

初期太陽系形成過程におけるL型アミノ酸過剰生成機構の理論的研究 Theoretical Investigation of a Mechanism of Chirality Induction for Amino Acids in the Early Solar System

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現在の地球上の生命は、生体高分子であるアミノ酸で形成されている。アミノ酸は鏡像異性体であり、L型とD型が存在する。化学合成ではL型とD型は等量生成されるが、生命のタンパク質合成ではL型アミノ酸のみが生成される。この不斉アミノ酸生成の原因は、未だ解明されておらず、分子進化や生命の起源に関わる謎の一つである。この原因を説明するシナリオとして、初期太陽系形成時、円偏光照射により宇宙空間中のラセミ化アミノ酸が特異的に破壊されることでL型アミノ酸過剰が引き起こされて、現在のL型世界を形成したとする説がある。

近年、上記のシナリオを裏付ける実験結果や観測事実が報告されている。基本的なアミノ酸であるアラニン、バリン、イソバリンやその他のアミノ酸前駆体が隕石中に発見され、それら高分子の存在比も同様にL型に偏っていることが判明した。また一方で、円偏光が広範囲に分布している領域がオリオン座の大質量星形成領域(OMC-1)で観測された。さらに実験室中で、アミノ酸に円偏光を照射することで一方のアミノ酸鏡像異性体により特異的に破壊されることも報告されている。加えて実験で、少量の鏡像異性体過剰が増大し、最終的に支配的になることも分かっている。これらの発見は、生命の起源が地球外由来であること、生命におけるこの偏りと、隕石中で観測された偏りの原因が同じであることを示唆している。この異性体過剰の起源を解明することは、初期太陽系形成時の様子と生命の起源を理解する上で必要不可欠である。しかしながらまた、解明されていない課題も多く残されている。星間空間におけるアミノ酸の化学合成機構や、円偏光照射によるL型アミノ酸過剰の生成機構などは未だ分かっていない。

これらの解明には、アミノ酸の光吸収性と光励起による崩壊・改変反応の過程を解析することが重要である。異性体の偏りは、鏡像異性体に対する特異的な光分解、すなわちラセミ化アミノ酸への円偏光照射による異性化反応が原因であると考えられる。このようなアミノ酸の崩壊過程や構造変化の機構を知るためには、励起状態と励起による解離反応過程を追跡することが必須である。特に異性化反応においては、反応に関わる原子である不斉炭素と主鎖-側鎖をつなげる炭素との結合解離反応について検討する事が最も重要であると考えられる。

本研究では特に、L型アミノ酸の光吸収性とその励起状態を解析した。「円偏光のアミノ酸への照射 電子励起 構造変化」の一連の過程を電子レベルで解明し、円偏光によるアミノ酸過剰の発生を理論的に解明する。そのため、アミノ酸鏡像異性体の円偏光照射下における光物性を、量子論に基づく第一原理計算法(密度汎関数法: DFT)により解析する。アミノ酸の基底状態と円偏光光励起によって生じる励起状態のポテンシャルエネルギー曲線を詳細に明らかにし、断熱過程及び非断熱過程におけるアミノ酸の光構造物性を解明する。得られるポテンシャルエネルギー曲線から、アミノ酸構造破壊につながるエネルギー励起とその円偏光依存性を明らかにする。特に、鏡像異性体を持っている最も基本的なアミノ酸であるアラニンやバリン、イソバリンは他のアミノ酸の異性化に対してもカギとなると考えられるため、これら3つのアミノ酸について解析を行う。

アミノ酸の光物性を調べるため、まず星間空間におけるアミノ酸の安定構造を決定した。さらにその構造における光吸収強度と円偏光二色性を計算し、星間空間においてアミノ酸がどのような光により励起されやすいかを検証した。その後、上述のアミノ酸におけるC-C結合の解離反応を仮定し、反応過程でのポテンシャルエネルギー曲面を計算した。得られたポテンシャルエネルギーから、アミノ酸の構造崩壊・改変を引き起こすような反応経路を定性的に推定した。

