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U-PB ZIRCON DATING OF NEOARCHEAN ROCKS IN THE LITTLE ELK TERRANE, BLACK HILLS, SOUTH DAKOTA

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ABSTRACT

Proterozoic metasedimentary rocks exposed in the core of the Black Hills, South Dakota, are generally interpreted to represent an ocean basin that closed during suturing of the Wyoming and Superior cratons. However, two Archean crystalline terranes are exposed at the western (Bear Mountain terrane) and eastern (Little Elk terrane) margins of the Black Hills Precambrian core and have an unclear relationship with the Proterozoic rocks. This study focuses on the Little Elk terrane, which has been mapped as two individual units: the Little Elk Granite and Biotite-Feldspar Gneiss. Previous work on the Little Elk terrane has argued either that these units are distinct entities based on structural features, or that they are variably deformed versions of the same granite body. We present U-Pb zircon data from each of the two units with the goal of determining whether the units are unique geologic features or have some genetic relationship. After LA-ICP-MS analyses on 315 zircons from each sample, the zircon U-Pb data were filtered for concordance (75-110%) and compared using concordia plots, kernel density estimate plots, weighted mean plots, and associated statistics. Both samples display significant discordance with a lower intercept at 0 Ma, suggesting simple Pb loss. The data that passed the filtering criteria display a normal unimodal distribution for each sample. The granite sample yielded a weighted mean age of 2545 ± 2.3 Ma (MSWD= 0.86, n= 139), and the gneiss sample yielded a weighted mean age of 2555 ± 2.3 Ma (MSWD= 0.7, n=149). Each sample contains few analyses older than ca. 2600 Ma. Given the normal distribution of the data, the under-dispersion of the analyses, and similarity between the mean ages, we interpret that the two units share an origin, and the Biotite-Feldspar Gneiss is a portion of the Little Elk Granite that experienced higher strain. Synthesizing our data with other recent work on the Little Elk Terrane reveals that a greenschist facies shear zone juxtaposes the western margin of the Little Elk Granite against Paleoproterozoic quartzites to the west. We interpret that the Biotite-Feldspar Gneiss represents the portion of that shear zone with Little Elk Granite protolith.

INTRODUCTION

The oldest rocks exposed in the Black Hills are Archean granites, and can be split into two terranes: the Little Elk in the east and the Bear Mountain in the west. Metasedimentary rocks are exposed between the two Archean granites, which have an unclear relationship to the Archean granites. Our focus here is on the Little Elk Terrane (LET), which consists of an Archean granite known as the Little Elk Granite (LEG), an Archean Biotite-Feldspar Gneiss (BFG), and a Proterozoic metasedimentary unit (Figure 1).

An early study of these units interpreted the BFG to be older than the LEG based on the presence of an older northeast-trending fabric only present in the BFG being crosscut by a younger northwest-trending fabric observed in both the BFG and LEG (Gosselin et al., 1988). However, this interpretation was challenged by more recent mapping that identified a northeast-trending fabric within the LEG and interpreted the shear fabrics, folding of the shear fabric, sinistral asymmetry, and grain-size reduction to argue for an east-side-up shear system responsible for both fabrics (Allard and Portis, 2013). The variation in the outcrop appearance of the LET, therefore, would be explained by strain-partitioning wihtin a single granitic body.

