Selected features of the Precambrian rocks of the eastern Beartooth Mountains, Montana and Wyoming

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General information about the Precambrian rocks of the Beartooth Mtns

Archean rocks are exposed in the Wyoming Province in the cores of mountain ranges uplifted during the Laramide Orogeny (Fig. 1). Archean rocks in the eastern and central Beartooth Mountains, Bighorn Mountains, and samples from deep-drill cores in eastern Wyoming and Montana are dominantly Late Archean granitoids (2.7-2.9 Ga), members of the tonalite-trondhjemite-granodiorite suite, with inclusions of older supracrustal rocks preserved as tectonic slices or pendants in the younger magmatic rocks (Barker et al., 1979; Peterman, 1981; Henry et al., 1982; Mueller et al., 1985, 1998). The Archean rocks in the western part and to the west of the Beartooth Mountains include a high-grade gneiss terrane with varying abundances of metasedimentary rocks (Mogk and Henry, 1988; Mogk et al., 1990). The dominantly magmatic terrane in the eastern and central Beartooth Mountains, and the high-grade gneiss terrane to the west, are separated by a major discontinuity in the Archean basement marked by a mobile belt in the North Snowy Block, western Beartooth Mountains (Mogk et al., 1988a, 1990). The differences in ages and compositions of associated magmatic and metamorphic rocks provide the basis for subdividing the Wyoming Province into three sub-provinces (Fig. 1).

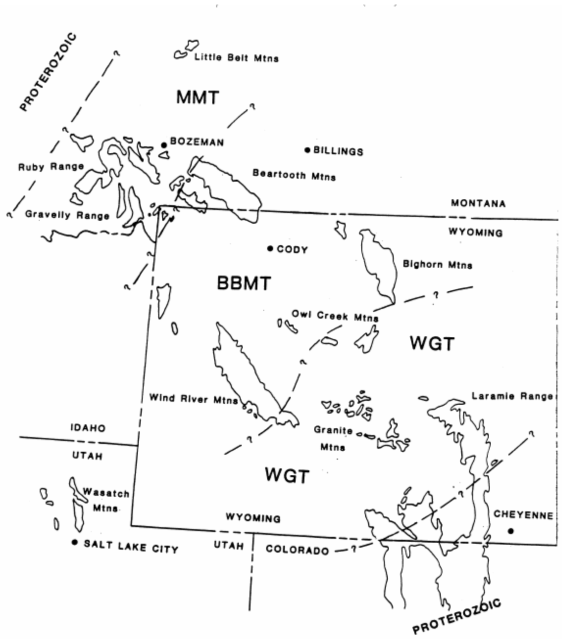

Fig. 1. General outline map of the Wyoming Province and its sub-provinces showing major areas of exposure of Archean rocks (WGT, Wyoming greenstone province; BBMT, Beartooth-Bighorn magmatic zone; MMT, Montana metasedimentary province). Map of Mogk et al. (1992).

The Beartooth Mountains have been divided into four geographically and geologically distinct domains: the main Beartooth massif, the North Snowy Block, the Stillwater Block, and the South Snowy Block (Fig. 2). A major project conducted by Arie Poldervaart and his students in the main Beartooth massif provided the first extensive field and petrologic studies (Eckelmann and Poldervaart, 1957; Spencer, 1959; Harris, 1959; Casella, 1964, 1969; Prinz, 1964; Butler, 1966, 1969; Larsen et al., 1966; Bentley, 1967; and Skinner et al., 1969). Their initial interpretation of this area called for granitization of a sequence of openly-folded supracrustal rocks. However, more recent petrologic, geochemical, and geochronological studies (e.g.