計算の結果、これらのアミノ酸では、励起エネルギーが8-12 eV(励起波長100-150nm)の領域に円偏光二色性のピークがあることが分かった。特に我々は、この領域内から計4本の結合解離反応経路を推定した。アラニンではエネルギー9.81 eVの励起が結合解離を引き起こしやすく、かつ光吸収強度・円偏光二色性共にピークを持つ。バリンでは10.00 eV, 10.91 eVの励起状態が同様の条件を持つ。またイソバリンでは9.32 eVの励起が結合解離反応を誘発している。これら4本の非断熱ポテンシャルカーブは、基底構造において光吸収強度・円偏光二色性共に高い値を持ち、エネルギー的に結合解離を引き起こしやすい。従って、このような反応経路に対する励起がアミノ酸異性体過剰を引き起こす原因となると考えられる。

これらの解析結果は、励起波長110-135nmの領域、従って真空紫外線波長領域の円偏光照射がアミノ酸の異性体過剰を誘発する事を示唆している。

キーワード: 鏡像異性体, アミノ酸, 偏光, 原始太陽系星雲

Keywords: enantiomer, amino acid, polarized light, proto-solar nebula

火星における CO₂, CH₄ ハイドレートの放射線分解による有機物生成の可能性 Possibility of organic matter formations in irradiated CO₂ and CH₄ hydrates on Mars

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To look for evidence of life on Mars, explorations of organic matter is important. There are some possibilities of the formations of organic matter on Mars; for example, by biological activity and by radiolysis and photolysis of mixtures of icy materials. If organic matter exist on Mars, to identify the detected organics as the matter by biological activity, it is necessary to investigate reaction products and their amount by radiolysis and photolysis of the ice mixtures, and to distinguish organics by biological activity from ones by radiolysis and photolysis. As the icy materials on Mars, it is suggested that gas hydrates would exist on Mars, based on the discussion of temperature and pressure conditions. Gas hydrates are crystalline inclusion-compounds, which are composed of hydrogen bonded water molecules encaging gas molecules (e.g. CO₂, CH₄). Most of them are stable at high pressures and/or low temperatures. Average temperature of Martian surface is about 210 K, the Martian atmosphere consists of about 95% CO₂ and the average atmospheric pressure is about 0.56 kPa (Kieffer et al., 1993). From the observations of the Mars Express spacecraft, methane with 10-40 ppmv concentrations has been detected in the Martian atmosphere and on surface of the ground (Formisano et al., 2004; Mumma et al., 2009). In Martian conditions, it is suggested that CO₂ and CH₄ hydrates are formed in about 10 m below the ground and on the polar caps in winter (e.g. Max and Clifford 2001; Prieto-Ballesteros et al., 2006). Since water ice exists on Martian surface, the environment on the Martian surface should be enough to form CO₂ and CH₄ hydrates. In this case, Martian gas hydrates should be irradiated by natural radiation from radioisotopes in sediments as well as cosmic rays, which may cause radical formation in CO₂ and CH₄ hydrates.

Radiation-induced radicals in CH₄ and CO₂ hydrates have been investigated by electron spin resonance (ESR) measurements. Methyl radical is mainly formed by gamma-ray irradiation at 77 K in CH₄ hydrate (Takeya et al., 2004), and not stable above 180 K at 0.1 MPa (Tani et al., 2006). Carboxyl radical, hydrogen atom and hydroxyl radical are formed by gamma-ray irradiation at 77 K in CO₂ hydrate, hydrogen atom and the hydroxyl radical are not stable above 120 K at 0.1 MPa and the carboxyl radical quickly disappears at 180 K (Oshima et al., submitted). In thermal conditions on Mars, these radicals in the hydrates are unstable, and some products may form through the radical reactions. In this study, to investigate the organic products from radicals induced in CO₂ and CH₄ hydrates on Martian conditions, we analyzed the aqueous solution after dissociation of the hydrates irradiated at 195 K by ion chromatography and gas chromatography-mass spectrometry (GC-MS).

