U/Pb Zircon Ages of Felsic Veins in the Sawtooth Metamorphic Complex, Idaho, U.S.A: Implications for Magmatism and Vein Source

Kyle Tollefson
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U/PB ZIRCON AGES OF FELSIC VEINS IN THE SAWTOOTH METAMORPHIC COMPLEX, IDAHO, U.S.A: IMPLICATIONS FOR MAGMATISM AND VEIN SOURCE

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science

in

The Department of Geology and Geophysics

by

Kyle Tollefson
B.S., University of Wisconsin – Eau Claire, 2017
December 2020
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ABSTRACT

Veins associated with igneous activity provide numerous insights into the geologic history of an area. The Sawtooth Metamorphic Complex (SMC) in Idaho is a roof pendant of high-grade rocks cross-cut by numerous felsic veins of unknown age and source. Obtaining U/Pb zircon geochronology of these veins can facilitate understanding the ages of magmatism in the region, their source, when nearby batholiths were juxtaposed to the SMC, and provide additional insights into the geologic evolution of the area. Each potential source of these veins has a distinct age: the Sawtooth batholith (ca. 47 Ma), the Idaho batholith (98-53 Ma), an anatectic melt associated with aluminous gneisses in the complex (>100 Ma), an undefined later melting and/or hydrothermal event (<43 Ma), or a combination of these. In each of these potential sources, plagioclase optical cathodoluminescence (OM-CL) responses are obtained to determine any correlation with vein source and as an alternative proxy to ages.

U/Pb ages of zircons were obtained for six vein samples spatially separated around the SMC. The ages range from 72.3 ± 1.2 Ma to 131.0 ± 2.2 Ma. Two samples contained zircons with inherited cores, with ages ranging from 317 ± 7 Ma to 1803 ± 55 Ma. Vein emplacement ages, determined by youngest ages, range from 75.5 ± 0.6 Ma to 101 ± 1 Ma. Zircon formation ages indicate an extended period of magmatism occurred episodically for at least 49 Ma. Inherited core ages indicate incorporation of rocks containing Proterozoic and Ordovician-aged zircons. Vein emplacement ages are consistent with the Idaho batholith time frame suggesting the SMC was juxtaposed to the Idaho batholith before vein emplacement.

Evaluation of OM-CL responses show that green plagioclase CL responses are characteristic of the Idaho batholith. Green is observed in ten of thirteen samples. This suggests that age and plagioclase CL color correlate for the Idaho batholith. This correlation suggests that OM-CL
plagioclase responses may be a useful proxy for source in the absence of geochronology. This study contributes new U/Pb zircon age data in a region that is poorly understood.
CHAPTER I. INTRODUCTION

Veins are found in many rocks and form from magmatic melts and hydrothermal solutions initiated from a variety of igneous (intrusion) or metamorphic (anatectic) processes. As such, veins are significant because they yield insight into the magmatic, metamorphic, structural, and/or tectonic evolution of the region (e.g. Bons et al., 2012; Kylander-Clark and Hacker, 2014). Emplacement of veins is controlled by far field processes such as the stress, strain, pressure, and temperature, and near field processes such as fluid composition, distance from the source, and crystallization paths. Minerals and structural indicators found within the veins may record these processes as well as the relative and absolute timing of vein emplacement (Bons et al., 2012). In felsic veins, zircon is likely. Zircons without any inherited component or the overgrowth rims on inherited cores reflect the emplacement age of veins. Inherited zircon cores within veins serve as a probe into subsurface geology (e.g. Gaschnig et al., 2008; Gaschnig et al., 2013). Thus, mineralogy, source and age of veins provide additional constraints on the geologic history of a region.

Within the Sawtooth Metamorphic Complex (SMC), a roof pendant of high-grade rocks located near Stanley, Idaho, numerous veins crosscut the metamorphic lithologies (Dutrow, personal communication). Thus, this area is optimally suited for vein-related studies. The SMC roof pendant is unique in the region because most basement rocks in the area are unavailable due to the pervasive magmatism of the Idaho batholith and Challis magmatic province.

The purpose of this study is to (1) characterize the mineralogy of select veins crosscutting the SMC, (2) obtain U/Pb zircon age dates on a subset of these veins, (3) evaluate chemical and optical signatures as a proxy for vein source, (4) determine the likely source of the veins, and (5) relate the source of the veins to the geologic evolution of the area.
Studying these veins within the SMC complements existing metamorphic studies in the area and could provide insights into the age and extent of previous magmatism, potential rocks in the subsurface, relative timing of metamorphism in the complex, as well as buoyancy and weakening of rocks which impact uplift and tectonic processes.
CHAPTER II. BACKGROUND

First mapped as undifferentiated Precambrian metamorphic rocks (Reid, 1963), the Sawtooth Metamorphic Complex (SMC) is located within the Sawtooth Range of Idaho, U.S.A. (Fig. 1). The complex is bounded by the Atlanta lobe of the Idaho batholith on the south and west, the Sawtooth batholith to the north, and the Sawtooth Fault to the east (e.g. Dutrow et al., 1995; Metz, 2010; Reid, 1963; Thackray et al., 2013) (Fig. 2).

Figure 1. Google Earth map showing location of the Sawtooth Metamorphic Complex (SMC) and samples for this study (yellow circles). Extent of the complex from B. Dutrow (personal communication) and based on Metz (2010).
Later studies characterized the lithologies of the SMC to contain a series of high-grade metamorphic rocks that include aluminous gneisses, amphibolites, calc-silicate gneisses, marbles, metapsammites, and quartzofeldspathic gneisses as major units (e.g. Metz, 2010).

At least three deformational and two metamorphic events are recorded in the calc-silicate gneisses (Fukai and Dutrow, 2017). Mineral assemblages and textures combined with geothermobarometry in the aluminous gneisses indicate clock-wise P-T-t paths that suggest the SMC experienced burial to mid-lower crust depths and exhumation within a collisional tectonic setting (e.g. Smith, 2016). Some garnet-bearing rocks within the SMC are migmatites (Metz, 2010) and retain evidence of anatectic melting. The interpreted residual melt has rare potassium
feldspar suggesting an earlier melting episode extracted this component from the garnet-bearing rocks (Smith, 2016).

Within the SMC, there are numerous felsic veins (Fig. 3) that vary in size from centimeter-scale to tens-of-meters (e.g. Ma et al., 2017). These veins occur as concordant lenses between SMC lithologies (Metz, 2010) and as discordant veins that cross-cut outcrop-scale banding and foliation (Fukai, 2013). The veins are not restricted to a single lithology or area. Felsic veins are quartz bearing, so if enough zirconium is present, zircon will crystallize. These felsic veins are suggested to have formed in the presence of hydrous fluids and an oxidizing environment (personal communication, Paul Mueller) which impacts zircon chemistry. In an oxidizing environment $\text{U}^{6+}$ is mobile while Th remains immobile (e.g. Keppler and Wyllie,

![Figure 3. Photos of the numerous felsic veins crosscutting the metamorphic rocks within the SMC. The veins range in width from centimeter to tens of meters and are fine grained to pegmatitic. (Photo Credit: B. Dutrow).](image-url)
An oxidizing environment results in zircon grains with high U and low Th during vein crystallization. Therefore, a low Th/U ratio is indicative of zircon growth during crystallization of these felsic veins in the SMC (Rubatto, 2002).

A portion of a previous study by Ma (2015), looked at granitic and gabbroic intrusions within the SMC to constrain the timing of tectonic processes as well as gain insight to the sub-SMC crust. Ma determined the granitic intrusions to be part of four separate phases of magmatism that occurred at ca.120 Ma, ca. 97-96 Ma, ca. 91-87 Ma, and ca. 84-73 Ma. However, for a subset of samples procured from Ma, U/Pb zircon vein crystallization ages have an age range of 77 ± 1 Ma to 101 ± 1 Ma (Tab. 1). These intrusions were hypothesized to be sourced by magma injection from beneath the SMC or by in-situ anatectic melting of aluminous gneisses, which Ma found both to be plausible sources for the intrusions.

### Table 1. Locations and ages of Ma (2015) samples

<table>
<thead>
<tr>
<th>Sample Number/unit</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Age ± 2σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC13ST-05</td>
<td>44°08.494'</td>
<td>115°00.023'</td>
<td></td>
</tr>
<tr>
<td>MC13ST-14</td>
<td>44°08.455'</td>
<td>115°00.299'</td>
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</tr>
<tr>
<td>MC13ST-18</td>
<td>44°08.566'</td>
<td>114°59.223'</td>
<td>92 ± 1 Ma</td>
</tr>
<tr>
<td>MC14ST-04</td>
<td>44°09.248'</td>
<td>115°00.017'</td>
<td>92 ± 1 Ma</td>
</tr>
<tr>
<td>MC14ST-08</td>
<td>44°09.174'</td>
<td>114°59.395'</td>
<td>99 ± 1 Ma</td>
</tr>
<tr>
<td>MC14ST-10</td>
<td>44°08.485'</td>
<td>115°00.587'</td>
<td>84 ± 1 Ma</td>
</tr>
<tr>
<td>MC14ST-12</td>
<td>44°08.492'</td>
<td>115°00.450'</td>
<td>101 ± 1 Ma</td>
</tr>
<tr>
<td>MC14ST-13</td>
<td>44°08.493'</td>
<td>114°59.470'</td>
<td>95 ± 1 Ma</td>
</tr>
</tbody>
</table>

### 2.1. Sawtooth Batholith

To the northeast and south, the Sawtooth batholith (STB) bounds the SMC. The STB is associated with the intrusive suites of the Challis volcanic field which range in age from 51 to 43 Ma (Armstrong et al., 1977; Gaschnig et al., 2010). The intrusive suites include the pink granite
suite consisting of granite and the quartz monzodiorite suite consisting of granite, granodiorite, quartz monzodiorite, diorite, and gabbro (Armstrong et al., 1977; Bennett and Knowles, 1985; Lewis and Kiilsgaard, 1991; Reid, 1963).

The pink granite suite is characterized by distinct pink perthitic alkali feldspars (Fig. 4) and by its subequal amounts of alkali feldspar, quartz, and plagioclase (Kiilsgaard et al., 1970; Lewis and Kiilsgaard, 1991; Reid, 1963). The pink granite suite also contains minor hornblende, biotite, muscovite, and accessory zircon, apatite, titanite, allanite, ilmenite, and magnetite (Kiilsgaard et al., 1970; Lewis and Kiilsgaard, 1991; Reid, 1963). This pink granite suite is a two feldspar subsolvus granite, but also contains perthitic alkali feldspar.

The quartz monzodiorite suite is characterized by variable proportions of plagioclase, quartz, alkali feldspar, hornblende, and biotite (Kiilsgaard and Lewis, 1985; Lewis and Kiilsgaard, 1991). The quartz monzodiorite suite also contains accessory apatite, titanite, allanite, and zircon (Kiilsgaard and Lewis, 1985; Lewis and Kiilsgaard, 1991).

The STB is comprised of the pink granite suite (Fig. 4) (e.g. Reid, 1963). U/Pb zircon ages of two samples near the SMC give crystallization dates of 47.1 ± 0.7 Ma and 46.6 ± 0.6 Ma.
Another sample of STB collected farther from the SMC than the previous two samples gives an U/Pb zircon crystallization date of 44.9 ± 1.0 Ma (Gaschnig et al., 2010).

2.2. Idaho Batholith

To the west, the Idaho batholith (IB) bounds the SMC. The IB covers a large region in Idaho and is comprised of a northern Bitterroot lobe and southern Atlanta lobe. The SMC is within the Atlanta lobe which contains lithologies of tonalite, hornblende-biotite granodiorite, porphyritic granodiorite, biotite granodiorite, muscovite-biotite granite, and leucocratic granite (Kiilsgaard and Lewis, 1985). The tonalite contains major biotite and quartz, minor alkali feldspar, hornblende, and accessory titanite, allanite, apatite, magnetite, and zircon (Kiilsgaard and Lewis, 1985). It is gray, medium-to-coarse grained and dark gray with some alteration of feldspar into sericite (Kiilsgaard and Lewis, 1985).

The hornblende-biotite granodiorite is characterized by the presence of hornblende and contains major quartz, plagioclase, alkali feldspar, and biotite with accessory titanite and allanite (Kiilsgaard and Lewis, 1985). It is gray to dark gray and has weak to prominent foliation (Kiilsgaard and Lewis, 1985).

The porphyritic granodiorite is characterized by feldspar megacrysts and contains major quartz, plagioclase, alkali feldspar, biotite, minor hornblende, and accessory titanite, apatite, allanite, and zircon (Kiilsgaard and Lewis, 1985; Reid, 1963). It is medium to coarse grained, typically foliated, contains moderate to pervasive feldspars altered to sericite, and pervasive biotite altered to chlorite (Kiilsgaard and Lewis, 1985; Reid, 1963).

The biotite granodiorite is characterized by predominant plagioclase with lesser alkali feldspar and quartz (Kiilsgaard and Lewis, 1985; Reid, 1963). The biotite granodiorite contains minor biotite and accessory muscovite, hornblende, allanite, titanite, opaques, and zircon
It is light gray, medium to coarse grained, and contains pervasive sericite from feldspar alteration and chlorite from biotite alteration (Kiilsgaard and Lewis, 1985; Reid, 1963).

The muscovite-biotite granite is characterized by igneous muscovite (Kiilsgaard and Lewis, 1985). The muscovite-biotite granite contains major quartz, alkali feldspar, plagioclase, minor biotite, and local garnet (Kiilsgaard and Lewis, 1985). It is light gray and medium to coarse grained (Kiilsgaard and Lewis, 1985).

The leucocratic granite is characterized by its white to light gray color (Kiilsgaard and Lewis, 1985; Reid, 1963). The leucocratic granite contains sub-equal amounts of plagioclase, alkali feldspar, and quartz with minor biotite, local garnet, accessory magnetite, allanite, apatite, and zircon (Kiilsgaard and Lewis, 1985; Reid, 1963). It is fine to medium grained and contains moderate sericite altered from feldspars and chlorite altered from biotite (Kiilsgaard and Lewis, 1985; Reid, 1963).

The differing lithologies that make up the Atlanta lobe of the IB, range in age from ca. 98 to 64 Ma (Gaschnig et al., 2010; Kiilsgaard and Lewis, 1985). However, the only lithologies observed near the SMC are porphyritic granodiorite, biotite granodiorite, and leucocratic granite (Reid, 1963). Four samples of IB collected near the SMC are grey in hand specimen (Fig. 4), with one having an U/Pb zircon crystallization age of 85.0 ± 2.4 Ma (Dutrow et al., 2014) and the three others having U/Pb crystallization ages of 92 ± 1 Ma, 92 ± 1 Ma, and 89 ± 1 Ma (Ma, 2015). Gaschnig and colleagues (2013) conducted a study on inherited zircon cores found within the IB. In this study they separated the Atlanta lobe of the IB into a northern and southern portion. In the southern portion, inherited core ages formed two major peaks at 2550 Ma and 670 Ma. For the northern portion of the Atlanta lobe, the majority of inherited core ages range from
2000 to 1000 Ma, containing peaks at 1700 to 1600 Ma and 1500 to 1400 Ma. Two cores of Ordovician age were also found in the Northern Atlanta lobe.

2.3. Potential Felsic Vein Sources

Within the SMC region, several possibilities exist for the source of the felsic veins that crosscut the complex. Each of these sources is characterized by a distinct age range and each source contains feldspars. Potential sources for these veins include: (1) The STB. If sourced by the STB, veins will have crystallization ages of ca. 47 Ma (Dutrow et al., 2014).

(2) The Atlanta lobe of the IB. If sourced by the IB, veins will have crystallization ages within the range of ca. 98 to 64 Ma (Gaschnig et al., 2010; Kiiilsgaard and Lewis, 1985).

(3) Anatectic melt derived from melting of aluminous gneisses. These conditions would have occurred near the peak of metamorphism, prior to exhumation. Peak metamorphic conditions for the aluminous gneisses occurred at a minimum depth of 22.5 km (Smith, 2016). The Idaho batholith which is found at the same elevations as the aluminous gneisses, has a maximum emplacement depth of its base at 18 km (Hyndman, 1981). To create the current day configuration of the Idaho batholith and aluminous gneisses, anatectic melts would have had to form at a depth greater than 22.5 km and then experience exhumation to a depth shallower than 18 km before emplacement of the Idaho batholith. Therefore, if anatectic melts are the vein sources, veins will have crystallization ages older than the Idaho batholith (~100 Ma).

(4) Another (unidentified) melting and/or hydrothermal event. Hydrothermal alteration has occurred throughout Idaho and could be a potential source of veining (Criss et al., 1991). An unidentified event would be suggested by an age unrelated to the proposed sources above.

(5) Multiple of these events. If there are multiple sources for these veins, age data for each event would be present.
2.4. Optical Microscope Cathodoluminescence (OM-CL)

Optical microscope cathodoluminescence (OM-CL) is a fast, powerful technique which elucidates textures not observed in plain-polarized light (PPL) or cross-polarized light (XPL). Cathodoluminescence occurs when the sample is excited by energetic electrons and generates photons in the visible light range. These responses can be indicative of structural defects or trace elements within the minerals (Tab. 2) (e.g. Geake et al., 1973; Götze, 2012; Götze et al., 2013; Marfunin, 1979). Plagioclase has a wide range of color responses in CL which make it a useful mineral to detect differences among samples (Götze, 2012). Previous studies have tested whether these differing CL color responses could be used to determine the provenance of that feldspar grain (e.g. Scholonek and Augustsson, 2016).

<table>
<thead>
<tr>
<th>CL Color</th>
<th>Suggested Activator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple</td>
<td>Eu$^{2+}$</td>
</tr>
<tr>
<td></td>
<td>Cu$^{2+}$</td>
</tr>
<tr>
<td>Dark Blue</td>
<td>Al-O-Al center</td>
</tr>
<tr>
<td></td>
<td>Al-O-Ti</td>
</tr>
<tr>
<td>Light Blue</td>
<td>O–Si…M$^+$</td>
</tr>
<tr>
<td>Green-Yellow</td>
<td>Mn$^{2+}$</td>
</tr>
<tr>
<td>Red</td>
<td>Fe$^{3+}$</td>
</tr>
</tbody>
</table>

Table 2. Suggested trace element CL activators for feldspars from (Goetze, 2012).
2.5. Zirconium Saturation Temperature

Calculating the zircon solubility in crustal melts is dependent on the zirconium content of the melt, the composition, and the temperature (Watson and Harrison, 1983). Therefore, determining whole rock major and trace elements allows for the calculation of the zirconium saturation temperature (Boehnke et al., 2013). If zirconium saturation is attained, zircon will form.

