RESILIENCE OF ENDANGERED ACROPORA SP. CORALS IN BELIZE. WHY IS CORAL GARDENS REEF THRIVING?:
Faculty: LISA GREER, Washington & Lee University, HALARD LESCINSKY, Otterbein University, KARL WIRTH, Macalester College
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TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE, SOUTH CENTRAL ALASKA:
Faculty: CAM DAVIDSON, Carleton College, JOHN GARVER Union College
Students: KAITLYN SUAREZ, Union College, WILLIAM GRIMM, Carleton College, RANIER LEMPERT, Amherst College, ELAINE YOUNG, Ohio Wesleyan University, FRANK MOLINEK, Carleton College, EILEEN ALEJOS, Union College

EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SW MONTANA: METASUPRACRUSTAL ROCKS OF THE RUBY RANGE
Faculty: TEKLA HARMS, Amherst College, JULIE BALDWIN, University of Montana
Students: BRIANNA BERG, University of Montana, AMAR MUKUNDA, Amherst College, REBECCA BLAND, Mt. Holyoke College, JACOB HUGHES, Western Kentucky University, LUIS RODRIGUEZ, Universidad de Puerto Rico-Mayaguez, MARIAH ARMENTA, University of Arizona, CLEMENTINE HAMELIN, Smith College

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GEOMORPHOLOGIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA:
Faculty: KELLY MACGREGOR, Macalester College, AMY MYRBO, LabCore, University of Minnesota
Students: ERIC STEPHENS, Macalester College, KARLY CLIPPINGINGER, Beloit College, ASHLEIGH, COVARRUBIAS, California State University-San Bernardino, GRAYSON CARLILE, Whitman College, MADISON ANDRES, Colorado College, EMILY DIENER, Macalester College

ANTARCTIC PLIOCENE AND LOWER PLEISTOCENE (GELASIAN) PALEOClimATE RECONSTRUCTED FROM OCEAN DRILLING PROGRAM WEDDELL SEA CORES:
Faculty: SUZANNE O’CONNELL, Wesleyan University
Students: JAMES HALL, Wesleyan University, CASSANDRE STIRPE, Vassar College, HALI ENGLERT, Macalester College

HOLOCENE CLIMATIC CHANGE AND ACTIVE TECTONICS IN THE PERUVIAN ANDES:
IMPACTS ON GLACIERS AND LAKES:
Faculty: DON RODBELL & DAVID GILLIKIN, Union College
Students: NICHOLAS WEIDHAAS, Union College, ALIA PAYNE, Macalester College, JULIE DANIELS, Northern Illinois University

GEOLOGICAL HAZARDS, CLIMATE CHANGE, AND HUMAN/ECOSYSTEMS RESILIENCE IN THE ISLANDS OF THE FOUR MOUNTAINS, ALASKA
Faculty: KIRSTEN NICOLAYSEN, Whitman College
Students: LYDIA LOOPESKO, Whitman College, ANNE FULTON, Pomona College, THOMAS BARTLETT, Colgate University

CALIBRATING NATURAL BASALTIC LAVA FLOWS WITH LARGE-SCALE LAVA EXPERIMENTS:
Faculty: JEFF KARSON, Syracuse University, RICK HAZLETT, Pomona College
Students: MARY BROMFIELD, Syracuse University, NICHOLAS BROWNE, Pomona College, NELL DAVIS, Williams College, KELSA WARNER, The University of the South, CHRISTOPHER PELLAND, Lafayette College, WILLA ROWEN, Oberlin College

FIRE AND CATASTROPHIC FLOODING, FOURMILE CATCHMENT, FRONT RANGE, COLORADO:
Faculty: DAVID DETHIER, Williams College, WILLIAM B. OUIMET, University of Connecticut, WILLIAM KASTE, The College of William and Mary
Students: GREGORY HARRIS, University of Connecticut, EDWARD ABRAHAMS, The College of William & Mary, CHARLES KAUFMAN, Carleton College, VICTOR MAJOR, Williams College, RACHEL SAMUELS, Washington & Lee University, MANEH KOTIKIAN, Mt. Holyoke College