Formic acid and oxalic acid are observed in aqueous solution after dissociation of irradiated CO₂ hydrate. Methanol and formaldehyde are observed in irradiated CH₄ hydrate. If CO₂ and CH₄ hydrates exist on Mars, these organics will be formed in the hydrates and accumulated on the polar caps and below subsurface.

キーワード: ガスハイドレート, 有機物, ラジカル, イオンクロマトグラフ, ガスクロマトグラフ質量分析, 火星

Keywords: Gas hydrates, Organic matter, Radicals, Ion chromatography, Gas chromatography-mass spectrometry (GC-MS), Mars

たんぽぽ：たんぽぽ計画:有機物・微生物の宇宙曝露と宇宙塵・微生物の捕集 Tanpopo: Astrobiology exposure and micrometeoroid capture experiments

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For the origin of life on Earth emerged within a short period after the end of heavy bombardment, Panspermia hypothesis was proposed (e.g. Arrhenius 1908; Crick 1981). Recent findings of the Martian meteorite suggested possible existence of extraterrestrial life, and interplanetary migration of life as well.

Microbes have been collected from high altitude using balloons, aircraft and meteorological rockets since 1936, even it is not clear how could those microbes be ejected up to such high altitude. Spore forming fungi, spore forming Bacilli, and Micrococci (probably Deinococci) have been isolated in these experiments. We have also isolated novel deinococcal species high altitude (Yang et al. 2010, 2011). These spores and Deinococci are known by their extremely high resistance against UV, gamma ray, and other radiation. If microbes could be found present even at the higher altitude of low earth orbit (400km), the fact would endorse the possibility of interplanetary migration of terrestrial life.

On the other hand, from the viewpoints of chemical evolution for study of origin of terrestrial life, where is the home of organic compounds which might have become precursors of materials such as protein and nucleic acids. Recent studies suggest that the some of such organic compounds were created in space. Then, they reached the surface of Earth via meteorites, cosmic dusts, and so on. One of problems to study such materials of extraterrestrial origin is contamination of materials of terrestrial origin. Avoiding contamination of terrestrial materials from the extraterrestrial materials is quite important issues for this kind of study. Capturing such extraterrestrial materials before falling down on the surface of Earth might be one of possible solutions.

TANPOPO, Japanese name of dandelion, is a plant species, whose seeds with floss are spread by wind. We propose this mission to examine possible interplanetary migration of microbes, and organic compounds on Japan Experimental Module (JEM) of the International Space Station (ISS) (Yamagishi et al. 2008). Ultra low-density aerogel will capture micrometeoroid and space debris. Particles captured by aerogel will be analyzed after the initial curation of the aerogel and tracks in it. Careful curation of the tracks in the aerogel will provide information on the size and velocity of meteorites captured. The particles will be characterized in terms of mineralogical, organic and microbiological properties. The aerogel with low density and layered structure is ready for production in Japan.

In addition to particle-capture on ISS, we also proposed direct exposure experiments of microorganisms and organic compounds with/without model-clay materials that might protect microorganisms and organic compounds from UV and cosmic ray. Spore of *Bacillus* sp., *Deionococcus radiodurans*, and novel Deionococcal species isolated from specimen collected from high altitude by us are candidate subjects for exposure. Amino acids and complex organic compounds that can be formed in space are planned to be exposed.

All the analytical techniques are ready to conduct the TANPOPO mission. Our proposal was accepted as a candidate experiments on Exposed Facility of ISS-JEM. In this paper, we discuss current status of exposure/capture experiments of microorganisms defined for the TANPOPO mission.

