio-hornblende partially replacing and overgrowing olivine and orthopyroxene (Fig 3 A). In the Christensen Ranch samples, small, anhedral orthopyroxene grains retain igneous textures in the form of small prismatic spinel grains within them (Fig. 3 D) (Alcock et al., 2013; Couto and Carneiro, 2007). This is in contrast to the larger, rounded spinel in the Mine Gulch samples. In the Mine Gulch location, amphibole does not seem to follow a fabric, but is randomly oriented (Fig 3 C). Orthopyroxene grains in the Mine Gulch location show poikiloblastic texture (Fig. 3 A) with subhedral to euhedral amphibole inclusions. The boundaries of the orthopyroxene megacrysts are commonly sutured. These textures are consistent with static metamorphism (Alcock et al., 2013). Magnetite is found in elongate veins along with serpentine and is preferentially formed in veins cutting though and replacing spinel. These veins are seen crosscutting the metamorphic and preserved igneous textures of the orthopyroxenes and amphiboles, (Fig 3 D) thus are interpreted to have formed after the most recent metamorphic event. Olivine shows mesh replacement textures with serpentine (Fig 3 B). Pentlandite is found as single grains associated with spinel.

Alteration textures observed in the rocks vary depending on location; the rocks from the Christensen Ranch location show pervasive serpentine-magnetite alteration, with large veins parallel to foliation. These veins contain high percentages of magnetite. In contrast, the rocks from Elk Gulch and Mine Gulch show minor serpentine alteration and share similar grain sizes and textures, with megacrystic orthpyroxene grains reaching up to 5 cm in length. (Fig. 2)

