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Geological Constraints on Claims for Earth's Earliest Life in the Eoarchean of Greenland and Labrador

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The time at which life on Earth began is one of humankind's most enduring scientific questions, complicated by the increasing difficulty both in identifying and accurately dating evidence of life the further back in time one looks. During the Hadean eon (>4.0 Ga), from which by definition no rock record is preserved, and into the early Archean eon, the inner solar system was subjected to intense meteorite bombardment, with impacts commonly thought to have "frustrated" (Maher and Stevenson 1988) the development of a persistent biosphere on the Earth. Prior to ca. 3.5 Ga (with the appearance of stromatolites in Pilbara, Australia), there are no preserved body or trace fossils. Instead, evidence for biological activity relies on chemofossil evidence, typically in the form of tiny graphite remnants that record a light carbon isotope signature ($\delta^{13}C < -20‰$) commonly attributed to organic activity. In itself, this evidence is far from unambiguous as there are potential abiotic pathways to isotopically light carbon, but accepting this at face value, two other key factors are required in order to support the veracity and true antiquity of these putative chemofossils (Whitehouse and Fedo 2007). First, it is generally accepted that the host rocks in which the chemofossils are found must represent a near surface environment with access to surface water necessary for metabolism to function. Second, and only if the first criterion is met, in order to claim great antiquity the host rock must be dated unambiguously.

Debates about Earth's earliest life in the form of chemofossils have played out in the Eoarchean of the North Atlantic Craton, specifically at two localities in Greenland, the Isua Greenstone Belt and the island of Akilia, and another in the Saglek area of northern Labrador. The status of each of these claims, both viable and discredited, has been reviewed in detail by Whitehouse et al. (2019) and is summarised here.

At Isua, Rosing (1999) documented low $\delta^{13}C$ in graphite from metamorphosed rocks derived from turbiditic sediment on the western side of the supracrustal belt. This is a suitable host rock for life and intercalated volcanics provide a reliable ca. 3.7 Ga age. However, speculation based on Pb isotopes that the organisms might have been photosynthesising cyanobacteria (Rosing and Frei 2004) has been challenged as a non-unique interpretation (Fedo et al. 2006) and their true nature remains a matter for debate.

Claims for >3.83 Ga chemofossils from the island of Akilia, which has experienced strong polyphase deformation and multiple episodes of high-grade metamorphism, were first made by Mojzsis et al. (1996). These have proven highly controversial and are now largely discredited. The very existence of isotopically light graphite as inclusions in apatite in a presumed "banded iron formation" was initially called into question. Subsequent studies have reported its presence, albeit in apatite that is only 1.7 Ga old (Whitehouse et al. 2009). The "BIF" interpretation of the host rock also has been questioned, with a suggestion that it is potentially a metasomatic quartz vein intruding deep-seated ultramafic rocks (Fedo and Whitehouse 2002). Supportive evidence in the form of mass-independent fractionation of (pre-2.4 Ga atmospheric) sulfur isotopes (Mojzsis et al. 2003) could not be reproduced (Whitehouse et al. 2005). Additionally, the claimed >3.83 Ga age relies on ambiguous field relationships with TTG gneisses that have been claimed to, but do not directly, cross-cut the supposed metasediments. Direct Sm-Nd isochron dating yields only 3.65 Ga, so even if the biogenicity is real, it would be younger than Isua and so of lesser interest. All aspects of the long-running Akilia saga have been exhaustively reviewed by Whitehouse et al. (2009).

Another chemofossil claim appeared in the Saglek region of northern Labrador, from where Tashiro et al. (2017) reported isotopically light carbon in gneisses derived from pelitic sediments supposedly deposited before 3.95 Ga. Although the host rock in this case is a suitable potential host for bioactivity, the age estimate relied on a combination of dubious field relationships extrapolated over many 100's of metres, together with a highly subjective interpretation of zircon geochronology in which a statistically rigorous treatment was not utilised; instead, a few of the oldest zircon analyses were selected arbitrarily to yield the oldest possible age. More egregiously, this study also ignored long-published geochronology (Schiøtte et al. 1989) and Hf isotopes (Stevenson and Patchett 1990) from the host rocks that are consistent only with a substantially younger (ca. 3.2 Ga) age. Ongoing work on the same gneiss outcrop used by Tashiro et al. (2017) to propose their 3.95 Ga age reveals a complex sequence of magmatic and structural events that contradicts previously published interpretations. Critically, a granite that cross-cuts gneissosity and was previously used to provide a minimum age of ca. 3860 Ma for metamorphism and ductile deformation, contains significant xenocrystic zircon from the host gneiss. Based on zircon rims, granite emplacement instead likely occurred at ca. 2.7 Ga, during and after deformation, which is consistent with a regionally recognised event (Whitehouse et al., in prep.). In addition, the claimed relationship between these gneisses and graphite-bearing metasediments can be refuted by ages from detrital zircon in the latter, indicating deposition after ca. 3Ga. This case is a demonstration that often it is not just the isotopic evidence for life which can be problematic – the context of a claim is equally critical.

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