KECK GEOLOGY CONSORTIUM

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

April 2011
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Students: *MOLLY CHAMBERLIN*, Texas A&M University, *ELIZABETH DALLEY*, Oberlin College, JOHN *SPENCE HORNBUCKLE III*, Washington and Lee University, *BRYAN MCATEE*, Lafayette College, *DAVID OAKLEY*, Williams College, *DREW C. THAYER*, Colorado College, *CHAD TREXLER*, Whitman College, *TRIANA N. UFRET*, University of Puerto Rico, *BRENNAN YOUNG*, Utah State University.

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Students: *JESSE DAVENPORT*, College of Wooster, *KRISTINA DOYLE*, Amherst College, *B. PARKER HAYNES*, University of North Carolina - Chapel Hill, *DANIELLE LERNER*, Mount Holyoke College, *CALEB O. LUCY*, Williams College, *ALIANORA WALKER*, Smith College.

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Students: *BRIANA BERKOWITZ*, Beloit College, *DAENA CHARLES*, Union College, *MELLISSA CROSS*, Colgate University, *JOHN MICHAELS*, North Carolina State University, *ERDENEBAYAR TSAGAANNARAN*, Mongolian University of Science and Technology, *BATTOGTOH DAMDINSUREN*, Mongolian University of Science and Technology, *DANIEL ROTHBERG*, Colorado College, *ESUGEI GANBOLD, ARANZAL ERDENE*, Mongolian University of Science and Technology, *AFSHAN SHAIKH*, Georgia Institute of Technology, *KRISTIN TADDEI*, Franklin and Marshall College, *GABRIELLE VANCE*, Whitman College, *ANDREW ZUZA*, Cornell University.

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Students: *MARY BADAME*, Oberlin College, *MEGAN D'ERRICO*, Trinity University, *STANLEY HENSLEY*, California State University, Bakersfield, *JULIA HOLLAND*, Trinity University, *JESSLYN STARNES*, Denison University, *JULIANNE M. WALLAN*, Colgate University.

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Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Big Sky Orogen

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Project Faculty: TEKLA A. HARMS, JOHN T. CHENEY, Amherst College, JOHN BRADY, Smith College

PROTOLITH DETERMINATION OF PRECAMBRIAN MYLONITIC ROCKS ADJACENT TO THE MADISON MYLONITE ZONE, HENRYS LAKE MOUNTAINS, SOUTHWEST MONTANA AND IDAHO
JESSE DAVENPORT, College of Wooster
Research Advisor: Shelley Judge

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ALIANORA WALKER, Smith College
Research Advisor: H. Robert Burger

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JESSE DAVENPORT, College of Wooster
Research Advisor: Shelley Judge

INTRODUCTION

Work in the summer of 2010 was completed in Island Park, Idaho, by a group of Keck faculty and students to determine the effects the 1.78 - 1.72 Ga orogenic event had on the Antelope Basin study area. These investigations will help further develop the understanding of the Big Sky orogeny and its implications for the formation of the Wyoming province.

The goals of this study are to:

1. Determine the protolith of mylonitic rocks located in discrete shear zones south of and adjacent to the Madison mylonite zone through geochemical and thin section analysis as well as to determine whether mylonitic rocks could have formed from adjacent meta-igneous rocks.
2. Use geochemical and thin section data to clearly distinguish and characterize any chemical alteration that may have accompanied shearing.

Please refer to Davenport (2011) for full data sets, results, and analysis for this project.

METHODS

Elemental and petrographic analysis was performed on mylonitic and meta-igneous sample sets, located in the Antelope Basin of the Henrys Lake Mountains. A total of 27 samples were collected in approximately 35 localities over the duration of the project. Once an outcrop that fit into the working definition of a mylonite was identified a record of the mineral assemblages, structures, UTM coordinates, strike/dip of foliation and trend/plunge of lineation (if appropriate for sample site), and photographs were taken. Five to six hand-sized samples or larger were collected from each outcrop. Most of the 35 sample sites had severe surface weathering and in places showed signs of alteration. It was therefore critical to collect samples that were: 1) fairly fresh, with minimal signs of chemical and/or physical weathering, 2) thick enough to cut a thin section billet, and 3) enough quantity for eventual grinding and powdering.

