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POLYPHASE DEFORMATION OF NEOARCHEAN-PALEOPROTEROZOIC ROCKS IN THE BLACK HILLS, SOUTH DAKOTA

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INTRODUCTION

The crystalline core of the Black Hills of western South Dakota exposes Neoarchean and Paleoproterozoic plutonic and metamorphic rocks that record processes related to the assembly of Laurentia (e.g., Lisenbee, 1988; Whitmeyer and Karlstrom, 2007; Redden and Dewitt, 2008). Whereas early analysis of the Black Hills Precambrian interpreted that the Black Hills conincide with the Trans-Hudson orogeny–the suture between the Wyoming and Superior cratons that forms the core of the Laurentian continent (Redden et al., 1990), exposure of Wyoming craton Archean orthogneisses along the eastern side of the Black Hills (e.g., Gosselin et al., 1988; McCombs et al., 2004) complicates this picture (Fig. 1). Subsequent work has partially reconciled this issue by reinterpreting the location of the eastern margin of the Wyoming Craton (Worthington et al., 2016), recognizing an earlier phase of continental rifting that could have displaced fragments of the Wyoming craton prior to assembly or Laurentia (Dahl et al., 2006; Van Boening and Nabelek, 2008), or considering that Black Hills metamorphic rocks may not represent the Trans-Hudson orogen (Dahl et al., 2010).

Little Elk Creek in the northeastern edge of the Black Hills crystalline core is an isolated erosional window that provides nearly continuous exposure of deformed Archean and Paleoproterozoic rocks along a ~7 km across-strike transect (Fig. 2). The Black Hills Keck group aimed to better characterize the formation and deformation features of rocks along Little Elk Creek to better understand how genetic relationships and shared deformation features among these rocks inform the various tectonic models.

