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Widespread tungsten isotope anomalies and W mobility in crustal and mantle rocks of the Eoarchean Saglek Block, northern Labrador, Canada: Implications for early Earth processes and W recycling

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ABSTRACT

Well-resolved ^{182}W isotope anomalies, relative to the present mantle, in Hadean–Archean terrestrial rocks have been interpreted to reflect the effects of variable late accretion and early mantle differentiation processes. To further explore these early Earth processes, we have carried out W concentration and isotopic measurements of Eoarchean ultramafic rocks, including lithospheric mantle rocks, meta-komatiites, a layered ultramafic body and associated crustal gneisses and amphibolites from the Uivak gneiss terrane of the Saglek Block, northern Labrador, Canada. These analyses are augmented by *in situ* W concentration measurements of individual phases in order to examine the major hosts of W in these rocks. Although the W budget in some rocks can be largely explained by a combination of their major phases, W in other rocks is hosted mainly in secondary grain-boundary assemblages, as well as in cryptic, unidentified W-bearing 'nugget' minerals. Whole rock W concentrations in the ultramafic rocks show unexpected enrichments relative, to elements with similar incompatibilities. By contrast, W concentrations are low in the Uivak gneisses. These data, along with the *in situ* W concentration data, suggest metamorphic transport/re-distribution of W from the regional felsic rocks, the Uivak gneiss precursors, to the spatially associated ultramafic rocks.

All but one sample from the lithologically varied Eoarchean Saglek suite is characterized by generally uniform ∼+11 ppm enrichments in ^{182}W relative to Earth's modern mantle. Modeling shows that the W isotopic enrichments in the ultramafic rocks were primarily inherited from the surrounding ^{182}W-rich felsic precursor rocks, and that the W isotopic composition of the original ultramafic rocks cannot be determined. The observed W isotopic composition of mafic to ultramafic rocks in intimate contact with ancient crust should be viewed with caution in order to plate constraints on the early Hf–W isotopic evolution of the Earth's mantle with regard to late accretionary processes. Although ^{182}W anomalies can be erased via mixing in the convective mantle, recycling of ^{182}W-rich crustal rocks into the mantle can produce new mantle sources with anomalous W isotopic compositions that can be tapped at much later times and, hence, this process should be considered as a mechanism for the generation of ^{182}W-rich rocks at any subsequent time in Earth history.

1. Introduction

Deciphering the geochemical evolution of Earth's mantle is rooted in both spatial and temporal dimensions. The former primarily relies on seismic and magnetotelluric studies that reveal the physical and dynamic state of the present-day mantle at depth, while the latter is focused on the rock record through time. The destruction of crustal rocks by plate tectonics means that the rock record diminishes backward in time, hence, our view of the Earth in the Eoarchean and Hadean remains clouded. Nevertheless, new information about the early Earth is beginning to emerge from Hadean and younger materials as a result of the study of short-lived isotope systems. For example, ^{142}Nd/^{144}Nd ratio measurements show small variations among Archean rocks, compared

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with the modern mantle. These ^{142}Nd variations could only have been produced by mantle differentiation processes within the first ∼500 Ma of Earth history, as a result of the decay of short-lived ^{146}Sm to ^{142}Nd. The variations provide an important tool for tracing the formation and evolution of early-formed, diverse reservoirs (e.g., Boyet et al., 2003; Caro et al., 2003; Bennett et al., 2007; O'Neil et al., 2008; Rizo et al., 2011; Debaille et al., 2013; Roth et al., 2013).

In some recent W isotopic studies involving mafic/ultramafic rocks, it has been found that W abundances in such rocks are high and that there are broad similarities between the W isotopic compositions of crust and mantle rocks (e.g., Touboul et al., 2012, 2014; Rizo et al., 2016; Puchtel et al., 2016). Such observations raise questions concerning the mobility of W in the crust and the potential for post-crystallization W isotopic exchange between felsic and mafic/ultramafic rocks. In order to further explore the usefulness of the ^{182}Hf–^{182}W short-lived isotopic system in revealing early Earth processes when applied to mantle-derived mafic–ultramafic rocks, we examine Eoarchean ultramafic rocks, including lithospheric mantle rocks, meta-komatiites and a layered ultramafic body, from the Saglek Block of northern Labrador, Canada. We also examine associated tonalitic Uivak gneisses and amphibolite that surround the ultramafic rocks. Many of these rocks have been previously well characterized for their petrology, whole-rock major and trace element geochemistry, as well as Nd–Pb isotopes (Collerson et al., 1991; Wendt and Collerson, 1999). We report whole-rock W concentrations and W isotopic compositions for these rocks, as well as whole-rock major and trace element concentrations for Uivak gneisses and amphibolite. In addition, before applying W isotopic data to understand the geological processes responsible for the formation of these rocks, we evaluate the potential for W mobility and overprinting in these ancient rocks using *in situ* measurements of the abundances of W in constituent primary minerals and grain-boundary alteration assemblages, within a subset of these rocks. Whole-rock W abundance measurements are used along with modes calculated from mineral and bulk rock major element data to examine the mass balance for W.

