Precambrian geology of Lake Plateau, Beartooth Mountains, Montana
by Douglas P Richmond

A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
The Lake Plateau area in the central Beartooth Mountains of southern Montana is comprised of voluminous late Archean intrusive rocks ranging from quartz diorite to granite in composition, with a variety of supracrustal inclusions. The inclusions range in size from centimeter to kilometer scale and include biotite hornblende schists (bio-qtz-hbld-epi-plag) and pelitic schists (bio-qtz-cord-plag-gar sill). These inclusions have experienced upper amphibolite grade metamorphism at 6-8 kbar and 580-650°C, with penetrative deformation creating a north striking foliation. The intrusive rocks vary in modal mineralogy and texture on a meter scale. In some places they have an hypidiomorphic-granular texture, and in others they have weak foliation or foliated augen texture. Assimilation of inclusions is common with foliated granites occurring at gradational contacts with inclusions. Pegmatite and aplite veins associated with the intrusive rocks cut across nearly all Archean rocks and comprise 15-20% of the total rock volume. Structural trends include north-south foliation with associated isoclinal folds, broad open kilometer scale folds, and unfolded shear zones with mylonitic textures and retrograde metamorphism to chlorite and epidote. Younger rocks include amphibolite dikes and a few Tertiary felsic dikes.

Lake Plateau and the surrounding Beartooth Mountains evolved by: 1) burial of supracrustal rocks to depths of 20-25 km; 2) penetrative deformation and upper amphibolite grade metamorphism; 3) generation of high-Na intrusives such as the Long Lake granites; and 4) generation of the K-rich granites of Lake Plateau. The Lake Plateau granitoids are interpreted as mid-crustal melts emplaced at approximately 20 km and generated from a slightly deeper crustal source. These large volumes of K-rich granites are different from the Na-rich rocks reported in the eastern Beartooths (Mueller and others, 1985). Large volumes of granite with subordinate quartz diorite and a variety of supracrustal inclusions are consistent with characteristics in younger examples of post-collisional tectonic settings. The Beartooth Mountains represent the remaining mid-crustal evidence of development of thickened continental crust in the late Archean by collisional tectonics and post-collisional uplift, similar in many ways to modern day tectonic processes.

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APPROVAL

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Douglas P. Richmond

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The Lake Plateau area in the central Beartooth Mountains of southern Montana is comprised of voluminous late Archean intrusive rocks ranging from quartz diorite to granite in composition, with a variety of supracrustal inclusions. The inclusions range in size from centimeter to kilometer scale and include biotite hornblende schists (bio-qtz-hbld-epi-plag) and pelitic schists (bio-qtz-cord-plag-gar sill). These inclusions have experienced upper amphibolite grade metamorphism at 6-8 kbar and 580-650°C, with penetrative deformation creating a north striking foliation. The intrusive rocks vary in modal mineralogy and texture on a meter scale. In some places they have an hypidiomorphic-granular texture, and in others they have weak foliation or foliated augen texture. Assimilation of inclusions is common with foliated granites occurring at gradational contacts with inclusions. Pegmatite and aplite veins associated with the intrusive rocks cut across nearly all Archean rocks and comprise 15-20% of the total rock volume. Structural trends include north-south foliation with associated isoclinal folds, broad open kilometer scale folds, and unfolded shear zones with mylonitic textures and retrograde metamorphism to chlorite and epidote. Younger rocks include amphibolite dikes and a few Tertiary felsic dikes.

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INTRODUCTION

The Lake Plateau study area encompasses sixty square kilometers in the central Beartooth Mountains of southern Montana (Fig. 1). It provides excellent exposures of Precambrian metamorphic and granitic rocks in a glacial topography of polished knobs and deep cirques. Lake Plateau is a small area in a region of extensive Archean exposures, and has difficult access (five hours on foot). But it is geologically important because it is located near the boundaries of three major tectonic blocks within the Beartooth Mountains. It provides a central link to other recent studies around the area, and it is therefore important to the understanding of the genesis and evolution of this Archean region.