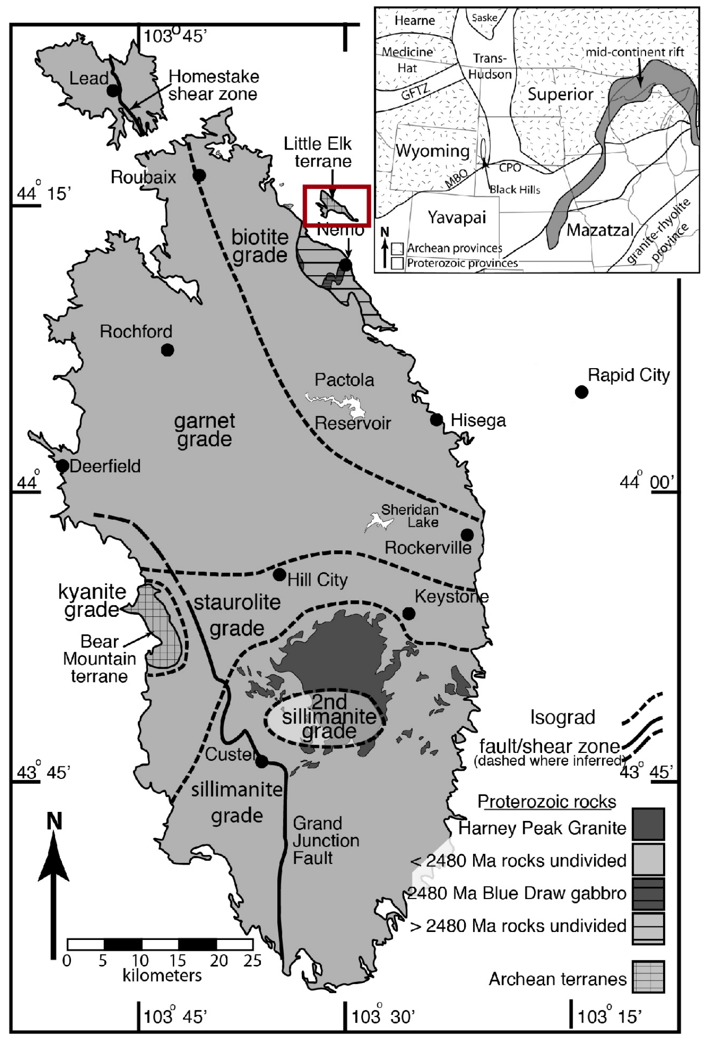

Figure 1. Generalized geologic map of the Black Hills crystalline core with cities (black circles) and regionally important structures. The study area and map units relevant to the proposed study are outlined in red. Inset: Regional map of Laurentian cratonic blocks and sutures between blocks relative to state borders. Note the location of the Black Hills within the Trans-Hudson domain. CPO–Central Plains Orogen; MBO–Medicine Bow Orogen. Modified from Allard and Portis, (2013).

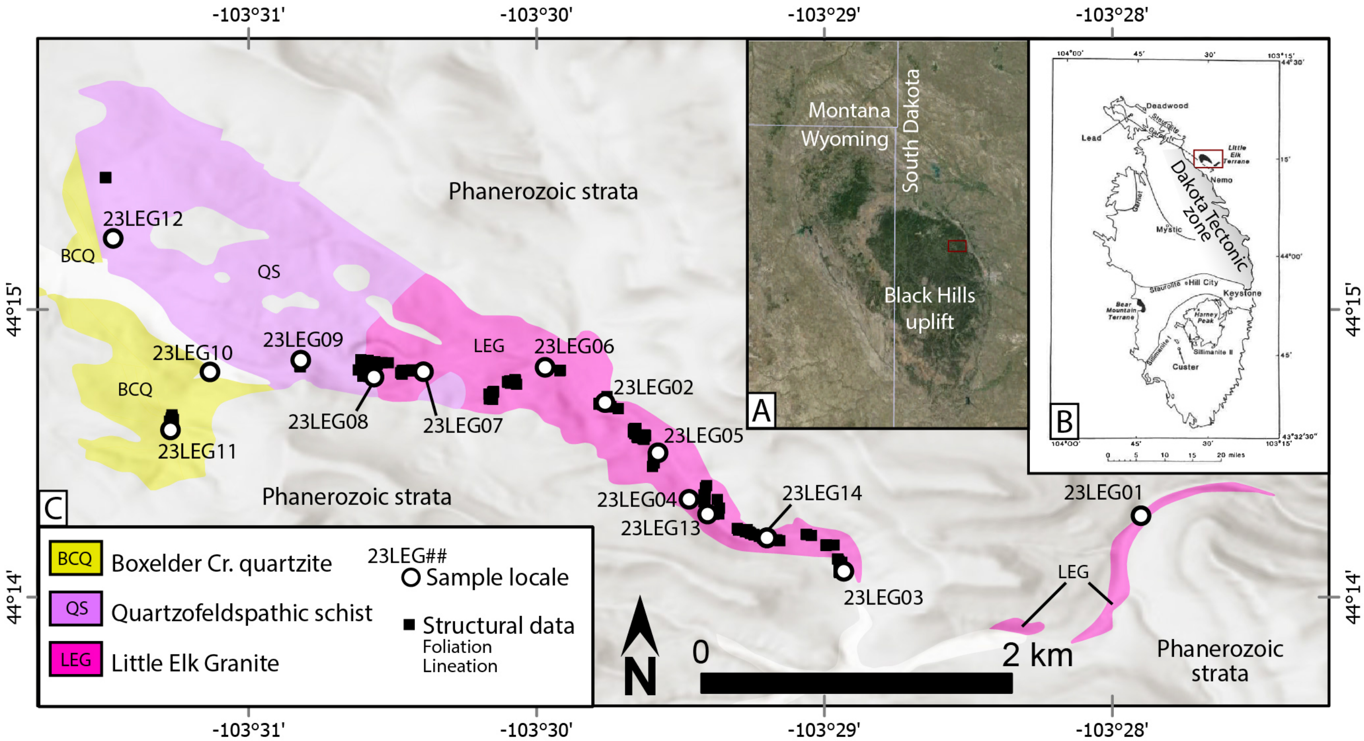

Figure 2. A) Google Earth image showing the location of the Black Hills (dark green region) relative to political borders. The Little Elk Creek area is outline by the red rectangle. B) Metamorphic isograd map of the Black Hills Precambrian core from Gosselin et al. (1988). Black shaded regions represent Archean rocks. The Little Elk Creek area is outline by the red rectangle. C) Geologic map of the Little Elk Creek area showing sample and structural data locations. Modified from Redden and DeWitt (2008).