More recently, whole rock major and trace element

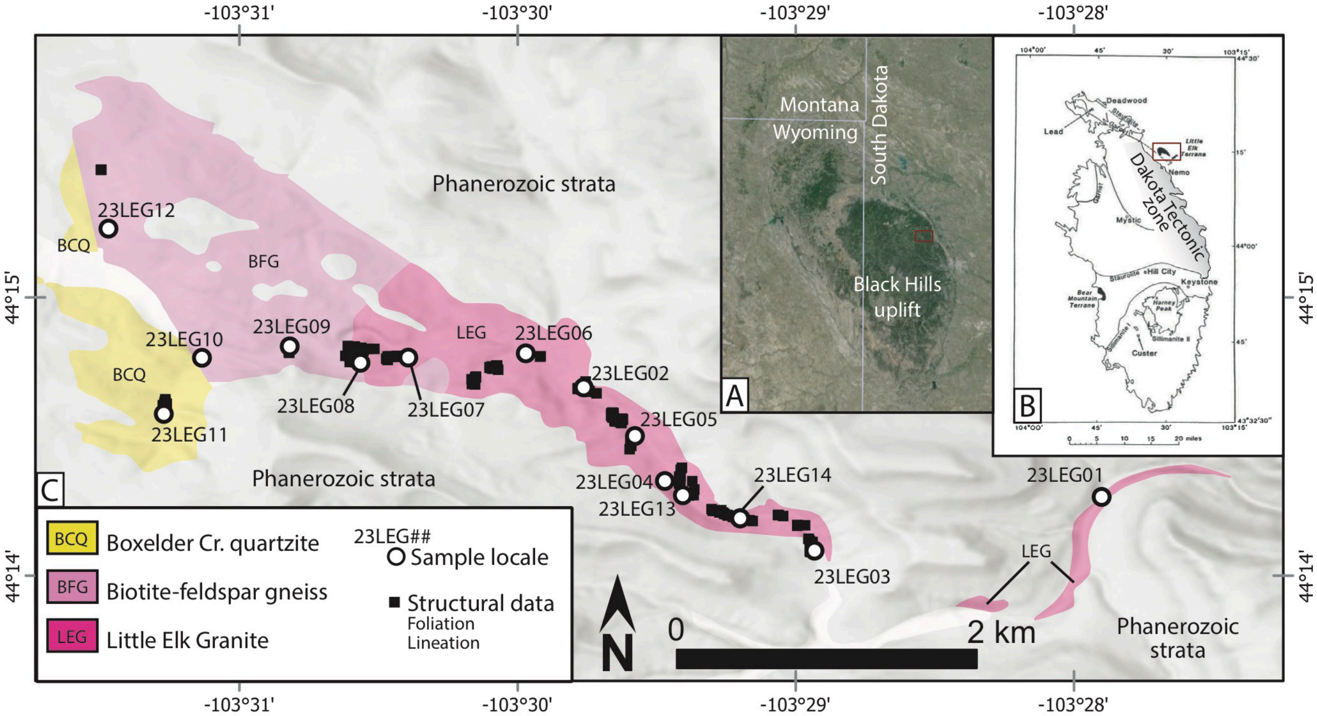

Figure 1. A) Google Earth image showing the location of the Black Hills (dark green region) relative to political borders. The Little Elk Creek area is outline by the red rectangle. B) Metamorphic isograd map of the Black Hills Precambrian core from Gosselin et al. (1988). Black shaded regions represent 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).

geochemical data from both the LEG and BFG has been interpreted to record a single granitic origin for both units (Nicosia and Allard, 2014). This study aims to further test this interpretation through the use of U-Pb zircon dating to determine whether the BFG and LEG should continue to be regarded as separate units or if the BFG is a portion of the LEG that experienced intense deformation.

GEOLOGIC BACKGROUND

The Black Hills of South Dakota are commonly interpreted as a southern extension of the Trans-Hudson Orogeny, which involved the east-west convergence of the Superior and Wyoming cratons (Gosselin et al., 1988). The dome was uplifted during the Laramide Orogeny between ca 65 - 55 Ma, and exposes mainly Paleoproterozoic metasedimentary rocks, which are intruded by the ca. 1715 Ma Harney Peak Granite (Redden and Dewitt, 2008). These Paleoproterozoic metasedimentary are bound in the east and west by the Archean Little Elk and Bear Mountain terranes, respectively (Gosselin et al., 1988). The granites within these units are interpreted to have formed due to crustal accretion along the edge of the Wyoming craton (Gosselin et al., 1988).

The Little Elk terrane is exposed in Little Elk Creek approximately 8 km north of Nemo, South Dakota and has been interpreted as a fragment of the Wyoming Craton that has been displaced to the east (Gosselin et al., 1988). Rocks mapped as LEG are granitic and characterized by large (1-5 cm) K-feldspar crystals that are variably deformed by flattening and simple shear deformation (Figure 2; Allard and Portis, 2013). Rocks mapped as BFG exhibit highly variable texture ranging from gneissic banding to mylonitic textures (Figure 3). The dominant foliation in both units dips steeply (~60-80º) southwest (Redden and DeWitt, 2008). Previous geochronology on the Little Elk terrane targeted both the LEG and BFG and yielded multi-grain Thermal-Ionization Mass Spectrometry ages of 2549 ± 11 Ma (LEG) and single grain Secondary-Ion Mass Spectrometry ages of 2559 ± 6 Ma (LEG, 8 single grain analyses) and 2563 ± 6 Ma (BFG, 7 single grain analyses) (Gosselin et al., 1988; McCombs et al., 2004).