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生化学機能の進化から考える生命の起源

Origins of life from the point of view of evolution of biochemical functions

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生命の起源は、通常、タンパク質や核酸といった物質レベルでの化学進化の面からのみ考察されてきた。しかし、無生物的に生成する有機物は、一般に高分子態の複雑有機物となることが多い。このような「がらくた分子」が機能を持ち、その機能の進化の末に生命が誕生した可能性を、種々の模擬実験の成果をもとに検証する。

キーワード: 生命の起源, ホモキラリティ, 触媒活性, 有機凝集体, がらくたワールド, 複雑有機物

Keywords: origins of life, homochirality, catalytic activities, organic aggregates, Garakuta World, complex organic compounds

地球生命の起源と誕生した場所 Origin and birth place of life on the Earth

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Birth of life

In spite of those new trends, and against reluctant astronomers, I point out the idea against it. First of all, the life cannot be formed only by water and CO₂. Phosphorous is a key critical element to run metabolism in life as an example. The related major and trace elements are all derived from the rock, not from ocean and atmosphere. The water-rock interaction driven by steady-state supply of heat by magma at mid-oceanic ridge was the birth place of life on the Earth, and another survival place of life is the surface of the Earth where continent (source of nutrients) interacts with ocean-atmosphere, resultant constant supply of nutrients to the ocean. Engine to drive the system is Sun, whereas the deep-sea hydrothermal system is plate tectonic supply of MORB magma. Phosphorous is nearly absent at MOR and absent in underlying mantle which are critically important if we discuss the origin of life in the Hadean time.

To form life, we it is critical to supply phosphorous and related other nutrients continuously to the birth place through the water-rock interaction which has never been considered seriously. Moreover, the chemical composition of primordial ocean could be pH=1-2 and enriched heavy metals in oxidized material of water.

Primordial continent, anorthosite with KREEP on the Hadean Earth

To overcome such hard conditions to bear life, hydrogen-producing environment under peridotite-water hydrothermal system with P-bearing ore as well as nutrients could be only available on the deep-lake on primordial continents with KREEP basalts. The latter could be erupted basalts, gabbro (dike or sill) and lower mafic crust. If primary ocean was thin, the primordial continents (20km upper crust of anorthosite + 20-25km lower mafic crust) could be above sea-level, to transport nutrients into lakes which were clean to bear life by evaporation through ocean.

How to synthesize life on the Hadean Earth: A new model

First life was synthesized by the successive FT reactions from inorganic compounds under the excess amounts of P-bearing and other nutrients (ore body) in the deeply fractured lake with constant magma supply underneath. The birth place was under anoxic conditions (H₂) local in an oxidized material of water. The most difficult process is the process from RNA world to DNA world, which may have taken over several hundreds of million years.

After the birth of life in such a localized area, the mother primordial continents have all gone into deep mantle remaining life on the deep-sea hydrothermal system. Plate tectonics has operated to clean-up ocean chemistry by the formation of ores at mid-oceanic ridges to transport them into mantle. Salinity was 3-5 times more in the Precambrian time, and plate tectonics was not effective to omit halogens from ocean into mantle. Continent-collision orogeny was critical to dilute salinity after the drop-down of sea-level at 800-600Ma.

イヌア地域における 3.8 億年前の非生物的炭素 Abiogenic graphite in the 3.8 Ga Isua Supracrustal Belt

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Graphite is known to occur in the >3.7 billion years old Isua Supracrustal Belt (ISB) of western Greenland. The unequivocal documentation of biogenicity for graphite is complicated by the possibility of secondary graphite precipitation from metamorphic or igneous fluids and the difficulties in distinguishing biogenic from secondary graphite. Here I report the discovery of siderite-rich veins enriched in reduced carbon in the western ISB. In the studied area, metamorphosed basaltic rocks are dominant. Three layers of banded iron formations, enriched in magnetite, quartz, grunerite, and Fe-rich garnet, are found in the studied area. It is found that the carbonate-rich vein occurs in some banded iron formations, and such veining extends approximately 100 m from north to south. The carbonate carbon concentrations of this vein range from 2.5 to 4.5 wt %C. The concentrations of graphite range from 0.1 to 5.0 wt %C. The mineralogy associated with abundant graphite is quite similar to the secondary carbonate veins found in eastern ISB (van Zuilen et al., 2002).