2. Geological setting of the Saglek Block

The Saglek–Hebron area is located in northern Labrador, Canada, and is one of the oldest early Archean terranes, referred to as the Saglek Block. The block belongs to part of the North Atlantic Craton that ranges from NW Scotland through southern Greenland to Labrador (Fig. 1). It is divided by a major, NS-trending fault, termed the Handy fault, into two portions including a western region, characterized by granulite facies metamorphism, and an eastern region, characterized by sub-granulite to amphibolite facies metamorphism. The Saglek Block consists of Eo- to Neoarchean rock suites dominated by orthogneisses, but also includes metasedimentary rocks, metavolcanics, ultramafic rocks and mafic–ultramafic dykes ("Saglek dykes" of Mesoarchean age), as well as younger ca. 2.5 Ga granites (Bridgwater et al., 1975; Collerson and Bridgwater, 1979; Schiøtte et al., 1989a, 1989b; Komiya et al., 2015). On the basis of their geological relationships with the Saglek dykes, the orthogneisses in the Saglek Block can be classified into two groups (Bridgwater et al., 1975), analogous to the Ameralik dykes in the Itsaq Gneiss Complex, Greenland (McGregor, 1973). Orthogneisses older than the Saglek dykes are referred to as the Uivak Gneisses and include the Uivak I and II suites. Uivak I gneisses are characterized by tonalite–trondhjemite–granodiorite (TTG) compositions and are extensively distributed throughout the block, while the Uivak II gneisses are a suite of deformed feldspar granodioritic gneisses with simple fabrics, in marked contrast to the dominantly composite fabrics observed in the Uivak I gneisses. The boundaries between the Uivak I and II gneisses are often obscure, but from less strained outcrops, it can be seen that the Uivak I gneisses were intruded by Uivak II gneisses; the Uivak II gneiss has protoliths that were formed ca. 3.62 Ga (Schiøtte et al., 1989a, 1989b). However, the age of the protoliths to the Uivak I gneisses is still under debate, ranging from 3.73 Ga (Schiøtte et al., 1989a, 1989b), to >3.95 Ga (Komiya et al., 2015). In addition, the Lister gneiss is found as a post-Saglek dyke gneiss (ca. 3.24 Ga; Schiøtte et al., 1989a), and has been interpreted to have been tectonically juxtaposed against the early Archean "Uivak continent" (Schiøtte et al., 1990) or intruded into the Uivak gneisses (Collerson et al., 1976).

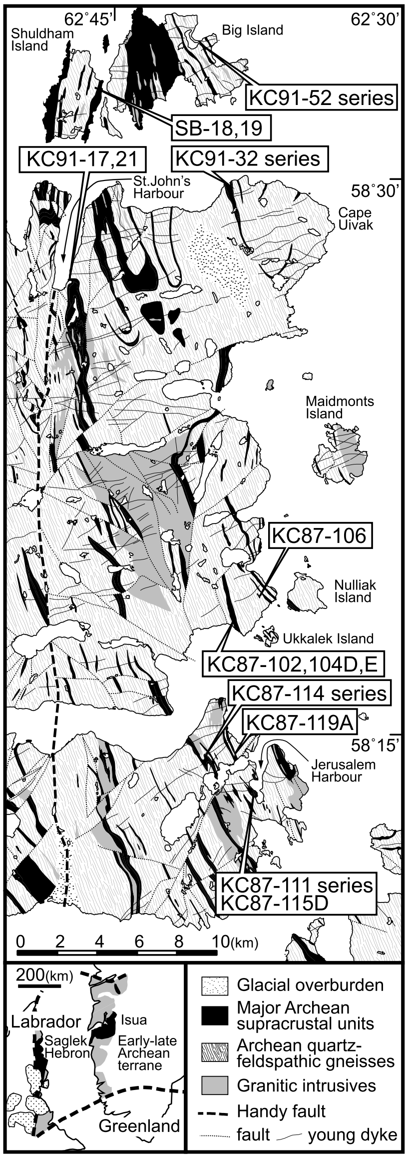

Fig. 1. Geological sketch map of the Saglek–Hebron area of the North Atlantic Craton (inset map below), northern Labrador, Canada, modified after Schiøtte et al. (1986) and Wendt and Collerson (1999), with sample localities for this study marked.

Based on the cross-cutting relationship with the Saglek dykes, the supracrustal rocks in the Saglek Block can also be divided into two groups, which are the pre-Saglek "Nulliak" group and the post-Saglek "Upernavik" group, respectively (e.g., Bridgwater et al., 1975; Collerson et al., 1976). Both groups, by and large, contain mafic and ultramafic rocks as well as rocks identified as chemical and clastic sedimentary rocks. The boundaries between the Nulliak supracrustal rocks and Uivak gneisses are often am-