Mueller et al., 1985, 1998; Wooden et al., 1988) have demonstrated that the main Beartooth massif consists predominantly of voluminous Late Archean igneous granitoids (2.8-2.74 Ga) with inclusions of metasupracrustal rocks which exhibit wide ranges in composition, metamorphic grade, and isotopic age. The North Snowy Block was first described by Reid et al. (1975) and interpreted as having a complex structural evolution of the area involving up to 5 discrete metamorphic and deformational events. However, Mogk et al. (1988a) demonstrated that this area is better interpreted as a collage of several allochthonous units. The Stillwater Block is dominated by the mafic igneous layered Stillwater Complex (2.7 Ga) and its contact aureole in older metasediments (e.g. Czamanske and Zientek, 1985). The South Snowy Block is dominated by metasedimentary rocks and a series of locally important 2.7 Ga old granitoid plutons (Casella et al., 1982; Wooden et al., 1982; Montgomery and Lytwyn, 1984).

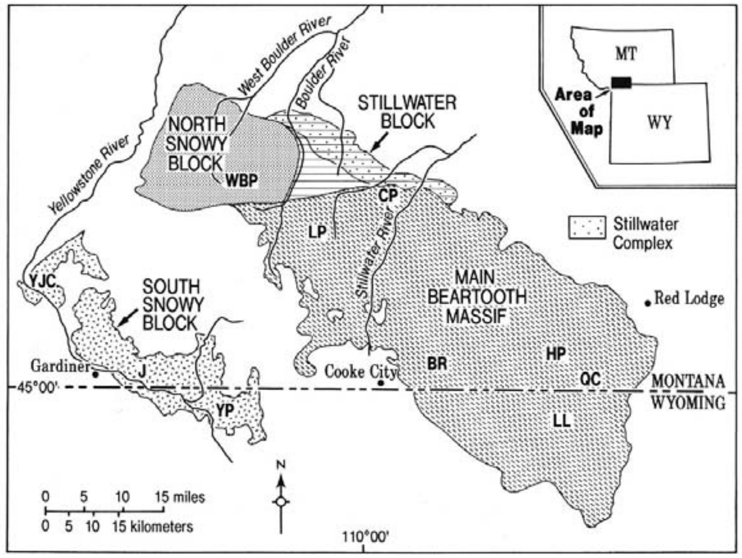

Fig. 2. Geographic and geologically-distinct blocks of the Archean rocks of the Beartooth Mountains. The abbreviated localities in the eastern portion of the map include Hellroaring Plateau (HP), Quad Creek (QC) and Long Lake (LL).

Geologic Timeline for the eastern Beartooth Mountains

I. Age and likely provenance of detritus in metasedimentary quartzites – zircons from quartzites typically contain well-rounded cores with a distinct chemical zoning pattern and an overgrowth with a fine zoning pattern (Mueller et al., 1988; Henry and Mueller, in preparation).

3.9 - 4.0 Ga - formation of early granitoid continental rocks that developed zircon found as detritus in younger quartzites (Mueller et al., 1992; 1998). Detrital zircons of this age range represent a relatively minor population (Fig. 3).

3.7-3.8 Ga – Second significant crust-forming event that served as a source for a significant amounts of detrital zircons.

3.56 Ga - Lu-Hf zircon age of average Hellroaring zircons (Stevenson and Patchett, 1990).

3.2-3.4 Ga - major crust-forming event that yielded the dominant zircon population in all quartzites (Mueller et al., 1998).

~3.2 Ga – $^{187}Os/^{188}Os$ model age for separation from the mantle of the melt that formed chromitites at Quad Creek and Hellroaring (Minarik and Henry, 2004).

≈ 3.1 Ga – youngest probable detrital zircon age (Hellroaring Plateau). ***This represents the upper age limit for deposition of quartzites (and other metasedimentary rocks) as well as the metamorphism that affected these rocks.*** Note: individual quartzite units may have different zircon distributions (Fig. 3). This may reflect sedimentation or tectonic mixing processes.