The purpose of this study is to characterize the Lake Plateau rock units and to establish the geologic history of this Archean terrane. By doing so, the following questions are addressed:

1) What Archean crustal levels are now exposed at Lake Plateau?
2) What was the source for these rock units?
3) What tectonic conditions created this terrane?
4) What constraints do these data place on theories about Archean crustal development in the Beartooth Mountains and surrounding Southwest Montana?

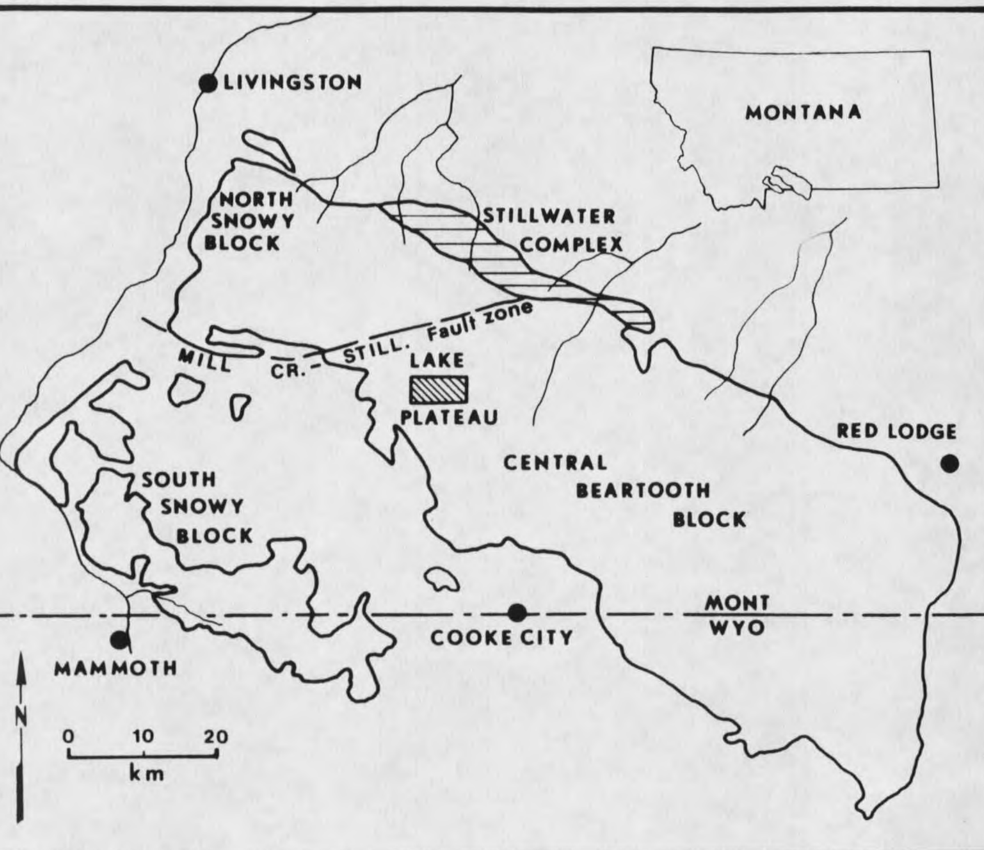

Figure 1. Precambrian outcrops of the Beartooth Mountains. Lake Plateau is shown in relation to the various blocks and to the Mill Creek - Stillwater Fault Zone.

REGIONAL SETTING

The Beartooth Mountains are near the north end of the Archean outcrops of the Wyoming Province (Fig. 2). This province consists of numerous mountain ranges cored by Archean granites and supracrustal rocks. In the southern part of the Wyoming Province, late Archean to Proterozoic accretion from the south has been demonstrated (Condie, 1982; Karlstrom and Houston, 1984), but tectonic conditions in the north are less clear.