GEOLOGIC CONTEXT

Precambrian crystalline rocks in the Black Hills are exposed in the core of a doubly plunging Laramide anticline, wherein syn- and post-Laramide erosion cut through Phanerozoic platform strata into the Precambrian core (Lisenbee, 1988). Much of the metamorphic core of the range consists of Paleoproterozoic metasedimentary rocks, which represent an ocean basin that was closed during Proterozoic suturing of the Superior and Wyoming cratons during the Trans-Hudson orogeny (Redden and DeWitt, 2008). Four generations of structures have been documented to record deformation and metamorphism during closure of the ocean basin: (1) N-vergent tight-to-isoclinal, recumbent folding estimated to have taken place at ca. 1883-1775 Ma prior to regional metamorphism (Dahl et al., 2005a). Fabrics associated with this folding (S1/F1) may be locally preserved as inclusion trails in porphyroblasts (Dahl et al., 2005b) (2) N-NW trending upright, isoclinal folding (F2) with a strongly developed axial planar cleavage (S2) at ca. 1760-1747 Ma (Dahl and Frei, 1998); (3) Vertically plunging folds (F3) and sinistral mylonite zones that deform S2 at ca. 1736-1719 Ma (Morelli et al., 2010). (4) Doming and associated folding (F4) related to emplacement of the Harney Peak granite in the southern Black Hills, which is dated at 1717-1715 Ma (Redden et al., 1990). The earliest evidence of regional metamorphism is associated with the F2 folding event (Nabelek et al., 2006), which persisted until crustal melting resulted in emplacement of the Harney Peak granite at ca. 1715 Ma (Redden et al., 1990).

Rocks exposed in Little Elk Creek consist of the Little Elk granite, quartzofeldspathic schist, and the Boxelder Creek quartzite (Fig. 2). The Little Elk granite is an augen gneiss that has been dated at 2559 ± 6 Ma (McCombs et al., 2004). A variably developed shear fabric defines the contact between the Little Elk granite, quartzofeldspathic schist, and the Boxelder Creek quartzite, which masks the original relationship among the rock units. Some previous work envisions the Little Elk granite as intruded into the quartzofeldspathic schist (e.g., Redden and DeWitt, 2008) (Fig. 2), whereas other work argues that the quartzofeldspathic schist is a high strain equivalent to the Little Elk granite (Nicosia and Allard, 2014). South of Little Elk Creek, the Boxelder

Creek quartzite is intruded by a suite of 2480 ± 6 Ma metagabbro bodies (Dahl et al., (2006), which brackets the age of the metasedimentary rocks to be earliest Proterozoic or Archean. Although the the Little Elk granite is interpreted to have been a source area for the Boxelder Creek quartzite (e.g., Redden and DeWitt, 2008), the lack of granite clasts in the quartzite have so far left the proposed genetic relationship tenuous.

METHODS

The Black Hills Keck group performed field work in August, 2023 with the goals of documenting potential genetic relationships and deformation phases among the rock types exposed in Little Elk Creek. We collected field data and samples along an east-west transect through Little Elk Creek. Along the profile, students worked together to 1) collect structural measurements with the FieldMove application on Apple iPad; 2) collect oriented samples for thin section microstructural analysis; 3) photograph cross cutting relationships; 4) collect large samples for geochronology; and 5) write field notes that give appropriate context to the samples and measurments. At the end of the field season, students used the facilities at the South Dakota School of Mines and Technology to cut thin section billets and perform rock crushing/mineral separation for geochronology. Thin section billets were sent to Wagner Petrographic to produce polished thin sections. Mineral separates were sent to the Arizona Laserchron Center for mounting and eventual analysis by a subset of the Keck group.