SOPHOMORE PROJECT: AQUATIC BIOGEOCHEMISTRY: TRACKING POLLUTION IN RIVER SYSTEMS
Faculty: ANOUK VERHEYDEN-GILLIKIN, Union College
Students: CELINA BRIEVA, Mt. Holyoke College, SARA GUTIERREZ, University of California-Berkeley, ALESIA HUNTER, Beloit College, ANNY KELLY SAINVIL, Smith College, LARENZ STOREY, Union College, ANGEL TATE, Oberlin College

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EXPLORING THE PRECAMBRIAN GEOLOGIC EVOLUTION OF THE RUBY RANGE IN SOUTHWEST MONTANA
TEKLA HARMS, Amherst College
JULIE BALDWIN, University of Montana

PETROLOGY, GEOCHEMISTRY, AND THERMOBAROMETRY OF AMPHIBOLITES IN THE RUBY RANGE, SOUTHWEST MONTANA
BRIANNA BERG, University of Montana
Research Advisor: Julie Baldwin

MONAZITE OCCURRENCE IN GARNET BEARING SCHIST AND GNEISS FROM THE RUBY RANGE, SOUTHWEST MONTANA
AMAR MUKUNDA, Amherst College
Research Advisor: Tekla Harms

CALCITE-GRAPHITE STABLE ISOTOPE THERMOMETRY IN MARBLES OF THE RUBY RANGE, SW MONTANA
REBECCA BLAND, Mount Holyoke College
Research Advisor: Steven R. Dunn

GEOTHERMOBAROMETRY AND PETROGRAPHIC INTERPRETATIONS OF CHRISTENSEN RANCH METAMORPHOSED BANDED IRON FORMATION FROM THE RUBY RANGE, MONTANA
JACOB HUGHES, Western Kentucky University
Research Advisor: Dr. Andrew Wulff

PETROGRAPHY AND MINERALOGY OF ULTRAMAFIC PODS IN THE RUBY RANGE WITH SPECIAL ATTENTION TO IDENTIFYING ACCESSORY MINERAL PHASES, INCLUDING ZIRCON
LUIS G. RODRIGUEZ, University of Puerto Rico-Mayaguez
AARON CAVOSIE, Curtin University Australia, University of Puerto Rico-Mayaguez

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

PETROGRAPHY, GEOTHERMOBAROMETRY, AND METAMORPHIC HISTORY OF METAPELITES FROM THE CENTRAL RUBY RANGE, SOUTHWEST MONTANA
CLÉMENTINE HAMELIN, Smith College
Research Advisor: John B. Brady

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

LUIS G. RODRIGUEZ, University of Puerto Rico-Mayaguez
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.
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).

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).

<table>
<thead>
<tr>
<th>Sample &amp; Location</th>
<th>Oliven</th>
<th>Orthopyroxene</th>
<th>Mg-Hornblende</th>
<th>Magnetite</th>
<th>Spinel</th>
<th>Talc</th>
<th>Apatite</th>
<th>Titanite</th>
<th>Ilmenite</th>
<th>Serpentine</th>
<th>Anthophyllite</th>
<th>Hydrothermal Minerals</th>
<th>Magnetite (Alteration)</th>
<th>Zircon</th>
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<tr>
<td>14-LR-1A (CR)</td>
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<td>14-LR-1B (CR)</td>
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<td>14-LR-2 (CR)</td>
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<td>14-LR-4 (CR)</td>
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<td>14-LR-7A (EG)</td>
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<td>14-LR-8A (MG)</td>
<td>5%</td>
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<td>14-LR-8B (MG)</td>
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<td>14-LR-10A (MG)</td>
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<td>14-LR-12 (CR)</td>
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<td>14-JB-6 (CR)</td>
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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 through 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 orthopyroxene grains reaching up to 5 cm in length. (Fig. 2)
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
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.

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.
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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REFERENCES


