Jake Meyer

Thesis Proposal

**Project Title:**
Fluid release during eclogite formation, North Qaidam Terrane, Western China

**Project Supervisor:**
Chris Mattinson, mattinson@geology.cwu.edu

**Introduction**

Fluids in subduction zones enhance element mobility and reaction kinetics and play important roles in arc magmatism, seismicity, and element recycling into the mantle (Austrheim, 1987; Tsujimori et al., 2006; Bebout, 2007), but observational constraints for fluid processes are scarce. Ultrahigh-pressure (UHP, depths ≥100 km) metamorphic rocks preserve a record of fluid in subduction zones and therefore can help close the data gap (Hermann et al., 2013). I propose to use thermodynamic models to determine the fluid release history and pressure-temperature (PT) path of eclogite samples from the Dulan area, North Qaidam terrane. I will combine these results with existing zircon U-Pb ages to link PT with time (t) and calculate rates of PT and fluid content changes; lawsonite pseudomorphs (Fig. 1) provide evidence of fluid release in these samples. Using rare earth element analysis (REE) to link zircon growth to PT + fluid history will also allow me to test the hypothesis that zircon grew during periods of enhanced fluid release.

**Geologic Setting**

The North Qaidam UHP terrane, located in the north Tibetan Plateau, is a major NW-SE trending terrane that represents an early Paleozoic continental suture zone in central Asia (Fig. 2) (Mattinson et al., 2007). The terrane extends over a distance of 350 km along the North Qaidam Mountains and constrains a 400 km offset of the south Altyn Tagh fault (Zhang et al., 2010). The
Dulan area (Fig. 3; site of this study), exposes metagranitic and metasedimentary gneiss and schist (including minor marble and calc-silicate rocks), with minor ultramafic rocks and eclogite lenses enclosed within gneiss (Mattinson et al., 2007; Zhang et al., 2010). Some eclogites contain lawsonite pseudomorphs (Fig. 1), and the UHP mineral coesite, as well as coesite pseudomorphs, are preserved in several samples (Fig. 3) (Zhang et al., 2010). Eclogites from the area yield 422-457 Ma zircon ages, interpreted to represent eclogite-facies metamorphism, with peak conditions of 610-830 °C and 26-35 kbar (Mattinson et al., 2007; Zhang et al., 2010).

**Fluid Release Background**

Fluids play important roles in subduction zones by enhancing element mobility and reaction kinetics, and by contributing to arc magmatism, seismicity, and recycling of trace elements into the mantle (Austrheim, 1987; Tsujimori et al., 2006; Bebout, 2007). Fluids also contribute to the recrystallization of accessory minerals such as zircon, thus documenting the fluid release history can test the hypothesis that periods of fluid release correlate with the timing of zircon growth (Rubatto and Hermann, 2007). Evidence of these subduction zone fluid processes are recorded by minerals and textures in UHP rocks that exhume to the surface. During subduction, mineral assemblages change as PT increases; hydrous minerals such as lawsonite (11.5 wt% H₂O) break down to epidote (1.9 wt% H₂O), releasing fluid that would presumably move down the pressure gradient and contribute to processes such as seismicity and arc magmatism (Fig. 4) (Tsujimori et al., 2006; Groppo and Castelli, 2010). Mineral assemblage alteration and associated fluid release is recorded by lawsonite pseudomorphs preserved in exhumed UHP rocks (Fig. 1). The PT conditions of such mineral assemblage changes can be constrained through pseudosection models, which are phase diagrams that display mineral assemblages, abundances, and compositions expected for a specific PT range (Fig. 4 & 5).
By constraining the PTt path of UHP rocks, the rate of PT changes and fluid release ($\Delta P/\Delta t$, $\Delta T/\Delta t$, $\Delta H_2O/\Delta t$) for a subduction zone environment can be calculated.

**Zircon and Garnet Rare Earth Element Analysis**

Coexistence of garnet, an important mineral for thermobarometry, and zircon, one of the best geochronometers, provides a link between U-Pb ages and metamorphic conditions, enabling construction of PTt paths (Rubatto, 2002). Garnet and zircon can be linked by comparing REE patterns in each mineral. In one of my eclogite samples, REE analysis of zircon and garnet shows that both minerals are zoned (Fig. 6 & 7). Using REE partition coefficients (Rubatto, 2002), zircon ages can be correlated with the middle zone and rim of garnet, but not the core due to the difference in REE pattern (Fig. 6 & 7). REE partitioning between zircon and garnet is still a subject of active research, but the strong zoning in garnet and zircon should allow non-equilibrium pairings (e.g. garnet core, Fig. 6) to be excluded (Harley et al., 2007).

By linking PT constraints (see below) with the ages of garnet zones, I will determine the fluid release history and PTt paths for the North Qaidam eclogites. I will link REE patterns of zircon to particular garnet zones and use pseudosections to determine PT conditions when particular garnet zones formed. From the pseudosections I will also determine if the growth of zircon correlates with fluid release during the breakdown of lawsonite. These results will also allow me to test the hypothesis that zircon grew when there was a higher availability of fluid due to lawsonite breakdown.

