Concentric slow cooling of a low-\(P\)–high-\(T\) terrane: Evidence from 1600–1300 Ma mica dates in the 1780–1700 Ma Black Hills Orogen, South Dakota, U.S.A.

Peter S. Dahl1,∗ and Kenneth A. Foland2

1Department of Geology, Kent State University, Kent, Ohio 44242, U.S.A.
2School of Earth Sciences, Ohio State University, Columbus, Ohio 43210, U.S.A.

ABSTRACT

The crystalline core of the southern Black Hills, South Dakota, exposes an extensive, low-\(P\)–high-\(T\) aureole of garnet- to second-sillimanite-zone schists centered on the plutonic core of the 1715 Ma Harney Peak Granite (HPG). This paper demonstrates regional patterns of apparent ages observed for 52 \(^{40}\)Ar/\(^{39}\)Ar dates of muscovite and biotite in diverse rocks from across the ~1000 km² metamorphic aureole and its plutonic center. About 20 biotite dates, sampled mostly near faults, are influenced by excess \(^{40}\)Ar and obscure the regional trends. The remaining mica dates reveal radial patterns of apparent younging from outer aureole toward inner granite, with previously unrecognized, elliptical age zones centered on the main HPG pluton and its outliers. The regional pattern of \(^{40}\)Ar/\(^{39}\)Ar cooling ages indicates non-uniform slow cooling of the mid-crust between ~1600–1250 Ma. This scenario of delayed slow cooling from aureole to pluton is consistent with published cooling ages for muscovite (Rb/Sr) and apatite (U/Pb), which range from 1690 to 1550 Ma and from 1700 to ~1500 Ma, respectively. To explain these results, it is likely that ambient pre-granite temperatures of the country rocks were ≥350 °C at the ~10–14 km depth of granite emplacement, as previously proposed, and that the entire complex resided at this depth and cooled slowly from aureole to granite for hundreds of millions of years. Alternatively, or in addition, the HPG and inner aureole were not uplifted until ~1480–1330 Ma, whereupon they finally cooled through ~300–350 °C.

Keywords: Geochronology, micas, high-temperature studies, argon retentivity of micas (field-based), radiogenic isotopes, argon, strontium, and lead, major and minor elements, pegmatites

INTRODUCTION

The work of Charles Guidotti amply demonstrates the underlying reality that geological histories of orogens are preserved in rocks because of the crystal-chemical properties of minerals contained therein. In the past two decades, for example, Charles Guidotti co-authored classic papers on the role of plutonism in low-pressure (\(P\)), high-temperature (\(T\)) metamorphic belt formation (Lux et al. 1986), and on thermal modeling in low-\(P\)–high-\(T\) metamorphic belts through time (DeYoreo et al. 1989, 1991). These and other papers described low-\(P\)–high-\(T\) metamorphism in western Maine as being related to ~300 Ma granitoid emplacement at mid-crustal levels (~10–14 km) into country rocks that previously had been tectonically buried and partially unroofed earlier in the orogenic cycle. In particular, Lux et al. (1986) described and DeYoreo et al. (1991) modeled a clockwise \(P-T-t\) path for tectonic burial of the country rocks and their subsequent unroofing, and a lower-\(P\) thermal transient to represent advective heating during granite magmatism. These workers further related the timescale of post-granite cooling to pre-granite, ambient temperature of the country rocks at the level of emplacement (DeYoreo et al. 1989).

This \(P-T-t\) model to explain Paleozoic thermotectonism, unroofing, and granitoid magmatism in western Maine, and cooling therefrom, was first adopted by Terry and Friberg (1990) and substantially refined by Holm et al. (1997) to describe a similar sequence of events in a Paleoproterozoic, low-\(P\)–high-\(T\) terrane located in the Black Hills, South Dakota (see Fig. 1). Parallel work has constrained these closely spaced events in the Black Hills to an ~1750–1715 Ma timeframe, during which the Archean Wyoming and Superior cratons collided (Dahl and Frei 1998; Dahl et al. 1999, 2005a, 2005b). Currently, it is widely accepted that the Harney Peak Granite (HPG) intruded at a depth of ~10–14 km and advected sufficient heat from its deeper-crustal sources to superimpose a wide, low-\(P\)–high-\(T\) metamorphic aureole (Fig. 1, inset) on metamorphic country rocks that had been tectonically buried, differentially exhumed, and variably cooled earlier in the orogenic cycle (Terry and Friberg 1990; Holm et al. 1997; Nabelek et al. 2006).

Both the sequence and timescale of collision-related events in the 1750–1715 Ma Black Hills and their younger Maine counterparts are strikingly similar to those documented elsewhere, in both Paleoproterozoic orogens (e.g., Central Arizona; Hodges et al. 1994) and Cenozoic orogens (e.g., the Himalayas of India-Pakistan; Vance and Harris 1999). Indeed, the ~50–15 million years interval from initial India-Eurasia collision to culminating leucogranite magmatism duplicates the record of Himalayan-type collisional tectonomagmatism preserved ~1700 Ma earlier in the Black Hills crystalline complex (Nabelek et al. 2001). Moreover,