Pre-*Nuna* supercontinent reconstruction: the role of the global Arrowsmith Orogeny and its impact in western Canada

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Introduction

The great interest in supercontinent reconstructions reflects the importance of the supercontinent cycle in understanding global plate tectonic processes and its influence on formation and preservation of ore deposits. In spite of the substantive progress that has been made in reconstructing Earth's younger supercontinents (e.g. *Rodinia, Gondwana, Pangea*), the number and possible makeup of supercontinents prior to the first known supercontinent *Nuna*, at 1.8 Ga, remain poorly understood. Traditionally the western Churchill Province (wCP,) was thought to have been part of *Kenorland,* a single supercontinent that *a*malgamated pre-2.6 Ga, was stable ca. 2.5 – 2.1 Ga and broke up by 2.1 Ga . The recent identification of the. 2.5 – 2.3 Ga Arrowsmith orogen on the western flank of the wCP (Berman et al., 2005) offers a very different picture for what has been considered a quiescent period, possibly linked to a plate tectonic shutdown on Earth (Condie et al., 2009). Here we present new geochronological data that provide important support for a broader distribution of the Arrowsmith orogen and review its possible global extent. Global recognition of this relatively uncommon period of orogenesis apparently negates the tectonic shutdown hypothesis and will provide a useful piercing point to explore pre-Nuna supercontinent reconstructions.

Extent of the Arrowsmith Orogen in western Canada

The western Churchill Province of the northwestern Canadian Shield comprises two Archean cratons, the Hearne and Rae, which were welded together at 1.9 Ga along the Snowbird tectonic zone (Berman et al., 2007,). The Rae craton, the backdrop for this study, consists of variably reworked, amphibolite- to granulite-facies continental crust. It is dominated by ca. 2.6 Ga granitoid rocks intrusive into ca. 3.4 – 2.7 Ga basement and ca. 2.7 Ga greenstone belts. Subsequent early Paleoproterozoic granitoid magmatism occurred in three major pulses: 2.50 – 2.45 Ga (Schultz et al., 2007), ca. 2.3 Ga (Hartlaub et al., 2007), and 1.85–1.81 Ga (Peterson et al., 2002). The latter two pulses have been linked to reworking/orogenesis of the Arrowsmith and Hudsonian orogenies.

The geochronological data presented herein come from two separate areas of the Rae: Boothia Peninsula (BP) in Nunavut and the southwestern Rae (swR) in the Northwest Territories. BP is underlain by a southern domain of dominantly 2.6 Ga plutonic rocks, an intervening belt of 2.6 Ga plutonic and granulite-facies metasedimentary rocks, and a northern domain of upper amphibolite- to granulite facies metasedimentary and plutonic rocks (Ryan et al., 2008). Each of these domains displays a single main transposition foliation that varies in age from 2.6 Ga to 1.8 Ga .(Berman et al., 2008) The swR is comparatively poorly known, having only been the subject of regional reconnaissance studies and little age dating. Original mapping and re-examination of archival material suggests that it comprises upper-amphibolite to granulite facies, low-pressure (5-6 kbar) metasedimentary and metavolcanic rocks, intruded by a variety of mafic through felsic magmatic rocks. Local studies on its eastern and southern margins suggest that regional foliations of varying trends range in age between 2.60-1.90 Ga (Martel et al., 2007, Ashton et al., 2009).

New in-situ SHRIMP monazite analysis of the northern domain and central granulite belt of BP yield ages of ca. 2.5 Ga. Textural relationships (elongate monazite habit, either situated in the matrix foliation or in garnet porphyroblasts parallel to the main foliation) suggest that these ages effectively constrain a major period of deformation in this region. U-Pb SHRIMP zircon data also reveal evidence for ca. 2.5 Ga high-grade metamorphism as well as granite plutonism. Monazites of ca. 2.36 Ga age in several samples date a granulite-facies metamorphism that culminated in retrograde breakdown of garnet to biotite.

New in-situ SHRIMP monazite ages from granulite to upper amphibolite-facies rocks of the swR define age clusters at 2.55 – 2.53 Ga, 2.49-2.47 Ga and 2.37 – 2.28 Ga. The two older age clusters are found in monazite cores. Whereas the few 2.55 – 2.53 Ga ages may derive from detrital monazite, the consistency of the 2.49 – 2.47 Ga analyses suggests that these ages date an earlier metamorphic event. Monazites of ca. 2.37- 2.34 Ga display textural relationships consistent with syn- to post-tectonic crystallization at upper amphibolite facies. Slightly younger ages of ca. 2.36 – 2.30 Ga are found in monazite cores and rims of grains aligned in a granulite-facies foliation, suggesting growth during granulite-facies metamorphism and deformation. Core monazite ages of ca. 2.27 – 2.21 Ga likely reflect retrograde recrystallization during later orthopyroxene breakdown, which may account for the excess scatter among the older analyses. Taken together these results suggest that high-grade metamorphism occurred, perhaps episodically, from ca. 2.37 – 2.28 Ga, with deformation ceasing by ca. 2.30 Ga.