Zirconium saturation temperatures have been used to determine minimum (zirconium undersaturated magmas) and maximum (zirconium saturated magmas) magma temperatures as well as to understand preservation of inheritance within rock samples (Miller et al., 2003). If a rock sample has no zircon inheritance, the calculated zirconium saturation temperature can also be used as the temperature of crystallization (Miller et al., 2003).
CHAPTER III. METHODS

To characterize the veins mineralogy, textures, and ages, several optical and analytical methods were used. Veins were made into thin sections for petrographic studies to determine the mineral assemblages, textures, and rock types of all veins. Select vein samples had zircons separated to obtain U/Pb age dates. Potential vein sources in the region all have distinct age ranges allowing for use of vein age as a source proxy. Feldspar mineral chemistry and optical cathodoluminescence plagioclase responses were evaluated as potential proxies of vein source by comparison of potential source samples to that of veins with undetermined source.

3.1. Sample Selection

Samples of lithologies that are possible vein sources as well as vein samples of undetermined source were selected for optical, mineralogical, and geochronologic study. Samples starting with LF or SMC were collected previously by B. Dutrow from 2011 through 2016. Thin sections of samples with known U/Pb ages, collected by Ma (2015), were available for petrographic and cathodoluminescent plagioclase response analyses. Samples starting with MC##ST were collected by Chong Ma from 2013 through 2014. Samples studied were selected to ensure a large spatial distribution (Tab. 3). Samples with previously obtained whole rock geochemical data with zirconium values were selected to calculate zirconium saturation temperatures. Two samples displaying differing OM-CL plagioclase responses were chosen for mineral chemical analysis. A subset of samples with sufficient material were selected for U/Pb zircon geochronology.
3.2. Optical Petrography

Polished thin sections of 19 felsic veins of unknown source were prepared for petrographic analyses at Wagner Petrographic in Lindon, UT, and at Louisiana State University. In addition, 8 thin sections from veins of unknown source as well as 14 from potential vein sources were used (collected by Barbara Dutrow and Chong Ma).

Petrographic analyses and point counting of samples were completed on a Leica petrographic microscope fitted with a PELCON automatic point counter stage. Optical petrography was used to examine mineral phases, textures, modal proportions as well as record any samples adequate for use in U/Pb zircon geochronology. Due to plagioclase coronas representing residual melt (Smith, 2016) and not accurately representing the mineral modes of the removed melt, anatectic melt samples were not analyzed petrographically in this study.

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LF and SMC samples collected by B. Dutrow. MC##ST samples collected by C. Ma.
Petrographic study of anatectic melts has been completed by Hoffmann (2016) and Smith (2016). To determine the rock classification, three-hundred points were counted with a 1mm spacing for each sample. Normalized point count values were used to determine rock name via the IUGS QAPF classification for plutonic rocks (e.g. Le Bas and Streckeisen, 1991).

For determining a likely source of veins by petrography, samples of known source were compared to vein samples of unknown source. Sawtooth batholith and Idaho batholith samples, as well as the residual of anatectic melts, served as known source reference materials with distinct petrographic characteristics of each source. These distinct characteristics were then compared to vein samples of unknown source to determine similarities that suggest a likely vein source.

3.3. Optical Microscope Cathodoluminescence (OM-CL)

OM-CL observations and imaging of polished and uncoated thin sections were completed in the OPI lab in the Department of Geology and Geophysics at Louisiana State University on a Leica DM 2700P petrographic microscope fitted with a cold cathode Reliotron stage and Leica DFC 7000T low light camera. An electron beam voltage of ~10kV and beam current of 0.2-0.5 mA was used and the Reliotron stage was under vacuum at 25-40 mTorr. The total amount of light collection varied per sample. After photographing the CL responses of samples, image processing was completed using FastStone image software. Image processing was used to adjust brightness and contrast but did not alter the observed color. Image processing also enhanced textures not seen in optical microscope observations. PPL, XPL and CL photos were taken of the same area. Observed CL colors were matched to a Munsell color chart for distinction (Fig. 5).
Primarily, feldspar OM-CL responses and observed textures were the targeted observations. The observed OM-CL color responses and textures of potential source samples were compared to determine distinct OM-CL characteristics for each potential source.

3.4. Zirconium Saturation Temperature

Whole rock geochemistry of both major and trace elements used for zirconium saturation temperature calculations were based on data obtained in previous work (Dutrow et al., 2014; Ma, 2015). Zirconium saturation temperature calculations used the equation of Boehnke et al. (2013). Calculated zirconium saturation temperatures of the Idaho batholith and Sawtooth batholith were compared for each batholith and to veins of unknown source.

3.5. Backscatter Electron (BSE) Imaging and Electron Microprobe Analysis (EMPA)

Two vein samples of unknown source were imaged using backscatter electrons (BSE) and feldspars analyzed. Data were collected using wavelength dispersive spectrometry (WDS) on the JEOL JXA-8230 Electron Superprobe, housed in the Chevron’s Geomaterials lab at LSU’s Department of Geology & Geophysics and the Shared Instrumentation Facility. BSE image gray levels are a function of the mean atomic weight and can reveal compositional zoning and/or alteration within minerals. Based on these images, targeted feldspar analysis points were chosen to avoid alteration and to traverse areas of compositional zoning. Analytical points were taken along plagioclase and alkali feldspar rim-rim traverses to determine compositional zoning.
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<th>Dark Green</th>
<th>Yellowish Green</th>
<th>Yellow</th>
<th>Pink</th>
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<th>Brown</th>
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Figure 5. Table of CL colors with Munsell color chart used for reference. Chart taken from (Vejdemo-Johansson et al., 2014).
Operating conditions of the EMPA included an accelerating voltage of 15 kV, a probe current of 20 nA, and a defocused 5 µm electron-beam diameter. Alkali and plagioclase feldspars were analyzed for Si, Al, Fe, Ca, Ba, Na, and K using well-characterized mineral standards (Tab. 4). Fe had a 40 second count time on the peak and 20 second count time on the background. Ba had a 60 second count time on the peak and 30 second count time on the background. All other analyzed elements had a 20 second count time on the peak and 10 second count time on the background. Instrument drift and data quality were examined by measuring multiple secondary standards as unknowns.

Structural formulae were calculated using an excel program (D. Henry, personal communication) that normalized the weight-percent oxide analyses to atoms per formula unit (apfu) based on eight oxygen atoms. Analyses with a total oxide weight percent of below 99% or above 101% were omitted.

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<td>Toronto plagioclase</td>
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<tr>
<td>Ba</td>
<td>Toronto barite</td>
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<td>Toronto albite</td>
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<td>K</td>
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### 3.6. Heavy Mineral Separation and Imaging

Six samples of felsic veins of unknown source and one sample from a unit mapped as the leucocratic granite phase of the IB (Field notes, B. Dutrow) were chosen for U/Pb zircon geochronologic studies. Each sample had a minimum amount of 3.5 kg (3 kg for heavy mineral separation, 400 g for future whole rock geochemistry work, and 100 g as a hand sample for observations) of rock material.
Rock samples were trimmed to be free of alteration, then crushed, and sieved so all grains were of less than 177 micrometers in size. Vein samples were cut into slabs to minimize contamination and washed with tap water to remove foreign rock particles. Slabs were disaggregated using a jaw crusher and pulverized using a disc grinder within the LSU’s Department of Geology & Geophysics rock lab. Crushing was continued until all the material passed through an 80-mesh sieve. The sieved material was then rinsed in tap water and baked at 100 C° overnight. The jaw crusher, disc grinder, and sieves were cleaned with soap and water, rinsed with acetone, and dried between samples to prevent cross contamination.

After the sieved material was dry, a hand magnet was used to remove magnetic grains and metal shavings from the machines used in the disaggregation process. Next the sample was passed through a Frantz magnetic separator multiple times with different front slope, side slope, and amps settings (Tab. 5). The final “non-magnetic” mineral separates were density separated using lithium metatungstate (ρ=2.95 g/mL) to concentrate heavy minerals i.e. zircon. Separated “heavies” were then rinsed with distilled and deionized water.

Zircons were handpicked under a binocular microscope based on optical properties and morphology. Picked zircons were mounted in epoxy blanks with FC-1 (Duluth Gabbro) standards and polished at the University of Florida Center for Isotope Geoscience. Polished pucks were imaged on a Zeiss scanning electron microscope (SEM) at the University of Florida separately using BSE imaging and CL imaging to observe zoning patterns, core and overgrowth relationships and alteration features. SEM-BSE and CL imaging were used to determine the

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growth textures of zircons and target analysis points. Imaging and targeted analyses allow for
dating of the crystallization age (i.e. magmatic zircons), potentially metamorphic events (i.e.
metamorphic overgrowths), and inherited core ages.

3.7. LA-ICP-MS and U/Pb Ages

To obtain U/Pb ages for zircons, U/Pb isotopic analyses of zircon cores and overgrowths
were performed at the University of Kansas using the LA-ICP-MS method. Mounted zircon
crystals were ablated with a Photon Machines Analyte G2 193nm ArF excimer laser coupled to a
Thermo Scientific Element 2 high resolution sector-field ICP-MS. Due to samples having ten
times the typical uranium content, spot size was set at 15 µm (Personal communication, Andreas
Möller). Fractionation and drift calibration were corrected by using GJ1 zircon (608.5 ± 0.4 Ma)
(Jackson et al., 2004) as a calibration standard. Calibration was checked using secondary
standards of FCT (28.196 ± 0.038 Ma) (Fish Canyon Tuff) (Wotzlaw et al., 2013), Plesovice
(337.13 ± 0.37 Ma) (Sláma et al., 2008), and FC-1 (1099.0 ± 0.6 Ma) (Duluth Gabbro) (Paces
and Miller Jr, 1993).

Data reduction was completed using VizualAge data reduction scheme (Petrus et al.,
2012) for Iolite software (Hellstrom et al., 2008; Paton et al., 2011; Paton et al., 2010). Reduced
ages were corrected for Pb-loss, inheritance, and common Pb (Personal communication, Andreas
Möller and Paul Mueller).

Age data were separated into inherited cores and vein crystallization dates by age
difference. Large clusters of continuous young dates represent vein crystallization data and few
older discontinuous dates represent inherited core data. Statistical analysis could not be
completed on inherited core dates due to the small amount of data. Therefore, inherited core
dates with <5% discordance are used as acceptable ages.
Reduced $^{206}\text{Pb}/^{238}\text{U}$ vein crystallization ages were plotted versus $^{206}\text{Pb}/^{238}\text{U}$ to $^{207}\text{Pb}/^{235}\text{U}$ discordance to determine if age and discordance were correlated. If no correlation was present, reduced age data were filtered to a discordance of $<1\%$ and a Th/U ratio of $<0.01$ (Pers. Comm. Paul Mueller). The mean age and $2\sigma$ were calculated and all dates outside of the calculated $2\sigma$ were discarded. Of the resulting dates, the ten youngest were plotted as kernel density estimates (KDEs) using Density Plotter 8.5 (Vermeesch, 2012) to determine age groupings. The youngest age grouping was plotted on a Terra-Wasserburg diagram and weighted mean plot using IsoplotR (Abramson, 1982; Botev et al., 2010; Ludwig, 1998; Ludwig, 2003; Vermeesch, 2012, 2018). Mean ages, $2\sigma$, and $2\text{s.e.m}$ (standard error of the mean) were calculated for the youngest age group determined by the KDE plots. Calculated ages $<1000\text{ Ma}$ are reported as $^{206}\text{Pb}/^{238}\text{U}$ ages and calculated ages $>1000\text{ Ma}$ are reported as $^{207}\text{Pb}/^{206}\text{Pb}$ ages based on (Bruguier et al., 2001).

To determine potential sources for the veins, vein crystallization ages were compared with the age ranges of potential sources. To determine potential sources of inheritance, core ages were compared to age dates of inherited cores within the IB reported by Gaschnig and colleagues (2013) as well as detrital zircon ages from SMC metapsammites reported by Ma (2015).
CHAPTER IV. RESULTS

Forty-one samples including five Sawtooth batholith, four Idaho batholith, the residual of five anatectic melts, one sample of a unit mapped as the leucocratic granite phase of the IB, and twenty-six veins of unknown source from throughout the SMC were examined via petrographic analyses and OM-CL. Two samples were examined for feldspar mineral chemistry and seven samples had U/Pb zircon geochronology performed (Tab. 6, see also Appendix A.).

Table 6. Methods used on each sample.

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<th>Whole rock Geochemistry</th>
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<th>U/Pb Zircon Geochronology</th>
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x=This study D=(Dutrow, 2014) M=(Ma,2015) SH=(Smith, 2016; Hoffman, 2016)

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**Vein Samples from Ma (2015)**

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<th>Sample Number</th>
<th>Petrography</th>
<th>OM-CL</th>
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x=This study D=(Dutrow, 2014) M=(Ma,2015) SH=(Smith, 2016; Hoffman, 2016)
4.1. Sawtooth Batholith Samples

Five Sawtooth batholith samples were analyzed in this study. STB samples are easily identified in the field because of their coarse grain size and pink color. STB samples in this study are two feldspar biotite-bearing granites with minor hornblende in four of five samples (Tab. 7). Accessory minerals include variable amounts of apatite, magnetite, and zircon. Secondary minerals include variable amounts of epidote, chlorite, hematite, and sericite. Samples are medium-to-coarse grained and contain pervasive perthitic alkali feldspars (Fig. 6). Myrmekitic texture is present in one sample. Hand specimens are pink-colored and coarse grained (Fig. 4).

![Figure 6. Cross polarized photomicrographs of STB sample LF-12 showing perthitic texture. Scalebar equals 500 microns.](image)

Plagioclase in Sawtooth batholith samples luminesces pink, red, brown, neon green, moderate green, dark-green, and neon orange (Tab. 8). All five STB samples contain albite exsolution with pink OM-CL responses. All samples display pink albite exsolution, however, only four of five STB samples contain plagioclase grains with a pink response (Fig. 7). These four samples also contain plagioclase with brown OM-CL responses; thus, the majority of samples contain plagioclase grains with both pink and/or brown responses. The one sample without pink and/or brown plagioclase responses displays neon orange, neon green and dark green responses (Fig. 7, SMC11-12) which contrasts with the four other samples. This sample is
Table 7. Rock type (based on modes), mineralogy, and textures observed.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Rock Type</th>
<th>Primary Minerals</th>
<th>Alterations</th>
<th>Textures</th>
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<td>Qz</td>
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<td>X</td>
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<td>SMC13-42</td>
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<td>Vein Samples</td>
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Mi=Minor  Mo=Moderate  Pe=Pervasive
Mineral abbreviations from Whitney and Evans (2010).

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<table>
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<tr>
<th>Sample Number</th>
<th>Rock Type</th>
<th>Primary Minerals</th>
<th>Secondary Minerals</th>
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Mi=Minor  Mo=Moderate  Pe=Pervasive
Mineral abbreviations from Whitney and Evans (2010).
Table 8. Observed textures, plagioclase OM-CL responses, and alkali feldspar OM-CL responses.

<table>
<thead>
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<th>Sample Number</th>
<th>Plagioclase Response</th>
<th>Alkali Feldspar Response</th>
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<td>Perthite and highly altered plagioclase cores</td>
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<td>Dark blue with pink albite exsolution</td>
<td>Perthite</td>
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<td>Moderate to dark blue with pink albite exsolution</td>
<td>Perthite and highly altered plagioclase cores</td>
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<td>Oscillatory zoned plagioclase and myrmekite</td>
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<td>Bright blue and moderate blue</td>
<td>Myrmekite</td>
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<td>Myrmekite and red zonation in alkali feldspar</td>
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<td>Oscillatory zoned alkali feldspar and myrmekite. Highly altered plagioclase cores</td>
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<td>Red zoning in alkali feldspar</td>
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<td>Bright blue and moderate blue</td>
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<td>Myrmekite and twin plane alteration</td>
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<td>Myrmekite</td>
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<td>Bright blue and moderate blue</td>
<td>Highly altered sample</td>
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<td>Bright blue</td>
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<td>SMC13-132</td>
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<td>Moderate blue and dark blue</td>
<td>Myrmekite</td>
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<td>SMC14-11</td>
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<td>Twin plane alteration</td>
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<td>Bright blue, brown, and red</td>
<td>Moderate blue</td>
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<td>SMC14-40</td>
<td>Moderate blue, brown, and red</td>
<td>Bright blue</td>
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</tr>
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<td>SMC14-43</td>
<td>Moderate green, red, and orange</td>
<td>Bright blue and moderate blue</td>
<td>highly altered sample</td>
</tr>
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<td>SMC14-44</td>
<td>Brown and red</td>
<td>Moderate blue and red</td>
<td>highly altered sample</td>
</tr>
<tr>
<td>SMC14-47</td>
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<td>Bright blue and red with pink albite</td>
<td>Perthite</td>
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(table cont’d.)
<table>
<thead>
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<th>Sample Number</th>
<th>Plagioclase Response</th>
<th>Alkali Feldspar Response</th>
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</tr>
<tr>
<td>SMC14-61</td>
<td>Moderate green, brown, and red</td>
<td>Bright blue, moderate blue, and red with oscillatory zoning</td>
<td>Oscillatory zoned alkali feldspar and highly altered plagioclase cores</td>
</tr>
<tr>
<td>SMC14-62</td>
<td>Moderate green, brown, and red</td>
<td>Moderate blue zoned with red and pink albite exsolution</td>
<td>Zoned alkali feldspar and perthite. Highly altered plagioclase cores</td>
</tr>
<tr>
<td>SMC14-112</td>
<td>Bright green and moderate blue</td>
<td>Bright blue and moderate blue</td>
<td></td>
</tr>
<tr>
<td>SMC15-03</td>
<td>Moderate green, brown, and pink</td>
<td>Moderate blue with pink albite exsolution</td>
<td>Perthite and highly altered plagioclase cores</td>
</tr>
<tr>
<td>SMC16-09</td>
<td>Brown</td>
<td>Bright to moderate blue</td>
<td></td>
</tr>
<tr>
<td>SMC16-22</td>
<td>Yellow</td>
<td>Moderate blue</td>
<td></td>
</tr>
<tr>
<td>SMC16-34</td>
<td>Moderate green and brown</td>
<td>Bright blue, moderate blue, and red with oscillatory zoning</td>
<td>Oscillatory zoned alkali feldspar</td>
</tr>
</tbody>
</table>
located the furthest south of all STB samples and is the furthest from the SMC. A moderate green plagioclase response was also observed in a single grain of a sample with pink and/or brown responses. Alkali feldspar luminesces moderate blue and dark blue (Tab. 8). Three of five samples contain moderate blue alkali feldspar response and three of five samples contain dark blue alkali feldspar responses. Pervasively sericitized plagioclase cores are common and perthitic texture is observed in all samples.

Figure 7. OM-CL photographs of STB samples SMC11-12 and SMC11-13 showing distinct colors of plagioclase CL response: SMC11-12: neon orange, neon green, dark green. SMC11-13: pink plagioclase and perthite within alkali-feldspar (blue). Note highly altered cores observed. Scale bar equals 500 micrometers.