In southwest Montana, Archean exposures are truncated by a west to northwest system of faults that have been active from the late Archean to the present (Geissman and Mogk, 1986; Schmidt and Garihan, 1986). North of these faults are extensive exposures of Proterozoic Belt rocks and Phanerozoic sediments and volcanics. To the south are Archean-cored Laramide uplifts (Foose and others, 1961; Schmidt and Garihan, 1983) that show changing characteristics from west to east. In the west, these uplifts include the Blacktail, Ruby, and Tobacco Root Ranges (Fig. 2) which are dominated by metasediments that include quartzofeldspathic gneisses, schists and marbles (Heinrich and Rabbit, 1960; Garihan and Okuma, 1974; Clark, 1987). In the Madison Range and western Beartooths, there is a complex set of terranes with varying rock types that include metasediments and a wide range of intrusive units (Spencer and Kozak, 1975; Erslev, 1983; Mogk, 1984; Salt, 1987). To the east, the Beartooth Mountains, including Lake Plateau, are dominated by major granitic intrusions (Mueller and others, 1985).

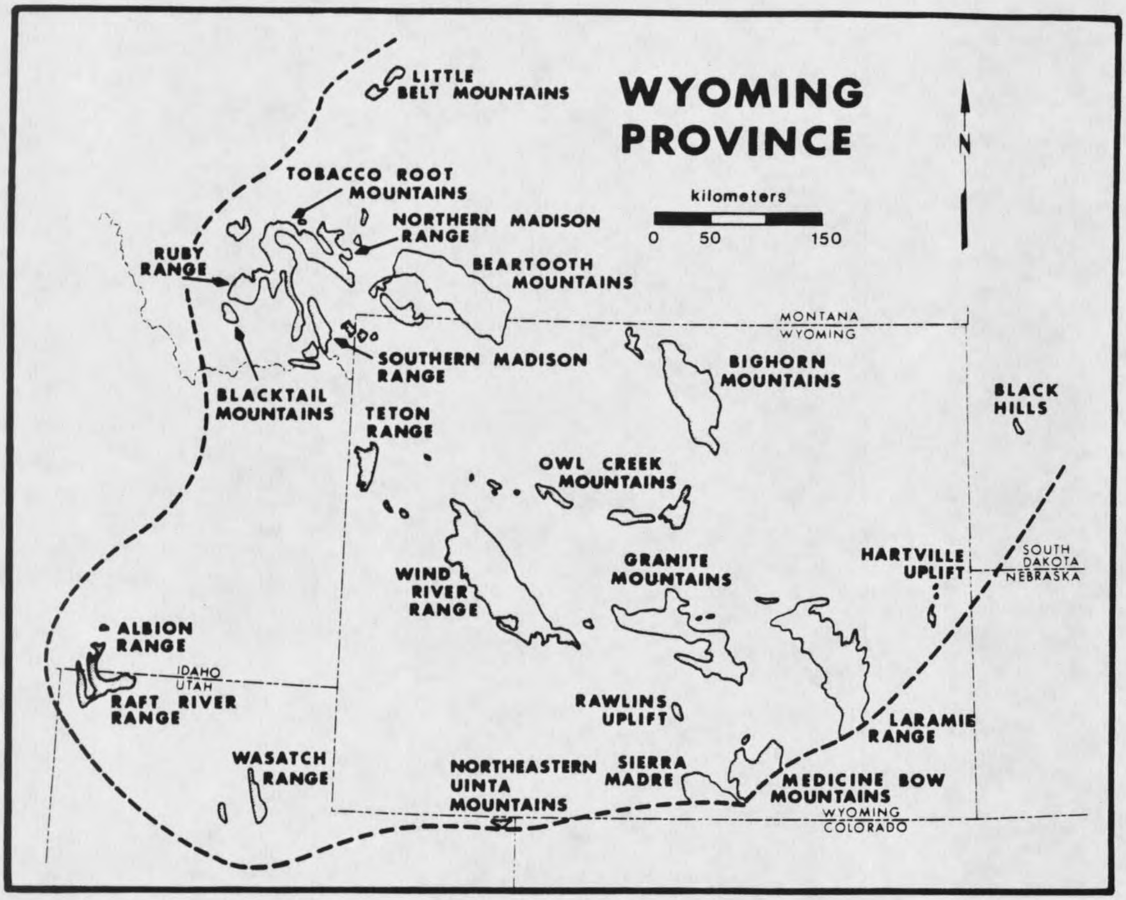

Figure 2. Archean outcrops of the Wyoming Province (Clark, 1987, after Condie, 1976).

