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Microbial remains in some earliest Earth rocks: Comparison with a potential modern analogue

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ABSTRACT

Carbonaceous matter (CM) from ca. 3.5 Ga hydrothermal black cherts of the Pilbara Craton of Western Australia and the Barberton Greenstone Belt of South Africa yielded transmission electron microscopy (TEM) images that are suggestive of microbial remains and possible remnants of microbial cell walls. These are compared to a potential modern analogue, the hyperthermophilic *Methanocaldococcus jannaschii*, derived from an active seafloor hydrothermal environment and cultured under similar conditions. A striking resemblance to the early Archaean forms was evident in wall structure and thermal degradation mode. Cell disintegration of the cultures occurred at 100 °C marking the limits of life. Complete disintegration, deformation and shrinkage occurred at 132 °C. A multidisciplinary approach to the characterisation of the CM was undertaken using organic petrology, TEM coupled with electron dispersive spectral analysis (EDS), high resolution TEM (HRTEM) to determine molecular ordering, and elemental and carbon isotope geochemistry. Reflectance measurements of the CM to determine thermal stress yielded a range of values corresponding to several populations, and pointing to different sources and processes. The $\delta^{13}C$ values of Dresser Formation CM (−36.5 to −32.1‰) are negatively correlated with TOC (0.13–0.75%) and positively correlated with C/N ratio (134–569), which is interpreted to reflect the relative abundance of high R_o/oxidised/recycled CM and preferential loss of ^{12}C and N during thermal maturation. TEM observations, inferred carbon isotopic heterogeneity and isotope fractionations of −27 to −32‰ are consistent with the activity of chemosynthetic microbes in a seafloor hydrothermal system where rapid silicification at relatively low temperature preserved the CM.

1. Introduction

The Warrawoona Group of the Pilbara Craton in Western Australia and the Barberton Greenstone Belt of the Kaapvaal Craton in South Africa host some of Earth's best-preserved early Archaean volcano-sedimentary rocks (e.g. Lowe and Byerly, 1999; Van Kranendonk, 2006). Comparative lithological and stratigraphic studies have shown that the two cratons may have shared a common geological history prior to 3.45 Ga (Zegers et al., 1998). For the last 40 years, numerous reports were made of fossiliferous microbial remains in these rocks, with a focus on microbial-like structures in the mineral matrix (Dunlop et al., 1978; Awramik et al., 1983; Schopf and Walter, 1983; Schopf and Packer, 1987; Westall et al., 2001; Furnes et al., 2004). In the search for viable and indisputable evidence of life in the early Archaean terraines, recent detailed studies have focussed on carbonaceous matter (CM) within low-temperature hydrothermal chert precipitates from the Warrawoona Group in the Pilbara Craton and the Onverwacht Group in the Barberton Greenstone Belt (e.g. Walsh and Lowe, 1999; Ueno et al., 2001; Westall et al., 2001; Ueno et al., 2004; Orberger et al., 2006; Hofmann and Bolhar, 2007; Marshall et al., 2007). Work on Warrawoona Group cherts suggested that hyperthermophilic methanogens were possibly major contributors to CM in the hydrothermal precipitates based on carbon isotope analysis of methane-bearing fluid inclusions (Ueno et al., 2006). However, an abiogenic origin of early Archaean CM has also been discussed (Holm and Charlou, 2001; Brasier et al., 2004; Brasier et al., 2005;

