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A review of structural patterns and melting processes in the Archean craton of West Greenland: Evidence for crustal growth at convergent plate margins as opposed to non-uniformitarian models

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ABSTRACT

The Archean craton of West Greenland consists of many fault-bounded Eoarchean to Neoarchean tectonic terranes (crustal blocks). These tectonic terranes are composed mainly of tonalite–trondhjemite–granodiorite (TTG) gneisses, granitic gneisses, metavolcanic-dominated supracrustal belts, layered anorthositic complexes, and late- to post-tectonic granites. Rock assemblages and geochemical signatures in these terranes suggest that they represent fragments of dismembered oceanic island arcs, consisting mainly of TTG plutons, tholeiitic to calc-alkaline basalts, boninites, picrites, and cumulate layers of ultramafic rocks, gabbros, leucogabbros and anorthosites, with minor sedimentary rocks. The structural characteristics of the terrane boundaries are consistent with the assembly of these island arcs through modern style of horizontal tectonics, suggesting that the Archean craton of West Greenland grew at convergent plate margins. Several supracrustal belts that occur at or near the terrane boundaries are interpreted as relict accretionary prisms. The terranes display fold and thrust structures and contain numerous 10 cm to 20 m wide bifurcating, ductile shear zones that are characterized by a variety of structures including transposed and redistributed isoclinal folds. Geometrically these structures are similar to those occurring on regional scales, suggesting that the Archean craton of West Greenland can be interpreted as a continental scale accretionary complex, such as the Paleozoic Altaids. Melting of metavolcanic rocks during tectonic thickening in the arcs played an important role in the generation of TTGs. Non-uniformitarian models proposed for the origin of Archean terranes have no analogs in the geologic record and are inconsistent with structural, lithological, petrological and geochemical data collected from Archean terranes over the last four decades. The style of deformation and generation of felsic rocks on outcrop scales in the Archean craton of West Greenland and the Mesozoic Sulu orogenic belt of eastern China are similar, consistent with the formation of Archean continental crust by subduction zone processes.

1. Introduction and scope

Generation and destruction of Earth's continental and oceanic crusts in the Phanerozoic Eon have been coupled with the Wilson cycle of plate tectonics (Oreskes, 2003). Phanerozoic continental crust has been produced at convergent plate margins mainly through tectonic accretion and emplacement of mantle-derived igneous rocks (Burke, 2011; Şengör et al., 1993, 2014). The main driving force behind present-day structural, magmatic, sedimentary and metamorphic processes involved in the formation and evolution of the continental crust is plate tectonics, resulting from the flow of matter and energy between the lithosphere and asthenospheric mantle along divergent, convergent, and transform plate boundaries (Şengör, 1990; Oreskes, 2003; Polat, 2014).

Nearly all geologists accept the idea that the Phanerozoic evolution of the Earth has been shaped by plate tectonic processes. However, when it comes to the interpretation of the style of tectonic processes and growth of the continental crust in the Precambrian, particularly in the Archean Eon, the opinions of geologists diverge. Despite growing lines of field, geochemical, geophysical and theoretical evidence indicating that the Earth has evolved through Phanerozoic-like plate tectonic processes at least since 3.8 Ga and that Archean continents originated mainly at convergent plate margins (see Adam et al. (2012); Amiguet et al. (2012); Arndt (2013); Furnes et al. (2007, 2013); Garde (2007); Kisters et al. (2012); Kusky and Polat (1999); Kusky et al. (2014); Dostal and Mueller (2013); Nagel et al. (2012); Nebel-Jacobsen et al. (2010); Nutman et al. (2009, 2013, 2015a); O'Neil et al. (2011); Polat

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et al. (2002); Santosh et al. (2013); Turner et al. (2014); Wang et al. (2013); Windley (1993); Windley et al. (1981)), the nature of tectonic processes that generated Archean terranes continues to be debated (e.g., Bédard, 2006; Dyck et al., 2015; François et al., 2014; Gerya, 2014; Hamilton, 1998, 2013; Johnson et al., 2014; Kamber, 2015; Moore and Webb, 2013; Robin and Bailey, 2009; Stern, 2005; Thébaud and Rey, 2013). In regards to the evolution of the Earth in the Archean, the following questions are hotly debated: How far back in Earth history were geological processes driven by plate tectonics? Were Archean crust-forming processes dominated by density-driven, vertical crustal overturns, diapirs, drips, residue delaminations, and volcanic heat pipes without any modern analogs? How did Archean greenstone belts form? Are Archean greenstone belts and associated layered anorthosite complexes fragments of ophiolites? How did Archean continents grow? Answers to all these questions remain elusive and controversial.