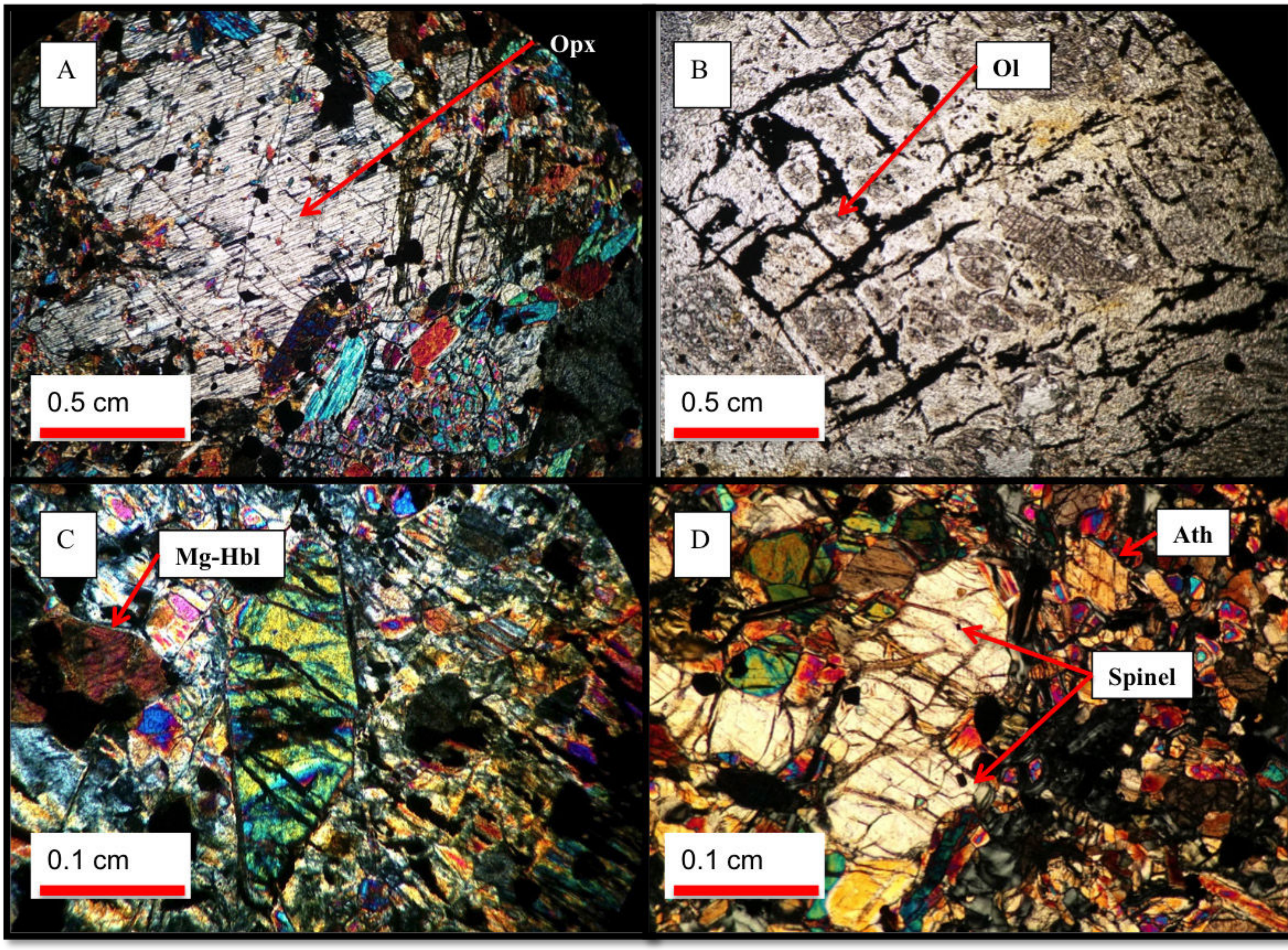

Figure 3. Thin section photomicrographs of ultramafic rocks of the different rock groups of the Ruby Range. (A) (Mine Gulch) Orthopyroxene grain with sutured and poikiloblastic texture. Euhedral amphiboles occur within the grain (cross-polarized light). (B) (Mine Gulch) Olivine mesh alteration texture (plane-polarized light). (C) (Mine Gulch) Orthoamphibole overgrowth (cross-polarized light). (D) (Christensen Ranch) Olivine and orthopyroxene grains with small prismatic spinel grains cross-cut by serpentine (cross-polarized light).

There is some indication of strain found in the minerals, with some orthopyroxene grains showing undulatory extinction. These deformation textures are confined to the Elk Gulch and Mine Gulch locations.

Zircon Morphology and Textures

This is the first report of zircon in Ruby Range ultramafic rocks. An appreciable quantity of zircon was found in all of the samples analyzed in the SEM, with varying degrees of abundances. Rocks with the greatest abundance and largest grain size of zircons are from the Mine Gulch area within the Dillon Gneiss. The majority of the zircons are small (10-20 µm), but some grains reach up to 100 µm in size (Fig 4). Most zircons are found within the Mg-hornblende and the orthopyroxene. Some are found within the serpentinized zones, but are interpreted to have been left over from later alteration processes as the main phase was consumed. The external morphology of the grains in all the analyzed samples ranges from rounded to irregular. The interior zonation of the grains ranges from weak irregular mottled texture to irregular sector zoning (Fig. 4C and D).

DISCUSSION AND CONCLUSIONS

Petrography and Zircon Textures

The notably consistent mineralogy of the meta-ultramafic rocks found through the Ruby Range suggests a common origin for these rocks. The