Younger Paleoproterozoic thermal overprints are noted at ca. 1.9 – 1.8 Ga in both study areas (Berman et al., unpub. data; Berman et al., 2008), although they include slightly older ages (ca. 1.95 Ga) for the swR. These results demonstrate that the western Rae did not escape the far-reaching effects of the Taltson-Thelon, Snowbird and Trans-Hudson orogenies.

The geochronological data reported here indicate that the Arrowsmith orogen extends across most of the Rae craton. The new ages for magmatism and metamorphism in the northern domain of BP overlap with similar events known from the Queen Maud region immediately to the southwest (Schultz et al., 2007). These regions can now be definitively linked to the Beaverlodge domain of northern Saskatchewan (Hartlaub et al. 2007) by the new data for the swR. The orogen can also be extended to the northeast based on sparse crystallization and metamorphic ages in the range 2.53 – 2.3 Ga that are found on northernmost Boothia Peninsula, Devon, Somerset, Prince of Wales and northern Baffin Islands (Skulski and Villeneuve,1999 and references therein; D. Scott, unpublished data). Overall, the Arrowsmith orogen appears to have a strike length of nearly 2000 km.

Geodynamic setting

A critical question is the geodynamic setting of the Arrowsmith Orogeny. While protracted, it includes two dominant magmatic phases, ca. 2.5 - 2.45 and ca. 2.3 Ga, with metamorphic pulses at ca. 2.5, 2.42, and 2.38-2.35 Ga. Schultz et al. (2007) have interpreted an extensional setting for the 2.5-2.45 Ga period, whereas Hartlaub et al., (2007) proposed late rift basins in a syn- to post-collisional setting for the 2.3 Ga period, leading to the impression of an overall extensional orogeny (Condie et al., 2009). The evidence for foliation development on a regional scale led Berman et al (2005) to consider a convergent margin setting, similar to the 2.4 – 2.2 Ga continental arc originally speculated to have been built on the west flank of the Rae craton (Hoffman, 1988). The arc-like geochemical signature of the 2.45 Ga granitoid rocks (Schultz et al., 2007) is not inconsistent with such a hypothesis. We envisage a shorter lived convergent margin setting comprising an earlier continental arc-contractional stage at ca. 2.5 – 2.4 Ga and a late collisional stage at ca. 2.38 – 2.30 Ga, although there may have been significant along-strike variations. The narrow age range (2.50 – 2.44 Ga) for detritus within the Queen Maud metasediments (Schultz et al., 2007) is consistent with their origin in a back-arc setting.

The western Churchill province, of which the Rae is a part, was proposed to have experienced extension from 2.5 – 2.1 Ga, culminating with the breakup of Kenorland . The data reported here highlight the great lateral and continuous extent of ca. 2.5 – 2.3 Ga orogenesis, sedimentation and magmatism along the western flank of the Rae craton, similar in strike length to the 2.0 – 1.9 Ga Taltson-Thelon and 1.9 – 1.8 Ga Trans-Hudson orogens. We consider that such a distribution is inconsistent with sporadic thermal-magmatic events leading to cratonic breakup.

Global extent and implications

Orogensis and crust formation between 2.5-2.3 Ga is known from other cratons globally, although it has not been as widely encountered as the major events at 2.7 and 1.8 Ga. This apparent scarcity implies that the Arrowsmith orogeny could have the potential to provide an important piercing point for supercontinent reconstructions if appropriate techniques are employed to see through younger events. Cratonic blocks with a documented history of 2.5-2.3 Ga magmatism, sedimentation and/or tectonometamorphism include North China, Gawler and Mawson, Sask , West Africa-Congo , Sao Francisco, northeast Brasil, Madagascar, Baidank-Siberia, and Central Asia. In almost all cases the related tectonometamorphism is considered to reflect a convergent rather than extensional setting. Based on this evidence, it seems likely that the Arrowsmith orogeny was a significant event on a global scale.

Pehrsson et al., (2005) proposed the Arrowsmith orogeny could relate to either amalgamation of a second latest Neoarchean-early Paleoproteorzoic supercraton, or a major late addition onto part of the existing Superia supercraton. Accurately determining the extent of Arrowsmith crustal addition and orogenesis will be important to resolving these alternate hypotheses and has significant geodynamic implications. Highly divergent tectonic scenarios have been proposed for this general time period. Condie et al. (2009) have interpreted the smaller volume of juvenile crustal additions in this period to signal a shutdown of plate tectonics on Earth, following the 2.6 Ga Neoarchean supercraton aggregation. Campbell and Allen (2008) have noted a greater component of Arrowsmith crustal ages in modern river drainages and propose that a major period of underappreciated Arrowsmith-age subduction contributed to oxygenation of the early atmosphere. These differing scenarios can be reconciled with a model in which ca. 2.5 – 2.3 Ga crustal addition was dominated by continental arc-magmatism and culminated in cratonic stability with only minor peripheral subduction on the margin of the newly aggregated supercraton.

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