II. Metamorphism and Deformation of High Grade Rocks

Tectonic mixing 1. Mixing of supracrustal and metaigneous lithologies, early through peak metamorphism (i.e. prograde) to granulite facies conditions; superimposed on post-kinematic blackwall i.e. Blackwall formation at lithologic contact, post-deformational, metasomatic zone reequilibrated at 800ºC

2.8-2.9 Ga - M1 granulite facies metamorphism (5-7 kbar 750-800ºC) – metabasites with granoblastic texture with Mg-hornblende + opx ± grt ; metapelites above second sillimanite zone with common crd-grt-sill assemblage and migmatization, metaironstones with qtz + mt + opx + grt ± cpx ± hastingsite; metaultramafic with 2-spinel harzburgite and Mg-hornblendite (Henry et al. 1982; Mogk and Henry, 1988; Maas and Henry, 2002; Henry and Mogk, in preparation). Early to synmetamorphic tectonic mixing and metasomatic zoning at 800 C. F1 folding is isoclinal with common transposition, and some disharmonic folding. 2.84 Ga Pb-Pb age of garnet (inclusions?) probably

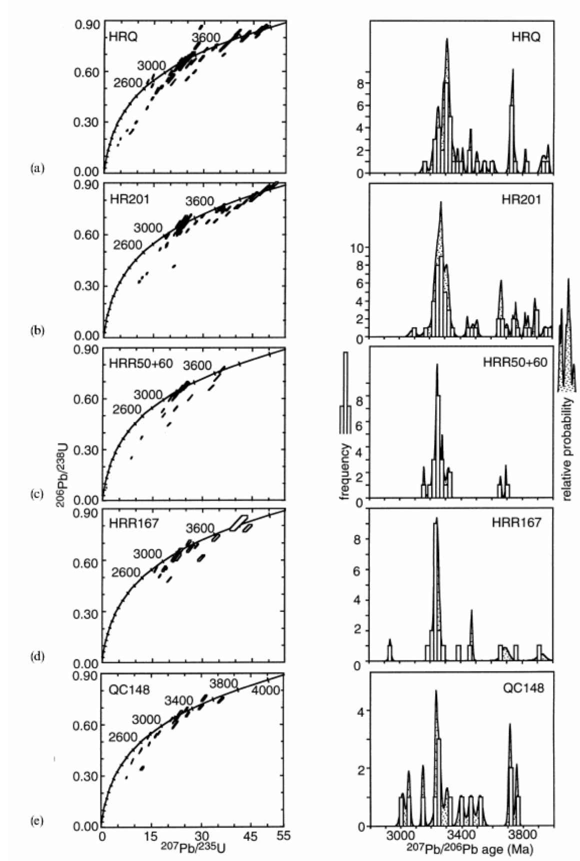

Fig. 3. Plots of $^{235}U/^{207}Pb$ vs. $^{238}U/^{206}Pb$ using the SHRIMP for detrital and metamorphic zircon for all data within 10% of concordia for quartzites of eastern Beartooth Mtns (Mueller et al., 1998).

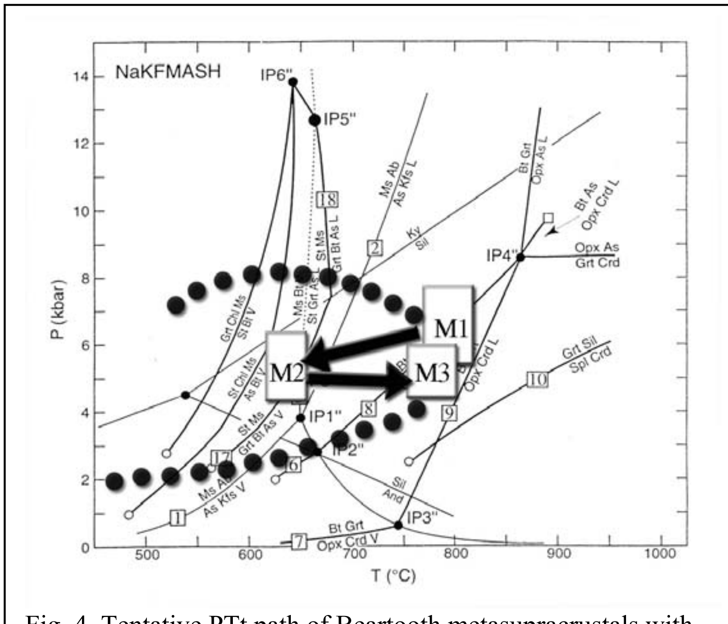

Fig. 4. Tentative PTt path of Beartooth metasupracrustals with reference petrogenetic grid of Spear et al. (1999).

representing the time of garnet growth (probably M1) (Dahl et al., 2000)

III. Late Archean Magmatism, Metamorphism and Alteration

2.78-2.79 Ga - andesitic magmatism and intrusion of Long Lake granodiorites (these overlap in time and space).

