KECK GEOLOGY CONSORTIUM

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

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Students: *HANNAH BOURNE*, Wesleyan University, *JONATHAN GRIFFITH*, Union College, *JACQUELINE KUTVIRT*, Macalester College, *EMMA LOCATELLI*, Macalester College, *SARAH MATTESON*, Bryn Mawr College, *PERRY ODDO*, Franklin and Marshall College, *CLARK BRUNSON SIMCOE*, Washington and Lee University.

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Research Advisor: H. Robert Burger

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EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SOUTHWEST MONTANA

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

INTRODUCTION

In a remarkable phase of crustal evolution, the period from approximately 2.0 to 1.7 Ga saw the amalgamation of small Archean continental bodies into the stable core of what is now the North American continent (Hoffman, 1988). A half-dozen Archean cratons were welded together across Proterozoic orogenic belts, many containing the remnants of juvenile arcs (Whitmeyer & Karlstrom, 2007). The Wyoming province is one such craton (Fig. 1), preserved as isolated exposures of crystalline basement in Laramide and younger uplifts (Fig. 2) that form the northern Rocky Mountains in Wyoming and southwest Montana (Frost & Frost, 1993).

A decade of work by previous Keck students (see Brady et al., 2004) has demonstrated the involvement of the northern Wyoming province in a major collision at 1.78 to 1.72 Ga, during what we call the Big Sky orogeny. The Big Sky orogenic belt (Fig. 1) most likely marks the suture between the Wyoming province, an intervening arc, and the Medicine Hat block of the Hearne province to the north (Harms et al., 2004; O'Neill, 1998). Evidence for the Big Sky orogeny is well preserved in the Tobacco Root Mountains, where the peak of metamorphism reached >700˚C and >1.0 GPa, indicating crustal thicknesses in excess of 40 to 50 km (Brady et al., 2004). Syn-metamorphic structures demonstrate that the ductile core of the Big Sky orogen extruded or was thrust to the south, towards the interior of the Wyoming province (Harms et al., 2004).

This project addresses the Proterozoic geologic evolution of metamorphic rocks exposed in and around Antelope Basin, in the western Henrys Lake Mountains, astride the Continental Divide between Montana and Idaho (Fig. 3 and 4). The study area lies south of and consequently on the inboard side of the Tobacco Root

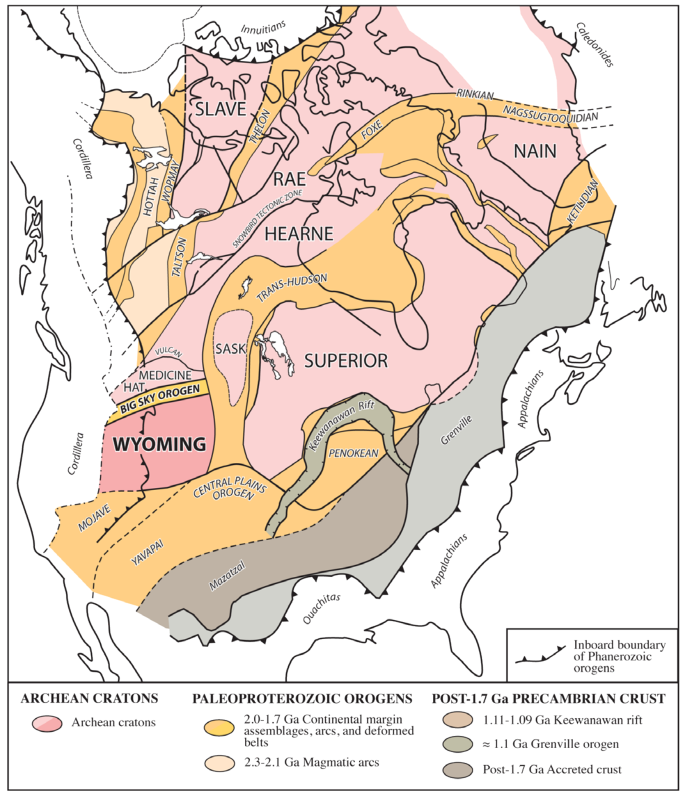

Figure 1. Archean cratons and intervening Proterozoic orogenic belts of North America, including the Wyoming province and the Big Sky orogen. Adapted from Hoffman (1988) and Bleeker & Hall (2007).

