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Petrology and geochemistry of mafic rocks in the Acasta Gneiss Complex: Implications for the oldest mafic rocks and their origin

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ABSTRACT

The Acasta Gneiss Complex, located in the western part of the Slave Province, Canada, is widely recognized as the oldest Eoarchean terrane. In addition to felsic gneisses with the ages of 3.6–4.0 Ga, minor mafic rocks occur as rounded to elliptical enclaves and inclusions within the felsic gneisses. Despite serving as potential sources of geochemical information on the Hadean mantle, the mafic rocks have received less attention in previous studies. Thus, we conducted a comprehensive geological petrological and geochemical investigation on the Acasta mafic rocks to constrain their petrogenesis and geodynamic setting.

The mafic rocks comprise massive to weakly foliated amphibolite, garnet amphibolite and hornblendite, with variable abundances of hornblende, plagioclase, chlorite and quartz and subordinate clinopyroxene, garnet and cummingtonite. They commonly underwent high-grade metamorphic recrystallization under amphibolite to upper-amphibolite facies conditions. The observed variations in mineral assemblages, abundances and compositions reflect large differences in whole-rock compositions, likely caused by crustal anatexis during the Eoarchean thermal events responsible for the generation of the surrounding felsic gneisses. Infiltration or extraction of felsic melts formed due to partial melting of precursor rocks can account for an overall negative correlation between Al_2O_3 and MgO contents and variable enrichments in the incompatible elements.

Despite the widespread influence of anatexis on the geochemistry of Acasta mafic rocks, we identified the precursor compositions of the least-modified amphibolites as basaltic magmas. They are characterized by intermediate Al_2O_3 and MgO contents on the observed array and by near chondritic patterns for incompatible trace elements, except for slightly negative Nb and Ta anomalies. We considered two scenarios to explain the origin of Eoarchean basaltic rocks with Nb–Ta anomalies: (1) generation of Nb–Ta deficient basaltic magma in a suprasubduction setting, analogous to modern arcs-derived magmas, and (2) generation of Nb–Ta deficient basaltic magma from the melting of a Nb–Ta deficient primitive mantle, possible if the core contains significant proportions of the Earth's Nb and Ta budget. Although the operation of plate tectonics and the presence of subduction zones at the end of Hadean may be an attractive explanation for the observed Nb–Ta depletions, the chondritic relative proportions of other immobile trace elements for Acasta mafic rocks leave open the possibility of their formation from an Nb–Ta deficient primitive mantle.

1. Introduction

The Hadean is the earliest period of Earth's history, from its birth to the beginning of Eoarchean at 4.03 Ga, which is the age of the oldest terrestrial rock (Bowring and Williams, 1999). A global magma ocean was thought to be present in the first hundred million years of the Hadean Earth, as a natural consequence of planetary evolution due to the gravitational energy released by core formation, as well as highly energetic collisions of Moon-to Mars-sized bodies (e.g. Rubie et al., 2011). To unravel the nature and timing of early differentiation processes via crystallization of magma ocean, several short-lived nuclide systems have been utilized. For example, the application of ^{182}Hf–^{182}W short-lived radioisotope system suggests that metallic core was rapidly separated from the silicate mantles in the first 30 million years of Solar system history (Kleine et al., 2002). Furthermore, ^{146}Sm–^{142}Nd isotope systematics of Archean igneous and sedimentary rocks suggest that the mantle underwent a rapid differentiation in the

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early Earth and that the differentiated mantle was not completely homogenized until at least the Eoarchean (e.g. Boyet and Carlson, 2005; Bennett et al., 2007; O'Neil et al., 2011; Rizo et al., 2013). However, details of the early differentiation of the solid Earth due to crystallization of magma ocean and the subsequent evolution of mantle-crust system still remain obscure (Caro et al., 2005; Labrosse et al., 2007; Caro, 2011).

Scarce Eoarchean rocks are preserved on Earth, possibly because subsequent mantle convection and plate tectonics have removed all Hadean rocks and almost all Eoarchean rocks. They include the Acasta Gneiss Complex, Canada (4.03 Ga; Bowring and Williams, 1999), the Itsaq Gneiss Complex, Greenland (3.85–3.60 Ga; Nutman et al., 1996), the Napier Complex, Antarctica (3.95–3.8 Ga; Williams et al., 1986), Saglek-Hebron block, Labrador (3.95 Ga; Komiya et al., 2015), the Nuvvuagittuq supracrustal belt, Canada (3.75 Ga; Cates and Mojzsis, 2007) and the Anshan area, North China (3.8 Ga; Song et al., 1996). Most of these terranes are predominantly composed of felsic rocks, including tonalite, trondhjemite and granodiorite (TTG), with minor ultramafic and mafic rocks and metasedimentary rocks. They have suffered severe deformation and metamorphism such that primary geological and geochemical signatures are poorly preserved. Many studies of the Earth's early crusts focus on felsic rocks because they commonly contain igneous zircons providing precise U-Pb ages (e.g. Bowring et al., 1989; Mojzsis et al., 2014; Reimink et al., 2014). However, mafic rocks, directly derived from the mantle, can be expected to provide more information on solid Earth evolution. Studies on mafic rocks in the Itsaq Gneiss Complex and Nuvvuagittuq supracrustal belt suggest that plate tectonics and the modern style of recycling of oceanic crust could go back to at least 3.8 Ga (e.g. Nutman et al., 1996; Komiya et al., 1999, 2004; Polat et al., 2002, 2003, 2011, 2012; Jenner et al., 2009; Furnes et al., 2009). Therefore, in order to decode the characteristics and evolution of the solid Earth before 3.8 Ga, it is necessary to clarify the origin of older mafic rocks.

