グリーンランド・イスア表成岩帯の石墨片岩中に含まれるモナザイトの CHIME 年代測定

CHIME dating of monazite in graphitic schist, Isua Supracrustal Belt, Greenland

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Abstract

Biogenic graphite in > 3.7 Ga metasediments, Isua Supracrustal Belt (ISB), West Greenland, has been reported as the oldest remnant of life. Little is yet understood, however, about the ecosystem distributed throughout the >3.7 Ga ocean. Our group performed a geological survey of the west side of the ISB and investigated the petrographic and geochemical characteristics of metasediments to reconstruct the depositional environment. The chemical Th-U-total Pb isochron method (CHIME) was conducted on monazite associated with biogenic graphite to determine the age.

Samples collected in the studied area were roughly divided into the magnetite-rich type, distributed in the northeast to south, and the silicate-rich type, distributed mostly in the northwest, based on the dominant minerals. Bulk, amphibole, and chlorite chemical compositions of the samples showed that the silicate-rich type is rich in Mg, whereas the magnetite-rich type is abundant in Fe, suggesting that the Mg-rich characteristics of the metasediments in the northwest are a primary signature. The Ti and Al concentrations of the banded iron formations (BIFs) and graphite-rich metasediments were positively correlated, indicating that detrital components contributed to both. The monazite in the graphite-rich sample had a CHIME age of 3630±91Ma, within the age range determined for prograde metamorphism and detrital zircon in a previous report. The occurrence of monazite suggests that the monazite was syngenetic with the host rocks and probably derived from detritus, and that its age was either modified during metamorphism or crystalized during diagenesis to early metamorphism. Our results indicate that the metasediments in the northwest of the area studied probably deposited where clastic components such as Mg, Ti and Al were supplemented at a relatively high rate. If this is so, photosynthetic microorganisms might have flourished in the shallow ocean of >3.7Ga.

Keywords: Isua Supracrustal Belt, biogenic graphite, rare earth elements, monazite, CHIME

本文

Biogenic graphite in > 3.7 Ga metasedimenrary rocks, Isua Supracrustal Belt (ISB), West Greenland, has been reported as the oldest remnants of life (Rosing, 1999; Ohtomo et al., 2014). However, ecosystem spreaded in the >3.7Ga ocean is still poorly understood. Depositional environments of metasedimentary rocks containing biogenic graphite and surrounding banded iron formations (BIFs) could give an insight into

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microbial activities in the >3.7Ga ocean. Graphite-rich schist reported by Ohtomo et al. (2014) contains rare earth element (REE) minerals such as monazite, zircon and xenotime. These REE minerals could have been derived by one or some of the following processes: detrital transport, precipitation from a seafloor hydrothermal fluid, generation during diagenesis and precipitation from a metamorphic fluid. Occurrence, geochemical composition and chronological information of the REE minerals might constrain their origin and provide information of depositional and/or alteration process of the graphite-rich schist. Here, we performed a geological survey in the west side of the ISB and investigated the petrographic and geochemical characteristics of metasedimentary rocks to reconstruct the depositional environment. Chemical Th-U-total Pb Isochron Method (CHIME) was conducted on monazite to determine the age.

Samples collected in the whole west side of the ISB consist of alternate layers of magnetite-amphibole-chlorite-rich and quartz-rich layers. The samples were roughly divided into magnetite-rich type, which distributed at northeast to south, and silicate-rich type, mostly distributed at northwest, based on the dominant minerals. Bulk chemical compositions of the examined samples showed that magnetite-rich type is abundant in Fe, whereas silicate-rich type is rich in Mg. Magnetite-rich type primary composed of Fe-rich amphibole, grunerite, whereas silicate-rich type contains more Mg or Ca-rich amphibole. Similarly, chemical compositions of chlorite in magnetite-rich type are Fe-rich, whereas that of silicate-rich type are Mg-rich. Amphibole and chlorite compositions in graphite-rich metasedimentary rocks are Mg-rich, which is similar to silicate-type BIF samples. The results suggest that Mg-rich characteristics of BIFs and graphite-rich metasedimentary rocks at north west, and Fe-rich characteristics of BIFs at north east to south are a primary signature. Ti and Al concentrations in BIFs and graphite-rich sedimentary rocks showed a positive correlation, indicating contribution of detrital components to them. Graphite-rich schist sample consisted of graphite-chlorite- and quartz-cummingtonite-dominated microlayers, containing high amounts of REE compared to samples showing low graphite content. The graphite-rich sample contained euhedral monazite, zircon and minor xenotime 2-10 μm in diameter, which were accumulated in graphite-chlorite microlayers and concordant with orientation of lamination, whereas most of the monazite in samples showing low graphite content were anhedral. CHIME