**Methods and Anticipated Results**

My research will involve 4 components: 1) calculation of pseudosections, using whole-rock compositions obtained through x-ray fluorescence (XRF), 2) analysis of major minerals, i.e. garnet and omphacite, by electron microprobe (EMP), 3) calculation of PT path constraints from
pseudosection analysis and EMP data, and 4) calculation of rates of PT change and fluid release
($\Delta P/\Delta t$, $\Delta T/\Delta t$, $\Delta H_2O/\Delta t$). I will use eclogite samples from the Dulan region of North Qaidam
containing the mineral assemblages of garnet + omphacite + quartz + rutile ± phengite ± epidote ± zircon; garnet is zoned and some samples contain lawsonite pseudomorphs (Fig. 1). I will
analyze eclogite samples D5A and D5B (collected from the same outcrop) along with one
sample from a second locality, D126A, to perform my research (Fig. 3).

I will calculate pseudosection models from whole-rock compositions using Perple_X
(Connolly and Petrini, 2002). In the preliminary models (Fig. 4 & 5) I have calculated
pseudosections for sample D126A that display stable mineral assemblages, $H_2O$ content and
garnet composition contours. I have already collected whole-rock data for D126A by XRF
analysis, but due to lack of sufficient samples for D5A and D5B, I will calculate whole-rock
compositions with EMP mineral data and modal abundances. The calculations will be done by
first converting mineral modal abundance estimates from volume percent to weight percent using
each mineral’s density. I will then multiply each mineral’s weight percent abundance by its
composition, measured by EMP, and add up the contributions from all minerals to determine
whole-rock values.

I will collect x-ray maps and use the maps to select locations for quantitative EMP
analysis of garnet and other major minerals needed for thermodynamic calculations. Mineral
assemblages, compositions, and abundances from the pseudosection models will then be
compared with EMP analyses to constrain the PT path and whole-rock $H_2O$ content, similar to
the approach of Groppo and Castelli (2010). I will also calculate reactions and their PT
intersections from measured mineral compositions using THERMOCALC to additionally delimit
the PT path (Holland and Powell, 1998). By combining the PT conditions of garnet zones that
are correlated with zircon ages (REE analysis section; Fig. 7) (Mattinson et al., 2006), I will calculate the rate of PT change and fluid release ($\Delta P/\Delta t$, $\Delta T/\Delta t$, $\Delta H_2O/\Delta t$) experienced by these eclogite samples during metamorphism.

I will also use my results to evaluate the hypothesis that zircon growth correlates with periods of elevated fluid release, such as lawsonite breakdown. If this prediction is correct, pseudosection models should show that garnet zones grown during periods of high fluid release are the zones that REE correlate to zircon. The results obtained from my research will increase our knowledge on the importance of fluid involved in subduction zone processes. Testing the connection between zircon growth and fluid release will also provide a better basis for interpreting zircon geochronology from metamorphic rocks.
**Schedule:**

*Spring 2014:*
- Perform pseudosection modeling with whole-rock compositions I have already collected.
- Conduct petrography to select locations for microprobe analyses.
- Formally present thesis proposal.

*Summer 2014:*
- Use electron microprobe at Washington State University GeoAnalytical Laboratory.
- Continue pseudosection modeling and begin THERMOCALC analyses.
- Interpret implications of PTt data.
- Submit an abstract on preliminary results to GSA or AGU.

*Fall 2014-Winter 2015:*
- Present results at GSA or AGU
- Write thesis

*Spring 2015:*
- Continue writing thesis / make revisions
- Defend Thesis

*Summer 2015:*
- Finish revisions

**Budget:**

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Figures:

**Fig. 1:** Garnet from eclogite D5A, in partially crossed polars, displaying laser ablation pits and a large lawsonite pseudomorph composed of polycrystalline epidote (outlined in yellow).

**Fig. 2:** Map of China showing the location of the study area and the trends of major mountain belts (dashed lines). The close up displays a map of the Qaidam-Qilian-Alryn Tagh area showing major tectonic units and HP/UHP localities in the North Qaidam terrane.
Fig. 3: Geologic map of the Dulan area, North Qaidam UHP terrane, showing the locations of eclogite samples (e) (D5A, D5B, and D126A for my study), coesite (gold stars), and coesite pseudomorphs (white stars).
Fig. 4: Preliminary pseudosection for D126A that displays stable mineral assemblages at varying pressures (y-axis) and temperatures (x-axis). Bold lines represent the quartz/coesite boundary (top) and the lawsonite in/out boundary (middle). Yellow contours represent the whole-rock H₂O weight % across the PT range. As T increases, the rock dehydrates and releases fluid. When enough fluid is released, the rock passes the lawsonite in/out boundary causing lawsonite to break down into epidote. Zoisite represents the epidote group minerals.
Fig. 5: Preliminary pseudosection for D126A similar to Fig. 4. Colored contours characterize garnet end member mole fractions. The intersection of contours that represent observed almandine, grossular, and pyrope compositions display the PT conditions at which specific garnet zones formed (i.e. core and rim).
**Fig. 6:** REE analysis of garnet from eclogite D5B. Zone 1 (blue) represents the core, zone 2 (orange) represents the middle zone, and zone 3 (pink) represents the rim. When compared with Fig. 6, zones 2 & 3 correlate with zircon, but not zone 1 (i.e. the core).

**Fig. 7:** REE analysis of zircon from eclogite D5B. Measured zircon compositions (black) match predicted zircon compositions in equilibrium with garnet middle zone (orange; left; zone 2 from Fig. 5) and garnet rim (pink; right; zone 3 from Fig. 5). The correlation links zircon ages to the formation of garnet zones.