This eastward progression of Archean sediments, accreted terranes, and major intrusions in southwest Montana is the product of Archean tectonic conditions. By answering the questions about granite compositions, source rocks, and crustal thickness at Lake Plateau, this study will add to the understanding of these tectonic conditions and of plate tectonics in general during the late Archean.

The Beartooth Mountains were subdivided into blocks by J.T. Wilson (1936) as shown in Figure 1. The South Snowy block consists mainly of metasediments, including metagraywackes and ironstones with minor granitic intrusions (Hallager, 1980; Casella and others, 1982; Thurston, 1986). Paleozoic and Mesozoic sediments and Tertiary volcanics separate this block from other Archean exposures in the Beartooths, making structural relationships unclear. Part of the North Snowy block has been mapped as a Late Archean mobile belt with large-scale eastward thrusting of supracrustal schists, marbles, and amphibolites over northeast-trending gneisses, schists and amphibolites (Mogk, 1984). Along the north edge of the Beartooths is the Stillwater Complex, a platinum-bearing, layered mafic and ultramafic intrusion with an associated contact aureole. The contact aureole has been shown to be in fault contact with the adjoining North Snowy and Central Beartooth blocks (Geissman and Mogk, 1986).

Lake Plateau is part of the fourth and largest block, the Central Beartooth block. Early studies of the central block with its large volumes of granite and granodiorite were done by Arie Poldervaart and his students (Eckelmann and Poldervaart, 1957, Poldervaart and Bentley, 1958, Larsen and others, 1966, Butler, 1966, and Butler, 1969). The earliest of these studies suggested that the granites formed by static metasomatism of folded sedimentary rocks. Later studies suggested that folding and metamorphism were contemporaneous and that layering may have been produced by flow of rocks rather than by sedimentary processes (Casella, 1969). The current study indicates a magmatic origin for the large volumes of granitic rock at Lake Plateau. This is consistent with recent magmatic interpretations of similar rocks fifty kilometers east of Lake Plateau in the central block (Mueller and others, 1985).

The intrusions to the east have been age dated at 2.75 Ga old intrusions (Mueller and others, 1985), with 3.4 Ga old granulite inclusions (Henry and others, 1982). Other available age dates from the region include 2.7 Ga for the Stillwater Complex (Lambert and others, 1985). The published age dates nearest to Lake Plateau are from a drill core study near Hawley Mountain, seven kilometers north of Lake Plateau (Lafrenz and others, 1986). This study yielded an age date of 2.75 Ga for a foliated biotite granite and 2.1 Ga for a poorly foliated pink granite. The timing and physical conditions of the magmatism at Lake Plateau is important to understanding the relationship of the Central Beartooth block to the Stillwater Complex and the North Snowy block.

ROCK UNITS

General Statement

The outcrops exposed at Lake Plateau are dominated by numerous tabular and irregular bodies of granodiorite to granite and by pegmatite and aplite veins associated with these late to post-kinematic intrusions. Mineralogical and textural variations are generally gradational within the intrusive units. The pegmatite and aplite veins are ubiquitous and crosscut nearly all other rock units. Within the intrusions are numerous aligned xenoliths of biotite-garnet schist and hornblende-biotite schist. These inclusions range from centimeter scale up to a few hundred meters by a few kilometers (Plate 1). They were metamorphosed in amphibolite facies with textures ranging from fine-grained schist to coarse compositionally banded gneiss. Contacts with granitic units are sharp in some places but are more commonly gradational, showing partial assimilation by the granite.