The samples were processed in The College of Wooster's rock preparatory laboratory. Using the diamond bit rock saw, the largest rock of each sample was cut into two aliquots. One aliquot was used to prepare a thin section billet, and the other section was pulverized for geochemical analysis. Twenty five billets were sent to Quality Thin Sections of Arizona to prepare standard petrographic thin sections. Geochemical samples were sent to Acme Analytical Laboratories, Inc. of Vancouver, British Columbia for XRF and ICP-MS analysis.

ROCK DESCRIPTIONS

The mineralogy of most hand samples collected was hard to distinguish in the field due to grain size, weathering, and possible alteration. In thin section, chlorite, epidote, and secondary amphibole were abundant in non-mylonitic meta-igneous samples. The samples noted to be mylonitic in the field have a distinct alignment of grains, characterized by mafic grains with largely quartz and a small percentage of plagioclase/feldspar that all show significant signs of grain shattering and breaking, recrystallization and neocrystallization.

RESULTS AND ANALYSIS

Three pairs of rock samples (10-JD-01, & 10-JD-02;, 10-JD-06, & 10-JD-07;, and 10-JD-10, & 10-JD-11) were collected at three different localities where one distinctly sheared rock is adjacent to another that is distinctly not sheared. The question posed is whether or not the highly sheared rock was formed from the non-sheared rock by some sort of metamorphic, meta-

somatic, alteration, or tectonic event.
Geochemistry and thin section analyses reveal that sheared and adjacent non-sheared rocks are not similar at all (Fig. 1). Mylonitic rocks are well foliated, lineated, and dominantly quartz bearing with very little alteration or secondary metamorphic minerals. Geochemical results show low silica content in the meta-igneous rocks and a higher silica content and depletion of elements like Fe and Al in mylonitic rocks. Therefore, it is reasonable to hypothesize that the sheared rocks are not simply deformed versions of the unsheared rocks.

Sample	SiO2	Al2O3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	LOI	Sum
10-JD-01	49.74558	15.26504	11.35661	5.429369	11.92233	2.400673	0.111424	1.175013	0.101294	0.1722	0.023298	2.127178	99.83
10-JD-02	69.98508	11.99802	5.778297	2.063417	0.825367	3.532973	2.848523	0.603927	0.130851	0.070458	0	2.01309	99.85
10-JD-06	72.95565	11.97659	5.103247	0.985479	0.22123	2.916215	4.042477	0.522907	0.140783	0.070391	0	0.905032	99.84
10-JD-07	51.40412	15.70203	12.57809	5.027893	7.045132	3.517498	0.912319	1.338068	0.152053	0.202738	0.004055	1.926007	99.81
10-JD-10	69.01295	13.41583	6.452666	3.071942	0.251799	0.05036	3.615827	0.574101	0.181295	0.030216	0	3.223021	99.88
10-JD-11	57.40786	14.19025	9.54901	3.709276	6.367422	3.35553	2.617718	1.111772	0.171819	0.141498	0.006064	1.111772	99.74

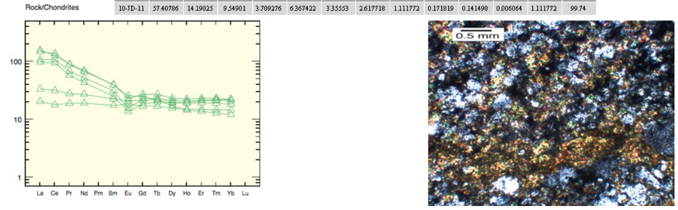

Figure 1. In the top left corner is a picture of a typical rock outcrop in the Antelope Basin. The top photomicrograph shows a typical meta-igneous rock in thin section and the bottom photomicrograph shows a typical mylonitic rock in thin section. The table gives geochemical data for the three pairs of samples [light grey bars = mylonitic rocks; dark grey bars = non-mylonitic, adjacent rocks] and the graph gives the samples normalized to chondrite values [samples enriched in the LILEs are non-mylonitic and samples with less enrichment are mylonitic rocks] (after the methods of Sun and McDonough, 1989).

The Antelope Basin samples show enrichment in the LILEs and the LREEs and depletion in the HREEs (Fig. 2). Lucy (2011) demonstrates the extent of alteration in meta-igneous rocks of the study area. The high likelihood of pre- or synmetamorphic alteration further complicates the interpretation of the protoliths of the Antelope Basin samples. Although no granitic samples were found or collected in the study area, mylonite range from 65 to 75% silica (Fig. 3) and are comparable to mylonites in the Madison Mylonite Zone (Erslev and Sutter, 1990).

