Tectonic evolution of the Beaverlodge domain, SW Rae Province, based on structural, petrological and geochronological study: implications for the nature and extent of Taltson(-Thelon) orogeny and the origin of the Snowbird tectonic zone

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Summary

Polydeformed high-grade rocks of the Beaverlodge domain provide insights into the multi-stage tectonic history of southwestern Rae Province. Structural analysis indicates that the Murmac Bay Group (MBG) occupies the highest structural level in the domain and was translated over older, deeper level rocks during Taltson(-Thelon) orogeny, which peaked at ~1.93 Ga. Two subsequent episodes of deformation, at 1.90 Ga and 1.80 Ga, are respectively linked to tectonic activity along the Snowbird tectonic zone (STZ) and the terminal stages of Trans-Hudsonian orogeny. The results presented herein indicate that tectono-metamorphic effects of the Taltson orogeny extend eastward across the Rae Province from the Taltson domain to the STZ. They also highlight fundamental differences in crustal history of potentially equivalent rocks in the Beaverlodge and Tantato domains. Whereas Archean rocks of the Tantato domain underwent high-*P* metamorphism at 2.6 to 2.5 Ga and again at ca. 1.9 Ga but remained deep in the crust between these events, those in the Beaverlodge domain were at the surface at 2.3 Ga or younger and underwent a later cycle of tectonic burial to reach granulite facies by 1.93 Ga.

Introduction and make-up of the Beaverlodge domain

Where it is exposed west of the STZ and north of the Athabasca Basin in Saskatchewan (Fig. 1), the southwestern Rae Province has a remarkably protracted tectonic history, extending from Archean to Mesoproterozoic time. In addition to Archean tectonism, polydeformed and metamorphosed pre-Athabasaca Group (≤1.75 Ga) Precambrian rocks in this region, which comprise a number of distinctive lithotectonic domains (Fig. 1b), record the effects of as many as four major Paleoproterozoic thermotectonic events: the 2.4–2.3 Ga Arrowsmith orogeny, the 1.99–1.93 Ga Thelon-Taltson orogeny, effects related to tectonism along the STZ at ca. 1.90 Ga, and the 1.9–1.8 Ga Trans-Hudsonian orogeny. Much of this record is preserved in the Beaverlodge domain, one the largest and most geologically diverse domains in this region. The Beaverlodge domain is bounded to the west by the Black Bay fault (BBF), to the north by the Oldman-Bulyea shear zone (OBSZ), and to the east by the Grease River shear zone (GRSZ) (Fig. 1). The domain is dominated by supracrustal rocks of the MBG, known for its association of orthoquartzite and mafic volcanic rocks, minor carbonate and komatiitic rocks, and voluminous psammopelitic rocks (Hartlaub and Ashton, 1998; Ashton et al., 2000). These rocks unconformably overlie and are strongly deformed with granitoid rocks that are as old as 3.0 Ga (Hartlaub et al., 2006). Recent work indicates that the basal quartzofeldpathic units of the MBG have a maximum depositional age of ~2330 Ma (Heaman et al., 2003; Card et al., 2007). In addition, dating of detrital and metamorphic zircon, and monazite in the overlying psammopelitic package indicates that the latter is younger than either ~2170 Ma (Ashton et al., 2009a) or ~2030 Ma (Knox et al., 2007, 2008), and was metamorphosed at ~1930–1900 Ma (Bethune et al., 2008; Knox et al., 2007, 2008; Ashton et al., 2009a). The timing of deposition of the MBG with respect to emplacement of the 2330–2275 Ma North Shore plutonic suite, thought to be related to Arrowsmith orogeny (Hartlaub et al., 2007), remains contentious. Current field relationships and geochronology (Bethune et al., 2008; Ashton et al., 2009a) suggest either that deposition of basal quartzite-mafic volcanic units was virtually contemporaneous with the onset of North Shore plutonism (~2330 Ma), and that the upper package (psammopelitic sediments) is appreciably younger (i.e. <2170 or 2030 Ma), or that the entire MBG is <2170 (or 2030) Ma and thus post-dates the Arrowsmith event.