4.2. Idaho Batholith Samples

Four Idaho batholith samples were analyzed in this study. Samples were identified by their mineralogy combined with sample location and U/Pb ages (Dutrow et al., 2014; Ma, 2015). All samples are biotite-bearing granodiorites; one sample contains minor hornblende (Tab. 7). Additional minor minerals include variable amounts of allanite, apatite, magnetite, and zircon. Secondary minerals include clinozoisite, chlorite and sericite. Samples are medium grained, display minor perthite and variable amounts of myrmekite (Fig. 8). Hand specimens are light gray and medium grained (Fig. 4).
Plagioclase in Idaho batholith samples luminesces light green, moderate green, and brown (Tab. 8). All four IB samples contain plagioclase grains with a moderate green OM-CL response (Fig. 9). Two samples also contain plagioclase with light green CL response and the other two contain dark green plagioclase. Oscillatory zoned plagioclase is observed two of the four samples. Alkali feldspar luminesces bright blue, moderate blue, dark blue, and in some cases, red (Tab. 8). Such color contrasts highlight textural features such as myrmekite which is observed in three of four samples.

Figure 9. OM-CL image of IB sample SMC11-14 and MC14ST-21 displaying bright green and moderate green plagioclase responses. Myrmekite texture also observed. Cores and altered rims are apparent. Alkali feldspar luminesces blue. Apatite luminescence yellow. Scale bar equals 500 micrometers.
4.3. Anatectic Melt Samples

Five anatectic melt samples were analyzed in this study. Remnants of anatectic melt are preserved in the samples as plagioclase-rich coronas surrounding garnets in the high grade metamorphic rock (Smith, 2016). These coronas largely lack alkali feldspar and primarily contain plagioclase with quartz and biotite.

Plagioclase in anatectic melt samples luminesces bright green, moderate green, bright blue, moderate blue, and brown (Tab. 8). Three of five samples have plagioclase response colors of bright green and/or moderate blue (Fig. 10). Alkali feldspar luminesces deep blue (Tab. 8). Alkali feldspar is rare in coronas and only found in two of the five samples. Within these two samples, myrmekitic texture is also observed.

Figure 10. OM-CL photographs of anatectic melt residual showing distinct plagioclase CL responses: 12-116: moderate blue. SMC12-117: plagioclase is yellowish green and moderate blue. Sillimanite luminesces red. Apatite luminesces yellow. Quartz and garnet non-luminescent for these dwell times. Photos: Barbara Dutrow

4.4. Distinct Optical Characteristics of Potential Vein Sources

By comparing distinct plagioclase CL characteristics of each known source to unknown veins, possible provenance can be explored. Distinct characteristics of STB samples are pink color in hand specimen, syeno-granitic composition, pervasive perthite observed as pink albite exsolution in OM-CL, and OM-CL plagioclase responses of pink, neon green, and neon orange.
Distinct characteristics of IB samples are gray color in hand specimen, granodioritic composition, myrmekitic texture and plagioclase OM-CL responses of bright green and moderate green, and red zoned alkali feldspar observed in OM-CL. Distinct characteristics of anatectic melts include plagioclase OM-CL responses of yellowish green, bright blue, and moderate-turquoise blue.

4.5. Vein Samples of Unknown Source

Twenty-seven vein samples were analyzed in this study by thin section. Three are syeno-granites, thirteen are monzo-granites, and eleven are granodiorites (Tab. 7). Likely sources are identified based on petrographic analyses, OM-CL plagioclase colors, and for a subset of samples, U/Pb zircon geochronology.

**Veins with a syeno-granite (QAP) composition**

Three syeno-granite samples are biotite syeno-granites with variable amounts of accessory magnetite and zircon. Secondary minerals include variable amounts of chlorite, sericite, and clinozoisite. Samples are coarse grained with pervasive perthite and variable amounts of myrmekite.

Plagioclase in these samples luminesces bright green, moderate green, moderate blue, brown, and pink (Tab. 8). Brown plagioclase response is found in two of the three samples and is the only color in multiple samples. Alkali feldspar luminesces bright blue and moderate blue. Perthite and highly altered plagioclase cores are observed in one sample.

**Veins with a monzo-granite (QAP) composition**

Ten of the monzo-granite samples are biotite monzo-granites and three are leucocratic monzo-granites. One of these sample contains trace hornblende. Minor minerals include variable amounts of magnetite, allanite, apatite, and zircon. Secondary minerals include variable amounts
of chlorite, hematite, sericite, clinozoisite, and epidote. Samples are fine-to-coarse grained and contain little to abundant perthite. Six samples contain myrmekite.

Plagioclase in these thirteen monzo-granite samples luminesces bright green, moderate green, bright blue, moderate blue, brown, red and pink (Tab. 8). Moderate green and/or brown plagioclase responses are most prevalent and are found in all thirteen samples. Alkali feldspar luminesces bright blue, moderate blue, dark blue, and red (Tab. 8). Perthite, myrmekite, and twin plane alteration are observed but are rare.

**Veins with a granodiorite (QAP) composition**

Ten biotite granodiorites occur within this grouping with one hornblende granodiorite. Minor minerals include variable amounts of allanite, apatite, magnetite, and zircon. Secondary minerals include variable amounts of clinozoisite, epidote, chlorite, hematite, and sericite. Samples are fine-to-coarse grained with variable amounts of perthite and myrmekite.

Plagioclase in the granodiorite samples luminesces bright green, moderate green, moderate blue, brown, red, pink, yellow, and neon orange (Tab. 8). The most prevalent observed plagioclase response was moderate green which occurred in eight of the eleven samples. Alkali feldspar luminesces bright blue, moderate blue, dark blue, and red (Tab. 8). Oscillatory zoning in alkali feldspar is observed in four of the eleven samples. Myrmekite and twin plane alteration are present but rarely observed.

### 4.6. Zirconium Saturation Temperatures

Major element compositions and trace zirconium content of sixteen samples previously analyzed (Dutrow et al., 2014; Ma, 2015) were used to determine zirconium saturation temperatures (Boehnke et al., 2013) (Tab. 9). Five Sawtooth batholith samples have zirconium
saturation temperatures ranging from 658 to 737 °C with an average of 688 ± 32 °C (1σ), three Idaho batholith samples have a temperature range of 592 to 693 °C with an average temperature

Table 9. Calculated zirconium saturation temperatures based on (Bohnke et al., 2013).

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<td>SMC 11-14</td>
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Whole rock geochemical data taken from Dutrow et al. (2014) and Ma (2015).

VEIN SAMPLES

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Whole rock geochemical data taken from Dutrow et al. (2014) and Ma (2015).

VEIN SAMPLES

Whole rock geochemical data taken from Dutrow et al. (2014) and Ma (2015).

MGr = Monzo-granite Grd = Granodiorite
of 648 ± 51 °C (1σ), four veins of unknown source are granodiorites and have a temperature range from 614 to 708 °C with an average temperature of 655 ± 40 °C (1σ), and four veins of unknown source belonging to the monzo-granite grouping have a temperature range from 552 to 748 °C with an average temperature of 659 ± 83 °C (1σ).

4.7. Feldspar Mineral Chemistry

Two vein samples of unknown source with differing rock type and plagioclase OM-CL response colors were chosen for feldspar mineral chemical analysis. SMC13-132 is a coarse grained monzo-granite with bright green and brown plagioclase in OM-CL and plagioclase twin planes show alteration in CL. SMC16-34 is medium-grained granodiorite with moderate green and brown plagioclase in OM-CL and contains oscillatory zoned alkali feldspar observed in CL.

SMC13-132

Three plagioclase grains and three alkali feldspar grains were analyzed to determine core to rim compositional differences and to determine minor elements that might give rise to the CL signature. Plagioclase cores have a compositional range of

\[(Na_{0.73-0.97}Ca_{0.15-0.24}K_{0.01-0.02})(Si_{2.75-2.98}Al_{1.02-1.25})O_8\]

and rims have a range of

\[(Na_{0.94-0.96}Ca_{0.02-0.04}K_{0.00-0.01})(Si_{2.96-2.97}Al_{1.04-1.04})O_8\] (Appendix C, Tab. 10). Anorthite content decreases from core to rim correlating to a change in plagioclase CL color (Appendix C, Fig. 11). Only one alkali feldspar data point taken from a core was reliable and had a composition of

\[(K_{0.91}Na_{0.07}Ba_{0.02})(Si_{2.96}Al_{1.05})O_8\] (Appendix C, Tab. 11).

SMC16-34

OM-CL displayed compositional zoning in the feldspars. Thus, five plagioclase grains and nine alkali feldspar grains were analyzed in this sample to determine core-to-rim compositional differences. Plagioclase cores have a compositional range of
(Na\textsubscript{0.85-0.98}Ca\textsubscript{0.04-0.14}K\textsubscript{0.01-0.01})(Si\textsubscript{2.84-2.93}Al\textsubscript{1.07-1.16})O\textsubscript{8} and rims have a range of

(4a\textsubscript{0.86-0.93}Ca\textsubscript{0.03-0.07}K\textsubscript{0.01-0.01})(Si\textsubscript{2.84-2.92}Al\textsubscript{1.03-1.08})O\textsubscript{8} (Appendix C, Tab. 12). Anorthite content decreases from core to rim correlating to a change in plagioclase CL color (Appendix C, Fig. 12). Alkali feldspar cores have a compositional range of

(K\textsubscript{0.90-0.94}Na\textsubscript{0.07-0.10}Ba\textsubscript{0.01-0.02})(Si\textsubscript{2.96-2.99}Al\textsubscript{1.00-1.04})O\textsubscript{8} and rims have a range of

(K\textsubscript{0.90-0.94}Na\textsubscript{0.07-0.09}Ba\textsubscript{0.01-0.03})(Si\textsubscript{2.94-2.99}Al\textsubscript{0.99-1.06})O\textsubscript{8} (Appendix C, Tab. 13).

Table 10. Mineral chemistry of plagioclase feldspar cores and rims for sample SMC13-132.

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Structural Formula Based on 8 Oxygens

|                       | T (iv) site: Si | 2.75 | 2.98 | 2.81 | 2.96 | 2.97 | 2.96 |
|                       | Al          | 1.02 | 1.25 | 1.19 | 1.04 | 1.04 | 1.04 |
|                       | T site total | 4.00 | 4.01 | 4.00 | 4.00 | 4.00 | 4.00 |
|                       | Fe2+       | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|                       | Ca         | 0.02 | 0.24 | 0.18 | 0.03 | 0.04 | 0.04 |
|                       | Ba         | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|                       | Na         | 0.73 | 0.97 | 0.80 | 0.94 | 0.96 | 0.95 |
|                       | K          | 0.01 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 |
|                       | M-site total | 0.98 | 1.00 | 0.99 | 0.99 | 1.00 | 0.99 |

Feldspar Components

|                       | albite (mol\%) | 73.61 | 97.12 | 80.29 | 94.97 | 96.27 | 95.62 |
|                       | anorthite (mol\%) | 2.11 | 24.08 | 18.47 | 3.33 | 4.14 | 3.73 |
|                       | orthoclase (mol\%) | 0.64 | 2.27 | 1.19 | 0.38 | 0.88 | 0.63 |
|                       | celsian (mol\%) | 0.01 | 0.07 | 0.04 | 0.01 | 0.02 | 0.01 |
Figure 11. (Top) BSE image of SMC13-132 showing the location of EMPA analysis points in relation to the plagioclase CL color at each location. (Bottom) Graph of anorthite content per analysis point. Points traverse plagioclase CL color change from green (core) to brown (rim).
Table 11. Mineral chemistry of Alkali feldspar cores and rims for sample SMC13-132.

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Table 12. Mineral chemistry of plagioclase feldspar cores and rims for sample SMC16-34.

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**Structural Formula Based on 8 Oxygens**

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**Feldspar Components**

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<td>Albite (mol%)</td>
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Figure 12. (Top) BSE image of SMC16-34 showing the location of EMPA analysis points in relation to the plagioclase CL color at each location. (Bottom) Graph of anorthite content per analysis point. Points traverse plagioclase CL color change from brown (core) to red (rim).
U/Pb zircon Geochronology

U/Pb zircon age dates were obtained for seven vein samples of unknown source. These data served as a calibration for, and test of, the validity of OM-CL plagioclase responses as a source proxy. Analyses points targeted both the inherited cores and the overgrowths of the zircon grains to determine the age of the latest overgrowth as well as the original crystallization age (Appendix F). Discordance calculated for ages <1000 Ma are reported as $^{207}\text{Pb}/^{235}\text{U}$ ages versus $^{206}\text{Pb}/^{238}\text{U}$ ages and discordance calculated for ages >1000 Ma are reported as $^{207}\text{Pb}/^{206}\text{Pb}$ versus $^{206}\text{Pb}/^{238}\text{U}$ ages based on (Bruguiere et al., 2001). Of the seven samples, only one sample, SMC14-43, had a high percentage (25 of 38 analyses) of zircon grains with discordance over

Table 13. Mineral chemistry of alkali feldspar cores and rims for sample SMC16-34.

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$^{4.8.}$ Structural Formula Based on 8 Oxygens

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$^{4.8.}$ Feldspar Components

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<tr>
<td>albite (mol%)</td>
<td>6.84</td>
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<td>anorthite (mol%)</td>
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<td>orthoclase (mol%)</td>
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<td>88.94</td>
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<td>celsian (mol%)</td>
<td>0.61</td>
<td>1.57</td>
<td>1.19</td>
<td>0.93</td>
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$^{4.8.}$ Of the seven samples, only one sample, SMC14-43, had a high percentage (25 of 38 analyses) of zircon grains with discordance over
5%. Appendix E contains all the data. A brief overview of analyzed samples is presented subsequently.

Sample SMC13-132 is a coarse-grained biotite monzo-granite (QAP) with accessory zircon. Secondary minerals include clinozoisite, chlorite, and sericite. The sample contains minor perthite and pervasive myrmekitic texture. Zircon grains show no zonation in BSE images and no response in SEM-CL images (Fig. 13), which is characteristic of metamict zircons. Uranium content ranges from $12020 \pm 830$ ppm to $1080 \pm 300$ ppm and thorium ranges from $2022 \pm 30$ ppm to $107 \pm 8$ ppm (Tab. 14).

![Figure 13. SMC13-132 BSE image showing no zonation and SEM-CL image showing no CL response.](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Uranium Content (ppm)</th>
<th>Thorium Content (ppm)</th>
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<td>SMC13-132</td>
<td>$12020 \pm 830$ ppm to $1080 \pm 300$ ppm</td>
<td>$2022 \pm 30$ ppm to $107 \pm 8$ ppm</td>
</tr>
<tr>
<td>SMC14-09</td>
<td>$1752 \pm 52$ ppm to $303 \pm 26$ ppm</td>
<td>$182 \pm 5$ ppm to $24 \pm 2$ ppm</td>
</tr>
<tr>
<td>SMC14-11</td>
<td>$13610 \pm 940$ ppm to $14 \pm 1$ ppm</td>
<td>$1930 \pm 240$ ppm to $3 \pm 1$ ppm</td>
</tr>
<tr>
<td>SMC14-43</td>
<td>$20800 \pm 2900$ ppm to $1560 \pm 190$ ppm</td>
<td>$7310 \pm 800$ ppm to $40 \pm 8$ ppm</td>
</tr>
<tr>
<td>SMC15-05</td>
<td>$5520 \pm 250$ ppm to $45 \pm 10$ ppm</td>
<td>$3320 \pm 230$ ppm to $24 \pm 4$ ppm</td>
</tr>
<tr>
<td>SMC16-09</td>
<td>$5650 \pm 240$ ppm to $235 \pm 7$ ppm</td>
<td>$132 \pm 5$ ppm to $18 \pm 1$ ppm</td>
</tr>
<tr>
<td>SMC16-22</td>
<td>$8230 \pm 580$ ppm to $17 \pm 1$ ppm</td>
<td>$2110 \pm 350$ ppm to $3 \pm 1$ ppm</td>
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Data from forty-one zircon spot analyses, give $^{206}\text{Pb}/^{238}\text{U}$ ages of ca. 84.0 ± 1.5 Ma to 105.3 ± 1.3 Ma for analyses with <5% discordance (Appendix E, Tab. 15). Plotting the filtered data results in a calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age of 87.4 ± 0.4 Ma (2s.e.m.). These ten data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age of 87.4 ± 0.4 Ma (MSWD = 0.99) and the weighted mean age of 87.4 ± 0.5 Ma (MSWD = 1.18) (Fig. 14).

Table 15. Vein crystallization age, inherited core dates, date range, and outlier ages.

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<th>Inherited Core Dates</th>
<th>Date Range (&lt;5% Discord.)</th>
<th>Outliers (r)=rim (c)=core</th>
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<td>SMC13-132</td>
<td>87.4 ± 0.4 Ma</td>
<td>84.0 ± 1.5 Ma – 105.3 ± 1.3 Ma</td>
<td>60.7 Ma ± 1.1 Ma (r) 103.0 Ma ± 2.1 Ma (c) 119.0 Ma ± 2.8 Ma (c)</td>
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</tr>
<tr>
<td>SMC14-09</td>
<td>93.9 ± 0.5 Ma</td>
<td>92.8 ± 1.5 Ma – 96.5 ± 1.6 Ma</td>
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<tr>
<td>SMC14-11</td>
<td>80.6 ± 0.7 Ma</td>
<td>78.2 ± 1.5 Ma – 107.3 ± 5.1 Ma</td>
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<tr>
<td>SMC14-43</td>
<td>75.5 ± 0.6 Ma</td>
<td>72.3 ± 1.4 Ma – 85.0 ± 1.7 Ma</td>
<td>101.0 ± 1.8 Ma (c)</td>
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<tr>
<td>SMC15-05</td>
<td>79.2 ± 1.2 Ma</td>
<td>71.4 ± 1.2 Ma – 100.7 ± 5.1 Ma</td>
<td>121.0 ± 2.7 Ma (c)</td>
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<tr>
<td>SMC16-09</td>
<td>86.5 ± 0.5 Ma</td>
<td>85.8 ± 1.9 Ma – 131.2 ± 2.2 Ma</td>
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<tr>
<td>SMC16-22</td>
<td>80.3 ± 0.6 Ma</td>
<td>79.4 ± 1.3 Ma – 102.3 ± 2.7 Ma</td>
<td>109.3 ± 2.9 Ma (c) 112.1 ± 2.1 Ma (c)</td>
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Sample SMC14-09 is a coarse-grained biotite granodiorite (QAP) with accessory allanite, apatite, magnetite, and zircon. Secondary minerals include chlorite and sericite. The sample contains minor perthite and some myrmekitic texture. Zircon grains show no zonation in BSE images, however SEM-CL images show zonation with inherited cores and overgrowths in n=10 A

Mean age = 87.3 ± 0.5 Ma

Intercept age = 87.4 ± 0.4 Ma

Figure 14. SMC13-132. (A) KDE showing age grouping used for calculating a mean age of 87.4 ± 0.4 Ma (2s.e.m.). Circles are ages plotted without error and n= total number of dates used. (B) Terra-Wasserburg Concordia diagram showing intercept age of 87.4 ± 0.4 Ma. (C) Weighted mean plot showing calculated mean age of 87.4 ± 0.5 Ma. Error bars are shown at 2 s.e.m.
multiple zircons. One such examples is shown in Fig. 15. Uranium content ranges from 1752 ± 52 ppm to 303 ± 26 ppm and thorium ranges from 182 ± 5 ppm to 24 ± 2 ppm (Tab. 14).