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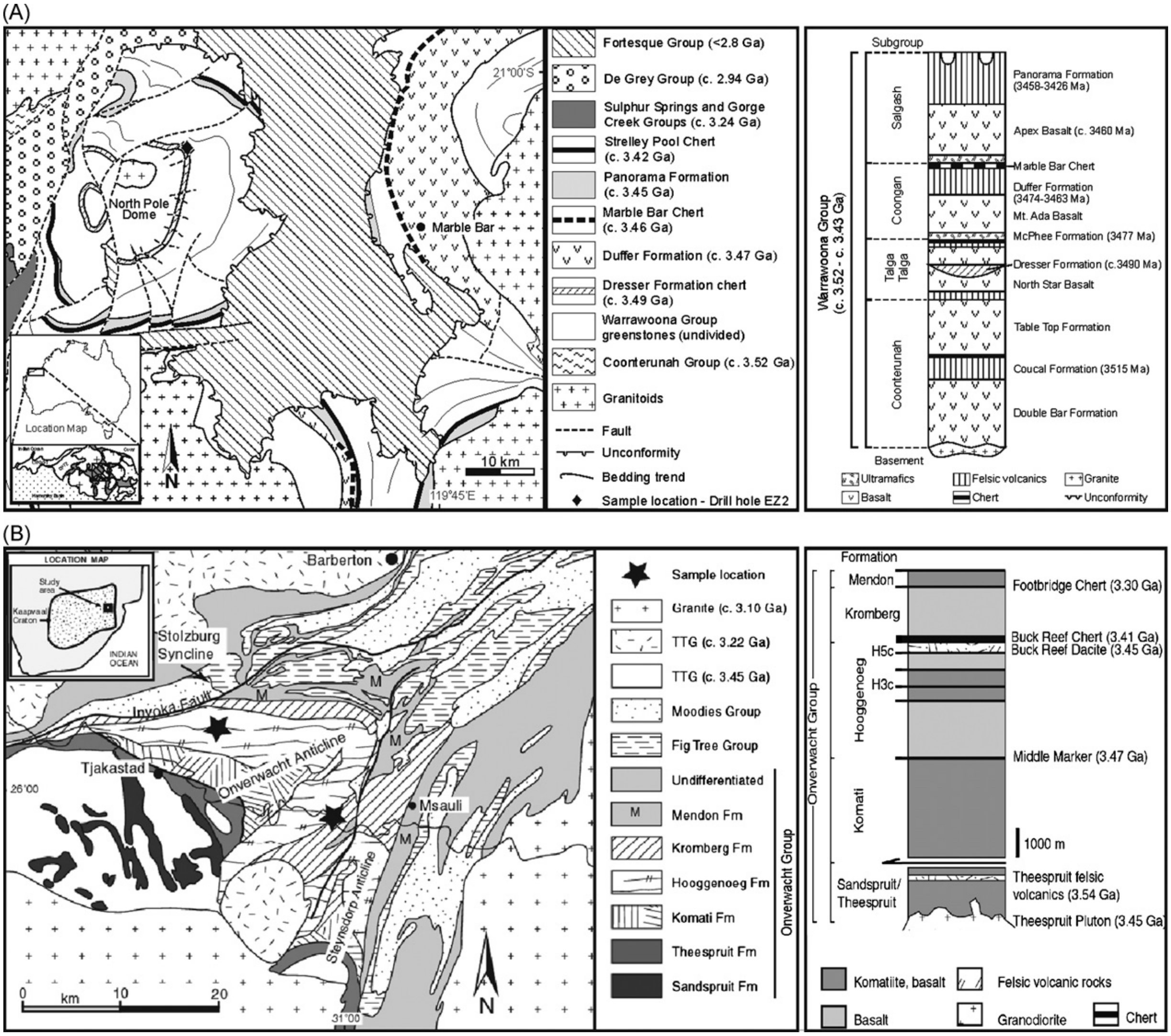

Fig. 1. (A) Location map and stratigraphic column for Pilbara samples. (B) Location map and stratigraphic column for Barberton samples.

Lindsay et al., 2005), as the synthesis of CM under simulated hydrothermal conditions suggested the possibility of organic compounds retrieved from 3.5 Ga rocks being the residue of abiotic processes (Rushdi and Simoneit, 2005; McCollom and Seewald, 2006).

Nevertheless, the presence of microbial remains in hydrothermally silicified seafloor sedimentary rocks would not be surprising, as hydrothermal systems in the early Archaean have been suggested as favourable for the development of life by several researchers (e.g. Corliss et al., 1981; Simoneit, 1995; Shock and Schulte, 1998; Holm and Charlou, 2001; Heijlen et al., 2004; Williams et al., 2005). Chert–barite beds of the Dresser Formation within the Warrawoona Group are a most promising source of microbial remains due to the occurrence of CM within relatively low thermal stress environments. Similarly, cherts with well preserved sedimentary structures and rich in CM are also common in the Onverwacht Group of the Barberton Greenstone Belt (Lowe, 1999; Hofmann and Bolhar, 2007). In this contribution, mineralogical–organic observations, geochemical data and electron microscopy of ancient CM from Archaean silicified sedimentary rocks in the Pilbara and Barberton are presented and compared with the thermally degraded remains of a modern hyperthermophilic organism derived from an active seafloor hydrothermal environment and cultured in our laboratory. Comparison with the living hyperthermophile *Methanocaldococcus jannaschii* DSM 2661, cultured under similar conditions to those possibly existing in the Archaean, provides a basis for defining the structures observed in the Archaean CM. This enables further constraints on the possible origin and nature of the structural features seen in the CM derived from early Archaean sedimentary rocks. The methanogen *M. jannaschii*, a hyperthermophilic autotrophic anaerobe isolated from an active sea-floor hydrothermal system, is known to grow under H_2/CO_2 and temperature conditions possibly widespread in the early Archaean (Stetter et al., 1990; Al-Hanbali et al., 2001). For the purpose of this study it was selected as a suitable representative of early Earth biota. Moreover, the location and the original isolation of *M. jannaschii* was a seafloor hydrothermal white smoker environment (Jones et al., 1983), a setting similar to the interpreted depositional environment of the 3.49 Ga Dresser Formation (cf. Van Kranendonk and Pirajno, 2004), although at a much greater water depth.

2. General geology and methods of study

2.1. Geological setting

The ca. 3.49 Ga Dresser Formation in the Warrawoona Group (Thorpe et al., 1992) is a 1000-m thick sequence of pillowed