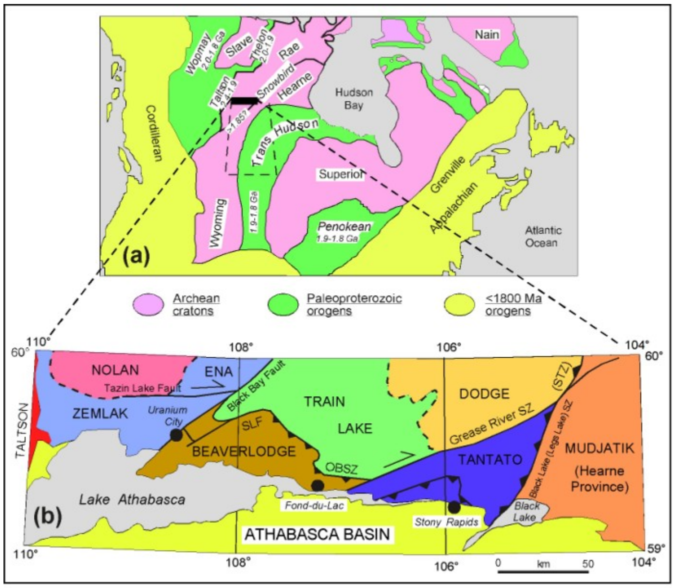

Figure 1. (a) Orogenic sketch map of North America. Rae Province outlined by thin black line, Saskatchewan by the dashed line. The black rectangle in northernmost SK is magnified in (b); (b) Domainal classification for the Rae Province north of Lake Athabasca.

Recent results

Consistent with its relatively younger age, mapping and related structural analysis indicates that the MBG occupies the highest structural level of the domain (Bethune, 2006; Bethune et al., 2008) and was translated over older, deeper level rocks during Thelon-Taltson orogeny. The deeper structural level, comprising mainly 3.0 and 2.6 Ga Archean orthogneiss, along with subordinate paragneiss, was exposed as a result of interference between an older set of ESE-trending recumbent folds ($F_{1/2}$) and a younger set of NNW-trending folds (F_3), producing a regional type 2 interference structure (Bethune, 2006; Bethune et al., 2008). The contact between the two levels most is most likely a tectonically transposed unconformity. U–Pb SHRIMP data from the western Beaverlodge domain (Bethune et al., 2008) indicates that the older, deeper level rocks underwent intrusive/thermal and (or) metamorphic events in the Archean (ca. 2.6 Ga) and early Paleoproterozoic (ca. 2.34 Ga). In contrast, psammopelitic rocks of the MBG at higher structural levels bear no record of these events, recording exclusively younger (i.e. 1.94–1.90 Ga) metamorphism. Metamorphic monazite analyses within this range also define two age groupings: while the majority of analyses are 1.94–1.92 Ga, a small number are ca. 1.90 Ga. Chemical monazite dating of psammopelitic rocks in the eastern Beaverlodge domain (Knox et al., 2007, 2008) has yielded broadly similar results. Collectively, these results corroborate evidence from detrital zircon geochronology that the psammopelitic package (and possibly the entire MBG) is younger than 2.17 Ga. The older monazite population is linked to development of the ESE-trending composite $S_0/S_1/S_2$ (transposition) foliation that dominates the domain whereas the younger ages are ascribed to recrystallization and resetting during subsequent refolding of this fabric about NE-trending (F_4) axes (Bethune et al., 2008).

Tectonic evolution

From these relationships, the tectonic evolution of the Beaverlodge domain is inferred to have involved three stages (Bethune et al., 2008) (Fig. 2). The first stage (Fig. 2a) involved NNE-directed recumbent folding and thrusting ($D_{1/2}$) during Taltson(-Thelon) orogeny. Deformation was progressive in nature, and characterized initially by displacement along the basement/cover contact, accompanied by tight folding and ductile transposition that led to development of the composite ESE-trending ($S_0/S_1/S_2$) foliation. This was superseded by folding about upright NNW-trending axes (D_3/F_3) with resultant fold interference patterns varying between type 2 and type 1. The northwest limit of thrusting is interpreted to have coincided with the OBSZ (Card, 2001). Petrological and geochronological data are consistent with a clockwise *P*–*T*–t path and attainment of moderate pressure (5–7 kbar) granulite-facies conditions by ca. 1.93 Ga. Graphite-bearing psammopelitic gneiss of the eastern Beaverlodge domain is a classic stromatic migmatite with abundant lit-par-lit leucosomes. The gneiss contains 10 to 30% combined garnet, sillimanite and biotite with biotite and sillimanite concentrated in the melanosome (Ashton et al., 2006, 2007). Cordierite occurs ubiquitously as a late phase surrounding garnet and sillimanite. Associated high-grade mafic volcanic rocks contain 40 to 60% orthopyroxene, clinopyroxene and magnetite, together with minor hornblende and biotite, but lack garnet.