Results of the present geological survey constrain that the carbonate vein was formed by interaction between pre-existing BIFs and carbonic fluids during metamorphism. Siderite was formed during the early stage of metasomatism and became a subject for further metamorphism, producing magnetite and graphite. Because BIFs do not contain recognizable amounts of graphite, graphite in the carbonate veins were certainly formed during the vein formation, thus the product by metamorphism. This finding is a second report of abiogenic graphite in the ISB. Such abiogenic graphite most likely widespread in ISB, because carbonation of BIFs are commonly found throughout the belt.

On the other hand, ¹³C-depleted graphite from sedimentary rocks are present in ISB, in particular 2 km north from the surveyed area of this study. Graphite in those sedimentary rocks are interpreted as biogenic in origin. Detailed geological, mineralogical and isotope analyses allow us to distinguish graphite generated during sedimentation from that produced during metamorphism.

Keywords: abiogenic, Isua, Archean

Was the Archean atmosphere reducing? Was the Archean atmosphere reducing?

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The current paradigm postulates the following scenarios for the evolution of the atmosphere and oceans: Oxygenic photoautotrophs evolved at ~2.7 Ga, but the atmosphere and oceans remained reducing (i.e., $p\text{H}_2 > 10^{-6}\text{atm} > p\text{O}_2$) until the 'Great Oxidation Event (G.O.E.)' at ~2.45 Ga when the atmospheric $p\text{O}_2$ dramatically rose to ~10% PAL and the ocean surface layer became oxygenated, while the deep oceans remained anoxic. Previous researchers have presented the following observations in some (but not all) Archean-aged rocks to support this paradigm: (a) loss of Fe from paleosols; (b) abundance of banded iron formations (BIFs); (c) presence of 'detrital' grains of uraninite and pyrite; (d) lack of U- and Mo enrichments in black shales; (e) presence of anomalous isotopic fractionations (AIF or MIF) of sulfur in shales and barite beds; (f) presence of unusual isotopic compositions of N and Fe in sedimentary rocks. However, none of these observations are unequivocal evidence for a reducing Archean atmosphere, since all these characteristics have also been found in younger rocks. We have also demonstrated experimentally that the AIF-S signatures, which were previously linked to the UV photolysis of volcanic SO_2 in an O_2 - and O_3 -free atmosphere, can occur during thermochemical sulfate reduction by solid organic matter. We can better explain the above characteristics (c)-(f) by diagenetic, hydrothermal, and metamorphic processes, rather than by atmospheric processes.

In an anaerobic world under a reducing atmosphere, organic synthesis would have occurred through anoxygenic photoautotrophy (e.g., $\text{CO}_2 + 2\text{H}_2 \Rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O}$), and the decomposition of the organic matter by fermentation (e.g., $\text{CH}_2\text{O} \Rightarrow \text{CO} + \text{H}_2$ and $3\text{CH}_2\text{O} \Rightarrow 2\text{CO} + \text{CH}_4 + \text{H}_2\text{O}$). As the atmospheric CO_2 was converted to reduced C compounds (CO , CH_4 , and C) and not completely recycled back to CO_2 , the atmospheric CO_2 would have continuously decreased, even with continuous supplies of CO_2 by volcanic gas and weathering of carbonates; CO_2 would have disappeared in <~100 million years since the emergence of anoxygenic photoautotrophs and created an icy, dead planet. But this did not happen. The maintenance of a CO_2 -rich atmosphere and the life on Earth through geologic history would have required the recycling of organic matter by aerobic organisms.