Data from forty-eight zircon spot analyses with <5% discordance give $^{206}\text{Pb}/^{238}\text{U}$ dates of ca. 92.8 ± 1.5 Ma to 96.5 ± 1.6 Ma (Appendix E, Tab. 15). Outlier dates included ca. 60.7 Ma ± 1.1 Ma, 103.0 Ma ± 2.1 Ma, and 119.0 Ma ± 2.8 Ma. Plotting the filtered data results in a calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age of 93.9 ± 0.3 Ma (2s.e.m.). These ten data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age of 94.0 ± 0.5 Ma (MSWD = 0.22) and the weighted mean age of 93.9 ± 0.6 Ma (MSWD = 0.33) (Fig. 16).
Sample SMC14-11 is a coarse-grained biotite-bearing monzo-granite (QAP) with accessory zircon. Secondary minerals include chlorite and sericite. The sample contains pervasive perthite. Zircon grains show no zonation in BSE images and hard to distinguish zonation in some SEM-CL images. Some grains look metamict in SEM-CL however, multiple images show clear zonation with inherited cores and overgrowths (Fig. 17). Uranium content
ranges from $13610 \pm 940$ ppm to $14 \pm 1$ ppm and thorium ranges from $1930 \pm 240$ ppm to $3 \pm 1$ ppm (Tab. 14).

Data from sixty-three zircon spot analyses with <5% discordance give $^{206}\text{Pb}/^{238}\text{U}$ ages of ca. $78.2 \pm 1.5$ Ma to $107.3 \pm 5.1$ Ma (Appendix E, Tab. 15). $^{207}\text{Pb}/^{206}\text{Pb}$ core ages are ca. $1322 \pm 42$ Ma, $1386 \pm 56$ Ma, $1454 \pm 39$ Ma, and $1803 \pm 55$ Ma. Plotting the filtered data results in a calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age $80.6 \pm 0.7$ Ma (2s.e.m.). These five data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age $80.6 \pm 0.6$ Ma (MSWD = 1.40) and the weighted mean age of $80.5 \pm 0.8$ Ma (MSWD = 1.47) (Fig. 18).

Figure 17. SEM-CL image of SMC14-11 zircon grain with rim (black) and core (white) ages indicated.

Data from sixty-three zircon spot analyses with <5% discordance give $^{206}\text{Pb}/^{238}\text{U}$ ages of ca. $78.2 \pm 1.5$ Ma to $107.3 \pm 5.1$ Ma (Appendix E, Tab. 15). $^{207}\text{Pb}/^{206}\text{Pb}$ core ages are ca. $1322 \pm 42$ Ma, $1386 \pm 56$ Ma, $1454 \pm 39$ Ma, and $1803 \pm 55$ Ma. Plotting the filtered data results in a calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age $80.6 \pm 0.7$ Ma (2s.e.m.). These five data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age $80.6 \pm 0.6$ Ma (MSWD = 1.40) and the weighted mean age of $80.5 \pm 0.8$ Ma (MSWD = 1.47) (Fig. 18).
Sample SMC14-43 is a fine-grained leucocratic monzo-granite (QAP) with accessory zircon. Secondary minerals include hematite and sericite. The sample contains some myrmekitic texture. Zircon grains show no zonation in BSE images and are completely black in SEM-CL images (Fig. 19). Uranium content ranges from 20800 ± 2900 ppm to 1560 ± 190 ppm and thorium ranges from 7310 ± 800 ppm to 40 ± 8 ppm (Tab. 14).

Figure 18. SMC14-11. (A) KDE showing age grouping used for calculating a mean age of 80.6 ± 0.7 Ma (2s.e.m.). Circles are ages plotted without error and n= total number of dates used. (B) Terra-Wassburg Concordia diagram showing intercept age of 80.6 ± 0.6 Ma. (C) Weighted mean plot showing calculated mean age of 80.5 ± 0.8 Ma. Error bars are shown at 2 s.e.m.
Data from thirty-four zircon spot analyses give $^{206}\text{Pb}/^{238}\text{U}$ ages of ca. 72.3 ± 1.4 Ma to 85.0 ± 1.7 Ma with an outlier of ca. 101.0 ± 1.7 Ma for analyses with <5% discordance (Appendix E, Tab. 15). Only thirteen age dates have discordance <5%. Therefore, the ten youngest age dates with <5% and Th/U ratio of <0.1 were plotted on a KDE to determine the best fitting age grouping (Fig. 20). Six age dates formed a consistent grouping and were used for calculating the mean age and error of vein crystallization. For these six age dates, the calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age and 2s.e.m. were 75.5 ± 0.6 Ma. These six data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age of 76.1 ± 0.6 Ma (MSWD = 3.00) and the weighted mean is 75.8 ± 0.8 Ma (MSWD = 1.91) (Fig. 20).
Sample SMC15-05 is a medium-grained biotite granodiorite (QAP) with accessory allanite, apatite, magnetite, and zircon. Secondary minerals include clinozoisite, epidote, chlorite, and sericite. The sample contains minor perthite and minor myrmekitic textures. Zircon grains show no zonation in BSE images. Some grains look metamict in SEM-CL however, images show clear zonation with inherited cores and overgrowths apparent in multiple zircons (Fig. 21).
Uranium content ranges from 5520 ± 250 ppm to 45 ± 10 ppm and thorium ranges from 3320 ± 230 ppm to 24 ± 4 ppm (Tab. 14).

Data from thirty-two zircon spot analyses with <5% discordance give $^{206}\text{Pb}/^{238}\text{U}$ dates of ca. 71.4 ± 1.2 Ma to 100.7 ± 5.1 Ma with one date of ca. 121.0 ± 2.7 Ma (Appendix E, Tab. 15). $^{206}\text{Pb}/^{238}\text{U}$ core ages are ca. 576 ± 9 Ma, 597 ± 19 Ma, 641 ± 10 Ma, 686 ± 15 Ma, and 715 ± 11 Ma. Plotting the filtered data results in a calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age 79.2 ± 1.2 Ma (2s.e.m.). These eight data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age 79.5 ± 1.4 Ma (MSWD = 2.90) and the weighted mean age of 79.5 ± 1.3 Ma (MSWD = 5.10) (Fig. 22).

Figure 21. SEM-CL image of SMC15-05 zircon grain with ages indicated.
Sample SMC16-09 is a coarse-grained biotite-bearing monzo-granite (QAP) with accessory zircon. Secondary minerals include chlorite and sericite. The sample contains pervasive perthite. Zircon grains show no zonation in BSE images, however SEM-CL images show clear zonation with inherited cores and overgrowths (Fig.23). Uranium content ranges from $5650 \pm 240$ ppm to $235 \pm 7$ ppm and thorium ranges from $132 \pm 5$ ppm to $18 \pm 1$ ppm (Tab. 14).
Data from thirty-nine zircon spot analyses give $^{206}\text{Pb}/^{238}\text{U}$ ages of ca. 85.8 ± 1.9 Ma to 131.2 ± 2.2 Ma for analyses with <5% discordance (Appendix E, Tab. 12). A wide dispersion of ten youngest dates (ca. 86 to 108 Ma) is observed for low discordances (<1%). Therefore, to narrow the dispersion, the discordance filter was raised to <3% which resulted in the ten youngest age dates having an age dispersion of 85.8 ± 1.9 Ma to 91.3 Ma ± 1.8 Ma. These ten ages were plotted on a KDE to determine the best fitting age grouping. Six age dates were used for calculating the mean age and error of vein crystallization. For these six age dates, the calculated $^{206}\text{Pb}/^{238}\text{U}$ mean age and 2s.e.m. were 86.5 ± 0.5 Ma. Plotting these six data points on a Tera-Wasserburg Concordia diagram and give an intercept age of 86.7 ± 0.7 Ma (MSWD = 0.42) and the weighted mean is 86.7 ± 0.6 Ma (MSWD = 1.4) (Fig. 24).

Figure 23. SEM-CL image of SMC16-09 zircon grain with ages indicated.
Sample SMC16-22 is a coarse-grained hornblende granodiorite (QAP) with accessory apatite, magnetite, and zircon. Sericite is the only secondary mineral observed. This sample contains minor perthite. Zircon grains show no zonation in BSE images. Some grains look metamict in SEM-CL, however, images show clear zonation with inherited cores and overgrowths apparent in multiple zircons (Fig. 25). Uranium content ranges from 8230 ± 580 ppm to 17 ± 1 ppm and thorium ranges from 2110 ± 350 ppm to 3 ± 1 ppm (Tab. 14).
Data from fifty-seven zircon spot analyses with <5% discordance give \(^{206}\text{Pb}/^{238}\text{U}\) ages of ca. 79.4 ± 1.3 Ma to 102.3 ± 2.7 Ma (Appendix E, Tab. 15). Outliers include ca. 109.3 ± 2.9 Ma and 112.1 ± 2.1 Ma. Analyses also give \(^{206}\text{Pb}/^{238}\text{U}\) core ages are ca. 317 ± 7 Ma, 446 ± 7 Ma, and 666 ± 13 Ma, 1074 ± 49 Ma, 1194 ± 72 Ma, 1238 ± 45 Ma, and 1503 ± 26 Ma. Plotting the filtered data results in a calculated \(^{206}\text{Pb}/^{238}\text{U}\) mean age 80.3 ± 0.6 Ma (2s.e.m.). These seven data points were also plotted on a Tera-Wasserburg Concordia diagram and give an intercept age 80.5 ± 0.6 Ma (MSWD = 0.81) the weighted mean age of 80.4 ± 0.8 Ma (MSWD = 1.18) (Fig. 26).

The sample of the leucocratic granite phase of the IB, SMC15-05 has a crystallization age of 79.2 ± 1.2 Ma (2s.e.m.) with inherited core ages of 576 ± 9 Ma, 597 ± 19 Ma, 641 ± 10 Ma, 686 ± 15 Ma, and 715 ± 11 Ma (Appendix E, Tab. 15).
Vein samples analyzed here have crystallization ages that range in age from 75.5 ± 0.6 Ma to 93.9 ± 0.5 Ma (2s.e.m.). In addition, numerous inherited cores are present, and include ages of 1322 ± 42 Ma, 1386 ± 56 Ma, 1454 ± 39 Ma, and 1803 ± 55 Ma in SMC14-11, 317 ± 7 Ma, 446 ± 7 Ma, 666 ± 13 Ma, 1074 ± 49 Ma, 1194 ± 72 Ma, 1238 ± 45 Ma, and 1503 ± 26 Ma in SMC16-22 (Appendix E, Tab. 15).
CHAPTER V. DISCUSSION

Vein samples analyzed for U/Pb zircon geochronology include three biotite-bearing monzo-granites (QAP), one biotite granodiorite (QAP), one leucocratic monzo-granite (QAP), and one hornblende-bearing granodiorite (QAP). A biotite-bearing granodiorite (QAP) (SMC15-05) sampled from a vein mapped as the leucocratic granite phase of the IB (Field notes, B. Dutrow) was also dated. With a U/Pb age date of 79.2 ± 1.2 Ma and a biotite-bearing granodiorite (QAP) composition, this suggests that SMC15-05 is a phase of the IB and therefore can be used as a reference for IB potential source material for OM-CL plagioclase response comparisons. OM-CL plagioclase colors of this sample (SMC15-05) are moderate green, brown, red, and orange. Moderate green is the distinct color for this source (IB). Brown, red, and orange OM-CL plagioclase responses are also observed in the STB, suggesting that these colors are not distinct responses for either the IB or STB.

For the six vein samples, zircon dates with <5% discordance and < 0.1 U/Th ratio give a range from 72.3 ± 1.2 Ma to 131.0 ± 2.2 Ma (Tab. 15). This range of zircon formation ages suggests that these veins may reflect multiple generations of igneous activity in the area. In addition, this suggests that an extended period of magmatism occurred in this region for at least 49 Ma.

Vein crystallization ages, (calculated using the youngest age peak) for six SMC vein samples, have a range from 75.5 ± 0.6 Ma to 93.9 ± 0.5 Ma (Tab.15). Supplementing these samples by seven samples from Ma (2015) gives an age range of 75.5 ± 0.6 Ma to 101 ± 1 Ma. These ages are consistent with IB crystallization ages (Gaschnig et al., 2010; Kiilsgaard and Lewis, 1985). This consistency suggests the IB was juxtaposed to the SMC before the onset of vein emplacement.
The difference in the oldest age of zircon formation (131.0 ± 2.2 Ma) and vein crystallization onset (101 ± 1 Ma) indicates that magmatism and zircon formation was taking place for ca. 30 Ma before the onset of vein formation.

Inherited zircon cores were observed in two (SMC14-11, SMC16-22) of the six vein samples analyzed in this study (Appendix D). Inherited core ages ranged from 317 ± 7 Ma to 1803 ± 55 Ma and include one Paleoproterozoic age, seven Mesoproterozoic age, one Neoproterozoic age, one Ordovician age, and one Pennsylvanian age.

Inherited zircon cores may provide insight into the likely basement/sub-SMC rocks in the region. While ages are younger than the xenocrystic 1.7 – 1.8 Ga zircon found in Cretaceous–Eocene granitoids (Foster et al., 2006; Gaschnig et al., 2008), the data here suggest rocks containing Proterozoic, Ordovician, and Pennsylvanian zircons were tapped for melting or assimilated during magma ascent.

The majority of inherited core ages found in these two vein samples fall within the range of inherited core ages found in Atlanta lobe IB rocks (Gaschnig et al., 2013). Gaschnig and colleagues found the northern Atlanta lobe of the IB to contain inherited cores with the majority of ages ranging from 2000 to 1000 Ma, with peaks at 1700 to 1600 Ma and 1500 to 1400 Ma. Two cores of Ordovician age were also found. The source material of Proterozoic inherited cores was considered to be Neoproterozoic metasedimentary rocks found near this region (Lewis et al., 2007; Lewis et al., 2010). The Ordovician inherited cores were suggested to be from plutons just east and north of the northern Atlanta lobe (Lund et al., 2010). The majority of inherited core ages in SMC veins range between 2000 and 1000 Ma with no apparent peaks. With one inherited core that is Ordovician in age the SMC inherited cores match the age distribution in Gaschnig et al. (2013), suggesting they may have similar sources.
In the thirteen vein samples with thin sections and U/Pb zircon ages (this study and Ma, 2015), OM-CL plagioclase colors include bright green, moderate green, brown, moderate blue, red, orange, and yellow. Bright and moderate green plagioclase colors are predominant (occurring in ten samples) and are consistent with OM-CL plagioclase responses observed in IB samples. A caveat, however, is that five of these ten samples also contain a moderate blue-colored plagioclase consistent with responses observed in AM. This suggests that, while plagioclase can be consistent with IB sources, some IB plagioclase shows a color consistent with anatectic melts. Brown, red, and orange are found in multiple potential sources and cannot be directly linked to a distinct source and are, therefore, not diagnostic. Yellow is observed in one vein sample but not observed in the potential source samples. However, only a few samples of each potential source were examined; with additional samples additional colors might be apparent. Ten of thirteen vein samples exhibiting OM-CL plagioclase responses matching IB source samples indicates that, in these samples, plagioclase OM-CL responses and age correlate (Tab. 16).

Extending the CL color and age information to veins without age determinations suggests that veins exhibiting the distinct OM-CL plagioclase responses can be attributed to potential sources. Bright green and/or moderate green colors are consistent with the IB. Veins with pink plagioclase OM-CL are inferred to be STB and veins with turquoise green and/or blue responses are inferred to be AM. However, no samples with pink or blue plagioclase have ages, thus making them the highest priority for future geochronology.
Twelve vein samples without age dates contain OM-CL plagioclase responses that suggest specific sources. Three of the twelve contain moderate green, consistent with the IB, two contain blue plagioclase consistent with AM, and one contains pink plagioclase consistent with the STB (Tab. 16). Two veins display both green and blue plagioclase which are distinct to the

<table>
<thead>
<tr>
<th>Sample Unit</th>
<th>Sample Number</th>
<th>Distinct OM-CL Plagioclase Color</th>
<th>Age ± (2σ)</th>
<th>Likely Source by OM-CL</th>
<th>Likely Source with Addition of Petrography</th>
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<tr>
<td>Leucocratic Granite Phase of IB</td>
<td>SMC15-05</td>
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<td>IB</td>
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<td>Age Dated Veins</td>
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<td>SMC14-43</td>
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<td>95 ± 1 Ma*</td>
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</table>

* = ages from (Ma, 2015)  ND = Not determined (OM-CL or petrography not distinct to a source)
IB and AM (Tab. 16). An additional two samples contain both green and pink plagioclase which are distinct colors for the IB and STB (Tab. 16). Two veins contain plagioclase with colors that do not match any potential source.

A potential reason for a single sample matching multiple sources could be due to post crystallization overprinting of primary plagioclase CL responses by altering fluids. Overprinting by altering fluids results in vein samples having single plagioclase grains with a primary plagioclase color distinct to one source observed with a secondary overprinting plagioclase response that matches the distinct color of another source. Pervasive overprinting causes difficulty in distinguishing the primary from the secondary CL responses and results in assigning multiple likely sources to a single sample.

Several caveats of the CL method should be taken into account. OM-CL feldspar imaging is a qualitative method, thus making a direct comparison between samples more difficult than a quantitative method. For example, distinguishing between both groupings of a color and differing shades within a color group can be difficult, especially if OM-CL work is performed with differing operating conditions or by multiple investigators whose perception of color may differ (e.g. bright green vs moderate green). Only a small subset of potential source rocks has been imaged. With the IB composed of numerous intrusions (e.g. Gaschnig et al., 2010), more samples are needed to characterize the variability in the region.