There are mafic intrusive rocks including a continuous 500 meter wide body of hornblende quartz diorite which predates the granites, and numerous amphibolite dikes which cut the granites. The only rocks younger than Precambrian at Lake Plateau are rare Tertiary felsic dikes associated with the Eocene Absaroka Volcanics which occur south of the study area, covering the older rocks with a layer of andesite and dacite (Chadwick, 1985).

Inclusions

Biotite garnet schist

Biotite garnet schist is the dominant rock type in inclusions of the western third of the study area (Plate 1). Inclusion size ranges from meter scale in single outcrops, to a north-south trending inclusion just west of Mirror Lake that measures over two kilometers in length. This inclusion is cut by numerous pegmatite veins and by irregular granitic intrusions. Contacts with surrounding units are sharp with pegmatite veins and generally gradational with granitic units, showing varying degrees of partial assimilation. Foliation of inclusions is typically concordant with foliation of intrusives.

The biotite garnet schist has the assemblage of biotite, garnet, cordierite, quartz, and plagioclase (An_{30}), plus or minus sillimanite (Fig. 3). Accessory minerals include allanite, zircon, apatite, iron titanium oxide, and secondary chlorite after biotite.

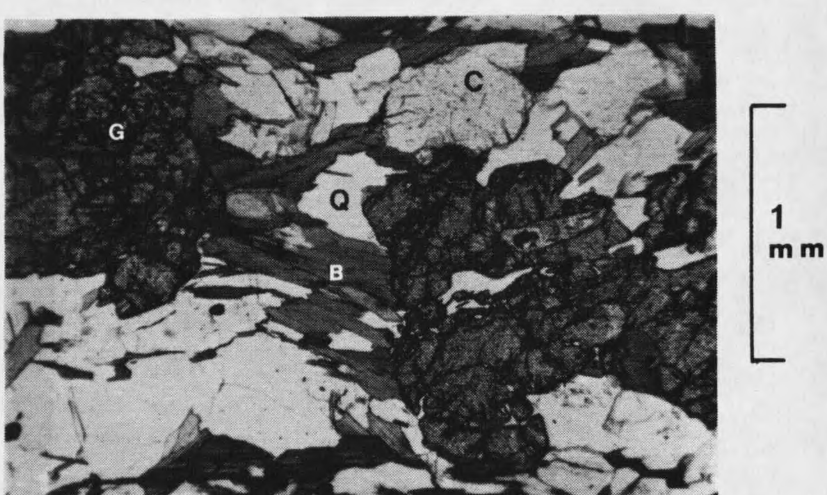

Figure 3. Photomicrograph of biotite garnet schist. B: biotite; G: garnet; C: cordierite; Q: quartz.

Foliation and centimeter scale isoclinal and open folds are defined by weak alignment of biotite grains and locally by compositional layering. The biotite is brown to red-brown. It is not bent or broken, and many grains have random orientations indicating both post- and syn-kinematic crystalization.

Garnet is poikiloblastic ranging in size up to two centimeters with inclusions of quartz and biotite. No internal pattern of inclusions was recognized.

Quartz occurs as scattered anhedral grains and also as aggregates of grains in irregular blebs to 15 centimeters long. These blebs contain strained grains showing slip bands and mosaics of smaller, strain free, recrystallized grains.

Cordierite occurs as irregular grains growing over biotite foliation with characteristic dusting of opaques, pleocroic halos, and pinite alteration. Cordierite locally comprises up to 20% of the rock in the large inclusion at Mirror Lake.

Metamorphic temperature and pressure estimates were made for the biotite garnet schist based on microprobe analyses done by D.W. Mogk on biotite, garnet, and cordierite. Analyses were done inside the rims of garnets, away from retrograde effects near the rim, and on biotite grains near, but not in contact with, the garnets (Mogk and Mueller, in review). Figure 4 shows the measured compositions of these three minerals. Peak metamorphic temperature estimates of 580-650°C were calculated using the biotite-garnet geothermometer of Ferry and Spear (1978). Pressure estimates of 7-8 kilobars were calculated based on the