A small, but growing, number of researchers postulate that the emergence of oxygenic photoautotrophs and the development of a fully-oxygenated atmosphere-ocean system took place before ~3.5 Ga. They cite the following similarities between Archean and Phanerozoic rocks to support their model: (i) the ranges of organic-C and pyrite-S contents in shales; (ii) the common $\delta^{13}\text{C}$ values of carbonates and shales; (iii) the abundance of sulfate-rich rocks; (iv) the wide $\delta^{34}\text{S}$ ranges for pyrite and sulfates in sedimentary rocks and ore deposits; (v) the common $\delta^{15}\text{N}$ values of shales and cherts; (vi) the Fe, Mo and Cr isotope values of sedimentary rocks; and (vii) the behaviors of various redox sensitive elements (e.g., Fe, Mn, U, Mo, W, As, Ce) in paleosols, BIFs, and hydrothermally-altered submarine basalts.

Keywords: Archean, atmosphere, MIF, GOE

Does bimodal distribution of carbon isotopes of 3.0 Ga kerogen mean oxygenic photosynthesis?

Does bimodal distribution of carbon isotopes of 3.0 Ga kerogen mean oxygenic photosynthesis?

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In order to constrain the mid-Archean anaerobic and aerobic ecosystem, geological and geochemical studies were performed on ca. 3.0 Ga sedimentary rocks at the northern section of Lundy Lake Greenstone Belt, Ontario, Canada [1][2]. The metamorphic grade reached to greenschist to amphibolite facies in the studied area. Mafic pillow lavas and gabbro are dominant rocks in the studied area. Banded iron formations and black shales, intercalated with mafic volcanics, are found at four different horizons. Each unit of sedimentary rocks has 1 to 15 m thickness. Black shales at all localities contain significant amounts of organic carbon, ranging from 0.3 to 9.2 wt %C. Such high concentrations suggest the microbial productivities were very high during sedimentation.

Pyrite is abundant in one a specific black shale horizon. Pyrite occurs as fine-grained or nodular shape. The fine-grained type occurs concordantly with sedimentary structure and this type is interpreted as direct precipitates from the contemporary submarine hydrothermal plume. Detailed petrography suggests that nodular type was formed during diagenesis by submarine hydrothermal fluids, which introduced peripherally in stratified sediments. Pyrrhotite-pyrite assemblage and sphalerite compositions in nodular samples suggest that associated fluids were very reducing and most likely containing hydrothermal hydrogen.

Bimodal distribution of carbon isotope compositions was found among examined kerogen samples. One mode appears between -47 to -41 per mil (PDB; mode 1), suggesting activities of methanogens during sedimentation. Geological survey indicates that activity of methanogens was strongly concealed with contemporary submarine hydrothermal activities and sulfide mineralization. On the other hand, carbon isotope compositions of kerogen from other horizons show -29 to -21 per mil (PDB; mode 2). Those samples are not accompanied with submarine sulfide mineralization and did not show carbon isotope signatures of methanogens. Widespread nature of such mode-2-type kerogen suggests that photosynthesizing bacteria were active in the water column.

Black shales of mode 2 type are often intercalated with magnetite-rich banded iron formations. Some samples show high mole ratios of C(org)/Fe, suggesting that anoxygenic photosynthesis, such as Fe-oxidizing bacteria, is not likely for the origin of mode-2-type kerogen [3]. In other words, the high C(org)/Fe ratios may imply the activity of cyanobacteria in the 3.0 Ga Lundy Lake ocean.

[1] Davis and Jackson (1988) Geol. Soc. Amer. Bull. 100, 818-824. [2] Fralick and King (1996) West. Super. Trans. Ann. Workshop, pp. 29-35. [3] Kohnhauser et al. (2007) EPSL 258, pp. 87-100.