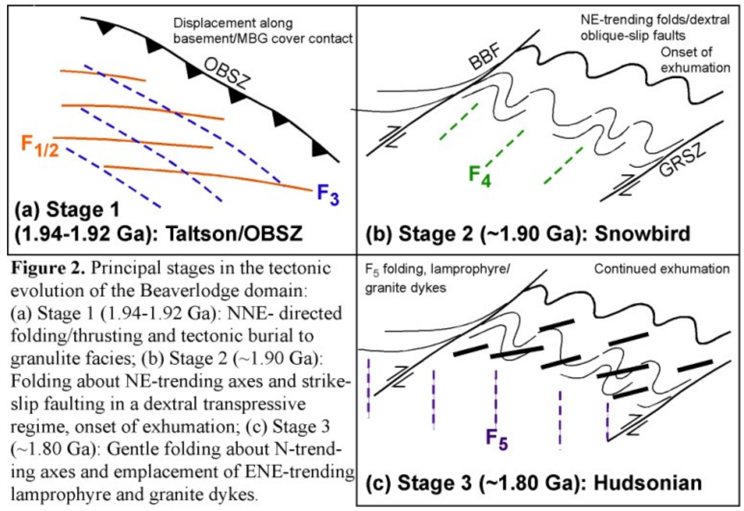

Figure 2. Principal stages in the tectonic evolution of the Beaverlodge domain: (a) Stage 1 (1.94-1.92 Ga): NNE- directed folding/thrusting and tectonic burial to granulite facies; (b) Stage 2 (~1.90 Ga): Folding about NE-trending axes and strike-slip faulting in a dextral transpressive regime, onset of exhumation; (c) Stage 3 (~1.80 Ga): Gentle folding about N-trending axes and emplacement of ENE-trending lamprophyre and granite dykes.

During the second stage of tectonism (Fig. 2b), thought to have been driven by activity along the STZ at ca. 1.90 Ga, D_1 to D_3 structures were refolded, forming a distinctive set of NE-trending, predominantly SW-plunging folds that characterize the domain (Ashton et al., 2007). F_4 folding is interpreted to have occurred in a dextral transpressive regime concurrent with dextral-oblique displacement along the BBF and GRSZ (Bethune et al., 2008). SW-plunging mineral/stretching lineations increase in intensity toward and within these zones, indicating regional strain partitioning. Outcrop- and thin-section-scale observations indicate that cordierite grew at the expense of garnet and sillimanite, and was flattened along S_4 foliation planes, suggesting that D_4 occurred under decreasing pressure conditions, and marked onset of exhumation of high-grade rocks. A final stage of penetrative deformation, expressed in the form of gentle, open N-trending folds (F_5) with steep axial planes and fold axes, is constrained as <1.82 Ga (Ashton et al., 2009b). F_5 folds are transected by a network of brittle fractures, including a prominent northeast-trending set that hosts a suite of ≥1.78 Ga lamprophyre and granitic dykes (Ashton et al., 2006; Ashton et al., 2009b). Together, late-stage structures are thought to reflect an east-west compressional regime extant during terminal collision in the Trans-Hudson orogeny to the east, coupled with plate interactions to the west (Ashton et al. 2009b).

Summary and discussion

A significant contribution of this work is recognition that tectonic effects of the Taltson orogeny (~1.93 Ga) extend eastward from the Taltson domain, as far as the STZ (Fig. 1), a relationship that has also been recognized south of the Athabasca Basin (Stern et al., 2003; Card et al., 2007). The absence of plutonic rocks, other than low-volume crustal melts, suggests that the Taltson(-Thelon) metamorphic cycle was driven by crustal thickening, and probably commenced some time (e.g. 20–30 Ma) before the ~1.93 Ga metamorphic peak. Based on similarities in lithology, namely the common occurrence of 3.0 and 2.6 Ga granitoid gneisses amongst more varied (heterogeneous) gneisses, the Tantato domain arguably represents an uplifted portion of the Beaverlodge domain. Despite this, the domains have markedly contrasting tectono-metamorphic histories. For example, whereas Tantato domain rocks underwent high-*P* metamorphism at 2.6–2.5 Ga and again at ~1.9 Ga but remained deep in the crust between these events (Baldwin et al., 2003; Mahan et al., 2006; Flowers et al., 2007), Archean and Paleoproterozoic rocks in the Beaverlodge domain were at the surface at 2.3 Ga or younger, depending on the exact age of the MBG, and were subsequently buried to reach granulite facies by 1.93 Ga. The relatively young detrital zircons in psammopelitic rocks in the upper MBG

(Ashton et al., 2009a; Knox et al., 2007, 2008), along with the character of the group as a whole, suggests that it may extend as far northeast as Snowbird Lake, where similar rocks have been interpreted as a <2.07 Ga passive margin that was deformed and metamorphosed at 1.92 Ga (Martel et al., 2008). In conclusion, future work in this part of the Rae Province needs to address how and why rocks in the Tantato domain apparently failed to record this ca. 2.1 to 1.93/1.92 Ga cycle of sedimentation and tectonic burial. The absence of any record of earlier Arrowsmith orogenic activity in the Tantato (relative to Beaverlodge) domain is also puzzling and requires consideration.

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