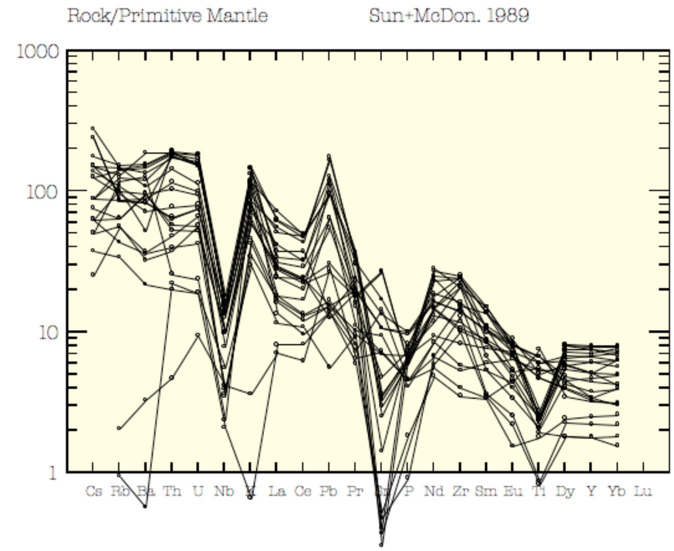

Figure 2. Primitive mantle-normalized "spider" diagram (after the methods of Sun and McDonough 1989) for samples of the mylonitic dataset. The depletion of elements Nb and P and the relative enrichment of LILEs and LREEs as compared to the HREEs suggests a continental arc setting.

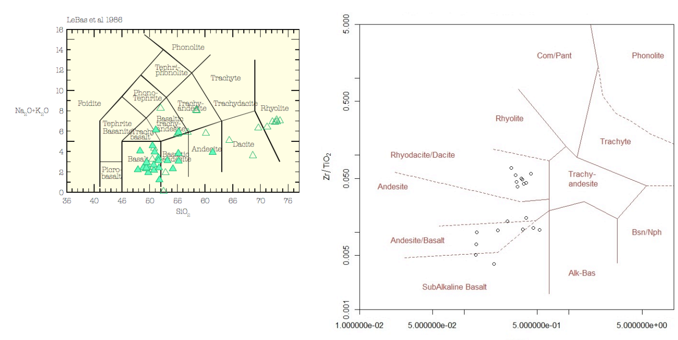

Figure 3. The graph on the right shows the geochemical classification of the mylonitic dataset of the Antelope Basin area (after the methods of Winchester and Floyd, 1977). The TAS diagram plots the mylonitic dataset and the meta-igneous dataset (adapted from Lucy, 2011) (after the methods of LeBas et al., 1986).

For the Antelope Basin mylonites to obtain enrichment in the siderophile elements (Mn, P, Mg, Ti, Ca, and Fe), localized shear zones, like the Madison Mylonite Zone, may have been thrust over large volumes of adjacent mafic rock. In this case, mafic rocks, from the Antelope Basin are those rocks with <65% silica and plot as andesite/basalt on discriminate diagrams (O'Hara, 1988; Singha et al., 1986).
Macroscopic and microscopic observations clearly indicate that feldspar grains and accessory miner-

als from feldspars (epidote, chlorite, etc.) were deformed more than quartz grains, as quartz grains are of the same or equal size in all of the mylonitic rocks, whereas feldspar and accessory minerals are almost always unrecognizable or reduced to the point where observation with magnification is not possible. According to Janecke and Evans (1988), feldspar conversion to the phyllosilicates is closely tied to the deformation of a region on a macroscopic scale and correlates to the introduction of large volumes of fluid into discrete shear zones, which does not produce feldspar porphyroclast-dominate foliated rocks, but rather quartz porphyroclast-dominate foliated rocks. The matrix mineral in these rocks is recrystallized quartz ribbons that have undergone ductile deformation due to grain size reduction, granoblastic texture, and undulatory extinction.