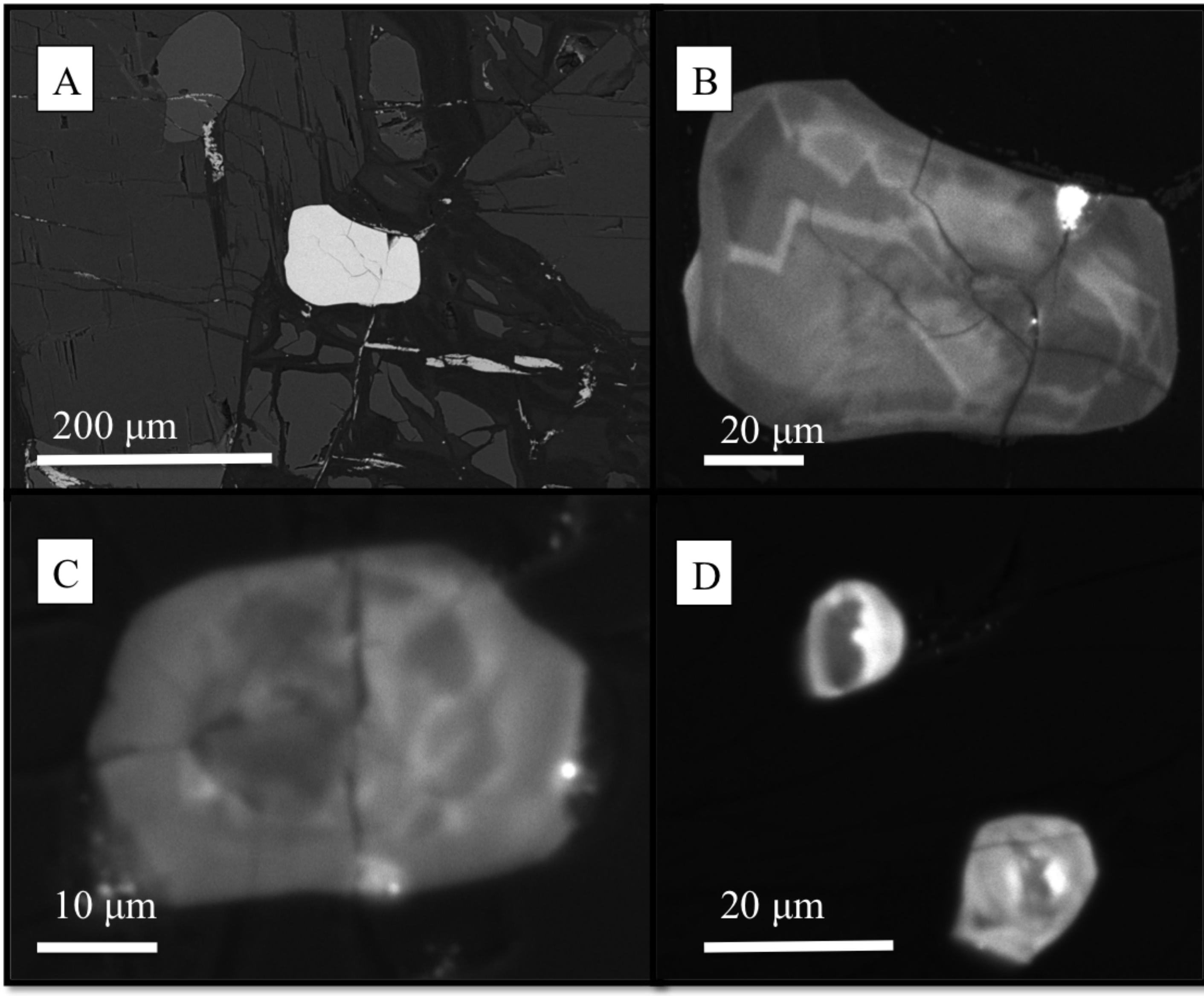

Figure 4. Zircon grains found in the Ruby Range meta-ultramafic rocks. (A) BSE image of a large zircon grain in the Mine Gulch sample 14-LR-9. Grain is located in the serpentine alteration zone. (B) CL image of the same grain shows sector zoning preserved. (C) Small zircon grain within Mg-hornblende in the Mine Gulch sample 14-LR-8. (D) Very small zircon grains in the Christensen Ranch location sample 14-LR-4.

similarity is also shared with the mineralogy of the meta-ultramafic rocks of the Tobacco Root Mountains, where the absence of clinopyroxene and the presence of anthophyllite were important constraints used in reconstructing their metamorphic history (Johnson et al., 2004).

Zircons found in the Ruby Range lack the internal oscillatory zoning characteristic of igneous zircon and also lack clear inherited cores, thus it is interpreted that the zircons did not crystallize in the igneous phase of the rock. The zircons may have metamorphic or hydrothermal origins. The textures found in the zircons such as sector zoning (Fig. 4B), external features such as roundness and petrographic setting are indicative of medium to high-grade metamorphic zircon (Corfu et al., 2003). Geochemical studies of the zircons are needed to conclusively determine the formation of the grains, as the textures of hydrothermal zircons may be similar to metamorphic zircons (Cavosie et al., 2009; Hoskin and Schaltegger, 2003). These studies are needed to confirm the origin of the Ruby Range zircons, as there is evidence of hydrothermal activity in the rocks.

Petrographical and mineralogical observations of these rocks are consistent with recent interpretations of the intrusive, magmatic origin of ultramafic pods found in the Ruby Range and the Tobacco Root Mountains. (Alcock et al., 2013; Johnson et al., 2004) Alcock and others (2013) interpret the ultramafic pods as supplying high temperatures during metamorphism of surrounding metapelites. If correct, this would imply intrusion of the ultramafic rocks during metamorphism. These observations are in contrast to Desmarais's (1981) interpretation of the Ruby Range ultramafic bodies as tectonically emplaced.

The findings of this study will help inform future geochemical studies to further characterize the nature of the protolith of the Ruby Range meta-ultramafic rocks. Special attention should be made to obtain the ages of metamorphic zircon grains.

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