A partial solution is to quantify the CL response by using spectroscopic methods. Use of OM-CL spectrum can distinguish two samples with the same OM-CL response (e.g. both Al-O-Al centers and REEs cause a blue OM-CL response in plagioclase (Götze, 2012; Götze et al., 1999). This method is another approach to improve sample matching and will allow for use of cathodoluminescent activators to categorize samples.
Rock classification for samples of the two potential vein source batholiths include syenogranitic, monzo-granitic, and granodioritic. The STB was found to have both syeno-granites (QAP) and monzo-granites (QAP). The IB was found to only have granodiorites (QAP). The six age-dated veins of this study and seven added from Ma (2015) include (five) monzo-granites (QAP) and (six) granodiorites (QAP). Due to STB samples and IB aged veins both including monzo-granites (QAP), this indicates that monzo-granites (QAP) are not distinct to one potential source. Therefore, only granodiorites (QAP) are distinctly found in the IB and only syeno-granites (QAP) are distinctly found in the STB, matching previous work in the region (Bennett, 1980; Bennett and Knowles, 1985; Kiilsgaard and Lewis, 1985; Reid, 1963).

Veins without age dates include five of twelve samples that are monzo-granites, four that are granodiorites likely sourced by the IB, and three that are syeno-granites likely sourced by the STB (Tab. 16). Adding the likely source determinations by rock composition to the likely vein sources determined by OM-CL plagioclase responses reduces the number of likely sources per sample and determines a likely source for samples. Two vein samples of unknown age had multiple likely vein sources reduced to a single likely source and one sample with an undetermined likely source by OM-CL plagioclase response had one determined by sample composition (Tab. 16). However, of the seven samples with likely sources determined by composition one did not match either of the likely sources as determined by OM-CL plagioclase responses. A potential reason could be due to the composition of the final melt evolving from the source.
Evaluating the spatial distribution of veins of unknown source shows no distinct locations. The Sawtooth batholith and anatetic melt sources show no apparent grouping. However, the Idaho batholith shows grouping in the east-central portion of the SMC (Fig. 27).

Figure 27. Google earth map of SMC showing the likely source of all veins of unknown source.

Zirconium saturation temperatures calculated for samples have an overlapping range of temperatures: STB of 658 to 737 °C with an average of 688 ± 32 °C (1σ) and a range for the IB of 592 to 693 °C with an average of 648 ± 51 °C (1σ). Thus, the zirconium saturation temperature averages are within error and are not helpful to determine potential sources.

Major element chemistry of samples analyzed by EMP have a decrease in anorthite content from core to rim with change in OM-CL plagioclase responses from green to brown (SMC13-132) and brown to red (SMC16-34, Fig. 11, 12). Rims of grains with quenched luminescence correspond to lower anorthite content. This chemical change suggests that calcium may have been leached in an altering fluid. SMC13-132 contains blue alteration on plagioclase
rims suggesting potential rare earth elements (Götze et al., 1999). SMC16-34 contains dark red alteration on plagioclase rims suggesting oxidation of Fe$^{2+}$ to Fe$^{3+}$ by altering fluids (Geake et al., 1973).

Major element feldspar mineral chemistry does correlate to OM-CL plagioclase responses. However, luminescence is caused by trace elements and not the major elements which were measured for feldspar mineral chemistry. This suggests that alteration of the rims of compositionally zoned plagioclase by fluids that mobilize calcium results in the apparent observed major element correlation to OM-CL plagioclase response.
CHAPTER VI. CONCLUSIONS

U/Pb ages of zircons found in the six felsic samples studied here from spatially throughout the SMC have an age range of $72.3 \pm 1.2$ Ma to $131.0 \pm 2.2$ Ma. Such a range in ages indicates that pulses of magmatism occurred in this area for at least 49 million years, beginning by 131 Ma. Vein crystallization ages give an age range of $75.5 \pm 0.6$ Ma to $101 \pm 1$ Ma, indicating 26 Ma of vein emplacement. These ages are consistent with those of IB emplacement and suggest the SMC was likely juxtaposed near the IB at that onset of vein formation.

Inherited zircon cores ($317 \pm 7$ Ma to $1803 \pm 55$ Ma) from the six veins have ages throughout the Proterozoic, with a few ages in the Ordovician and Pennsylvanian. This range indicates melting or assimilation of older zircons with Proterozoic, Ordovician, and Pennsylvanian ages.

OM-CL plagioclase responses correlate with U/Pb geochronology data for the IB. This correlation indicates that for select samples, plagioclase OM-CL responses provide a first order approximation to a possible source in the absence of geochronology.
APPENDIX A. PETROGRAPHIC REPORTS

SAMPLE: LF-12

Last update: 2/26/20

Petrographer: Kyle Tollefson

LOCATION: 44°09.765N, 115°02.176W
COLLECTOR: Barbara Dutrow

DATE COLLECTED:

AGE DATE:

ROCK TYPE: Hornblende-bearing Biotite Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline megacrysts within matrix of plagioclase, quartz, and minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (22%) [0.25-6 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization.

**Microcline** (40%) [5-10 mm] Subhedral to euhedral megacrysts with pervasive perthitic intergrowths. Grains also exhibit carlsbad twinning and major sericite alteration.

**Quartz** (28.3%) [0.25-4 mm] Subhedral to euhedral grains with slight sweeping extinction.

**Biotite** (9.3%) [<2.5 mm] Anhedral to subhedral laths with brown to green pleochroism and birds eye extinction. Grains exhibit pervasive chloritization.

**Hornblende** (tr%) [<0.2-1 mm] Subhedral to euhedral grains with red to brown pleochroism and simple twinning.

**Apatite** (tr%) [<0.125 mm] Euhedral colorless grains with moderate relief and 1st order birefringence.

**Sericite** (tr%) [<0.1 mm] Subhedral colorless laths exhibiting high birefringence.

**Magnetite** (tr%) [<0.25 mm] Anhedral opaque grains exhibiting brownish-grey, isotropic, and pitted nature in reflective light.

**Chlorite** (tr%) [0.1-2.5 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.125 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic porphyritic texture dominated by microcline megacrysts in a matrix of, plagioclase, quartz, and biotite, respectively. Microcline has pervasive perthitic exsolution.
ALTERATION: Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.

OPTICAL CATHODOLUMINESCENCE
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with pervasive pink albite exsolution (perthite). Highly altered (sericitized) cores of plagioclase ranging in color from pink to brown.

**COMMENTS AND INTERPRETATION:**
Based on the QAP ratio of 31.34:44.30:24.36 of the likely primary magmatic minerals, this rock is best classified as Hornblende-bearing Biotite Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Microcline + quartz) > (Biotite + opaques) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed access to aqueous fluids associated with alteration.

Pervasive perthitic microcline, cl responses of pervasive pink albite exsolution, and sample location suggest this sample is part of the Sawtooth Batholith.
SAMPLE: SMC 11-12

LOCATION: 44°01.138N, 114°56.427W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 21st 2011

AGE DATE: 47.18 +0.54 Ma

ROCK TYPE: Muscovite-bearing Biotite Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (20%) [0.1-1 mm] Subhedral to euhedral grains exhibiting albite twinning and minor seritization.

Microcline (35%) [0.1-3 mm] Anhedral to subhedral grains exhibiting pervasive perthite and major seritization.

Quartz (40%) [0.125-3.75 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction and checkerboard extinction.

Biotite (5%) [0.25-3 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and minor chloritization.

Sericite (0.3%) [0.1 mm] Anhedral to subhedral colorless laths exhibiting high birefringence.

Hematite (tr%) [0.1 mm] Anhedral to subhedral opaque grains with red rims.

Magnetite (tr%) [0.075 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Chlorite (tr%) [0.1-0.75 mm] Subhedral green laths replacing biotite.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits pervasive perthite texture.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with pervasive pink albite exsolution (perthite). Plagioclase ranging in color from neon orange to neon green.

**COMMENTS AND INTERPRETATION:**
Based on the QAP ratio of 42.11:36.84:21.05 of the likely primary magmatic minerals, this rock is best classified as Muscovite-bearing Biottite Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (plagioclase+opaques) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 47.18 +0.54 Ma, pervasive perthitic microcline, neon orange plagioclase CL responses, and sample location suggest this sample is part of the Sawtooth Batholith.
SAMPLE: SMC 11-13

LOCATION: 44°06.047N, 114°57.670W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 22nd 2011

AGE DATE: 46.50+0.48 Ma

ROCK TYPE: Hornblende Biotite-bearing Syeno-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline phenocrysts in a matrix of plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (11%) [0.1-2 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (52.7%) [0.5-5 mm] Anhedral grains exhibiting pervasive perthite, carlsbad twinning, and major seritization. Pervasive myrmekites or graphic texture of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (33%) [0.5-2, 0.025-0.1 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction.

**Biotite** (3.3%) [0.25-2 mm] Anhedral to subhedral laths exhibiting brown to reddish brown pleochroism, birds eye extinction, and minor chloritization.

**Hornblende** (tr%) [0.4 mm] Subhedral to euhedral grains exhibiting red to beige pleochroism.

**Hematite** (tr%) [0.4 mm] Euhedral opaque to dark red grains.

**Magnetite** (tr%) [0.5-0.25 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Chlorite** (tr%) [0.05 mm] Subhedral green laths replacing biotite.

TEXTURES: Allotriomorphic porphyritic texture dominated by microcline megacrysts in a plagioclase, quartz, and biotite matrix, respectively. Microcline exhibits pervasive perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with pervasive pink albite exsolution (perthite). Highly altered (seritized) cores of plagioclase ranging in color from pink to brown.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 34.13:54.50:11.38 of the likely primary magmatic minerals, this rock is best classified as Hornblende Biotite-bearing Syeno-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Hornblende) > (plagioclase+opales) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 46.50+0.48 Ma, Syeno-Granite classification, pervasive perthitic microcline, pink plagioclase and pervasive albite exsolution CL responses, and sample location suggest this sample is part of the Sawtooth Batholith.
SAMPLE: SMC 13-39  

Last update: 2/26/20  
Petrographer: Kyle Tollefson

LOCATION: 44°12.772N, 115°03.923W  
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 14th 2013

AGE DATE:

ROCK TYPE: Hornblende Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

- **Plagioclase** (22.7%) [0.1-10 mm] Subhedral grains exhibiting albite twinning and moderate seritization.
- **Microcline** (30.7%) [0.25-9 mm] Subhedral grains exhibiting pervasive perthite, and moderate seritization.
- **Quartz** (43%) [0.1-7.5 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction.
- **Biotite** (3.7%) [0.1-1.75 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.
- **Hornblende** (tr%) [0.3 mm] Subhedral grains exhibiting dark reddish brown pleochroism.
- **Magnetite** (tr%) [<0.75 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.
- **Sericite** (tr%) [<0.1 mm] Subhedral colorless laths exhibiting high birefringence.
- **Epidote** (tr%) [<0.1 mm] Subhedral light green grains exhibiting moderate relief and high birefringence.
- **Chlorite** (tr%) [0.05-0.2 mm] Subhedral green laths replacing biotite.
- **Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate to dark blue alkali feldspar with pervasive pink albite perthite. Brow to red/pink plagioclase with highly altered cores.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 44.61:31.85:23.55 of the likely primary magmatic minerals, this rock is best classified as Hornblende Biotite-bearing Monzo-Granite with secondary alteration to muscovite-sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Biotite + opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Pervasive perthitic microcline and sample location suggest this sample is part of the Sawtooth Batholith.
SAMPLE: SMC 13-42

LOCATION: 44°12.510N, 115°04.257W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 14th 2013

AGE DATE:

ROCK TYPE: Hornblende-bearing Biotite Syeno-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

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MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (18.7%) [0.1-10 mm] Subhedral grains exhibiting albite twinning and major seritization.

Microcline (48.7%) [0.25-9 mm] Subhedral to euhedral grains exhibiting pervasive perthite, carlsbad twinning, and moderate seritization.

Quartz (27.7%) [0.1-7.5 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction.

Biotite (5%) [0.1-2 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Hornblende (tr%) [0.2-0.75 mm] Subhedral grains exhibiting dark reddish brown to brown pleochroism.

Magnetite (tr%) [<0.75 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Sericite (tr%) [<0.1 mm] Subhedral colorless laths exhibiting high birefringence.

Hematite (tr%) [<0.5] Anhedral opaque grains with red rims.

Epidote (tr%) [<0.1 mm] Subhedral light green grains exhibiting moderate relief and high birefringence.

Apatite (tr%) [<0.1 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

Chlorite (tr%) [0.1-1.5 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

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TEXTURES: Hypidiomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture.
**ALTERATION:** Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.

**OPTICAL CATHODOLUMINESCENCE**

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 29.13:51.21:19.66 of the likely primary magmatic minerals, this rock is best classified as Hornblende-bearing Biotite Syeno-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is (Plagioclase + microcline) > (Biotite + opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Syeno-Granite classification, pervasive perthitic microcline, and sample location suggest this sample is part of the Sawtooth Batholith.
SAMPLE: SMC 11-14

LOCATION: 44°06.056N, 114°57.566W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 22nd 2011
AGE DATE: 85.00+2.4 Ma

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic equigranular granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (42.3%) [0.3-2 mm] Subhedral to euhedral grains exhibiting albite twinning and moderate seritization.

Microcline (21.7%) [0.1-5 mm] Anhedral to subhedral grains exhibiting minor perthite and minor seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (32%) [0.1-3 mm] Anhedral grains exhibiting minor sweeping extinction.

Biotite (3.3%) [0.05-0.75 mm] Anhedral to subhedral laths exhibiting brown to reddish brown pleochroism, birds eye extinction, and minor chloritization.

Sericite (tr%) [<0.1 mm] Subhedral colorless laths exhibiting high birefringence.

Apatite (tr%) [<0.1 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

Magnetite (tr%) [0.05-0.25 mm] Anhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Chlorite (tr%) [0.1 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.05 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained equigranular texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits minor perthite. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Dark blue alkali feldspar and moderate to dark green plagioclase. Oscillatory zoning present in plagioclase and myrmekitic texture observed.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 33.33:22.60:44.06 of the likely primary magmatic minerals, this rock is best classified as Muscovite Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (plagioclase) > (biotite + opaques) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 85.00+2.4 Ma, Granodiorite classification, myrmekitic texture, green plagioclase with oscillatory zoning CL responses, and sample location suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-19

LOCATION: 44°09.278N, 115°03.085W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 92±1Ma

ROCK TYPE: Hornblende-bearing Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (35.3%) [0.25-8 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

Microcline (19%) [0.25-2.5 mm] Anhedral to subhedral grains exhibiting, minor perthite, and minor seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (36%) [0.25-8 mm] Anhedral to subhedral grains exhibiting moderate sweeping extinction.

Biotite (6.7%) [0.1-5 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and minor chloritization.

Sericite (1.7%) [<0.5 mm] Subhedral colorless laths exhibiting high birefringence.

Apatite (tr%) [<0.25 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

Clinozoisite (tr%) [0.01-1 mm] Anhedral to subhedral colorless grains with moderate relief and lst order birefringence.

Hornblende (1.3%) [1-5 mm] Subhedral to euhedral grains exhibiting green to brown pleochroism and 60-120 clevage.

Chlorite (tr%) [0.1-0.75 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits minor perthite. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate to dark blue alkali feldspar and moderate to brown plagioclase. Myrmekitic texture and carbonate minerals observed.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 39.87:21.04:39.09 of the likely primary magmatic minerals, this rock is best classified as Hornblende-bearing Biotite Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 92±1 Ma, Granodiorite classification, minor perthitic microcline, myrmekitic texture, and sample location suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-21

LOCATION: 44°09.147N, 115°03.081W
COLLECTOR: Chong Ma

DATE COLLECTED: 
AGE DATE: 92±1 Ma

ROCK TYPE: Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with foliated biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (33%) [0.2-2.5 mm] Subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (15%) [0.1-4 mm] Anhedral to subhedral grains exhibiting minor perthite, and moderate seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (40%) [0.01-8 mm] Anhedral to subhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

**Biotite** (11.7%) [0.2-1.5 mm] Subhedral laths with dark brown to tan pleochroism, birds eye extinction, and minor chloritization. Biotites are foliated suggesting magma flow or syndeformational crystallization.

**Sericite** (0.7%) [<0.5 mm] Subhedral colorless laths exhibiting high birefringence.

**Clinozoisite** (tr%) [<1 mm] Anhedral colorless grains with moderate relief and 1st order birefringence.

**Allanite** (tr%) [<0.3 mm] Anhedral to subhedral light brown grains exhibiting high relief and 1st order birefringence.

**Apatite** (tr%) [<0.2 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

**Magnetite** (tr%) [<0.1 mm] Subedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Chlorite** (tr%) [0.2 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibiting minor perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.
ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.

OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with red zonation. Moderate green and brown plagioclase. Myrmekitic texture observed.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 45.45:17.05:37.50 of the likely primary magmatic minerals, this rock is best classified as Biotite Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Biotites are foliated suggesting magma flow or syndeformational crystallization. Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 92±1 Ma, Granodiorite classification, minor perthitic microcline, myrmekitic texture, and sample location suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-25

Last update: 2/26/20

Petrographer: Kyle Tollefson

LOCATION: 44°05.510N, 114°57.557W
COLLECTOR: Chong Ma

DATE COLLECTED: 

AGE DATE: 89±1 Ma

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (39%) [0.5-2.5 mm] Anhedral to subhedral grains exhibiting faint albite twinning and moderate sericitization.

Microcline (18%) [0.25-1.5 mm] Anhedral to subhedral grains exhibiting minor perthite and moderate sericitization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (41%) [0.25-4.5 mm] Anhedral grains exhibiting minor sweeping extinction.

Biotite (1%) [<0.5 mm] Subhedral laths exhibiting light brown to brown pleochroism, birds eye extinction, and moderate chloritization.

Sericite (0.3%) [<1.75 mm] Subhedral colorless laths exhibiting high birefringence.

Magnetite (tr%) [0.05-0.4 mm] Anhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Apatite (tr%) [<0.125 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

Chlorite (tr%) [0.05 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.2 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Dark blue alkali feldspar and moderate to dark green plagioclase. Oscillatory zoning present in plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 41.84:18.37:39.80 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite + opaques) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 89±1 Ma, Granodiorite classification, myrmekitic texture, green plagioclase with oscillatory zoning in CL, and sample location suggest this sample is part of the Idaho Batholith.
SAMPLE: MC13ST-05

LOCATION: 44°08.494N, 115°00.023W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 78±4 Ma

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (20%) [0.05-4 mm] Anhedral to subhedral grains exhibiting kink structures (deformed albite twinning) and major seritization.

**Microcline** (36%) [0.1-5 mm] Anhedral to subhedral grains exhibiting tartan twinning/ minor perthite and moderate seritization.

**Quartz** (43%) [0.05-8 mm] Anhedral grains exhibiting major sweeping extinction. Recrystallized quartz.

**Biotite** (0.7%) [0.1-2.25 mm] Subhedral laths with green to brown pleochroism and major chloritization.

**Magnetite** (tr%) [<0.2 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Sericite** (tr%) [<0.5 mm] Subhedral colorless laths exhibiting high birefringence.