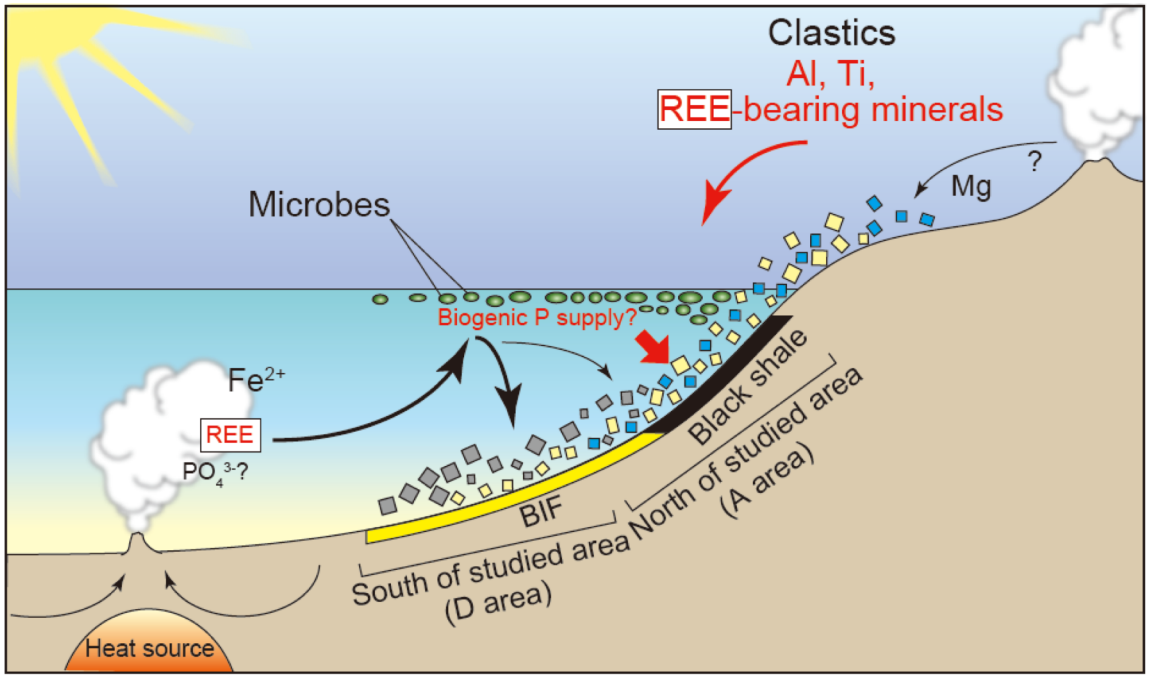

Fig. 1 Cartoon of the possible habitat environments spreaded in the > 3.7 Ga ocean.

age of the monazite in graphite-rich schist samples indicated 3630±91Ma, which ranges in the ages of prograde metamorphism and detrital zircon in previous report (Nutman et al., 2009).

Considering monazite occurrence concordant with lamination of the graphite-rich schist, it is most likely that monazite was syngenetic with host rocks, probably derived from detritus and the age was modified during metamorphism, or crystalized during diagenesis to early metamorphism. Our results suggest that BIFs and graphite-rich schist at north west of west side of the ISB deposited where clastic components such as Mg, Al, Ti and REE were supplemented at a relatively high rate, evoking that photosynthetic microorganisms might have been flourished in >3.7Ga shallow ocean.

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日本語要旨

西グリーンランド･イスア表成岩帯 (約 38 億年前)では生物由来グラファイトが発見されている。しかしながら、グラファイトの前駆物質である微生物の棲息環境や微生物種について詳細は明らかになっていない。本研究では生物由来グラファイトの報告があったイスア表成岩帯の西部において、黒色片岩及び縞状鉄鉱層 (Banded iron formation: BIF)の地質学的・地球化学的特徴及び希土類元素含有鉱物の産状と Chemical Th-U-total Pb Isochron Method (CHIME)年代測定から堆積環境を復元することにより、当時の微生物の棲息環境に制約を与えることを目的とした。

イスア表成岩帯西部では BIF の層が複数南北に渡り分布しており、黒色片岩層は西部北端に位置する BIF の層間に分布している。露頭では黒色片岩及びその周辺の BIF はシリケイトに富むのに対して、南側の BIF はマグネタイトに富む様子が観察された。誘導結合プラズマ質量分析計による全岩化学組成分析結果では、黒色片岩及びその周辺の BIF の Fe_2O_3/MgO 比は低く Mg に富む傾向を示すのに対して、南側の BIF は Fe_2O_3/MgO 比が高く Fe に富むことがわかった。緑泥石及び角閃石の化学組成においても同様に、北側は Mg に富み、南側は Fe に富む傾向がみられた。黒色片岩及び BIF 試料中の Al_2O_3 及び TiO_2 量 (wt%)は正相関を示しており、黒色片岩及びその周辺の BIF が Al、Ti に富むのに対して、南側の BIF は Al、Ti に乏しい傾向が見られた。また、グラファイトに富む黒色片岩試料中の希土類鉱物を走査型電子顕微鏡で観察したところ、モナザイトがグラファイトに富む層のみに葉理に調和的な産状で卓越していることがわかった。モナザイトの CHIME 年代測定結果は 3630±91Ma であり、過去の研究で報告された砕屑性ジルコンの年代とプログレード変成作用の年代を範囲に含むことがわかった。モナザイトの産状から考えると、モナザイトはもともと砕屑物として混入した後、変成中に年代のリセットを受けた可能性、初期続成作用から変成作用の間に岩石中で結晶化した可能性の両方が考えられる。以上の結果は、黒色片岩及びその周辺の BIF が Mg、Al、Ti、希土類元素を含む地殻砕屑物が多く混入するような浅海域で堆積したことを示しており、当時繁茂していた微生物は浅海で繁茂していた光合成細菌であった可能性を示唆するものと考えられる。