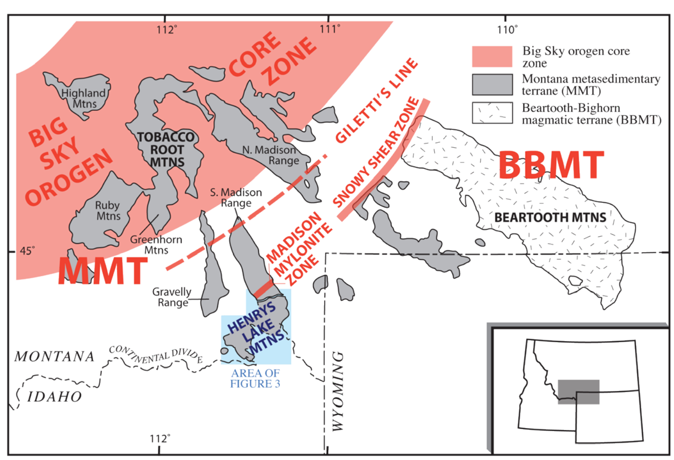

Figure 2. Outline map of Precambrian basement rocks exposed in the northern Wyoming province. Inset map shows area covered.

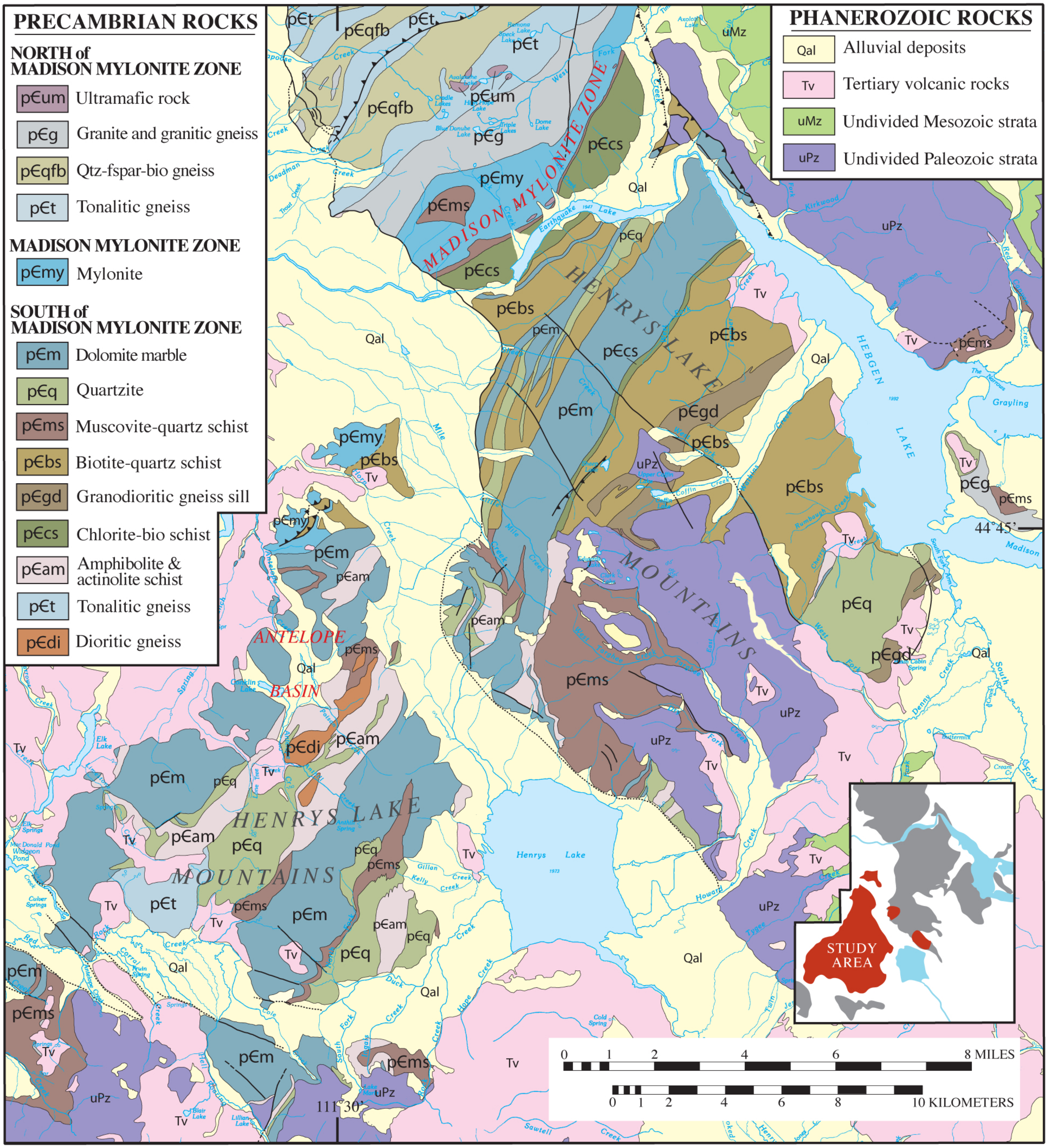

Figure 3. Simplified geologic map of the study area. Adapted from O'Neill & Christiansen (2004) and Witkind (1972). Inset map shows study area for this project (red) relative to other Precambrian exposures within the map area (gray).

Mountains relative to the rest of the Wyoming province. It is across or adjacent to several fundamental geologic boundaries whose origin and relationship to one another, and to the Big Sky orogeny, are poorly understood (Fig. 2).

The first of these boundaries is thermochronological. Almost 50 years ago, Giletti (1966) recognized that, while rocks of the northern Wyoming province generally yield K-Ar ages > 2.5 Ga, rocks northwest of what is now known informally as "Giletti's Line" (Fig. 2) gave him ages in the range of 1.6 Ga, which he attributed to a Proterozoic thermal disturbance. We now understand that the rocks of the Tobacco Root Mountains are not simply reset Archean units, but were subject to high-grade metamorphism and penetrative recrystallization at 1.78 Ga and may be principally, if not entirely, Proterozoic in age and character. But Giletti's point remains salient: where is and what is the southern limit of the thermal effects of the Big Sky orogen? Somewhere south of the Tobacco Root Mountains, we expect the ductile, deep core of the orogen to transition into rocks that were at higher structural levels and farther from the suture, but the position and nature of this transition are undocumented.

The second important boundary is a NE trending, NW dipping, SE verging shear zone, the Madison mylonite zone (Fig. 2), at the southern end of the Madison Range, south of Giletti's line (Erslev 1988; Erslev & Sutter, 1990). The Madison mylonite zone thrusts quartzofeldspathic gneisses on the north over a distinctly different suite of metasedimentary schists, marbles, and amphibolites - the Cherry Creek metamorphic suite - on the south (Erslev & Sutter, 