Low temperature conditions may have produced the brittle deformation of feldspars, the alteration to phyllosilicates, and the grain size reduction of quartz seen in the Antelope Basin mylonites, suggesting that the rocks in the Antelope Basin were deformed at middle to upper level crustal conditions (Janecke and Evans, 1988). Janecke and Evans (1988) suggest that these deformation mechanisms and feldspar reactions produced weak fault zones that are typically interpreted to be a part of a larger and more developed regional hydrated fault zone. Smaller, discrete shear zones, north of the Antelope Basin study area and adjacent to the larger Madison Mylonite Zone, have been observed by Sumner and Erslev (1988). They noted that the repetition of regional stratigraphy was produced by thin-skinned thrusting along a number of southeast dipping mylonite zones. Results from Walker (2011) replicate the southeast dipping mylonitic zones in the Antelope Basin study area. Due to the distance away from the main core of thrust faulting, folding, and metamorphism in the Big Sky orogen, the study area did not experience the high temperatures and pressures that rocks in the Tobacco Root Mountains experienced.

CONCLUSION

Trends observed from variation diagrams (Fig. 4 and 5) coupled with rare earth element (REE) plots (Fig. 2) suggest an igneous, continental arc setting with a bimodal volcanic distribution spanning a basalt-andesite-dacite-rhyolite series.

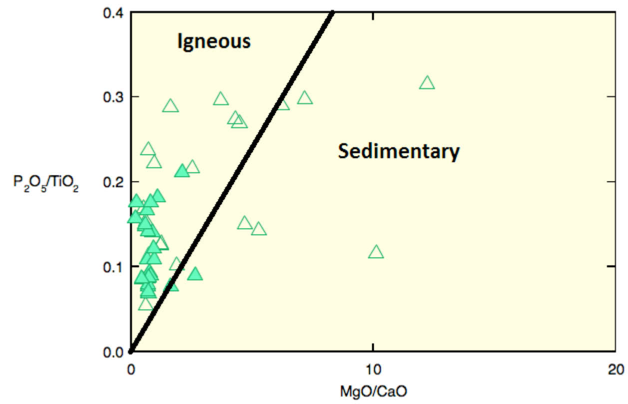

Figure 4. Plot of the ratio of MgO/CaO against P2O5/TiO2 to determine an igneous versus sedimentary origin. Filled triangles show the meta-igneous data set (adapted from Lucy, 2011) and open triangles show the mylonitic dataset (after the methods of Werner, 1987).

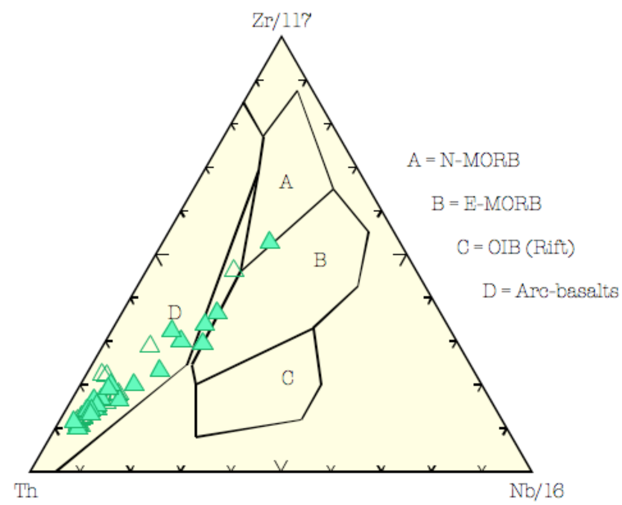

Figure 5. Ternary diagram plotting Zr, Th, and Nb for determination of the setting of origin for all samples. Filled triangles show the meta-igneous data set (adapted from Lucy, 2011) and open triangles show the mylonitic dataset (after the methods of Wood, 1980).

It is difficult to distinguish geochemically between felsic volcanic rocks and felsic sedimentary rocks. However, given the area and nature of events, it is more likely that weathering and/or other sedimentary processes have contributed to the current geochemical signature of samples that plot as having a sedimentary protolith. (Fig. 4)

Based on geochemical results indicating the basalt-andesite-dacite rhyolite series comparable to Mogk et al. (2004), with the tectonic setting, metamorphic processes, and alteration possibilities, the mylonitic quartzofeldspathic gneisses in the Antelope Basin have an igneous origin. They most likely formed from one or more bimodal volcanic associations.

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