In this paper, we present new field data from Eoarchean to Neoarchean terranes in West Greenland (Fig. 1), showing that the geometry and style of outcrop scale structures (e.g., fold patterns) in shear zones are remarkably similar to those of regional-scale structures. We discuss the importance of these similarities and their tectonic significance for the growth of Archean continental crust. Then, we compare these Archean structures and the formation of Archean felsic rocks (TTGs: tonalite, trondhjemite, granodiorite suites, granites) with those in the Mesozoic Sulu orogen, eastern China, to address the above questions and revisit the tectonic models proposed for the origin of Archean crust. Given the fact that all rocks in the Archean craton of West Greenland (also known as the North Atlantic craton) have been variably metamorphosed, the prefix 'meta' will be taken as implicit.

2. Archean geological record in West Greenland

The Archean craton of West Greenland contains the world's best exposed rocks from the interval ranging in age from 3850 to 2550 Ma, providing an excellent opportunity to study the early evolution of the Earth

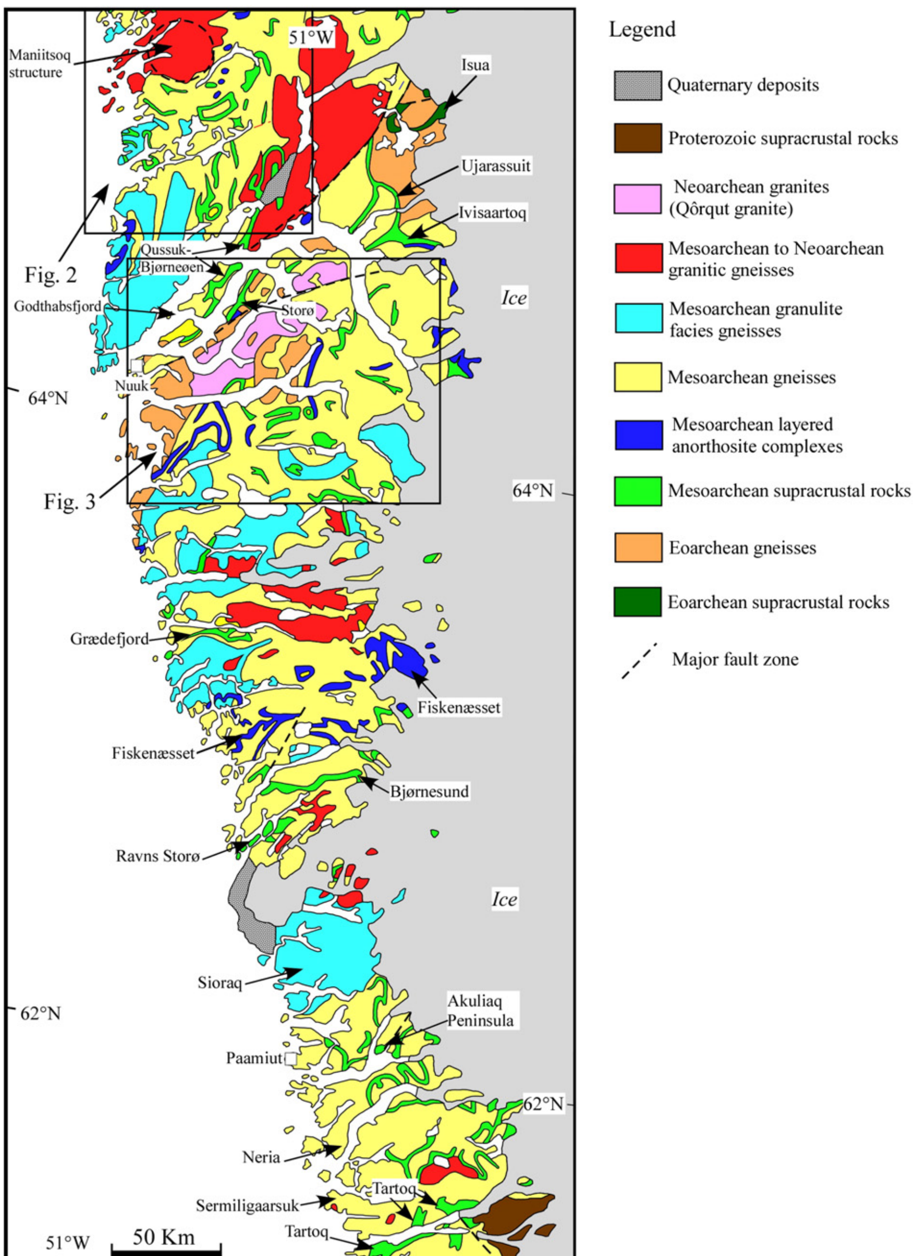

Fig. 1. Simplified geological map of the Archean craton of West Greenland, showing the locations of the Isua, Ivisaartoq–Ujarassuit, Qussuk, Bjørneøen, Storø, Grædefjord, Ravns Storø, Bjørnesund, Akuliaq Peninsula, and Tartoq supracrustal belts, the Fiskenæsset anorthositic complex, and the Maniitsoq impact structure (modified after Escher and Pulvertaft (1995)).