STUDENT PROJECTS

Four students (Fig. 3) from four colleges performed research projects focused on determining the identity and deformation history of rocks in Little Elk Creek. Their work elucidates processes that took place during the formation of the oldest rocks in the Black Hills and subsequent deformation phases that juxtaposed them.

Liam Fry (Eckerd College) performed a kinematic analysis of shear zones within the Little Elk Granite. Liam found that shear zones in the granite can be split into two groups based on their fabric types. The type 1 fabric is a high temperature augen gneiss fabric characterized by plastically deformed feldspar crystals up to ~5 cm in diameter. Asymmetry within the augen gneiss fabric suggests top-down shear sense along a moderately SW-dipping foliation. The type 2 fabric crosscuts the type 1 fabric and is characterized by fracturing of the preexisting feldspar augens within a low-temperature mylonitic fabric. Opposing strike-slip shear sense indicators and a steeply plunging stretching lineation suggest that the type 2 fabric formed in a pure shear dominated transpression zone. Liam’s data collectively demonstrate that the Little Elk granite records at least two deformation events that are distinguishable with detailed field observations. The first event likely formed late in the intrusion history of the Little Elk granite at ca. 2560 Ma, and the second event likely formed late in the suturing of the Wyoming and Superior cratons around ca. 1720 Ma.

Figure 3. Students of the Black Hills Keck group. Back: Alex Robinson (left) and Liam Fry (right). Front: Rebecca Braun (left) and Willa Obringer (right).

Rebecca Braun (South Dakota School of Mines and Technology) performed petrography and microstructural analysis on a suite of oriented thin sections of mylonitized orthogneiss (Liam's type 2 fabric). Rebecca found that the microstructures in thin section, like the outcrop, show opposing shear sense indicators, suggesting a significant component of pure shear deformation in addition to the strike-slip motion. Fractures between feldspar crystals are filled with polygonal quartz and quartz in the main shear fabric displays undulatory extinction. Rebecca used the contrasting deformation textures in quartz and feldspar to bracket the deformation temperature of the mylonite to 300-450ºC. Rebecca's data collectively show that the late mylonitic fabric in the Little Elk granite represents a greenschist facies pure shear dominated transpression zone.

Willa Obringer (Lake Superior State University) performed a combined structural and geochronological analysis of the Boxelder Creek Quartzite juxtaposed along the western margin of the Little Elk granite. Willa's structural data show that the quartzite was deformed by a combination of flattening and left lateral simple shear. Detrital zircon U-Pb data from the quartzite contain ages consistent with derivation from Wyoming craton sources, including a distinctive ca. 2550 Ma age population that overlaps the age of the Little Elk granite. Willa also leveraged a newly acquired Scanning Electron Microscope at her home institution to show that the Boxelder Creek quartzite is endowed in Cr and Ag. Willa's data collectively show that the Boxelder Creek quartzite may represent a ca. 2550-2480 Ma syn-rift depocenter that formed along the eastern margin of the Wyoming craton and was sybsequently deformed along with the Little Elk Granite from which it was likely derived.

Alex Robinson (Pomona College) performed U-Pb dating of samples mapped as "Little Elk granite" and "biotite-feldspar gneiss" (Fig. 2) to test whether the biotite-feldspar gneiss may represent a mylotinized version of the Little Elk granite (as supported by Liam and Rebecca's analyses). Alex found that zircons grains from the two samples yielded unimodal distributions of ages centered on ca. 2550 Ma, with few analyses that span back to ca. 2800 Ma. The U-Pb data support the field data and suggest that the biotite-feldspar gneiss is best interpreted as a portion of the Little Elk granite that has experienced intense deformation, resulting in grain size reduction and the development of mylonitic shear zones.

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