**Clinozoisite** (tr%) [<0.1 mm] Anhedral colorless grains with moderate relief and lst order birefringence.

**Epidote** (tr%) [<0.1 mm] Subhedral pale green grains with moderate relief and high birefringence.

**Apatite** (tr%) [<0.2 mm] Subhedral to euhedral colorless grains with moderate relief and 1st order birefringence.

**Hematite** (tr%) [<0.1 mm] Anhedral opaque grains with red edges.

**Chlorite** (tr%) [0.1-1 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline has perthitic exsolution. The kink banding in plagioclase and recrystallization in the quartz indicates post-crystallization deformation.
**ALTERATION:** Pervasive metasomatic/hydrothermal alteration from biotite to chlorite, plagioclase to sericite/muscovite.

**OPTICAL CATHODOLUMINESCENCE**

Mineral abbreviations taken from (Whitney and Evans, 2010). Light to moderate blue alkali feldspar with extensive red alteration (Fe3+ from fluids) and brown plagioclase with extensive alteration.

**COMMENTS AND INTERPRETATION:**

Based on the QAP ratio of 43.43:36.36:20.20 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the plagioclase deformation bands, quartz deformation features and allowed access to aqueous fluids associated with alteration.

An age date of 78±4 Ma, and red zonation in CL suggest this sample is part of the Idaho Batholith.
SAMPLE: MC13ST-14

LOCATION: 44°08.455N, 115°00.299W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 77±1 Ma

ROCK TYPE: Biotite–bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite and muscovite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (23.3%) [0.2-12 mm] Subhedral exhibiting kink structures (deformed albite twinning) and moderate seritization.

Microcline (38.7%) [0.1-6 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and moderate seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (33.3%) [0.05-8 mm] Anhedral grains exhibiting moderate sweeping extinction. Resorption/recrystallization boundaries.

Biotite (4.3%) [0.1-5 mm] Anhedral to subhedral laths with green to brown pleochroism, birds eye extinction, and moderate chloritization.

Sericite (0.3%) [0.05-0.75 mm] Subhedral colorless laths exhibiting high birefringence.

Magnetite (tr%) [<0.2 mm] Subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Apatite (tr%) [<0.1 mm] Subhedral to euhedral colorless grains with moderate relief and 1st order birefringence.

Chlorite (tr%) [0.1-1 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.05 mm] Euhedral colorless grains with high relief and high birefringence.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar and moderate green plagioclase altered blue. Yellow apatite also present.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 34.94:40.61:24.45 of the likely primary magmatic minerals, this rock is best classified as Biotite–bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite + opaques) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the plagioclase deformation bands, quartz deformations features, and allowed access to aqueous fluids associated with alteration.

An age date of 77±1 Ma, myrmekitic texture, and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: MC13ST-18

LOCATION: 44°08.566N, 114°59.223W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 92±1Ma

ROCK TYPE: Allanite-bearing Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, equigranular, medium-grained phaneritic granitoid chiefly composed of orthoclase, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (28%) [0.1-2.5 mm] Subhedral grains exhibiting albite twinning and minor seritization.

**Microcline** (12%) [0.1-2.5 mm] Anhedral to subhedral grains exhibiting minor perthite.

**Quartz** (50%) [0.1-2.5 mm] Anhedral grains exhibiting minor sweeping extinction.

**Biotite** (9%) [0.05-0.75 mm] Subhedral to euhedral laths with light brown to moderate brown pleochroism and birds eye extinction.

**Apatite** (tr%) [<0.1 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

**Allanite** (5%) [0.01-0.5 mm] Subhedral to euhedral equant grains with brown to reddish brown pleochroism, high relief, and high birefringence.

**Clinozoisite** (tr%) [<0.1 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

**Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic medium-grained, equigranular texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline has minor perthitic exsolution.

ALTERATION: Minor metasomatic/hydrothermal alteration from plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with moderate green and moderate blue plagioclase.

**COMMENTS AND INTERPRETATION:**
Based on the QAP ratio of 55.56:13.33:31.11 of the likely primary magmatic minerals, this rock is best classified as Allanite-bearing Biotite Granodiorite with secondary alteration to muscovite/sericite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite-granodiorite subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite.

An age date of 92±1 Ma, Granodiorite classification, minor perthitic microcline, and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-04

LOCATION: 44°09.248N, 115°00.017W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 92±1 Ma

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (16.3%) [0.01-6 mm] Subhedral grains exhibiting albite twinning and minor seritization.

**Microcline** (25.3%) [0.1-5 mm] Anhedral to subhedral grains exhibiting pericline twinning and minor perthite.

**Quartz** (54.7%) [0.01-4 mm] Anhedral grains exhibiting major sweeping extinction. Recrystallized quartz.

**Biotite** (3%) [<0.75 mm] Subhedral to euhedral laths with light brown to brown pleochroism, birds eye extinction, and moderate chloritization. Biotites are foliated suggesting-magma flow or syn-deformational crystallization.

**Clinozoisite** (tr%) [<0.1 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

**Magnetite** (tr%) [<0.05 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Chlorite** (tr%) [0.1-0.25 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.05 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Grains are aligned, visible in biotite. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar, moderate green and moderate blue plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 56.80:26.27:16.93 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite-granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (Microcline + Quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Biotites are foliated suggesting-magma flow or syndeformational crystallization. Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 92±1 Ma and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-08

LOCATION: 44°09.174N, 114°59.395W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 99±1 Ma

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white with reddish-orange alterations, fine-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (40%) [0.25-2 mm] Subhedral grains exhibiting albite twinning and minor seritization.

Microcline (20%) [0.2-0.5 mm] Subhedral grains exhibiting pericline twinning and minor seritization.

Quartz (40%) [0.1-4 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction.

Biotite (0.7%) [<0.25 mm] Subhedral laths with brown to green pleochroism, birds eye extinction, and moderate chloritization.

Sericite (tr%) [<0.1 mm] Subhedral to euhedral colorless laths exhibiting high birefringence.

Clinozoisite (tr%) [<0.01 mm] Anhedral colorless grains with moderate relief and 1st order birefringence.

Magnetite (tr%) [<0.1 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Hematite (tr%) [<0.05 mm] Anhedral opaque grains with red rims. Found filling fractures and along grain boundaries.

Chlorite (tr%) [0.1 mm] Subhedral green laths replacing biotite.

TEXTURES: Hypidiomorphic fine-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite, plagioclase to sericite/muscovite, and precipitation of hematite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with moderate green and moderate blue plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 40.00:20.00:40.00 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite-granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Post-crystallization deformation likely allowed excess to aqueous fluids associated with alteration and precipitation of hematite.

An age date of 99±1 Ma, Granodiorite classification, and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-10

LOCATION: 44°08.485N, 115°00.587W
COLLECTOR: Chong Ma

DATE COLLECTED: 

AGE DATE: 84±1Ma

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (35.3%) [0.1-8 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (13%) [0.25-4 mm] Subhedral grains exhibiting faint pericline twinning, minor perthite, and moderate seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (45.3%) [0.05-6 mm] Anhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

**Biotite** (3.3%) [<0.5 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

**Sericite** (3%) [0.1-3 mm] Subhedral colorless laths exhibiting high birefringence.

**Magnetite** (tr%) [<0.15 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Allanite** (tr%) [<0.1 mm] Subhedral light brown grains exhibiting high relief and 1st order birefringence.

**Apatite** (tr%) [<0.1 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

**Chlorite** (tr%) [0.1-1 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.15 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
MINERAL ABBREVIATIONS TAKEN FROM (WHITNEY AND EVANS, 2010). MODERATE GREEN PLAGIOCLASE.

COMMENTS AND INTERPRETATION:

Based on the QAP ratio of 48.40:13.89:37.71 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 84±1 Ma, Granodiorite classification, myrmekitic texture, and moderate green plagioclase CL responses, suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-12

LOCATION: 44°08.492N, 115°00.450W
COLLECTOR: Chong Ma

DATE COLLECTED:

AGE DATE: 101±1 Ma

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of orthoclase, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (30%) [0.1-2.6 mm] Subhedral grains exhibiting albite twinning and moderate seritization.

Microcline (14.7%) [0.2-4 mm] Subhedral grains exhibiting moderate seritization. Pervasive myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (40%) [0.01-5 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction. Recrystallized quartz.

Biotite (1.3%) [<0.25 mm] Subhedral laths with tan to brown pleochroism and birds eye extinction. Biotites are foliated suggesting magma flow or syndeformational crystallization.

Sericite (12.7%) [0.1-2.5 mm] Euhedral colorless laths exhibiting high birefringence.

Apatite (tr%) [<0.1 mm] subhedral, clear, mod relief, low birefringence

Clinozoisite (tr%) [<0.5 mm] Anhedral colorless grains with moderate relief and 1st order birefringence.

Magnetite (tr%) [<0.1 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with moderate green and moderate blue plagioclase. Myrmekitic texture observed.

**COMMENTS AND INTERPRETATION:**

Based on the QAP ratio of 47.23:17.36:35.42 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Muscovite Granodiorite with secondary alteration to muscovite/sericite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite + opaques) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite.

Biotites are foliated suggesting magma flow or syndeformational crystallization. Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 101±1 Ma, Granodiorite classification, myrmekitic texture, and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: MC14ST-13

Last update: 2/26/20

Petrographer: Kyle Tollefson

LOCATION: 44°08.493N, 114°59.470W
COLLECTOR: Chong Ma

DATE COLLECTED:
AGE DATE: 95±1 Ma

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (25%) [0.1-5 mm] Subhedral grains exhibiting faint albite twinning and moderate seritization.

Microcline (43%) [0.25-10 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (28.3%) [0.01-7 mm] Anhedral to subhedral grains exhibiting minor sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (4.7%) [0.1-2 mm] Subhedral laths exhibiting dark brown to tan pleochroism, birds eye extinction, and minor chloritization. Biotites found interstitial to feldspars and quartz.

Apatite (tr%) [0.1-0.4 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

Magnetite (tr%) [<0.3 mm] Anhedral to subedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Epidote (tr%) [0.05 mm] Subhedral colorless grains exhibiting high relief and high birefringence.

Sericite (tr%) [<0.1] Subhedral colorless laths exhibiting high birefringence.

Chlorite (tr%) [0.1 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.02 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits minor perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar and moderate blue. Moderate green, brown, and moderate blue plagioclase. Carbonates and myrmekitic texture observed.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 29.39:44.65:25.96 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite + opaques) > (Microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 95±1 Ma, myrmekitic texture, perthitic microcline, and moderate green plagioclase CL responses suggest this sample is part of the Idaho Batholith.
SAMPLE: SMC11-30

LOCATION: Barbara Dutrow

DATE COLLECTED:

AGE DATE:

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (22.3%) [0.2-10 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization.

**Microcline** (34.3%) [0.1-14 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (42.3%) [0.01-4 mm] Anhedral grains exhibiting moderate sweeping extinction. Recrystallized quartz.

**Biotite** (1%) [0.2-1.5 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and moderate chloritization.

**Sericite** (tr%) [0.1-1.75 mm] Subhedral colorless laths exhibiting high birefringence.

**Magnetite** (tr%) [<0.2 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Chlorite** (tr%) [0.1-1 mm] Subhedral green laths replacing biotite.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits minor perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with moderate green and brown plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 42.77:34.68:22.55 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Biotite + opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Moderate green and moderate blue plagioclase CL responses and no other distinct characteristics suggest this sample is sourced by the Idaho batholith or anatectic melts.
SAMPLE: SMC 13-05

LOCATION: 44°10.554N, 115°02.692W
COLLECTOR: Barbara Dutrow
DATE COLLECTED: June 27th 2013
AGE DATE:

ROCK TYPE: Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (40.3%) [0.25-6 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization.

Microcline (6.7%) [0.25-7 mm] Anhedral to subhedral grains exhibiting moderate perthite, and moderate seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (46.3%) [0.05-7 mm] Anhedral grains exhibiting minor sweeping extinction. Recrystallized quartz.

Biotite (6%) [0.1-2.5 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Sericite (0.7%) [0.1-0.5 mm] Subhedral colorless laths exhibiting high birefringence.

Hematite (tr%) [<0.25 mm] Anhedral to euohedral opaque grains with red rims.

Magnetite (tr%) [<0.1 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Chlorite (tr%) [0.1-3 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.2 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 49.62:7.18:43.19 of the likely primary magmatic minerals, this rock is best classified as Biotite Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granodiorite is subsolvus.

The magmatic paragenetic sequence is likely (Plagioclase) > (Biotite + opaques) > (microcline + quartz) then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification, and myrmekitic texture suggest this sample is likely sourced by the Idaho Batholith.
SAMPLE: SMC 13-31

LOCATION: 44°09.051N, 115°00.801W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 10th 2013

AGE DATE:

ROCK TYPE: Biotite-bearing Syeno-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline megacrysts in a matrix of plagioclase and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (13%) [0.1-2 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

Microcline (56.3%) [1-15 mm] Anhedral to subhedral grains exhibiting pervasive perthite and minor seritization.

Quartz (30%) [0.1-2 mm] Anhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (0.7%) [<1 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Chlorite (tr%) [0.2 mm] Subhedral green laths replacing biotite.

TEXTURES: Hypidiomorphic coarse-grained to porphyritic texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright to moderate blue alkali feldspar with brown plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 30.21:56.70:13.09 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Syeno-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (microcline + plagioclase) > (biotite + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Syeno-Granite classification and pervasive perthitic microcline suggest this sample is likely sourced by the Sawtooth Batholith.
SAMPLE: SMC 13-132

LOCATION: 44°08.513N, 115°00.438W

COLLECTOR:

DATE COLLECTED: July 17th 2013

AGE DATE:

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (32.3%) [0.1-9 mm] Subhedral grains exhibiting faint albite twinning and moderate seritization.

Microcline (26.3%) [0.1-10 mm] Anhedral to subhedral grains exhibiting tartan twining, minor perthite, and minor seritization. Pervasive myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (39%) [0.01-10 mm] Anhedral grains exhibiting moderate sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (1.3%) [0.1-5 mm] Subhedral to euhedral laths exhibiting reddish-brown to green pleochroism, birds eye extinction, and minor chloritization.

Sericite (1%) [0.1-0.4 mm] Subhedral colorless laths exhibiting high birefringence.

Clinozoisite (tr%) [0.05 mm] Anhedral colorless grains with moderate relief and 1st order birefringence.

Chlorite (tr%) [0.1 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.15 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthitic texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with moderate green plagioclase. Extensive blue alteration (REE fluids) on albite twinning planes present and myrmekitic texture observed.

**COMMENTS AND INTERPRETATION:**

Based on the QAP ratio of 39.96:26.95:33.09 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite-sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Microcline + quartz) > (Biotite) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 87.41 ± 0.44 Ma and moderate green plagioclase CL responses suggest this sample is likely sourced by the Idaho Batholith.
SAMPLE: SMC 14-09

LOCATION: 44°08.842N, 114°59.757W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 7th 2014

ROCK TYPE: Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (40%) [0.1-7 mm] Subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (20%) [0.1-4 mm] Anhedral to subhedral grains exhibiting tartan twining, minor perthite, and minor seritization. Moderate myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (33.7%) [0.01-5 mm] Anhedral grains exhibiting moderate sweeping extinction.

**Biotite** (5.7%) [0.1-2.5 mm] Subhedral to euhedral laths exhibiting reddish-brown to green pleochroism, birds eye extinction, and moderate chloritization.

**Sericite** (tr%) [0.1-0.75 mm] Subhedral colorless laths exhibiting high birefringence.

**Apatite** (tr%) [<0.1-0.25 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

**Allanite** (tr%) [0.2 mm] Subhedral to euhedral equant grains with brown to reddish brown pleochroism, high relief, and high birefringence.

**Chlorite** (tr%) [0.1-2 mm] Subhedral green laths replacing biotite.

**Magnetite** (tr%) [<0.2 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Zircon** (tr%) [<0.2 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Hypidiomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits minor perthitic texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with brown plagioclase. Myrmekitic texture observed.

**COMMENTS AND INTERPRETATION:**
Based on the QAP ratio of 35.97:21.34:42.69 of the likely primary magmatic minerals, this rock is best classified as Biotite Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Magnetite + Biotite) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Granodiorite classification and an age date of 93.94 ± 0.46 Ma suggest the likely sourced of this sample is the Idaho batholith.
SAMPLE: SMC 14-11

LOCATION: 44°10.262N, 115°01.018W

COLLECTOR: Barbara Dutrow

DATE COLLECTED: 

AGE DATE: 80.6 ± 0.7 Ma

ROCK TYPE: Biotite-bearing monzo-granite

MEGASCOPIQUE DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (28.3%) [0.1-8 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

Microcline (33.3%) [1-10 mm] Anhedral to subhedral grains exhibiting pervasive perthite and minor seritization.

Quartz (38%) [0.1-2 mm] Anhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (0.3%) [<1-1.5 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Chlorite (tr%) [0.2 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with hi relief and hi birefringence.

TEXTURES: Hypidiomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue alkali feldspar with green plagioclase.

COMMENTS AND INTERPRETATION:

Based on the QAP ratio of 38.15, 33.43, 28.41 of the likely primary magmatic minerals, this rock is best classified as biotite-bearing monzo-granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (microcline + plagioclase) > (biotite + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Green plagioclase OM-CL responses and an age date of 80.6 ± 0.7 Ma suggest this sample is likely sourced by the Idaho batholith.
SAMPLE: SMC 14-26

LOCATION: 44°09.994N, 115°01.019W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 25th 2014

ROCK TYPE: Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (29%) [0.2-6 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization.

Microcline (36.7%) [0.2-8 mm] Anhedral to subhedral grains exhibiting minor perthite, and minor seritization. Moderate myrmekite and graphic texture of plagioclase-quartz develop at margins with plagioclase.

Quartz (33.3%) [0.02-1 mm] Anhedral grains exhibiting moderate sweeping extinction. Recrystallized quartz.

Hematite (tr%) [<0.1 mm] Anhedral to subhedral opaque grains with red rims.

Biotite (0.7%) [0.2-4 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Magnetite (tr%) [<0.25 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Sericite (0.3%) [<2 mm] Subhedral colorless laths exhibiting high birefringence.

Chlorite (tr%) [0.2 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Pervasive metasomatic/hydrothermal alteration from plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with brown and blue plagioclase. Orange carbonates observed.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 33.64:37.07:29.29 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Blue plagioclase and no other distinct characteristics suggests the likely source of this sample is anatectic melts.
SAMPLE: SMC 14-40

Last update: 2/26/20

Petrographer: Kyle Tollefson

LOCATION: 44°09.048N, 115°01.005W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 16th 2014

AGE DATE:

ROCK TYPE: Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with no visible mafics.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (23.7%) [0.2-2 mm] Anhedral grains exhibiting albite twinning and moderate seritization.

Microcline (24.3%) [0.2-5 mm] Anhedral to subhedral grains exhibiting tartan twinning, Moderate perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (52%) [0.01-2 mm] Anhedral grains exhibiting major sweeping extinction. Recrystallized quartz.