METHODS

Samples were collected from both the LEG and BFG, and then washed, crushed, sieved to less than 250 micrometers, and poured onto a Wilfley table to

Figure 2. Representative field photographs of the Little Elk granite at site 23LEG05 showing relatively undeformed granite (top) and gneissic texture that has been previously interpreted as a high strain zones in the granite (bottom).

remove light mineral grains. Magnetic grains were removed from the heavy grains using a hand magnet and Frantz LB-1 isodynamic separator. Lithium heteropolytungstate (LST) was used to separate the denser non-magnetic minerals, such as zircon, from the low-density, non-magnetic minerals. The zircon grains retrieved were mounted in 1” epoxy rounds, imaged using a scanning electron microscope, then dated using the Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) at the Arizona Laserchron Center.

Three well characterized zircon reference materials were mounted along with the sample grains, the Duluth Gabbro (FC1; 1009± 2 Ma), Sri Lanka (SL; 563.5 ± 2.3 Ma), and R33 (419.3 ± 0.4 Ma) (Gehrels et al., 2008). 315 analysis spots were handpicked manually on the TeamViewer platform for each sample. A 193 nm Photon Machine Excimer laser was then used to ablate the grains and isotopes were measured using a Thermo Element 2 HR ICP-MS. An uncertainty of ~2% for each analysis was achieved, and the data were then filtered with a concordance threshold of 75-110%. 142 data points from sample 23LEG05 and 151 data points from sample 23LEG10 passed the filtering criterion. With the filtered data, IsoplotR (Vermeesch, 2018) was used to create kernel density estimate (KDE) plots, calculate the weighted mean age of each sample, and plot data on a Wetherill Concordia diagram.

RESULTS

Using a Wetherill Concordia plot, the data from sample 23LEG05 (LEG) generally plot beneath the concordia curve, with the exception of six data points (Figure 4A). The KDE plot demonstrated a normal unimodal distribution with a slight positive skew (Figure 4B). The weighted mean of the 142 analyses yielded an age of 2545 ± 2.3 Ma, and a Mean Square Weighted Deviation (MSWD) of 0.86 (Figure 4C).

Using the same approach, the data from sample 23LEG10 (BFG) the data largely fell beneath the concordia curve, with the exception of 13 data points (Figure 5A), and one concordant date at ca. 1615 Ma. The KDE plot demonstrated a normal unimodal distribution (Figure 5B). The weighted mean of 151

Figure 3. Representative field photographs of the biotite-feldspar gneiss at site 23LEG10 showing mylonitic textuures (top) and gneissic texture that have been previously interpreted as variable deformation within the biotite-feldspar gneiss unit.