1990; Sumner and Erslev, 1988). The Cherry Creek metamorphic suite in this area appears to have cooled at around 2.5 Ga, whereas the mylonites have disturbed Ar-Ar spectra that indicate shearing at approximately 1.8 Ga (Erslev & Sutter, 1990). It therefore seems likely that the Madison mylonite zone juxtaposes major building blocks of the Big Sky orogen. The along-strike continuation of the Madison mylonite zone may lie just to the north of the Antelope Basin study area, in an area presently covered by Tertiary volcanic rocks and Quaternary alluvium. Can correlations be drawn between the Cherry Creek metamorphic suite south of the Madison mylonite zone and the rocks of the study area? What was the setting in which the supracrustal rocks south of the Madison mylonite zone originated? Do they define the nature of the northern margin of the Wyoming province at that time? What caused their metamorphism? How did they become incorporated in the Big Sky orogen?

A third boundary is lithotectonic, dividing the northern Wyoming province into two distinct domains (Fig. 2): the Beartooth-Bighorn magmatic terrane, a largely tonalite-trondhjemite-granodiorite domain, and the Montana metasedimentary terrane, dominated by quartzofeldspathic gneisses in which belts of distinct metasupracrustal sequences are preserved (Mogk et al., 1992.) Both domains have been interpreted to be Archean and to have been a part of the Wyoming province since about 2.55 Ga (Mogk et al., 1992). The Snowy shear zone (Erslev, 1992) at the north end of the Beartooth Mountains, in part, separates these two terranes (Mogk et al., 1988; Erslev, 1992). The time and sense of motion on that shear zone are unresolved, but it is along strike from and parallel with the Madison mylonite zone. This close spatial correlation between the Montana metasedimentary terrane, its boundary, and the crustal blocks involved in the Big Sky orogen raises the question of whether, in fact, the suture between the Montana metasedimentary and Beartooth-Bighorn terranes predates the Big Sky orogeny and is unrelated, or could be a feature of Big Sky orogenesis.