Hematite (tr%) [<0.01 mm] Anhedral opaque grains with red rims.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, and quartz, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with moderate green and moderate blue plagioclase.

**COMMENTS AND INTERPRETATION:**

Based on the QAP ratio of 52.00:24.30:23.70 of the likely primary magmatic minerals, this rock is best classified as Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (microcline + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Blue plagioclase and no other distinct characteristics suggest this sample is likely sourced by anatectic melts.
SAMPLE: SMC 14-43

LOCATION: 44°09.765N, 115°02.176W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 20th 2014

AGE DATE:

ROCK TYPE: Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, fine-grained phaneritic equigranular granitoid chiefly composed of microcline, plagioclase, and quartz with no visible mafics.

MINERAL ASSEMBLAGES: (Point counted modes)

- **Plagioclase** (26.3%) [0.2-2.5 mm] Anhedral to subhedral grains exhibiting deformed albite twinning (kink structure) and moderate seritization.

- **Microcline** (36%) [0.2-4 mm] Anhedral to subhedral grains exhibiting moderate perthite and minor seritization.

- **Quartz** (37.3%) [0.02-1 mm] Anhedral grains exhibiting moderate sweeping extinction. Recrystallized quartz.

- **Sericite** (0.3%) [<0.5 mm] Subhedral colorless laths exhibiting high birefringence.

- **Hematite** (tr%) [<0.1 mm] Anhedral to subhedral opaque grains with red rims.

- **Magnetite** (tr%) [<0.25 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

TEXTURES: Allotriomorphic fine-grained texture dominated by microcline, plagioclase, and quartz, respectively. Microcline exhibits perthite texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright to moderate blue alkali feldspar with brown and red plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 37.45:36.14:26.41 of the likely primary magmatic minerals, this rock is best classified as Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is (Plagioclase + microcline) > (opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 75.46 ± 0.63 Ma an no other distinct characteristics suggests this sample was likely sourced by the Idaho batholith.
SAMPLE: SMC 14-44

LOCATION: 44°10.258N, 115°02.313W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 20th 2014

AGE DATE:

ROCK TYPE: Hornblende Biotite-bearing Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, fine-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (18%) [0.25-3 mm] Anhedral grains exhibiting faint albite twinning and major seritization.

**Microcline** (33%) [0.1-5 mm] Anhedral grains exhibiting moderate perthite, and major seritization.

**Quartz** (48%) [0.05-2 mm] Anhedral grains exhibiting minor sweeping extinction. Recrystallized quartz.

**Biotite** (tr%) [0.1-0.75 mm] Anhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

**Magnetite** (tr%) [<0.1 mm] Subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Apatite** (tr%) [<0.25 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

**Hornblende** (tr%) [0.1-0.25 mm] Subhedral grains exhibiting reddish brown to tan pleochroism.

**Clinozoisite** (tr%) [<0.2 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

**Chlorite** (tr%) [0.05-0.1 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic fine-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue and red alkali feldspar with brown and red plagioclase.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 48.48:33.33:18.18 of the likely primary magmatic minerals, this rock is best classified as Hornblende Biotite-bearing Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Biotite + opaques) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Red zonation of alkali feldspar suggests this sample was sourced by the Idaho batholith.
SAMPLE: SMC 14-47

LOCATION: 44°10.964N, 115°03.458W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 22nd 2014
AGE DATE:

ROCK TYPE: Monzo-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, fine-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (19%) [0.1-0.5 mm] Anhedral grains exhibiting albite twinning and minor seritization.

Microcline (34%) [0.2-1 mm] Anhedral grains exhibiting pervasive perthite, and moderate seritization.

Quartz (47%) [0.01-3 mm] Anhedral grains exhibiting minor sweeping extinction.

Magnetite (tr%) [<0.25 mm] Subhedral to euhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic fine-grained texture dominated by microcline, plagioclase, and quartz, respectively. Microcline exhibits perthite texture.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Dark to moderate blue and red alkali feldspar with pink to red albite exsolution (perthite). Moderate green to light orange plagioclase. Myrmekitic texture observed.

**COMMENTS AND INTERPRETATION:**
Based on the QAP ratio of 47.00:34.00:19.00 of the likely primary magmatic minerals, this rock is best classified as Monzo-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Magnetite + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Perthitic microcline and orange plagioclase CL responses suggest this sample was likely sourced by the Sawtooth Batholith.
SAMPLE: SMC 14-61

LOCATION: 44°10.829N, 115°04.397W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 28th 2014

AGE DATE:

ROCK TYPE: Biotite Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (35%) [0.2-3 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization.

**Microcline** (17%) [0.2-2.5 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (42.7%) [0.01-1.75 mm] Anhedral grains exhibiting moderate sweeping extinction. Recrystallized quartz.

**Biotite** (5%) [0.1-2 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and moderate chloritization.

**Magnetite** (tr%) [<0.25 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Allanite** (tr%) [<0.1 mm] Subhedral light brown grains exhibiting high relief and 1st order birefringence.

**Chlorite** (tr%) [0.1 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE


COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 45.09:17.95:36.96 of the likely primary magmatic minerals, this rock is best classified as Biotite Granodiorite with secondary alteration to muscovite-sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Magnetite + Biotite) > (quartz) and then hydrothermal alteration to muscovite-sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification, minor myrmekitic texture, green plagioclase CL responses, and red zoned alkali feldspar suggests this sample was likely sourced by the Idaho batholith.
SAMPLE: SMC 14-62

LOCATION: 44°10.769N, 115°04.147W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 28th 2014

AGE DATE:

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (35.3%) [0.2-3 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization of cores.

Microcline (14.7%) [0.2-2.5 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization.

Quartz (48%) [0.01-1.75 mm] Anhedral grains exhibiting moderate sweeping extinction. Recrystallized quartz.

Biotite (2%) [0.1-2 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and moderate chloritization.

Magnetite (tr%) [<0.25 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Chlorite (tr%) [0.1-0.2 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Moderate blue and red zoned alkali feldspar with pink to red albite exsolution (perhite). Brown and moderate green to orange plagioclase with some highly altered cores.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 48.98:15.00:36.02 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + microcline) > (Magnetite + Biotite) > (quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification, moderate green plagioclase CL, and red zoned alkali feldspar suggests this sample was sourced by the Idaho batholith.
SAMPLE: SMC 14-112

LOCATION: 44°08.294N, 115°00.355W

COLLECTOR:

DATE COLLECTED: July 26th 2014

AGE DATE:

ROCK TYPE: Biotite-bearing Syeno-Granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline megacrysts in a plagioclase, and quartz matrix.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (9%) [0.1-5 mm] Anhedral to subhedral grains exhibiting albite twinning and minor seritization.

Microcline (48%) [0.25-15 mm] Anhedral to subhedral grains exhibiting tartan twinning, pervasive perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (40.7%) [0.01-5 mm] Anhedral to subhedral grains exhibiting moderate sweeping extinction.

Biotite (1.3%) [0.1-1.75 mm] Anhedral to subhedral laths exhibiting tan to light green pleochroism, birds eye extinction, and minor chloritization.

Sericite (1%) [0.2-2.25 mm] Subhedral to euhedral colorless laths exhibiting high birefringence.

Magnetite (tr%) [<0.3 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Clinozoisite (tr%) [<0.2 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

Chlorite (tr%) [0.05-0.75 mm] Subhedral green laths replacing biotite.

TEXTURES: Allotriomorphic dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture.

ALTERATION: Minor metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Bright blue alkali feldspar with moderate green plagioclase.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 41.66:49.13:9.21 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Syeno-Granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is (Microcline megacrysts) > (Plagioclase + Biotite) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Syeno-Granite classification and pervasive perthitic microcline suggest this sample is likely sourced by the Sawtooth batholith.
SAMPLE: SMC 15-03

LOCATION: 44°10.523N, 115°02.504W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 2\textsuperscript{nd} 2015

AGE DATE:

ROCK TYPE: Biotite-bearing Syeno-granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite and muscovite.

MINERAL ASSEMBLAGES: (Point counted modes)

- **Plagioclase** (9\%) [0.2-4 mm] Anhedral grains exhibiting faint albite twinning and major seritization.
- **Microcline** (59.7\%) [0.2-13 mm] Anhedral grains exhibiting pervasive perthite and major seritization.
- **Quartz** (31.3\%) [0.05-3 mm] Anhedral grains exhibiting minor sweeping extinction. Recrystallized quartz.
- **Magnetite** (tr\%) [<0.1 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.
- **Biotite** (tr\%) [<0.05 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.
- **Chlorite** (tr\%) [0.01-0.05 mm] Subhedral green laths replacing biotite.
- **Zircon** (tr\%) [<0.1 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright to moderate blue alkali feldspar with pink albite exsolution (perthite). Brown, green, and orange plagioclase with highly altered cores.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 31.30:59.70:9.00 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Syeno-granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Syeno-Granite classification, perthitic microcline, and orange plagioclase CL responses suggest this sample is likely sourced by the Sawtooth Batholith.
SAMPLE: SMC 15-05

LOCATION: 44°10.323N, 115°14.715W
COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 3rd 2015

AGE DATE:

ROCK TYPE: Biotite-bearing Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic equigranular granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (40%) [0.1-4 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (20%) [0.02-2 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

**Quartz** (37.7%) [0.05-4.5 mm] Anhedral grains exhibiting minor sweeping extinction. Recrystallized quartz.

**Biotite** (1%) [0.1-1.5 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and moderate chloritization.

**Sericite** (0.3%) [<0.3 mm] Anhedral to subhedral colorless laths exhibiting high birefringence.

**Apatite** (tr%) [<0.1 mm] Subhedral colorless grains with moderate relief and 1st order birefringence.

**Magnetite** (tr%) [<0.25 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Epidote** (tr%) [<0.1 mm] Subhedral light green grains exhibiting moderate relief and high birefringence.

**Clinozoisite** (tr%) [<0.25 mm] Anhedral to subhedral colorless grains with moderate relief and 1st order birefringence.

**Allanite** (tr%) [<0.2 mm] Euhedral light brown grains exhibiting high relief and 1st order birefringence.

**Chlorite** (tr%) [0.1 mm] Subhedral green laths replacing biotite.

**Zircon** (tr%) [<0.2 mm] Euhedral colorless grains with high relief and high birefringence.
TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthite texture. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.

OPTICAL CATHODOLUMINESCENCE
Mineral abbreviations taken from (Whitney and Evans, 2010). Bright to moderate blue alkali feldspar with red oscillatory zoning. Plagioclase is moderate green to orange. Myrmekitic texture observed.

COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 38.59:20.47:40.9421 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite secondary alteration to muscovite-sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Microcline + Biotite) > (Quartz) and then hydrothermal alteration to muscovite-sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification, myrmekitic texture, moderate green plagioclase CL responses, and an age of 79.16 ± 1.18 Ma suggests this sample was most likely sourced by the Idaho batholith.
SAMPLE: SMC 16-09

LOCATION: 44°08.927N, 114°59.599W
COLLECTOR: Barbara Dutrow
DATE COLLECTED:
AGE DATE: 86.5 ± 0.5 Ma
ROCK TYPE: Biotite-bearing monzo-granite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained granitoid chiefly composed of microcline megacrysts in a matrix of plagioclase and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (24.3%) [0.1-2 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

Microcline (40.3%) [1-10 mm] Anhedral to subhedral grains exhibiting pervasive perthite and minor seritization.

Quartz (35%) [0.1-2 mm] Anhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (tr%) [<1 mm] Subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Chlorite (tr%) [0.2 mm] Subhedral green laths replacing biotite.

TEXTURES: Hypidiomorphic coarse-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline exhibits perthitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
OPTICAL CATHODOLUMINESCENCE

Mineral abbreviations taken from (Whitney and Evans, 2010). Bright to moderate blue alkali feldspar with brown plagioclase.

COMMENTS AND INTERPRETATION:

Based on the QAP ratio of 35.14, 40.46, 24.40 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Monzo-granite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (microcline + plagioclase) > (biotite + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

An age date of 86.5 ± 0.5 Ma suggests this sample is likely sourced by the Idaho batholith.
SAMPLE: SMC 16-22

Last update: 2/26/20

Petrographer: Kyle Tollefson

LOCATION: 44°10.790N, 115°03.140W

COLLECTOR: Barbara Dutrow

DATE COLLECTED: July 8th 2016

AGE DATE:

ROCK TYPE: Granodiorite

MEGASCOPIC DESCRIPTION: Leucocratic, white, coarse-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor hornblende.

MINERAL ASSEMBLAGES: (Point counted modes)

**Plagioclase** (45.3%) [0.2-7.5 mm] Anhedral to subhedral grains exhibiting albite twinning and moderate seritization.

**Microcline** (11.3%) [0.2-4 mm] Anhedral to subhedral grains exhibiting minor perthite and moderate seritization.

**Quartz** (38.7%) [0.05-4 mm] Anhedral grains exhibiting major sweeping extinction. Recrystallized quartz.

**Sericite** (0.7%) [0.1-1 mm] Subhedral colorless laths exhibiting high birefringence.

**Hornblende** (4%) [0.1-4 mm] Subhedral light green grains exhibiting high relief, moderate birefringence.

**Apatite** (tr%) [<0.1 mm] Subhedral to euhedral colorless grains with moderate relief and 1st order birefringence.

**Allanite** (tr%) [<0.1 mm] Subhedral to euhedral light brown grains exhibiting high relief and 1st order birefringence.

**Magnetite** (tr%) [<0.05 mm] Anhedral to subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

**Zircon** (tr%) [<0.15 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic coarse-grained texture dominated by microcline, plagioclase, and quartz, respectively. Microcline exhibits minor perthite texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Moderate metasomatic/hydrothermal alteration from plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Dark blue alkali feldspar. Yellow plagioclase. Orange carbonates observed.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 40.61:11.86:47.53 of the likely primary magmatic minerals, this rock is best classified as Granodiorite with secondary alteration to muscovite/sericite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase) > (Microcline + quartz) > (Biotite + hornblende + opaques) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification and with an age date of 80.27 ± 0.64 Ma suggests this sample is likely sourced by the Idaho batholith.
SAMPLE: SMC 16-34  

LOCATION: 44°08.863N, 115°00.845W  
COLLECTOR: Barbara Dutrow  
DATE COLLECTED: July 14th 2016  
AGE DATE:  
ROCK TYPE: Biotite-bearing Granodiorite  

MEGASCOPIC DESCRIPTION: Leucocratic, white, medium-grained phaneritic granitoid chiefly composed of microcline, plagioclase, and quartz with minor biotite.

MINERAL ASSEMBLAGES: (Point counted modes)

Plagioclase (34.7%) [0.5-4 mm] Anhedral to subhedral grains exhibiting albite twinning and major seritization of cores.

Microcline (12.7%) [0.1-0.5 mm] Anhedral to subhedral grains exhibiting tartan twinning, minor perthite, and minor seritization. Minor myrmekites of plagioclase-quartz develop at margins with plagioclase.

Quartz (52%) [0.01-5 mm] Anhedral grains exhibiting major sweeping extinction and checkerboard extinction. Recrystallized quartz.

Biotite (0.7%) [0.25-1 mm] Anhedral to subhedral laths exhibiting brown to green pleochroism, birds eye extinction, and major chloritization.

Apatite (tr%) [<0.1 mm] Subhedral to euhedral colorless grains with moderate relief and 1st order birefringence.

Magnetite (tr%) [0.1-1.25 mm] Subhedral opaque grains exhibiting brownish-grey, isotropic, and a pitted nature in reflective light.

Hematite (tr%) [< 0.3 mm] Anhedral opaque grains with red rims.

Chlorite (tr%) [0.01-1 mm] Subhedral green laths replacing biotite.

Zircon (tr%) [<0.2 mm] Euhedral colorless grains with high relief and high birefringence.

TEXTURES: Allotriomorphic medium-grained texture dominated by microcline, plagioclase, quartz, and biotite, respectively. Microcline, plagioclase, and quartz exhibit myrmekitic texture. Recrystallization in the quartz indicates post-crystallization deformation.

ALTERATION: Pervasive metasomatic/hydrothermal alteration from biotite to chlorite and plagioclase to sericite/muscovite.
Mineral abbreviations taken from (Whitney and Evans, 2010). Dark to moderate blue alkali feldspar with oscillatory zoning indicated by red bands. Brown and moderate green plagioclase.
COMMENTS AND INTERPRETATION:
Based on the QAP ratio of 52.31:12.78:34.91 of the likely primary magmatic minerals, this rock is best classified as Biotite-bearing Granodiorite with secondary alteration to muscovite/sericite and chlorite. The fact that the alkali-feldspar and plagioclase from separate phenocrysts implies that the granite is a subsolvus granite.

The magmatic paragenetic sequence is likely (Plagioclase + Microcline) > (Biotite + quartz) and then hydrothermal alteration to muscovite/sericite + chlorite.

Following the crystallization of the igneous minerals there are a series of subsolidus changes to the minerals. Post-crystallization deformation likely generated the quartz deformations features and allowed excess to aqueous fluids associated with alteration.