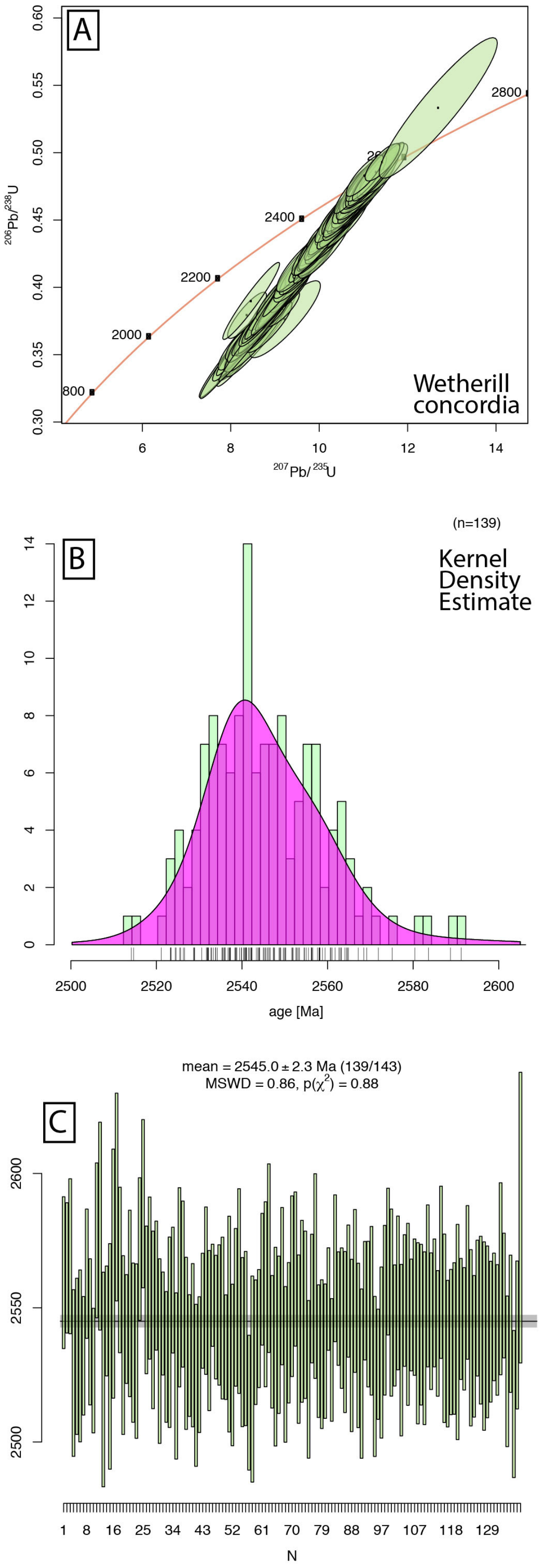

Figure 4. Geochronology plots for the granite sample (23LEG05). A) Wetherill Concordia plot of the data that passed the filtering criterion. B) Kernel Density Estimate plot (purple) and histogram (green). C) Weighted mean plot of the data that passed the filtering criterion and were not rejected by IsoplotR.