GEOLOGIC SETTING

Semi-continuous NE-trending bands of low to intermediate grade metamorphic rocks underlie the Henrys Lake Mountains study area (Fig. 3), the most significant of which are mafic meta-intrusive rocks variously mapped as tonalite, diorite, and amphibolite, and dolomitic marble intercalated with quartzite, mica-schist, phyllite, and local metaconglomerate (O'Neill & Christiansen, 2004; Witkind, 1972). The study area hosts few index minerals by which to constrain metamorphic grade, but most metasedimentary rocks are relatively fine grained and are considered to be low grade on that basis. This contrasts with the locally impressive development of garnet, amphibole, sillimanite, and tremolite in rocks immediately east of Henrys Lake.

A range of fabrics and structures are locally developed in the rocks of the study area. Cascades of tight, recumbent folds traced out by quartzitic horizons in marble can be found in some outcrops. Discrete, thin mylonitic zones occur in many places and in different units. Elsewhere, mica schists are overprinted with multiple crenulation cleavages. The presence of these outcrop-scale structures suggests the potential for unrecognized map-scale structures. The simple banded appearance of the map pattern probably does not represent a primary stratigraphy. Field relations indicate that few of the meta-igneous bodies represent flows; although some may have a volcaniclastic origin, most appear to have been intrusive. For the most part, original contact relationships are obscured by poor exposure, metamorphism, and shearing.

PROJECT GOALS

The overall objectives of study in the Henrys Lake Mountains area are to characterize the nature of the rock units prior to metamorphism, to constrain the pressure and temperature conditions of metamorphism and when that metamorphism occurred, and to determine the tectonic setting of the area prior to the Big Sky orogeny. What was the relationship of these rocks to the rest of the Wyoming province before the Big Sky orogeny? We hope to determine which aspects of the area, if any, can be attributed to effects of the Big Sky orogeny, and to compare and contrast those aspects with the Proterozoic geology across strike to the north in the Tobacco Root Mountains.

Figure 4. Project participants in the study area. From left to right: Parker Haynes, Alianora Walker, Kristina Doyle, John Brady, Tekla Harms, Danielle Lerner, Jesse Davenport, Caleb Lucy.

To these ends, the 2011 project team undertook investigations that would characterize the grade of metamorphism across the area, constrain the probable protoliths of those rock units, determine the kinematics of shear imposed on the rocks, and assign ages to intrusive and/or metamorphic events, if possible.

Jesse Davenport, College of Wooster has undertaken a geochemical analysis of mylonitic rocks from across the study area. The degree of textural change and, possibly, mineralogic or chemical alteration, experienced by these rocks makes their protoliths difficult to determine by visual inspection or by comparison to adjacent rock types.
Kristina Doyle, Amherst College will characterize the grade of metamorphism experienced by mica schists in the Henrys Lake Mountains both east and west of Henrys Lake. Appearance in the field suggests there may be different metamorphic grades juxtaposed in this small area.

Parker Haynes, University of North Carolina will use the U-Pb isotope system to constrain the time of intrusion and metamorphism of the many coarse- to medium-grained meta-intrusive rocks in the study area. Although mapped as tonalite, diorite, and even amphibolite, field relations suggest they constitute a suite of related mafic intrusions.

Danielle Lerner, Mount Holyoke College has taken on the dolomitic marbles that underlie so much of the study area. She is bringing petrology, stable isotope geochemistry, and structural analysis to bear on this unit to determine its grade of metamorphism, characterize its deformation, and possibly constrain its origin.

Caleb Lucy, Williams College is seeking to clarify the nature of the mafic meta-intrusive suite of rocks by use of petrology and whole rock geochemistry. There are significant discrepancies between published accounts of this suite and their actual characteristics in the field that make this work essential.

Alianora Walker, Smith College is the kinematic analyst for the project. To the extent possible, Ali will determine the sense or senses of shear experienced across the numerous discrete shear zones in the study area.

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