2.79-2.74 Ga - deformation and amphibolite facies metamorphism (M2) of andesites and granodiorites. Overprinting of hornblende after opx. Hornblende-plagioclase-epidote-biotite in intermediate rocks. Hornblende-plagioclase conditions indicate 600-650 C and 4-6 kbar.

Open folding of country rocks (F2)

2.74 Ga - massive intrusion of the Long Lake Granite and local M3 granulite facies overprint. Some new growth of zircon rims in Hellroaring quartzites (Mueller et al., 1988, 1992, 1998)

The style is multiple, subparallel sill-like intrusions possibly injected along the axial surface of F2. Long Lake granites are subsolvus with two separate plagioclase and K-feldspar phenocrysts.

Late tectonic mixing 2 - brittle/ductile mylonitization in shear zones with quartz ribbons and brittle plagioclase and pyroxene.

2.57 Ga – Rb-Sr emplacement age for mafic dike intrusion cutting open F3 folds. This indicates that the rocks were still within the ductile regime at that time (Mueller and Rowan, 1973).

IV. Proterozoic and Phanerozoic uplift and erosion

2.5 Ga - cooling of terrain below 350°C (K-Ar in muscovite)

Carbonation and propylitization. A CO_2-N_2-H_2O fluid entered all of the rocks and locally produced carbonate minerals and various hydrous minerals. The estimated conditions, based on carbonate thermometry and fluid inclusions, are T=350-400 C, 1-2 kbar. Note: the fractures are tensional (i.e. Mode I type) and are probably related to uplift.

2.3 Ga - cooling of terrain below 300°C (K-Ar in biotite). K-Ar mineral ages (Gast et al., 1958) of 2470 and 2520 Ma for muscovite in pegmatites and of 2290 and 2340 Ma for biotite indicate that the terrain had cooled to less than 300ºC by 2290 Ma and had not been subsequently heated above that temperature since that time

1.3 Ga – Rb-Sr and K-Ar emplacement age of alkali-olivine mafic dikes (Baadsgaard and Mueller, 1973)

780 Ma – $^{40}Ar/^{39}Ar$ emplacement age of mafic dike (diabase) from Christmas Lake. Common ages and paleomagnetic characteristics with other mafic dikes that cut at Mt. Moran (Tetons) and the Belt Supergroup of Montana suggest there was a regional magmatic dike swarm event that affected the western part of the Laurentian craton (Harlan et al., 1997).

530 Ma - deposition of Cambrian Flathead sandstone on exposed Precambrian basement. The southeastern portion of the Beartooth Mountains (Main Beartooth Massif) is a high altitude flat or gently rolling plateau that have a few patches of Cambrian sedimentary rocks (e.g. Flathead sandstone on Beartooth Plateau) (Simons et al., 1976). The plateaus are apparently very close to the sub-Cambrian depositional surface (i.e.the Precambrian basement was at the surface in early Cambrian times). The Beartooth Butte contains a package of Paleozoic sediementary rocks.

65-57 Ma - rapid uplift (apatite fission track data)

57-50 Ma - shedding of Precambrian detritus into the Wasatch Formation northeast of the present mountain front in the early Eocene (57-50 Ma) (Foose et al., 1961). Simons et al. (1976) argue that the sub-Cambrian surface in the northeast Beartooths may have been exposed for up to 30-40 Ma longer than the southwest Beartooths resulting in the greater erosional rounding.