Granodiorite classification, moderate green plagioclase CL, and red zoned alkali feldspar CL suggest this sample was likely sourced by the Idaho Batholith.
APPENDIX B. BSE IMAGES WITH EMPA ANALYSIS POINTS

SMC16-34 Area 1
## APPENDIX C. EMPA DATA AND STOICHIOMETRIC CALCULATIONS

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Structural formula based on 8 oxygens

| T (iv) site: Si | 2.985 | 2.990 | 2.991 | 2.985 | 2.982 |
| Al       | 1.007 | 1.002 | 1.002 | 1.001 | 1.005 | 1.012 |
| Fe³⁺    |       |       |       |       |       |       |
| T site total | 3.992 | 3.992 | 3.992 | 3.992 | 3.990 | 3.994 |

<p>| Fe³⁺    |       |       |       |       |       |       |
| Fe²⁺    | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.004 |
| Mn      |       |       |       |       |       |       |
| Mg      |       |       |       |       |       |       |
| Ca      | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| Ba      | 0.010 | 0.009 | 0.009 | 0.010 | 0.013 | 0.014 |
| Sr      |       |       |       |       |       |       |
| Na      | 0.074 | 0.077 | 0.078 | 0.079 | 0.086 | 0.079 |
| K       | 0.944 | 0.938 | 0.935 | 0.930 | 0.928 | 0.921 |
| M-site total | 1.028 | 1.024 | 1.023 | 1.020 | 1.028 | 1.014 |</p>
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| Si     | 2.153  | 2.175  | 2.163  | 2.170  | 2.168  | 2.174  |
| Al     | 0.533  | 0.549  | 0.549  | 0.549  | 0.545  | 0.545  |
| Fe3+   | 0.003  | 0.003  | 0.001  | 0.000  | 0.000  | 0.000  |
| Fe2+   | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  |
| Mn2+   |        |        |        |        |        |        |
| Mg     |        |        |        |        |        |        |
| Ca     | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  |
| Ba     | 0.005  | 0.005  | 0.004  | 0.004  | 0.004  | 0.003  |
| Sr     | 0.015  | 0.013  | 0.014  | 0.018  | 0.017  | 0.015  |
| Na     | 0.170  | 0.170  | 0.170  | 0.165  | 0.166  | 0.167  |
| K      | 2.878  | 2.914  | 2.901  | 2.907  | 2.900  | 2.904  |
| Total  | 2.780  | 2.745  | 2.757  | 2.752  | 2.759  | 2.755  |
| Factor (8 O2-) | 2.780 | 2.745  | 2.757  | 2.752  | 2.759  | 2.755  |

<p>| Si     | 2.992  | 2.985  | 2.982  | 2.986  | 2.990  | 2.994  |</p>
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| Si        | 2.260 | 2.198 | 2.199 | 2.184 | 2.182 | 2.180 |
| Al        | 0.596 | 0.637 | 0.636 | 0.641 | 0.648 | 0.650 |
| Fe3+      |       |       |       |       |       |       |
| Fe2+      | 0.000 | 0.001 |       |       | 0.000 | 0.000 |
| Mn2+      |       |       |       |       |       |       |
| Mg        |       |       |       |       |       |       |
| Ca        | 0.016 | 0.044 | 0.044 | 0.049 | 0.052 | 0.050 |
| Ba        | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sr        |       |       |       |       |       |       |
| Na        | 0.181 | 0.167 | 0.167 | 0.163 | 0.163 | 0.164 |
| K         | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.002 |
| Total     | 3.055 | 3.049 | 3.048 | 3.040 | 3.046 | 3.045 |
| Factor (8 O2-) | 2.619 | 2.624 | 2.625 | 2.632 | 2.627 | 2.627 |

<p>| Si        | 2.959 | 2.884 | 2.886 | 2.874 | 2.865 | 2.863 |</p>
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**Comment**

- Plag_002
- Plag_003
- Plag_004
- Plag_005
- Plag_006
- Plag_007

**SiO₂**

- **66.05**
- 65.62
- 65.55
- 65.48

**Al₂O₃**

- 21.65
- 21.79
- 22.01
- 22.08

**FeO**

- 0.03
- 0.04
- 0.01
- 0.01

**MnO**

- 0.043
- 0.116
- 0.116
- 0.130
- 0.135
- 0.132

**MgO**

- 0.000
- 0.000
- 0.000
- 0.000
- 0.000
- 0.000

**CaO**

- 0.92
- 2.48
- 2.49
- 2.77
- 2.89
- 2.83

**BaO**

- 0.03
- 0.03
- 0.02
- 0.04
- 0.01
- 0.00

**SrO**

- 11.20
- 10.36
- 10.35
- 10.11
- 10.11
- 10.17

**Na₂O**

- 0.14
- 0.14
- 0.16
- 0.17
- 0.13
- 0.15

**K₂O**

- 0.14
- 0.14
- 0.16
- 0.17
- 0.13
- 0.15

**Total**

- 100.45
- 100.75
- **100.67**
- 100.49
- 100.71
- 100.71

**T (iv) site: Si**

- 2.959
- 2.884
- **2.886**
- 2.874
- 2.865
- 2.863

**Al**

- 1.040
- 1.114
- **1.113**
- 1.125
- 1.134
- 1.138

**Fe³⁺**

- 3.999
- 3.998
- **3.999**
- 3.999
- 4.000
- 4.001

**Fe³⁺**

- 0.000
- 0.000

**Fe²⁺**

- 0.001
- 0.002

**Mn**

- 0.043
- 0.116
- **0.116**
- 0.130
- 0.135
- 0.132

**Mg**

- 0.000
- 0.000
- **0.000**
- 0.001
- 0.000
- 0.000

**Ca**

- 0.947
- 0.877
- **0.876**
- 0.858
- 0.857
- 0.862

**Ba**

- 0.000
- 0.000
- 0.000
- 0.001
- 0.000
- 0.000

**Sr**

- 0.008
- 0.008
- **0.009**
- 0.009
- 0.007
- 0.008

**Na**

- 0.947
- 0.877
- **0.876**
- 0.858
- 0.857
- 0.862

**K**

- 0.008
- 0.008
- 0.009
- 0.009
- 0.007
- 0.008

**Total**

- 0.998
- 1.002
- **1.002**
- 0.998
- 1.000
- 1.003
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All Fe as Fe2O3 | 0.03 | 0.01 | 0.01 | 0.03
Assumed FeO
Assumed Fe2O3

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| Si        | 2.107    | 2.106    | 2.128    | 2.125    | 2.194    | 2.191    |
| Al        | 0.554    | 0.554    | 0.648    | 0.651    | 0.640    | 0.648    |
| Fe³⁺      |          |          |          |          |          |          |
| Fe²⁺      | 0.000    | 0.000    | 0.000    | 0.000    | 0.000    | 0.000    |
| Mn²⁺      |          |          |          |          |          |          |
| Mg        |          |          |          |          |          |          |
| Ca        |          |          | 0.050    | 0.051    | 0.047    | 0.049    |
| Ba        | 0.005    | 0.005    | 0.000    | 0.000    |          |          |
| Sr        |          |          |          |          |          |          |
| Na        | 0.014    | 0.012    | 0.162    | 0.164    | 0.162    | 0.165    |
| K         | 0.163    | 0.163    | 0.001    | 0.001    | 0.002    | 0.001    |
| Total     | 2.842    | 2.840    | 2.989    | 2.992    | 3.045    | 3.055    |
| Factor (8 O₂⁻) | 2.815 | 2.817 | 2.676 | 2.674 | 2.627 | 2.619 |

<p>| Si        | 2.965    | 2.966    | 2.848    | 2.841    | 2.882    | 2.869    |</p>
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| T (iv) site: Si | 2.965 | 2.966 | 2.848 | 2.841 | 2.882 | 2.869 |
| Al              | 1.039 | 1.040 | 1.156 | 1.160 | 1.121 | 1.132 |
| Fe³⁺            |       |       |       |       |       |       |
| T site total    | 4.004 | 4.006 | 4.003 | 4.001 | 4.003 | 4.001 |

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**T (iv) site: Si**

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| Fe2+ | 0.001 | 0.001| 0.000| 0.000| 0.000| 0.000|
| Mn2+ |       |      |      |      |      |      |
| Mg   |       |      |      |      |      |      |
| Ca   | 0.000 | 0.000| 0.000| 0.000| 0.000| 0.000|
| Ba   | 0.004 | 0.004| 0.005| 0.012| 0.009| 0.003|
| Sr   |       |      |      |      |      |      |
| Na   | 0.016 | 0.016| 0.015| 0.013| 0.013| 0.015|
| K    | 0.160 | 0.161| 0.159| 0.158| 0.158| 0.163|
| Total| 2.855 | 2.836| 2.844| 2.810| 2.832| 2.845|
| Factor (8 O2-) | 2.803 | 2.821| 2.813| 2.847| 2.825| 2.812|
| Si   | 2.965 | 2.964| 2.966| 2.938| 2.952| 2.972|</p>
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| All Fe as Fe2O3 | 0.03 | 0.04 |
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### Other Elements

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Fe³⁺  
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| Al     | 0.612 | 0.626 | 0.556 | 0.552 | 0.557 | 0.556 |
| Fe3+   | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Fe2+   | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Mn2+   | 0.020 | 0.035 | 0.000 | 0.000 |
| Mg     | 0.000 | 0.000 | 0.006 | 0.006 |
| Ca     | 0.180 | 0.172 | 0.012 | 0.012 |
| Ba     | 0.002 | 0.001 | 0.162 | 0.163 |
| Sr     | 0.000 | 0.000 | 0.006 | 0.005 |
| Na     | 2.660 | 2.673 | 2.820 | 2.815 |
| K      | 2.917 | 2.885 | 2.960 | 2.968 |
| Total  | 3.007 | 2.993 | 2.837 | 2.842 |
| Factor (8 O2-) | 2.660 | 2.673 | 2.820 | 2.815 |

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| T (iv) site: Si | 2.917 | 2.885 | 2.960 | 2.968 | 2.965 | 2.957 |
| Al            | 1.085 | 1.115 | 1.046 | 1.036 | 1.041 | 1.047 |
| Fe³⁺          |       |       |       |       |       |       |
| T site total  | 4.002 | 3.999 | 4.006 | 4.005 | 4.006 | 4.004 |

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- 2.846
- 2.933
- 2.866
- 2.963
- 2.963

T site total
- 4.004
- 4.002
- 4.003
- 4.001
- 4.005
- 4.006

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### Analysis of Elemental Concentrations

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| All Fe as FeO   | 0.02     | 0.02     | 0.02     | 0.00     |          |          |
| All Fe as Fe2O3 | 0.02     | 0.02     | 0.02     | 0.00     |          |          |
| Assumed FeO     |          |          |          |          |          |          |
| Assumed Fe2O3   |          |          |          |          |          |          |

| Si | 2.060 | 2.067 | 2.107 | 2.077 | 2.104 | 2.047 |
| Al | 0.566 | 0.562 | 0.551 | 0.562 | 0.553 | 0.565 |
| Fe3+ |       |       |       |       |       |       |
| Fe2+ | 0.000 | 0.000 | 0.000 | 0.000 |       |       |
| Mn2+ |       |       |       |       |       |       |
| Mg |       |       |       |       |       |       |
| Ca | 0.001 | 0.000 | 0.000 | 0.001 |       |       |
| Ba | 0.014 | 0.011 | 0.004 | 0.012 | 0.004 | 0.016 |
| Sr |       |       |       |       |       |       |
| Na | 0.013 | 0.013 | 0.012 | 0.014 | 0.014 | 0.012 |
| K  | 0.157 | 0.158 | 0.164 | 0.158 | 0.162 | 0.155 |
| Total | 2.811 | 2.812 | 2.837 | 2.823 | 2.837 | 2.795 |
| Factor (8 O2-) | 2.846 | 2.844 | 2.820 | 2.834 | 2.820 | 2.862 |

<p>| Si | 2.931 | 2.940 | 2.970 | 2.943 | 2.967 | 2.930 |
| Al | 1.075 | 1.065 | 1.035 | 1.062 | 1.040 | 1.078 |
| Fe3+ |       |       |       |       |       |       |</p>
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**Main feldspar components**

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| All Fe as Fe2O3    | 0.01   | 0.03   | 0.01   |        |        |        |

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Structural formula based on 8 oxygens

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| Fe3+ |          |          |          |          |          |          |
| Fe2+ | 0.000    | 0.001    | 0.000    |          |          |          |
| Mn   |          |          |          |          |          |          |
| Mg   |          |          |          |          |          |          |
| Ca   | 0.241    | 0.231    | 0.212    | 0.223    | 0.206    | 0.041    |
| Ba   | 0.000    | 0.001    | 0.001    | 0.001    | 0.000    | 0.000    |
| Sr   |          |          |          |          |          |          |
| Na   | 0.736    | 0.729    | 0.772    | 0.755    | 0.779    | 0.942    |
| K    | 0.023    | 0.020    | 0.009    | 0.012    | 0.009    | 0.009    |
| M-site total | 1.000 | 0.980 | 0.993 | 0.991 | 0.993 | 0.992 |
### Main feldspar components

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<p>| Si    | 2.088 | 2.094 | 2.086 | 2.078 | 2.091 | 2.143 |
| Al    | 0.556 | 0.554 | 0.558 | 0.554 | 0.559 | 0.677 |
| Fe3+  | 0.000 |    |    |    |    |    |
| Fe2+  | 0.000 |    |    |    |    |    |
| Mn2+  |    |    |    |    |    |    |
| Mg    |    |    |    |    |    |    |
| Ca    | 0.000 |    |    |    |    |    |
| Ba    | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.000 |
| Sr    |    |    |    |    |    |    |
| Na    | 0.015 | 0.015 | 0.016 | 0.015 | 0.013 | 0.152 |
| K     | 0.157 | 0.160 | 0.158 | 0.160 | 0.161 | 0.001 |
| Total | 2.824 | 2.830 | 2.825 | 2.814 | 2.831 | 3.044 |
| Factor (8 O2-)            | 2.833 | 2.827 | 2.832 | 2.843 | 2.826 | 2.628 |
| Si    | 2.957 | 2.960 | 2.954 | 2.954 | 2.955 | 2.816 |</p>
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T (iv) site: Si 2.957 **2.960** 2.954 2.954 2.955 **2.816**
Al 1.050 **1.044** 1.053 1.050 1.053 **1.186**
Fe³⁺ 0.008 **4.004** 4.007 4.004 4.008 **4.002**

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| All Fe as FeO| 0.02     | 0.01     | 0.00      | 0.01      |           |           |
| All Fe as Fe₂O₃ | 0.02 | 0.01 | 0.00 | 0.01 |           |           |
| Assumed FeO   |          |          |           |           |           |           |
| Assumed Fe₂O₃ |          |          |           |           |           |           |

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- **Assumed FeO:**
- **Assumed Fe₂O₃:**

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Barian species
APPENDIX D. SEM IMAGES FOR ZIRCON LA-ICP-MS ANALYSES

SMC13-132

BSE

CL
## APPENDIX E. REDUCED U-Pb ISOTOPE GEOCHRONOLOGY DATA

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<td>2SE</td>
<td>Discordance 207Pb/235U vs 206Pb/238U</td>
<td>2SE</td>
<td>Discordance 207Pb/206Pb vs 206Pb/238U</td>
<td>Th/U Ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
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</tr>
<tr>
<td>SMC16-22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1622-56</td>
<td>0.1092</td>
<td>0.0070</td>
<td>0.0155</td>
<td>0.0005</td>
<td>0.0514</td>
<td>0.0026</td>
<td>105.6</td>
<td>6.6</td>
<td>99.0</td>
<td>3.4</td>
<td>260.0</td>
<td>100.0</td>
<td>6.25%</td>
</tr>
<tr>
<td>1622-57</td>
<td>0.0884</td>
<td>0.0044</td>
<td>0.0128</td>
<td>0.0003</td>
<td>0.0494</td>
<td>0.0025</td>
<td>85.9</td>
<td>4.1</td>
<td>81.8</td>
<td>2.2</td>
<td>140.0</td>
<td>100.0</td>
<td>4.77%</td>
</tr>
<tr>
<td>1622-58</td>
<td>0.1067</td>
<td>0.0035</td>
<td>0.0160</td>
<td>0.0004</td>
<td>0.0477</td>
<td>0.0010</td>
<td>102.9</td>
<td>3.2</td>
<td>102.3</td>
<td>2.7</td>
<td>81.0</td>
<td>47.0</td>
<td>0.58%</td>
</tr>
<tr>
<td>1622-58-b</td>
<td>2.4380</td>
<td>0.0540</td>
<td>0.2183</td>
<td>0.0039</td>
<td>0.0815</td>
<td>0.0020</td>
<td>1257.0</td>
<td>14.0</td>
<td>1273.0</td>
<td>21.0</td>
<td>1238.0</td>
<td>45.0</td>
<td>-1.27%</td>
</tr>
<tr>
<td>1622-60</td>
<td>0.2170</td>
<td>0.0200</td>
<td>0.0223</td>
<td>0.0012</td>
<td>0.0672</td>
<td>0.0058</td>
<td>199.0</td>
<td>17.0</td>
<td>142.2</td>
<td>7.6</td>
<td>850.0</td>
<td>170.0</td>
<td>28.54%</td>
</tr>
<tr>
<td>1622-60-b</td>
<td>2.2260</td>
<td>0.0820</td>
<td>0.2018</td>
<td>0.0047</td>
<td>0.0794</td>
<td>0.0028</td>
<td>1195.0</td>
<td>26.0</td>
<td>1185.0</td>
<td>25.0</td>
<td>1194.0</td>
<td>72.0</td>
<td>0.84%</td>
</tr>
<tr>
<td>1622-61A</td>
<td>0.0845</td>
<td>0.0018</td>
<td>0.0127</td>
<td>0.0002</td>
<td>0.0477</td>
<td>0.0011</td>
<td>82.3</td>
<td>1.7</td>
<td>81.6</td>
<td>1.3</td>
<td>87.0</td>
<td>51.0</td>
<td>0.85%</td>
</tr>
<tr>
<td>1622-61B</td>
<td>0.0894</td>
<td>0.0014</td>
<td>0.0135</td>
<td>0.0002</td>
<td>0.0478</td>
<td>0.0010</td>
<td>86.9</td>
<td>1.3</td>
<td>86.7</td>
<td>1.3</td>
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<td>47.0</td>
<td>0.23%</td>
</tr>
<tr>
<td>1622-63</td>
<td>0.0824</td>
<td>0.0023</td>
<td>0.0127</td>
<td>0.0002</td>
<td>0.0472</td>
<td>0.0013</td>
<td>80.4</td>
<td>2.1</td>
<td>81.5</td>
<td>1.5</td>
<td>57.0</td>
<td>61.0</td>
<td>-1.37%</td>
</tr>
<tr>
<td>1622-65</td>
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<td>0.0042</td>
<td>0.0124</td>
<td>0.0003</td>
<td>0.0470</td>
<td>0.0024</td>
<td>80.3</td>
<td>4.0</td>
<td>79.5</td>
<td>2.1</td>
<td>80.0</td>
<td>120.0</td>
<td>1.00%</td>
</tr>
<tr>
<td>1622-66</td>
<td>0.0656</td>
<td>0.0014</td>
<td>0.0093</td>
<td>0.0002</td>
<td>0.0482</td>
<td>0.0008</td>
<td>64.5</td>
<td>1.4</td>
<td>59.5</td>
<td>1.3</td>
<td>107.0</td>
<td>39.0</td>
<td>7.75%</td>
</tr>
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</table>
REFERENCES


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VITA

Kyle Tollefson was born in November 1992 in Arcadia, Wisconsin. He graduated from Cochrane-Fountain City High School in May 2011 and enrolled at the University of Wisconsin-Eau Claire as a materials science student. After taking his first geology class he added geology as a major and changed his materials science emphasis area to geomaterials.

Here he found his interest in mineralogy and petrology and switched from applied materials research to characterization of watermelon tourmaline by fourier transform infrared spectroscopy (FTIR). During this time, he served as a teaching assistant for mineralogy and petrology and completed a capstone project on his tourmaline research. He completed the requirements for the materials science degree and graduated with a Bachelor of Science in geology during August 2017.

In August 2018 Kyle entered the master’s program in geology at Louisiana State University. During this time, he served as a teaching assistant for igneous and metamorphic petrology, mineralogy, structural geology, and senior field camp.

Upon graduating with his MS thesis in December of 2020, Kyle will be taking time off before pursuing a doctorate.