Keywords: Archean, photosynthesis, Lundy Lake

複合イオウ同位体比の特徴と堆積環境との関連

Linking multiple sulfur isotopic characteristics of Archean sedimentary rocks to their depositional environments

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Many researchers have linked the anomalously fractionated (or commonly called mass independently fractionated) isotopes of sulfur (AIF-S or MIF-S) in sedimentary rocks to UV photolysis of volcanic SO₂ and to an O₂-poor atmosphere. However, serious discrepancies exist between the AIF-S signatures in natural samples and those of the products (S₀ and SO₄²⁻) of SO₂ photolysis using a broad-band UV lamp which simulates the sun light. The produced S₀ and residual SO₂ possess only very small AIF-S signatures (i.e., $\delta^{33}\text{S}/\delta^{34}\text{S} = 0.58 \pm 0.04$). Based on theoretical and experimental investigations, we have proposed that the AIF-S signatures in some (if not all) Archean sedimentary rocks were produced by chemisorption-redox reactions involving solid phases (e.g., organic matter, iron oxides, carbonates, clays and aqueous S-bearing species (SO₄²⁻ and H₂S)) during the diagenesis of sediments in hydrothermal environments. According to our model, the characteristics of AIF-S signatures may vary depending conditions of the chemisorption-redox reactions (e.g., type and surface area of the solid phase, concentration of the aqueous species, temperature, reaction time, open or closed-system). To evaluate the validity of our model, we have examined the relationships among the AIF-S characteristics ($\delta^{34}\text{S}$, $\Delta^{33}\text{S}$ and $\Delta^{36}\text{S}$ values) of sulfides and sulfates, their modes of occurrence (e.g., disseminated, nodules, layers, veins), and the lithology of their host rocks.

We have recognized that sulfides (and sulfates) that formed in similar depositional environments generally exhibit similar AIF-S characteristics. For example, sediments accumulated in closed euxinic basins under the influence of submarine hydrothermal activity (e.g., pyritic black shales and siderite-rich sediments in the 2.5 Ga McRae and 2.7 Ga Jeerinah Formations) generally possess $+\delta^{34}\text{S}$ and $+\Delta^{33}\text{S}$ values or $-\delta^{34}\text{S}$ and $-\Delta^{33}\text{S}$ values. Barite- and sulfide-bearing sediments accumulated in shallow, evaporitic basins (e.g., the 3.5 Ga Dresser and 2.7 Ga Tambiana Formations) often possess $-\delta^{34}\text{S}$ and $+\Delta^{33}\text{S}$ values for the sulfides and $+\delta^{34}\text{S}$ and $-\Delta^{33}\text{S}$ values for the barite.

The observed relationships between AIF-S signatures and depositional environments, and the frequent occurrence of sediments with no AIF-S signatures in Archean sedimentary rocks (e.g., 2.7 Ga Hardy lacustrine Formation), are difficult to explain by the current popular model that links AIF-S to atmospheric UV reactions. Rather, the data can be best explained by our model that links AIF-S to chemisorption-redox reactions (e.g., thermochemical sulfate reduction (TSR), replacement of iron oxides by pyrite) under large-scale hydrothermal conditions. Therefore, the AIF-S record of sedimentary rocks may be linked to the thermal and biological evolution of the Earth, rather than to the atmospheric evolution.

Keywords: sulfur isotope, Archean

全生物共通祖先の遺伝子を再現する

Molecular resurrection of the genes of common ancestor of all the living organisms

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地球上の全生物は1種類の生物を祖先として進化してきた。その共通祖先の性質を進化系統樹をもとに解析することができる。現存する生物の遺伝子を解析することから分子進化系統樹を作製することができるが、同じ手法をもちいて共通祖先の遺伝子の配列を推定する事もできる。推定した遺伝子を大腸菌内で発現し、精製することにより、過去の生物がもっていたタンパク質の性質を調べる事ができる。こうした方法によって、全生物の共通祖先、古細菌の共通祖先、細菌の共通祖先の性質を調べた結果を報告する。

キーワード: 全生物の共通祖先, コモノート, LUCA, タンパク質, 耐熱性

Keywords: Common ancestor, Commonote, LUCA, Protein, thermostability