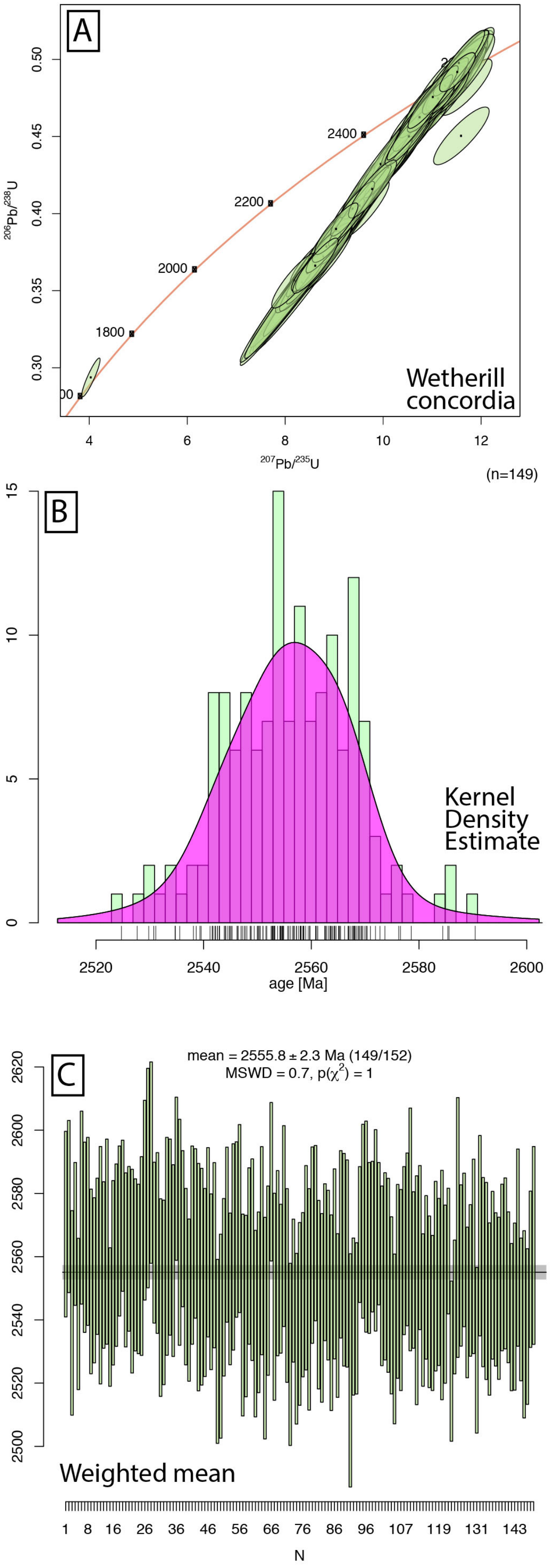

Figure 5. Geochronology plots for the gneiss sample (23LEG10). A) Wetherill Concordia plot of the data that passed the filtering criterion. B) Kernel Density Estimate plot (purple) and histogram (green). C) Weighted mean plot of the data that passed the filtering criterion and were not rejected by IsoplotR.

analyses yielded an age of 2555 ± 2.3 Ma, and an MSWD of 0.7 (Figure 5C).

DISCUSSION

The data show several similarities between samples 23LEG05 (LEG) and 23LEG10 (BFG). First, the MSWDs of both samples is less than 1, indicating that the analytical uncertainties are overestimated, and the data is underdispersed. However, the values near 1 suggest that the data can be interpreted as having a largely normal distribution, which is corroborated by the KDE plots (Figures 4 and 5). These interpretations together suggest that the U-Pb data from both samples can be interpreted as being derived from a single source. For the granite sample (23LEG05), this implies a simple zircon crystallization history related to emplacement of the pluton with minimal inheritance from the country rock. For the gneiss sample (23LEG10), this implies either that the quartzofeldspathic sedimentary protolith was derived from a single age source, or that the protolith is an igneous rock with a single zircon age population, such as the LEG. The ages of both samples, as calculated by the weighted mean plot, are comparable to previous age determinations for the LEG, which were 2549 ± 11 Ma (Gosselin et al., 1988) and 2559 ± 6 Ma (McCombs et al., 2004).

The weighted mean ages from both samples contribute additional information regarding potential linkages between the two samples. The weighted mean age of the granite (2545 ± 2.3 Ma) is slightly younger than that of the gneiss sample (2555 ± 2.3 Ma), which could imply that the gneiss is older than the granite. However, the LEG and BFG are nearly identical in whole rock major and trace element geochemical data (Nicosia and Allard, 2014), implying that the units are either variably deformed versions of the same granite body, or that the BFG was metamorphosed from a sedimentary protolith that was derived from the LEG and is therefore younger. We interpret the similarity in the weighted mean ages (Figures 4 and 5), and field observations suggesting a systematic intensification in deformation features from the LEG into the BFG unit (Fry et al., 2024), and geochemical data (Nicosia and Allard, 2014) together to record that the BFG unit is a portion of the LEG that experienced higher strain than exposures to the east that have been mapped as LEG.

Synthesizing the new geochronology data and associated interpretations with other work on the Little Elk Terrane reveals that the BFG unit occupies the position between the LEG in the east and Boxelder Creek conglomerate in the west (Figure 1). Deformation features in the Boxelder Creek conglomerate suggest that it was sheared along the western side of the BFG unit by a left-lateral shear zone (Obringer et al., 2024). We interpret that this evidence of ductile deformation along the western margin of the BFG unit and within the BFG unit that wanes to the east into the LEG (Fry et al., 2024) to record that the BFG unit is best interpreted as the portion of the LEG that was involved in the shear zone between relatively undeformed LEG and the Boxelder Creek conglomerate.

CONCLUSIONS

Previous research in the Black Hills mapped the BFG and LEG as two separate units, based on structural data that differentiated the two. More recent studies use structural and geochemical evidence to argue that the two units formed from a single granitic body, and that the differences in appearance are due to strain partitioning. After dating two samples from the Little Elk Terrane – one from the BFG and one from the LEG – using U-Pb zircon dating techniques for both samples, the mean ages of each sample were found to be very similar. The adjacency of the two ages in addition to field relationships supports the interpretation of a single origin for the two units. The BFG can be interpreted to be part of a greenschist facies shear zone along the western margin of the LEG, with the protolith being the LEG.

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