The Acasta Gneiss Complex (AGC) is one of the oldest Eoarchean terranes and is dominated by felsic rocks composed of tonalitic, granodioritic and granitic gneisses (e.g. Bowring et al., 1990; Iizuka et al., 2007). Geochronological studies show different generations of felsic plutonic rocks, with the oldest suites formed at 3.92–4.03 Ga (Bowring et al., 1990; Bowring and Williams, 1999; Bowring and Housh, 1995; Iizuka et al., 2007; Reimink et al., 2014). Zircons extracted from these have sub-chondritic initial $^{176}Hf/^{177}Hf$ values, suggesting that they were formed from a Hadean crustal component (Amelin et al., 1999, 2000; Iizuka et al., 2009). The presence of a 4200 Ma inherited zircon core also supports the presence of Hadean granitoid crust in the area (Iizuka et al., 2006). Although previous studies analyzed whole-rock geochemistry mainly from felsic rocks (Bowring et al., 1990; Mojzsis et al.,

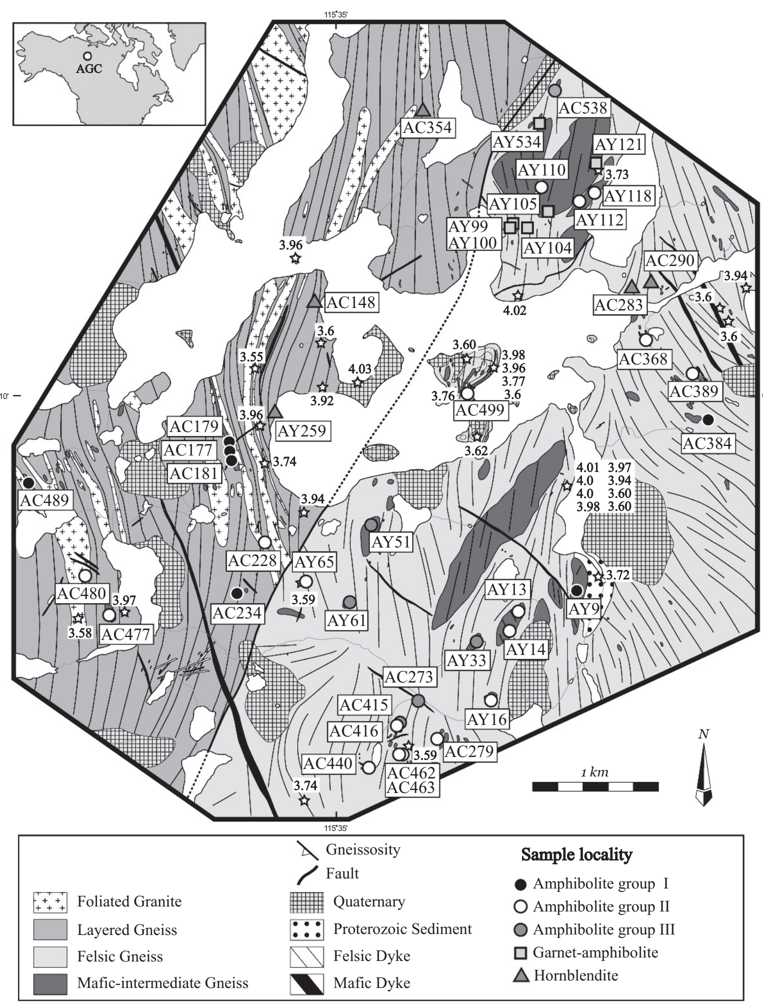

Fig. 1. Geological map of the Acasta Gneiss Complex (AGC), modified after Iizuka et al. (2007), sample localities are also shown. Mafic to intermediate rocks occur as blocks, pods and layers all over the AGC. They are intruded by, or occur as enclaves within, the felsic gneisses. The numbers beside open star symbols show magmatic ages of the felsic and layered gneisses (Bowring et al., 1989; Bowring and Housh, 1995; Bleeker and Stern, 1997; Stern and Bleeker, 1998; Bowring and Williams, 1999; Iizuka et al., 2006, 2007; Mojzsis et al., 2014; Reimink et al., 2014).